CONCEPT OF WEATHER FORECASTING

Dr. N. K Pruthi
Anwar Khan

ALEXIS PRESS
JERSEY CITY, USA

CONCEPT OF
WEATHER FORECASTING

CONCEPT OF WEATHER FORECASTING

Dr. N. K Pruthi
Anwar Khan

ALEXIS PRESS

ALEXIS PRESS

Published by: Alexis Press, LLC, Jersey City, USA
www.alexispress.us

First Published 2022

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication Data

Includes bibliographical references and index.

Concept of Weather Forecasting by *Dr. N. K Pruthi, Anwar Khan*

ISBN 978-1-64532-127-9

CONTENTS

CHAPTER 1

OVERVIEW OF WEATHER FORECASTING

Dr. N. K Pruthi , Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

Today's society places a great deal of importance on weather forecasting since it offers vital information to a number of industries, including agriculture, transportation, disaster relief, and public safety. This study provides an overview of weather forecasting, including its core ideas, approaches, and technological developments. The fundamentals of weather forecasting are covered, emphasizing the importance of atmospheric conditions, pressure systems, and patterns of world circulation. It is examined how meteorological data gathering techniques, such as observations from weather stations, satellites, and remote sensing devices, contribute to the precision of weather forecasts. The pros and weaknesses of conventional numerical weather prediction models, such as the Global Forecast System (GFS), are explored. Additionally, improvements in ensemble forecasting, data assimilation strategies, and the inclusion of machine learning and artificial intelligence are studied, displaying their potential to improve forecast accuracy and result in more trustworthy forecasts. The difficulties and unknowns associated with weather forecasting are discussed in section three. These include the atmosphere's abysmal structure, the lack of data in far-flung areas, and the need for ongoing model parameterization improvements. The effects of climate change on weather patterns and their consequences for forecasting are also covered. This segment emphasizes the value of weather forecasting across a range of industries. Achieving social well-being and economic stability depends on the practical uses of accurate weather forecasts, which range from assisting agricultural choices and optimizing energy resources to allowing effective transportation planning and early warnings for catastrophic weather occurrences.

KEYWORDS:

Development, Science, Society, Technology, Weather Forecasting.

INTRODUCTION

Utilizing science and technology, weather forecasting predicts the atmospheric conditions for a certain area and time frame. People have been making informal weather predictions for millennia, and official ones since the eighteenth century. Previously performed manually with a primary emphasis on fluctuations in barometric pressure, current weather patterns, and sky status or cloud cover, weather forecasting is now carried out using computer-based models that take into consideration a range of atmospheric factors. By obtaining factual information about the atmosphere's existing state at a specific area and utilizing meteorology to project how the weather will behave in the future, weather forecasts are made. To choose the optimal prediction model on which to base the forecast, human input is also necessary. The economics includes weather forecasting; for instance, in 2009, the United States spent $5.1 billion on weather forecasting, with benefits anticipated to be six times that amount. Since we are aware of the prediction, let's examine the significance of weather forecasting pdf and the many predicting techniques [1].

Forecasting the weather's importance

There are many applications for weather forecasting in daily life, from choosing your attire to determining whether to bring an umbrella to work. The areas listed below are just a few where weather forecasting is very important: Agriculture and farming are greatly influenced by the seasons and environment. Temperature is crucial when it comes to growing different fruits, vegetables, and pulses. Before, farmers relied on estimations to complete their work since they lacked a deeper grasp of weather predictions. They do, however, sometimes experience losses as a consequence of incorrect weather predictions. Thanks to technological advancements and the adoption of novel weather forecasting techniques, farmers will soon get all of their predictions on their cellphones. Education in this area is important, of course, but the majority of farmers today are familiar with the basics, making it easy for them to utilise the features. It facilitates the movement and storage of food grains. It facilitates the management of cultural tasks like harrowing and hoeing, among others. It helps with the execution of efforts for protecting cattle.

Forecasting the weather is important because it can predict how the climate will change in the future. We can calculate the likelihood that snow and hail will reach the surface using latitude. We can determine the thermal energy that the sun is exposing an area to. The study of climates, or simply the weather over a period of time, is known as climatology. Numerous research in the field of atmospheric sciences also make use of the variables and accumulated averages of short- and long-term weather conditions. In contrast to meteorology, climatology is a field of study that may be further broken down. This section may be approached in a variety of ways. Our current main research objective is to encourage and aid in the development of effective and efficient environmental activity measures [2].

Weather Forecasting Techniques

Forecasting for the short term: This forecast will last one to two days. Human daily routines, food production, and individual comfort zones are all greatly influenced by the weather. Planning for the present and the future involves a lot of forecasting. Therefore, there are additional factors that might have a significant influence on the predicting result. But proper forecasting is really essential. For many types of studies, forecasting is a crucial tool. The most accurate global model is ECMWF. The ECMWF outperforms the GFS by a wide margin.

Forecasting for the medium term: This kind of forecasting covers the next 3–4 days to 2 weeks. Small strategic decisions are given medium-term estimates based on the nature of the firm. They play a crucial role in the planning and growth of businesses, and it is from this projection that corporate budgets are made. Inaccurate forecasting may have negative effects on the rest of the company, forcing it to keep unsold inventory and incurring additional manufacturing costs. Banks and creditors must be paid a significant sum of money, and shares may need to be sold for a very low price. Lack of focus on medium-term sales forecasts may cause businesses to fail. A medium-term projection typically covers a period of one year.

Forecasts for the long term are made for periods longer than four weeks. Long-term projections are mostly used for important impending strategic choices inside an organisation and for the organisation. They place a strong emphasis on how to utilise resources as efficiently as possible. Instead of dealing with individual goods, they deal with fundamental ones. As a result, organisations focus more on broad continuing patterns, keep track of these trends, and often make predictions about revenue-generating sales for periods longer than two years. For large enterprises, precise estimates may be required for ten years or more to address the changes in certain tactics. The drawback of such projections is that they are only ever vague. When something completely contrary of what was expected goes wrong, prediction planners blame the forecast, and forecasting as a result is criticised by everyone who is affected.

Techniques for Finding Weather Prediction

Synoptic Approach: This approach of weather forecasting makes use of a systematic analysis of previous weather predictions from a vast region. Predictions are made based on the assumption that the present scenario will act similarly to the analogous situation in the past given the relationship between the current weather conditions and similar prior situations. This approach of weather forecasting uses regression equations or other sophisticated correlations to establish a connection between different weather components and the ensuing climate. Typically, forecasts or meteorological criteria are determined based on the likelihood of a physical contact.

Techniques for Numerical Weather Prediction: According to the definition of numerical weather prediction, it predicts weather based on statistical models of the atmosphere and oceans. A set of equations based on physical rules affecting airflow, air pressure, and other variables are used in this system to represent how the atmosphere acts. It has been shown that the approach produces the best medium-term estimates.

Process of weather forecasting

Three processes make up a weather forecast: observation, analysis, extrapolation to predict the future condition of the atmosphere, and estimate of certain variables. Concluding that the weather characteristics will continue to move in the same direction they have is one form of qualitative extrapolation [3].

Monitoring and Evaluation

All of these reports are delivered to regional and international centres through the World Meteorological Organization's (WMO) Global Telecommunications System (GTS), albeit data-access regulations vary by nation. After then, the information is collated, transmitted once again inside the GTS, and used to different numerical forecasting models. These numerical models typically start with data that was gathered between 0000 and 1200 UTC (7 AM and 7 PM Eastern Standard Time, respectively). The data is printed, mapped, and graphed in various ways to help the forecaster. Furthermore, when data enters a prediction model, just for that model, certain "initialization" methods subtly alter the data [4].

Extrapolation

Between models, there are huge differences in how well the equations are approximated. The more accurate the approximation, the more costly the model is to utilise since more computation time is required to complete the task. The National Centres for Environmental Prediction (NCEP) of the National Weather Service in Suitland, Maryland, is where forecast-model research is centralised in the United States. There, four main models are being run by a state-of-the-art supercomputer. Two of the trends are related to North America and its surroundings. The other two options standardise the whole world by encircling it. Every domain has a fundamental model that is designed for quick computation as an early update even when there are machine issues. The alternative approach is more complete for each domain and offers a better solution at a greater price.

Estimation

A forecaster has access to a plethora of observable and model-generated information when attempting to estimate a specific variable, such as the lowest temperature on a certain night in the city in which he or she is headquartered. None of the information, however, can be used to generate a specific forecast. The forecaster must also use their understanding of typical model behaviour, regional microclimate changes, and average climatic variables in the present situation. The NWS has put a lot of work into employing statistical regression equations to convey this kind of supplementary data. Depending on the location and season, the coefficients in these equations change [5].

History

Weather forecasting has been an ongoing endeavour for generations. In 650 BCE, the Babylonians employed astrology and cloud patterns to predict weather. Written about 350 BCE, Aristotle's Meteorologica described weather patterns. The work of Signs, a work on weather predictions, was also written by Theophrastus. At least 300 BCE, when ancient Indian astronomy began to establish its techniques of weather prediction, is when Chinese weather prediction knowledge first appeared. Observed cycles of occurrences are employed in traditional weather forecasting techniques, also known as pattern recognition. For instance, it's been observed that the next day is often sunny if the sunset is very crimson. Weather legend was created as a consequence of the transmission of this information through time. But not all of these projections are correct, and following rigorous statistical analysis, many of them have been shown to be inaccurate [6].

DISCUSSION

The Indian Metrological Department (Pune) provides advance weather predictions for India, which are then disseminated through media outlets including radio, television, newspapers, etc. In order to anticipate the atmospheric conditions for a certain area and time, science and technology are used. predicting involves correct knowledge of the current local weather conditions with respect to all of the weather aspects at the time of predicting as well as knowledge of the average and seasonal weather conditions of the area.

Different kinds of weather forecasting

Weather forecasts come in four different varieties.

1. A short-term forecast
2. A further prediction
3. Long-term outlook
4. Start casting

Short-range forecast: The daily weather predictions are short-range forecasts and are mostly based on current weather data. Pressure, temperature variations, and cyclonic tendencies are the main influencing factors. Irrigation engineers, mariners, and aviators can take timely precautions during storms, cyclones, heavy rains, etc.; they can also take preventative measures against potential flood and storm damages by installing suitable embankments and drains where necessary. It has a 70-80% accuracy rate and is valid for 24 to 48 hours [7].

Uses

scheduling irrigation, modifying the timing of agricultural activities, and protecting plants from frost. Long-range forecasting is useful for predicting the weather for the next one to two months. The ability to adapt cropping to the projected climate is made possible by long-range seasonal predictions.

Uses

To make decisions on crop choices, managing irrigation with a restricted water supply, managing soil moisture management, and crop pattern

Lengthy Forecast: This prediction is accurate to within 60% to 70% and is excellent for 5-7 days. It emphasises the kind of weather, the sequence of rainy days, common weather dangers in farming, such as high winds, lengthy dry or wet periods, and keeps true for 5-7 days. It is beneficial for several agricultural processes, including planting, spraying, etc.

Uses

1. Useful for timing the sowing process and judging the sowing depth.
2. Harvesting schedule Pesticide and foliar nutrition spraying window.

Agriculture management

Weather forecasts are provided two to three hours in advance. For aviation and navigation, it will be helpful. Lighting may be predicted by now casting, which makes predictions up to 6 hours in advance using the environment as seen from satellites and radar [8].

Important facts: Approximately 300 meteorological observation stations of various sorts are dispersed across India, and IMD has six Regional Meteorological Centres. Chennai, Guwahati, Kolkata, Mumbai, Nagpur, and New Delhi are the locations of these. Every state capital (Punjab=Chandigarh) also has a meteorological centre.

Parent: The Government of India's Ministry of Earth Sciences.

Synoptic chart: The observations are shown on a sizable outline map that is formally known as a Synoptic chart but is more often referred to as a weather map. The forecaster moves on to the analysis after finishing the synoptic chart charting. The isobars (lines along which the pressure is the same) are drawn as the initial step in the study [9].

Agriculture-related norms for field crops

Climate norms are the levels of temperature, precipitation, humidity, and other factors that separate the ideal circumstances for development from those that are deemed abnormal due to excess or deficiency. Field crop agroclimatic normals research may be used for the following purposes: For agricultural planning. Helpful for introducing any crop. The advantage will be greatest if the crop is introduced in a climate that is compatible with its needs. effective for predicting unusual weather

Climate scales and their significance:

Microclimate

Microclimate is concerned with the climatic characteristics unique to tiny places as well as the physical processes that occur in the air layer that is very close to the ground. Conditions of the soil-ground, the type of vegetation cover, the aspect of slopes, the condition of the soil surface, and relief patterns can all produce unique local conditions of temperature, humidity, wind, and radiation in the layer of air close to the ground that are significantly different from the general climatic conditions. Studying the characteristics of the surface layer of soil and the air near the ground, which is referred to as the micro climate, is one of the most important jobs in agricultural meteorology [10].

Mesoclimate: Meso climates are situated between micro and macro climates in terms of size. It focuses on the analysis of climate across comparatively smaller regions between 10 and 100 km in size.

The overall climate: The study of the atmosphere across a vast portion of the earth's surface and the large-scale atmospheric processes that produce weather are both topics covered by macro climate.

CONCLUSION

Science and technology develop, the prospect for greater data assimilation, higher-resolution models, and the incorporation of real-time observations promises to revolutionise weather forecasting capabilities. More long-range predictions and climate change projections may be made possible through the development of complete global climate models. In conclusion, weather forecasting is still a crucial area of research that is always developing to address the problems brought on by changing atmospheric processes and social expectations. Weather forecasting will surely continue to be a key component of managing weather-related hazards and promoting sustainable development via a mix of scientific understanding, cutting-edge technology, and multidisciplinary partnerships.

REFERENCES:

[1] J. G. Powers *et al.*, "The weather research and forecasting model: Overview, system efforts, and future directions," *Bull. Am. Meteorol. Soc.*, 2017, doi: 10.1175/BAMS-D-15-00308.1.

[2] A. Sibley, D. Biesecker, G. Millward, and M. Gibbs, "Space weather, impacts and forecasting: An overview," *Weather*. 2012. doi: 10.1002/wea.1915.

[3] A. Papadopoulos, P. Katsafados, G. Kallos, and S. Nickovic, "The weather forecasting system for POSEIDON - An overview," *Glob. Atmos. Ocean Syst.*, 2002, doi: 10.1080/1023673029000003543.

[4] F. J. Doblas-Reyes, J. García-Serrano, F. Lienert, A. P. Biescas, and L. R. L. Rodrigues, "Seasonal climate predictability and forecasting: Status and prospects," *Wiley Interdiscip. Rev. Clim. Chang.*, 2013, doi: 10.1002/wcc.217.

[5] H. Zhang and Z. Pu, "Beating the Uncertainties: Ensemble Forecasting and Ensemble-Based Data Assimilation in Modern Numerical Weather Prediction," *Adv. Meteorol.*, 2010, doi: 10.1155/2010/432160.

[6] S. Bingham, S. A. Murray, A. Guerrero, A. Glover, and P. Thorn, "Summary of the plenary sessions at European Space Weather Week 15: space weather users and service providers working together now and in the future," *J. Sp. Weather Sp. Clim.*, 2019, doi: 10.1051/swsc/2019031.

[7] F. Ardhuin, "The Interaction of Ocean Waves and Wind," *Eos, Trans. Am. Geophys. Union*, 2005, doi: 10.1029/2005eo170005.

[8] P. B. Chilson *et al.*, "Moving towards a network of autonomous UAS atmospheric profiling stations for observations in the earth's lower atmosphere: The 3D mesonet concept," *Sensors (Switzerland)*. 2019. doi: 10.3390/s19122720.

[9] J. T. Heming *et al.*, "Review of Recent Progress in Tropical Cyclone Track Forecasting and Expression of Uncertainties," *Trop. Cyclone Res. Rev.*, 2019, doi: 10.1016/j.tcrr.2020.01.001.

[10] G. J. Maglaras, J. S. Waldstreicher, P. J. Kocin, A. F. Gigi, and R. A. Marine, "Winter weather forecasting throughout the eastern United States. Part I: an overview," *Weather Forecast.*, 1995, doi: 10.1175/1520-0434(1995)010<0005:WWFTTE>2.0.CO;2.

CHAPTER 2

ANALYSIS OF WEATHER PREDICTION

Dr.Ashiwini Kr Tyagi, Associate Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

Analysing several atmospheric characteristics to anticipate weather conditions over a certain period and place is a key component of meteorology. An overview of the analytical methods used in weather forecasting is provided in this study, covering data collecting, numerical modelling, and the use of cutting-edge technologies like machine learning and artificial intelligence. The importance of weather forecasting in many industries and its influence on decision-making processes are introduced in the first part. In order to reduce weather-related hazards and improve resource management, it emphasises the necessity for precise and timely predictions. The second part of the article concentrates on the systems and procedures for gathering meteorological data. This covers radar systems, satellite observations, ground-based weather stations, and other remote sensing tools. The quality and thoroughness of weather analysis are improved by combining data from several sources. The core of contemporary weather analysis, numerical weather prediction models, are covered in depth in the third part. To mimic atmospheric behaviour and forecast weather, these models make use of meteorological equations and physical principles. The research examines several numerical modelling techniques, including global and regional models, and identifies their advantages and disadvantages. The integration of ensemble forecasting methods to evaluate forecast uncertainty is explored in the fourth part. Ensemble forecasting generates probabilistic predictions, which are essential for informing the public and decision-makers about uncertainties. It does this by performing numerous simulations with modest modifications in the beginning circumstances. The rise of machine learning and artificial intelligence in weather prediction is covered in the fifth part. These technologies are used to anticipate severe weather occurrences, enhance model performance, and assimilate data. Their potential to increase forecast efficiency and accuracy is discussed in the study.

KEYWORDS:

Development, Science, Society, Technology, Weather Forecasting.

INTRODUCTION

Weather is only the state of the atmosphere on Earth at a certain location and time. This process is ongoing, data-intensive, complex, chaotic, and dynamic. These characteristics make predicting the weather a difficult task. Forecasting is the practice of making assumptions about future events based on past experience. One of the most difficult scientific and technical tasks in the past century has been predicting the weather. Making an accurate forecast is one of the biggest difficulties that meteorologists face globally. The ability to anticipate the weather has long been one of the most intriguing and engaging fields. Numerous techniques have been used by scientists to anticipate meteorological features, some of which are more accurate than others. The foundation of scientific weather forecasting, which focuses on predicting the atmosphere's condition at a specific region, is meteorological knowledge [1].

Human weather forecasting is an example of needing to make decisions in the face of uncertainty. Forecasts for the weather are often created by gathering quantitative data on the atmosphere's present condition and utilising scientific knowledge of atmospheric processes to predict how the atmosphere will change in the future. In recent years, it has become apparent how important it is to learn more about how the brain works when predicting the weather. Although most human forecasters employ methods based on the science of meteorology in common to address the problems of the endeavour, predicting the weather for human practitioners becomes a task for which the specifics might be uniquely personal.

The goal of weather forecasting is to foresee future changes to the atmosphere. Ground observations, observations from ships, observations from aeroplanes, radio noises, doppler radar, and satellites are all used to determine the current weather conditions. These details are sent to meteorological facilities where the data is gathered, examined, and transformed into a variety of charts, maps, and graphs. The tens of thousands of observations are transferred into surface and upper-air maps using today's high-speed computers. Critical information about the weather's future is provided through weather forecasts. Weather forecasting uses a variety of methods, from very simple sky observation to extremely intricate computerised mathematical models. Weather forecasts might be made for the next day, week, or even months. However, after a week, weather prediction accuracy substantially declines. Due to the chaotic and unpredictable character of the weather, weather forecasting is still a challenging field.

It is still a process that is equal parts art and science. People with little to no formal training are recognised to be able to gain significant predicting skills. Like pilots, anglers, mountain climbers, etc., farmers are often fairly competent of creating their own short-term predictions of those meteorological conditions that directly impact their livelihood. The safety and/or economic stability of such people are directly impacted by weather events, which are often complicated in nature. Third world nations, where the whole crop relies on the weather, need accurate weather forecasting models. The country's economy would be severely impacted if any patterns for weather parameters to depart from their periodicity were to emerge. The danger posed by the greenhouse effect and global warming has made this anxiety worse. Extreme weather events have an increasingly expensive effect on civilization, resulting in infrastructure damage, injury, and fatalities.

Weather forecasting nowadays is a highly developed ability that is based on scientific theory and methodology and makes use of cutting-edge technical instruments, as practised by the professionally educated meteorologist. Since 1950, there has been a noticeable increase in prediction accuracy, which may be directly attributed to technology advancements, fundamental and applied research, and the use of new information and techniques by weather forecasters. Tools that have significantly improved weather predictions include meteorological satellites, weather radars, and high-speed computers.

This improvement in predicting accuracy has been strongly influenced by a number of different variables. The first is the development of statistical techniques for expanding the range and precision of model predictions. The enhanced observational capacity made possible by meteorological satellites is another. The ongoing development of the starting conditions created for the forecast models is a third major factor contributing to the growth in accuracy. Statistical techniques enable the prediction of a larger range of meteorological components than do the models by themselves, and also target the geographically less accurate model predictions to particular regions. The capacity to see and remotely sense the atmosphere on a large scale is now made possible by satellites. An increase in observations and improved computational tools' exploitation of those data are what improved the beginning circumstances [2].

DISCUSSION

Traditionally Forecast Weather

The use of science and technology to anticipate the atmosphere's condition at a specific area is known as weather forecasting. Weather predictions are created by gathering quantitative information about the atmosphere's present condition and utilising scientific knowledge of atmospheric processes to predict how the atmosphere will change. Weather predictions have many different end users. Weather warnings are crucial predictions because they serve to save property and human life. Forecasting in the past relied mostly on the observation of weather patterns. Various methods for predicting rainfall have evolved throughout time as a consequence of research into weather patterns. Forecasting rainfall at the moment combines computer models, interpretation, and knowledge of meteorological trends. For current weather forecasting, use the following method.

Using A Barometer

Since the late 19th century, forecasting has made use of measurements of the barometric pressure and the pressure tendency. The size of the pressure shift will determine how much of a change in the weather to anticipate. There is a higher likelihood of rain if the pressure drops quickly, which indicates the approach of a low-pressure system.

Observing the sky: The state of the sky is one of the most crucial factors used to anticipate weather in mountainous places, along with pressure tendency. Rain is likely to fall soon if the cloud cover thickens or a higher cloud deck invades the sky. Halos around the moon may form at night under high, thin clouds, signalling the arrival of a warm front and the accompanying rain. As rainy circumstances are preceded by wind or clouds that hinder fog development, morning fog heralds favourable conditions.

Nowcasting

The term "nowcasting" refers to the process of predicting the weather for the next six hours. Smaller characteristics, such as individual showers and thunderstorms, as well as other elements too tiny to be resolved by a computer model, may be reasonably projected in this time range. Given the most recent radar, satellite, and observational data, a person will be better able to analyse the small scale characteristics present and, as a result, will be able to provide a prediction for the next few hours that is more accurate [3] .

Analogue Method

The analogue approach is a difficult strategy to predict the weather since it requires the forecaster to recall a past weather event that is anticipated to be duplicated by an impending occurrence. It is still an effective way to monitor rainfall in areas like seas and to predict future precipitation levels and distribution. When systems in different places are utilised to assist in locating another system within the surrounding regime, this method is known as teleconnections in medium-range forecasting.

Model for Numerical Weather Prediction

The science of numerical weather prediction (NWP) makes weather predictions by employing computer methods and atmospheric model simulations. In order to anticipate the weather, mathematical models of the atmosphere are fed current weather data. This model typically outputs points with a few-kilometer spatial resolution around the wind farm.NWP creates a forecast using the power of computers. A forecaster looks at how the computer-predicted characteristics will combine to create the weather for the day. The NWP technique has a problem since the models' simulations of the atmosphere employ imprecise equations.

Several weather forecasting organisations offer modelling facilities where supercomputers are utilised to perform global NWP models. These include the European Centre for Medium-range Weather Forecasts (ECMWF), the United Kingdom Meteorological Office (UKMO), and the National Centre for Environmental Prediction (NCEP) in the United States. A worldwide approach to NWP is necessary, even if it is expensive, particularly for long-range forecasting. As a result, in order to provide reliable projections, the model must be begun with an accurate analysis. The most recent meteorological data from across the globe is blended with model projections in a process known as data assimilation to provide a worldwide picture of the present situation. This serves as the starting point for the subsequent NWP model run and is the computer counterpart of the ongoing human analysis cycle that forecasters do. Modern weather forecasting relies heavily on global models, and Met Service meteorologists often employ the NCEP, UKMO, and ECMWF models to help with day-to-day forecast and weather warning output [4]. Without placing considerable focus on regional specifics, these models provide insight into the behaviour of weather systems on a broad scale.

Group forecasting

In order to anticipate the weather, meteorologists have created atmospheric models that roughly represent the environment by describing how atmospheric temperature, pressure, and moisture would vary over time using ensemble forecasting. Equations are entered into a computer, which is also provided data on the current atmospheric conditions. To predict how the many atmospheric factors will change over the next minutes, the computer solves the equations. The output from one cycle serves as the input for the subsequent cycle as the computer repeatedly performs this process.

The computer outputs the results of its calculations for a selected future time. The data is then analysed, and lines are drawn to represent the different pressure systems' predicted positions. The prognostic chart serves as a guidance for forecasters when making weather predictions. The atmosphere is represented by a variety of atmospheric models, each of which interprets the atmosphere somewhat differently. 12 and 24-hour weather predictions are frequently accurate. Two- or three-day forecasts are often accurate. Forecast accuracy significantly decreases for forecasts longer than five days. Radar and satellite remote sensing, in particular, may provide weather data.

Radar

Radio Detection and Ranging is known as radar. A transmitter in radar emits radio waves. The radio waves return to the receiver after bouncing off the closest object. The location, speed, intensity, and possibility of future precipitation are only a few of the features of precipitation that may be detected by weather radar. Doppler radar, which can also detect how quickly precipitation falls, makes up the majority of weather radar. In order to evaluate the likelihood that a storm may create severe weather, radar can sketch the structure of the storm. Since the first weather satellite was launched in 1952, they have become one of the most significant sources of weather information. The greatest method to keep an eye on large-scale processes, like storms, is through weather satellites. Satellites can also track the movement of pollutants, fire smoke, and ash from volcanic eruptions. They have the capacity to document lengthy changes [5].

Climate Charts

Weather maps clearly and visually represent atmospheric meteorological conditions. Weather maps may just show one atmospheric aspect or a variety of elements. They may represent data derived from both human observations and computer simulations. Newspapers, television, and the Internet all include weather maps. Each weather station will have significant meteorological conditions depicted on a weather map. Temperature, the present state of the weather, dew point, cloud cover, air pressure at sea level, and wind speed and direction may all be considered. The symbols that meteorologists use on a weather map are quite diverse. They now have a fast and simple approach to add information to the map thanks to these symbols.

The two main approaches employed in weather predicting are the empirical and dynamical approaches. analogues and is sometimes referred to as analogue forecasting by meteorologists. This method often works well in areas where there are plenty of locally reported instances. The dynamical technique, often known as computer modelling, is based on equations and forward simulations of the environment. This dynamical technique can effectively simulate and forecast short-term weather. The majority of weather forecasting systems include both dynamical and empirical methods.

Different Kinds of Weather Forecasting

The labour of thousands of observers and meteorologists from across the globe goes into a daily weather prediction. Forecasts are more precise than ever thanks to modern technology, and weather satellites orbit the earth. The empirical technique and the dynamical approach are typically the two methodologies utilised in weather forecasting. The empirical method, which is based on the existence of analogues, is sometimes referred to as analogue forecasting by meteorologists. If there are many records, this method often works well for forecasting local weather. The dynamical technique, often known as computer modelling, is based on an equation and the forward ns of the atmosphere. Although it may not accurately predict weather, this dynamical technique is effective for modelling large-scale weather occurrences. The majority of weather prediction systems mix rical and dynamical methods.

Categories of Weather Prediction

The labour of thousands of observers and meteorologists from across the globe goes into a daily weather prediction. Forecasts are more precise than ever thanks to modern computers, and weather satellites that circle the planet capture images of clouds from space.

There are typically two approaches used in weather forecasting: the empirical

If there are many examples of documented occurrences, meteorologists will often refer to the empirical technique as analogue scale weather. The dynamical technique, often known as computer modelling, is based on an equation and the forward ns of the atmosphere. This kind of meteorological phenomenon may not be accurately described as weather. the majority of weather prediction systems combine. The labour of thousands of observers and meteorologists from across the globe goes into a daily weather prediction. Forecasts now are more precise than images of clouds taken from space by citing the earth. In order to create their predictions, forecasters use data from the air and space with calculations and guidelines derived from previous events. To create their daily weather predictions, meteorologists really use a number of diverse techniques. They are

Forecasting for Persistence

Persistence forecasting is the simplest approach of weather prediction. It uses the situations of today to predict the conditions of future. When the weather is stable, as it is throughout the summer in the tropics, this may be a reliable method of predicting the weather. There must be a persistent weather pattern for this forecasting technique to work. Both short-term and long-term projections may benefit from it. This presupposes that the current weather will continue to be how it is. Meteorologists make meteorological observations to learn more about the weather.

Synoptic Prediction

The fundamental forecasting criteria are used in this strategy. The guidelines are then applied to the data by meteorologists to provide a short-term prediction.

Statistical Prediction

What does it typically do at this time of year, wonder meteorologists? Forecasters may get a notion of what the weather is "supposed to be like" at a certain period of the year by looking at historical records of average temperatures, rainfall, and snowfall [6].

Electronic forecasting

Forecasters use their observations to input data into challenging calculations. These numerous equations are processed by a number of very fast computers to create computer "models" that provide forecasts for the next few days. The other forecasting techniques must always be used by meteorologists in addition to this one since various equations often provide different outcomes. The following characteristics may be used to define each weather forecast:

1. Dominant technology
2. Temporal range of validity after emission
3. Time and spatial resolution characteristics
4. Broadcasting requirements
5. Accuracy

Weather Forecasting's Importance

The use of weather forecasting is widespread, including for severe weather warnings and advisories, cloud behaviour forecasting for air travel, marine waterway forecasts, agricultural planning, and forest fire prevention.

Severe Weather Warnings and Alerts: The National Weather Service's severe weather warnings and advisories, which are issued in advance of the possibility of severe or dangerous weather, play a significant role in contemporary weather forecasting. To safeguard both life and property, this is done. The severe thunderstorm and tornado warning and severe thunderstorm and tornado watch are two of the most well-known severe weather advisories. Winter weather, strong winds, floods, tropical cyclones, and fog are further types of these warnings. Using emergency systems like the Emergency Alert System, which interrupts normal programming, severe weather warnings and alerts are issued via the media, including radio [7].

Predicting the cloud's behaviour for transport via air

Since the aviation sector is particularly weather-sensitive, precise weather forecasting is crucial. Many aeroplanes may be unable to land or take off due to fog or unusually low ceilings. Additional severe in-flight risks include turbulence and ice. Because of the extreme turbulence caused by thunderstorms' updrafts and outflow limits, ice from the heavy precipitation, enormous hail, high winds, and lightning, which may all seriously harm an aircraft in flight, thunderstorms are a danger for all types of aircraft. In addition to being a major issue for aviation, volcanic ash may cause aeroplanes to lose engine power.

prediction of a sea's waterways

Wind direction, speed, wave frequency, high tides, and precipitation may all considerably restrict the usage of waterways for commercial and recreational purposes. Each of these elements has the potential to affect how safe sea travel is. As a result, a number of codes, such as marine forecast, have been developed to effectively send thorough maritime weather predictions to vessel pilots through radio. Radio fax may be used to obtain standard weather predictions at sea.

Weather has a big impact on how much food is produced in agriculture. It has a significant impact on a crop's growth, development, and yields as well as the prevalence of pests and diseases, the need for water and fertiliser due to variations in nutrient mobilisation caused by water stress, and the timeliness and efficacy of preventative and cultural operations on crops. Weather anomalies have the potential to harm crops physically and erode soil. Weather affects the crop's quality as it is transported from the farm to storage and then to the market. The viability and vigour of seeds and planting materials during storage as well as the quality of the product during transportation may be impacted by bad weather.

Avoiding tree fire

For the purpose of putting out and managing wildfires, weather forecasting of wind, precipitation, and humidity is crucial. To identify the places most vulnerable to fire from either natural or human sources, many indexes, such as the Forest fire weather index and the Haines Index, have been created. Weather forecasting may also be used to anticipate the conditions that will lead to the emergence of dangerous insects [8].

Applications in the military

Military weather forecasters inform the military community of the meteorological conditions. Military weather forecasters provide pilots weather briefings before to takeoff and throughout flight, as well as real-time resource protection services for military facilities. Weather predictions for ships and the oceans are covered by naval forecasters. Through its Joint Typhoon Warning

Centre, the Navy offers a unique service to both themselves and the rest of the federal government by providing predictions for tropical cyclones throughout the Pacific and Indian Oceans.

Armed Forces

Armed Forces the Air Force and the Army get weather forecasts from Weather. Forecasters from the aviation Force serve the Army and cover aviation operations in both war and peacetime. In the analysis and production of weather prediction products, military and civilian forecasters actively collaborate [9].

The Indian Meteorological department in Kanyakumari District, Tamil Nadu, has provided weather data for ten years (2001-2010) to researchers. Two groups of the selected weather data are created: the training group, which contains 75% of the data, and the test group, which contains 25% of the data. Today's weather predictions rely on gathering and examining information and observations from all around the globe. AccuWeather.com and Weather.com are where some of the incorrectly categorised data came from. Instead of giving regular users the ability to manipulate and interactively identify potential threats associated with impending weather hazards, it supported meteorologists in their analysis and forecasting of customised weather forecasts for a city or metropolitan area. There are fourteen characteristics in the data collection. One is Bar Temperature.

These are the research study's goals: creating effective and efficient prediction models for weather analysis for the Kanyakumari District, Tamil Nadu, India, in order to investigate the applicability of the neural network technique. to create a weather forecasting system based on fuzzy ARTMAP neural network, generalised regression neural network, back propagation neural network, and radial basis function neural network. MATLAB was used as a tool to compare and assess the performance of the aforementioned models and to carry out the programming. The purpose of this study is to assess the effectiveness of the aforementioned neural network models using a selected dataset [10].

CONCLUSION

The difficulties and restrictions associated with weather prediction analysis are assessed in the sixth part. This includes problems with data gaps, model biases, and the atmosphere's innate chaos, all of which add uncertainty to projections. The practical uses of weather prediction analysis in a variety of industries, including disaster management, agriculture, transportation, and aviation. It demonstrates how precise predictions help with operational optimisation and reducing weather-related interruptions. The potential for weather prediction analysis in the future. Technology advances, better data assimilation, higher-resolution models, and the possible incorporation of real-time observations all promise to revolutionise weather forecasting capabilities. In conclusion, weather prediction analysis continues to be a critical and dynamic area that is always developing to meet the problems provided by an environment that is intricate and constantly changing. The accuracy and effectiveness of weather predictions may be significantly increased by fusing conventional meteorological techniques with cutting-edge technology, enabling a safer and more robust future for civilization.

REFERENCES:

[1] A. LORENC, "Analysis methods for numerical weather prediction," *Q. J. R. Meteorol. Soc.*, 1986, doi: 10.1256/smsqj.47413.

[2] S. Dirren, M. Didone, and H. C. Davies, "Diagnosis of 'forecast-analysis' differences of a weather prediction system," *Geophys. Res. Lett.*, 2003, doi: 10.1029/2003GL017986.

[3] F. Sheikh, S. Karthick, D. Malathi, J. S. Sudarsan, and C. Arun, "Analysis of data mining techniques for weather prediction," *Indian J. Sci. Technol.*, 2016, doi: 10.17485/ijst/2016/v9i38/101962.

[4] S. Karthick, D. Malathi, and C. Arun, "Weather prediction analysis using random forest algorithm," *Int. J. Pure Appl. Math.*, 2018.

[5] S. Madan, P. Kumar, S. Rawat, and T. Choudhury, "Analysis of Weather Prediction using Machine Learning Big Data," in *Proceedings on 2018 International Conference on Advances in Computing and Communication Engineering, ICACCE 2018*, 2018. doi: 10.1109/ICACCE.2018.8441679.

[6] L. Dong, L. Wang, S. F. Khahro, S. Gao, and X. Liao, "Wind power day-ahead prediction with cluster analysis of NWP," *Renewable and Sustainable Energy Reviews*. 2016. doi: 10.1016/j.rser.2016.01.106.

[7] A. Hollingsworth, "Objective Analysis for Numerical Weather Prediction," *J. Meteorol. Soc. Japan. Ser. II*, 1986, doi: 10.2151/jmsj1965.64a.0_11.

[8] M. J. Souto, C. F. Balseiro, V. Pérez-Munuzuri, M. Xue, and K. Brewster, "Impact of cloud analysis on numerical weather prediction in the Galician region of Spain," *J. Appl. Meteorol.*, 2003, doi: 10.1175/1520-0450(2003)042<0129:IOCAON>2.0.CO;2.

[9] P. T. R, "A Comparative Study on Decision Tree and Random Forest Using R Tool," *IJARCCE*, 2015, doi: 10.17148/ijarcce.2015.4142.

[10] A. Mariotti, P. M. Ruti, and M. Rixen, "Progress in subseasonal to seasonal prediction through a joint weather and climate community effort," *npj Clim. Atmos. Sci.*, 2018, doi: 10.1038/s41612-018-0014-z.

CHAPTER 3

IMPORTANCE OF WEATHER FORECASTING

Dr. Raj Kumar, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

The ability to predict the weather has a significant impact on a variety of industries and facets of everyday life in today's society. This study examines the crucial contributions that weather forecasting makes to a variety of fields, such as agriculture, transportation, disaster management, public safety, and economic planning. The need of precise weather forecasts for the agricultural industry is emphasised in the first part. Weather predictions help farmers plan planting times, regulate irrigation, and use crop protection techniques more effectively, thus increasing agricultural production and food security. The importance of weather forecasting in transportation is covered in the second part. Planning air, marine, and land transport with accurate predictions helps to minimise risks from bad weather and maximise route effectiveness. This results in increased safety, fewer delays, and cheaper operating expenses. The crucial function that weathers forecasting plays in catastrophe management is examined in the third segment. Early warnings of severe weather conditions, such as hurricanes, floods, and heatwaves, enable governments and communities to mobilise resources for disaster planning and response to take preventive actions. This segment, which focuses on public safety, discusses how weather predictions provide people crucial information that they may use to make choices and take the appropriate safety measures when faced with hazardous weather conditions like intense heat, cold, or storms. The importance of weather forecasting on the economy is covered in the fifth part. To optimise resource allocation, manage operations, and reduce weather-related losses, industries including energy production, construction, tourism, and retail significantly depend on accurate weather forecasts.

KEYWORDS:

Accurate, Atmosphere, Forecasting, Radar, Weather.

INTRODUCTION

Weather is only the state of the atmosphere on Earth at a certain location and time. This process is ongoing, data-intensive, complex, chaotic, and dynamic. The foundation of scientific weather forecasting, which focuses on predicting the atmosphere's condition at a specific region, is meteorological knowledge. Human weather forecasting is an example of needing to make decisions in the face of uncertainty. Critical information about the weather's future is provided through weather forecasts. Weather forecasting uses a variety of methods, from very simple sky observation to extremely intricate computerized mathematical models. Forecasts for the weather might be made for the next day, week, or even months. Temperature is the primary factor used in weather predictions, but wind speed and relative humidity are also crucial factors for the agricultural industry and many other sectors that heavily rely on the weather [1].

The application that uses science and technology to anticipate the atmosphere's condition at a specific point in the future is called weather forecasting. Actually, accurate weather forecasting required a significant investment of time, money, skill, and technological resources. Complex mathematical computations must be performed. Weather predictions are created by gathering quantitative information about the atmosphere's present condition at a specific location and utilising scientific knowledge of atmospheric processes to predict how the atmosphere will evolve. The goal of weather forecasting is to foresee future changes to the atmosphere. A strong data collection is essential for weather forecasting. An effective forecasting technique. The following weather factors are regularly measured:

1. Humidity, pressure, temperature, and wind direction and speed.
2. Current and historical weather, precipitation, cloud (kind and quantity), visibility, pressure change temperature ranges, minimum and maximum, etc.

Observation types

The following are the primary observations utilized in various methods of weather forecasting:

1. Surface observations
2. Observations from above
3. Aviation observances
4. Radar observations
5. Observations from satellites

In order to create various charts, maps, and graphs, the data are gathered, analyzed, and delivered to meteorological centers. The tens of thousands of observations are transferred into surface and upper-air maps using today's high-speed computers.

Value Of Weather Prediction

The use of weather forecasting is widespread, including during severe weather warnings and alerts, predicting cloud patterns for air travel, and forecasting waterways in a sea, the expansion of agriculture, and stopping forest fires. The ability to utilize weather forecasts to safeguard people and property makes them incredibly valuable. The organization and planning of our everyday lives depend on weather forecasts. Its forecast helps us make the right choice on a certain day and at a specific moment. To plan a flight, a pilot has to be aware of the weather. A businessman should be aware of the loss and profit in his enterprise for a sudden and impetuous circumstance. For a farmer to produce a robust crop. Among the several elements that affect crop. In terms of output, the weather is crucial because: Up to 50% of variability in crop productivity may be accounted for by aberrations in it alone. Rainfall is the most crucial component of the needed prediction since it determines the harvest. Output in an area, and eventually the economy of the whole nation. Making preparations for moisture preservation during a poor monsoon and for a area needs flood assistance when there is a severe monsoon. When properly communicated, a trustworthy weather prediction will open the door for successful sustainability.

One can reduce any harm that poor weather may bring, either directly or indirectly. If accurate predictions on the occurrence of pests and diseases are delivered in a timely manner based on meteorological factors, the repeated crop losses may be reduced. By using buffer stock activities, aid in limiting the price of food grains. This implies that the government may buy during excellent monsoon years when prices are down and that it may sell some of its purchases during terrible monsoon years when prices are rising. Depending on the prediction, judicious water usage in an area may be planned [2].

DISCUSSION

Development Of Agriculture

The weather has a big impact on how much food is produced. It has a significant impact on a crop's growth, development, and yields as well as the prevalence of pests and diseases, the need for water and fertiliser due to variations in nutrient mobilisation caused by water stress, and the timeliness and efficacy of preventative and cultural operations on crops. Weather anomalies might result in: (i) physical crop damage (ii) soil erosion. Weather affects the crop's quality as it is transported from the farm to storage and then to the market. The viability and vigour of seeds and planting material during storage as well as the quality of the product during transportation might be impacted by bad weather.

Preventing Forest Fire

For the purpose of avoiding and managing wildfires, weather forecasting of wind, precipitation, and humidity is crucial. A variety of indexes, like the Haines Index and the Forest Fire Weather Index, have been established to identify places that are more likely to incur fire due to either human or natural causes.

Applications in the military

Military weather forecasters inform the military community of the meteorological conditions. Military weather forecasters provide pilots weather briefings before to takeoff and throughout flight, as well as real-time resource protection services for military facilities. Weather predictions for ships and the oceans are covered by naval forecasters. Through its Joint Typhoon Warning Centre, the Navy offers a unique service to both themselves and the rest of the federal government by providing predictions for tropical cyclones throughout the Pacific and Indian Oceans.

Armed Forces

The Air Force and the Army get weather forecasts from Weather. Forecasters from the aviation Force serve the Army and cover aviation operations in both war and peacetime. In the analysis and production of weather prediction products, military and civilian forecasters actively collaborate.

Area Of Weather Projections

Crops should be planted at the best time for greatest production, which reduces crop losses from extreme weather conditions including cyclones, heat waves, and cold waves. Through short-, medium-, and long-range projections, it assists in predicting pests and diseases, crop selection, irrigation, and other cross-cultural activities. The following are a few scopes:

1. To do research on the local climate resources in order to plan crops efficiently.
2. To develop weather-based efficient farming methods.
3. To investigate the links between agricultural weather and all significant crops and to anticipate crop yields using agroclimatic and spectral indicators.
4. To research the connection between meteorological variables and the prevalence of pests and illnesses in different crops.

5. Delineate climatic, agroecological, and agroclimatic zones in order to define agroclimatic analogues and facilitate efficient and quick technology transfer for increasing crop yields.
6. In order to create crop weather calendars and infographics [3].
7. Create crop growth simulation models to calculate prospective yields in various agroclimatic zones.
8. To keep track of agricultural droughts in order to handle them effectively.
9. To provide weather-based agro-advisories that take into account seasonal climate forecasts and different sorts of weather forecasts in order to maintain crop output.
10. To look at crop canopy microclimatic elements in order to alter them for better crop development.
11. To investigate how the weather affects the soil environment where a crop is cultivated.
12. To better understand how weather affects protected environments, such as glass houses, in order to increase agricultural production,

The following characteristics may be used to define each weather forecast:

1. Prevailing technology
2. Validity window following emission
3. Time and spatial resolution characteristics of the input and output
4. Needs for broadcasting
5. Accuracy

Weather Prediction Methods

Analogous Method

This method is arbitrary. With this approach, weather charts are evaluated and the current condition is compared to a comparable one that occurred in the past. This approach is effective in the current environment. This approach is helpful for short-range forecasting as well. The forecaster's expertise and experience are key factors in the forecast's success.

Statistical techniques

This approach uses meteorological data to generate correlations and regressions. The long-range weather prediction may be made using this strategy. Forecasters may get a notion of what the weather is "supposed to be like" at a certain period of the year by looking at historical records of average temperatures, rainfall, and snowfall.

Numerical Processes

This method is essentially objective. Numerous equations are numerically solved utilising fast computers with plenty of memory. For projections over the short- and medium-term, this strategy is helpful.

Classical Weather Prediction

Forecasting in the past relied mostly on the observation of weather patterns. Various strategies for predicting rainfall have evolved throughout time as a consequence of research into weather patterns. Forecasting rainfall at the moment combines computer models, interpretation, and knowledge of meteorological trends. For current weather forecasting, use the following method [4].

Persistence

The simplest form of weather prediction was persistence, which used the circumstances of today to predict the conditions of tomorrow. When the weather is stable, as it is throughout the summer in the tropics, this may be a reliable method of predicting the weather. There must be a persistent weather pattern for this forecasting technique to work. As a result, this form of predicting becomes unreliable during a changing weather pattern. Both short-term and long-term projections may benefit from it.

Utilizing a barometer

Since the late 19th century, forecasting has made use of barometric pressure readings and the pressure tendency (the change in pressure over time). The greater the shift in pressure, particularly if it is more than 3.5 hPa (2.6 mmHg), the greater the projected change in the weather. There is a higher likelihood of rain if the pressure drops quickly, which indicates the approach of a low-pressure system. Rapid pressure increases are related to better weather, such as clearer sky.

Observing the sky

One of the key factors used to anticipate weather in hilly places, along with pressure tendency, is the state of the sky. Rain is likely to fall soon if the cloud cover becomes thicker or a higher cloud deck invades. Halos around the moon may form at night in high, thin cirrostratus clouds, signalling the arrival of a warm front and the accompanying rain. Fair weather is predicted by morning fog since wet circumstances are preceded by wind or clouds that prohibit fog production. A line of thunderstorms moving in might be a sign of an impending cold front. The absence of clouds is a sign of good weather in the near term. A bar may signal the approach of a tropical storm [5].

Current Weather Prediction

Utilizing forecasting models

The complete weather prediction used to be produced by a human forecaster. Forecast made using the data at hand. Currently, the majority of human involvement is limited to selecting a model based on a variety of factors, such as model biases and performance. Using a forecast model consensus and ensemble members of the different models might be useful lessen the predicted inaccuracy. The model data must be translated into weather predictions by humans.

Analogue methodology

The analogue approach is a difficult strategy to predict the weather since it requires the forecaster to recall a past weather event that is anticipated to be duplicated by an impending occurrence. It is still an effective way to monitor rainfall in areas like seas and to predict future precipitation levels and distribution. By using systems in different places to assist pinpoint the position of another system within the surrounding regime, a similar concept called as tele-connections is employed in medium-range forecasting [6].

Statistical Prediction

Several weather forecasting organizations offer modelling facilities where supercomputers are utilized to perform global NWP models. These include the European Centre for Medium-range

Weather Forecasts (ECMWF), the National Centre for Environmental Prediction (NCEP) in the United States, and the Met Office in the United Kingdom.

Group forecasting

In order to anticipate the weather, meteorologists have created atmospheric models that roughly represent the environment by describing how atmospheric temperature, pressure, and moisture would vary over time using ensemble forecasting. Equations are entered into a computer, which is also provided data on the current atmospheric conditions. To predict how the many atmospheric factors will change over the next minutes, the computer solves the equations. The output from one cycle serves as the input for the subsequent cycle as the computer repeatedly performs this process. The computer outputs the results of its calculations for a selected future time. The data is then analysed, and lines are drawn to represent the different pressure systems' predicted positions. 12 and 24-hour weather predictions are frequently accurate. Forecasts for the next two to three days are often accurate. Over a period of five days or more, prediction accuracy progressively decreases. Additionally, remote sensing techniques, notably radar and satellites, may provide weather information [7].

Radar

Radio Detection and Ranging is known as radar. A transmitter in radar emits radio waves. The radio waves return to the receiver after bouncing off the closest object. The location, speed, intensity, and possibility of future precipitation are only a few of the features of precipitation that may be detected by weather radar. Doppler radar, which can also detect how quickly precipitation falls, makes up the majority of weather radar. Radar can depict the general shape of a storm, estimating the likelihood that it will bring about severe weather [8].

Satellite Weather

Since the first weather satellite, Sputnik I, was launched in 1952, they have become one of the most significant providers of meteorological information. The greatest method to keep an eye on large-scale processes like hurricanes is using weather satellites. Satellites can also track the movement of pollutants, fire smoke, and ash from volcanic eruptions. They have the capacity to document lengthy changes. One of the geostationary satellites that monitors conditions across the globe. All electromagnetic radiation at all wavelengths can be observed by weather satellites. The infrared (heat) and visible light frequencies are the most significant ones.

Weather charts

Meteorological conditions are easily and visually represented on weather maps atmosphere. Weather maps may just show one atmospheric aspect or many features. They may represent data derived from both human observations and computer simulations. Newspapers, television, and the Internet all include weather maps. On a forecast map, there will be a plot of significant meteorological conditions for each weather station. These circumstances include things like temperature, the current weather, dew point, cloud cover, and air pressure at sea level wind direction and speed. Meteorologists depict the weather using a wide variety of symbols. They have a fast and simple approach to add information to the map thanks to these icons [9].

Modern weather predictions have substantially improved over the last 2,000 years, going from predicting one day in advance based on the colour of the sky to roughly a two-week perspective.

The risk management community evolved more swiftly because, in just a few years, the idea of a weather prediction transformed from being one best estimate at the future to a range of potential future weather possibilities. On time spans ranging from a few hours to many months, the ultimate goal of accurate probability predictions of economically significant variables is being sought [10].

CONCLUSION

The significance of weather forecasting in environmental monitoring and climate research is highlighted in the sixth part. In order to comprehend long-term climatic patterns and evaluate the effects of climate change, weather data is used in climate modelling. This segment explores weather forecasting from a global viewpoint, highlighting its importance for international collaboration and coordinated catastrophe response. For international commerce, humanitarian initiatives, and climate change adaption, accurate and fast meteorological information is essential. The summary closes by highlighting the ongoing efforts made by meteorologists and academics to increase the accuracy of weather forecasts via technological improvements, data assimilation methods, and multidisciplinary partnerships. Reliable weather predictions are an essential instrument in guaranteeing social well-being, economic stability, and environmental sustainability. Their advantages go well beyond meteorology.

REFERENCES:

[1] S. A. Murray, "The Importance of Ensemble Techniques for Operational Space Weather Forecasting," *Space Weather*. 2018. doi: 10.1029/2018SW001861.

[2] N. Boers, B. Goswami, A. Rheinwalt, B. Bookhagen, B. Hoskins, and J. Kurths, "Complex networks reveal global pattern of extreme-rainfall teleconnections," *Nature*, 2019, doi: 10.1038/s41586-018-0872-x.

[3] D. Lazos, A. B. Sproul, and M. Kay, "Optimisation of energy management in commercial buildings with weather forecasting inputs: A review," *Renewable and Sustainable Energy Reviews*. 2014. doi: 10.1016/j.rser.2014.07.053.

[4] E. L. Segarra, G. R. Ruiz, and C. F. Bandera, "Probabilistic load forecasting for building energy models," *Sensors (Switzerland)*, 2020, doi: 10.3390/s20226525.

[5] D. Ji *et al.*, "Assessing Parameter Importance of the Weather Research and Forecasting Model Based On Global Sensitivity Analysis Methods," *J. Geophys. Res. Atmos.*, 2018, doi: 10.1002/2017JD027348.

[6] J. Oh and B. Kim, "Prediction model for demands of the health meteorological information using a decision tree method," *Asian Nurs. Res. (Korean. Soc. Nurs. Sci).*, 2010, doi: 10.1016/S1976-1317(10)60015-1.

[7] J. Li, J. K. Ward, J. Tong, L. Collins, and G. Platt, "Machine learning for solar irradiance forecasting of photovoltaic system," *Renew. Energy*, 2016, doi: 10.1016/j.renene.2015.12.069.

[8] M. Lompar, M. Ćurić, and D. Romanic, "Simulation of a severe convective storm using a numerical model with explicitly incorporated aerosols," *Atmos. Res.*, 2017, doi: 10.1016/j.atmosres.2017.04.037.

[9] S. Mehrkanoon, “Deep shared representation learning for weather elements forecasting,” *Knowledge-Based Syst.*, 2019, doi: 10.1016/j.knosys.2019.05.009.

[10] J. Anderson, V. Daultani, T. Muman, and M. Batran, “The Importance of Weather for E-Commerce Orders Forecasting,” in *ACM International Conference Proceeding Series*, 2019. doi: 10.1145/3385061.3385064.

CHAPTER 4

A BRIEF STUDY ON WEATHER AND CLIMATE FORECASTING

Dr.Mohd Rizwan, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

In order to support informed decision-making across numerous industries, weather and climate forecasting are crucial scientific disciplines. They provide insightful knowledge about atmospheric conditions and climatic trends. The characteristics, methodology, and applications of weather and climate forecasting are highlighted in this study. The essential distinction between weather and climate forecasting is explained in the first section. While climate forecasting works with long-term trends and changes, spanning months to decades, weather forecasting concentrates on short-term atmospheric conditions, often lasting up to a week. It involves the gathering of meteorological data via satellites, radar systems, ground-based weather stations, and other remote sensing tools. Accurate and timely weather forecasts are made possible by the use of numerical weather prediction models, data assimilation methods, and ensemble forecasting. The third portion explores the difficulties associated with predicting weather as a result of the chaotic nature of the environment, data shortages, and uncertainty. The conversation centres on initiatives to boost prediction accuracy via improvements in model resolution, parameterizations, and observational methods. The subject of the fourth portion is climate forecasting, which entails examining past climate records, paleoclimate data, and global climate models. In order to better understand climatic variability, gauge the effects of climate change, and develop adaptation plans, climate models estimate long-term climate trends.

KEYWORDS:

Atmosphere, Climate, Forecasting, Prediction, Weather.

INTRODUCTION

The Biblical passage mentioned above is a classic example of a meteorologist making forecasts based on actual data. In the next 2,000 years, the concept it contains has been articulated in a variety of ways, with the tendency to function as a forecasting method. It is one of several proverbs and rhymes from folklore that provide a detailed account of the weather. The development of tools to monitor atmospheric variables in the 17th century led to meteorology's transformation into a quantitative discipline. Europe-wide meteorological data collection began in the 19th century. Many scientists started bemoaning the fact that efforts to study and comprehend meteorological data had lagged considerably behind endeavours to acquire the data in the 1800s . There have been attempts to identify patterns in meteorological tables, but they have mostly failed. The Palatine Mteorological institution of Mannheim, the world's first such institution, made attempts to connect weather to celestial movements in the late 18th century, as one example [1].

The discovery that mid-latitude low-pressure systems tend to advance eastward was made when scientists started plotting the expanding meteorological database on maps. Clouds in the west create a red sky at dawn before bringing bad weather, while clouds in the east redden the sky at sunset before clearing the way for clear skies. In addition to providing an explanation for the popularity of traditional folk knowledge, the discovery of mid-latitude eastward flow and the development of the telegraph enabled predictability to be extended beyond the horizon. There were several attempts to find cycles in time series of weather data in the late 19th and early 20th centuries.

Sir Gilbert Walker was one of the most active cycle hunters and finally one of the few who found success. Walker collected information on weather patterns throughout the world and spent years looking for connection. He found that the pressure in Tahiti and Darwin had an opposite relationship when carrying out this research. The "Southern Oscillation" is a finding that passed the following testing. It is now understood to be the El Nine-Southern Oscillation's atmospheric component. There were many more assertions that weather cycles existed, but few of them held up to statistical tests of robustness. By the 1930s, statistical methods that relied only on data had largely been abandoned by mainstream meteorology in their attempts to anticipate the status of the atmosphere. Since then, calculations of the atmosphere's recurrence period have shown that globally "similar" atmospheric conditions may only be anticipated to occur on time scales far larger than the age of the Earth. This finding implies that, with the exception of extremely short lead periods, when the local condition of the atmosphere is all that matters, there will never be enough data to build pure data-based prediction models.

A rising number of scientists began to hold the belief that the behaviour of the atmosphere could be predicted using the rules of physics as early as the 19th century. A scientist from Oregon by the name of Vilhelm Bjerknes was the main supporter of this viewpoint. Bjerknes thought that seven factors might be used to quantitatively express the challenge of forecasting the future development of the atmosphere: Each of the three components of air velocity pressure, temperature, density, and humidity is a function of both place and time. A differential equation might also be created for each of these seven variables using the recognised rules of dynamics and thermodynamics.

The flow of mass, momentum, energy, and water vapour are described by the equations. However, since these equations are non-linear partial differential equations, an analytical solution was not an option. British inventor Lewis Fry Richardson was working on a plan to solve the atmospheric motion equations of Bjerknes as the First World War raged. Richardson created a technique in 1911 for finding approximative PDE solutions. The strategy required partitioning space into a limited number of grid boxes and assuming that the variables are uniform within each grid box in order to approximate infinitesimal differences as finite differences. Although the provided answer is not precise, it becomes closer as the number of grid boxes rises. The atmospheric equations were subjected to Richardson's methodology, which resulted in a set of finite difference equations that could be resolved using simple arithmetic operations.

It is impossible to overstate how tough Richardson's accomplishment was. He had to make sure the issue was expressed in terms of quantifiable elements while designing his numerical weather prediction system, occasionally coming up with brand-new measuring techniques when necessary. He also needed to figure out how to handle turbulence. He connected the vertical stability of the atmosphere, which is today known as the Richardson number, with the vertical transmission of heat and moisture. The issue was that Richardson was really decades ahead of his time. His recipe was simple, but it was exceedingly time-consuming. He needed six weeks to complete only one six-hour prediction for two grid sites in Europe. The computations required to provide an operational prediction were not completed by an army of clerks as Richardson had anticipated.

The digital computer was created during the Second World War. John von Neumann, a pioneer of computers, tried to convince the US government of the value of this new technology after the War. Von Neumann chose weather forecasting as the perfect application to show the potential of the computer, despite not being a meteorologist. Richardson was responsible for formulating the issue in an algorithm that could be carried out by a computer but was impracticable to carry out manually. Furthermore, laypeople, generals, and politicians might all profit from accurate weather predictions. The first numerical weather prediction program was run on the ENIAC computer in 1950 by von Neumann's team under the direction of meteorologist Jules Charney. Thus started the development of an ongoing, close link between meteorology and cutting-edge computer science. For a thorough history of weather forecasting. It would be foolish to try to generate a perfect prediction of the atmosphere's future condition since we can never know the atmosphere's exact state. Due to this, operational prediction centers have created probability forecasts, a collection of potential outcomes based on somewhat varied perspectives of the status of the atmosphere right now. These probabilistic projections are more in line with the kind of data needed for efficient risk management and the costing of weather derivatives [2].

Modern Numerical Forecasting Weather forecasting may be split into three categories: short-, medium-, and long-range, rather arbitrarily. Short-range forecasting in this chapter refers to predicting the weather for the next one to two days. Long-range, or seasonal, forecasting seeks to anticipate the weather at lead periods of a month or more. Medium-range forecasting spans lead durations of three days to around two weeks. While many customers, like energy corporations, find short- and medium-term predictions useful for managing their operations, the weather derivatives markets are particularly interested in seasonal forecasts. These days, it is more and more typical for seasonal predictions to be created using computer models that are almost identical to those that are used to provide forecasts for the next day. In order to provide the reader some insight into the development of forecast products, we will briefly describe the main characteristics of these models in this section. Additionally, we want the reader to get acquainted with some of the technical terms that meteorologists use to describe their models. Limited area models may be used to provide short-range projections. These models cover a limited portion of the world using grid boxes. But weather systems may move halfway across the world in only two weeks. Therefore, a global model of the atmosphere is necessary for predicting in the medium or long term. The European Centre for Medium Range Weather Forecasting, financed by 19 nations and situated in Reading, UK, is the most sophisticated global model in use for operational forecasting.

ECMWF now produces daily predictions up to 10 days. The national meteorological services of the member nations disseminate these predictions. The current ECMWF global model is a T511 spectral model, which has 60 vertical levels and a horizontal resolution of 40 km. There are around 10 million different variables that together characterize the whole model state at any one moment. By moving ahead in time in stages of around 10 minutes, the state is developed. As a result, the model's ultra-high dimensional state space depicts the evolution of the atmosphere as a trajectory. The approximations introduced by representing continuous fields on a finite grid can be thought of as well-defined or mathematical approximations, which are sometimes referred to as "errors of representation." However, all numerical weather models also include a different set of physical assumptions. "Parameterizations" are the name given to these approximations. The geographic resolution of mathematical models is limited. As was already noted, the ECMWF global model is unable to accurately simulate weather or terrain at sizes less than 40 km. Even though it would be ideal to have knowledge on the distribution of rainfall on a much smaller scale, meteorological data that is averaged across tens of kilometres may still be highly helpful. The weather on lower "sub-grid" sizes may have a significant influence on the weather on larger scales, even if one is happy to accept weather predictions averaged across relatively wide areas. For instance, thunderstorms are too tiny to be resolved by global models, yet the convection and rainfall they produce have a significant effect on the energy balance of the atmosphere, which in turn affects the weather across a region considerably bigger than the storm itself. As a result, the equations that explain the development of the atmosphere at the higher scales must parameterize and incorporate the influence of sub-grid processes [3].

A parameterization scheme for cumulus convection must essentially forecast the amount of convection in a grid box solely as a function of the meteorological variables averaged over the grid box, and then forecast the impact this amount of convection will have on the time evolution of those meteorological variables. The construction of parameterization schemes often takes into account both the analysis of actual findings and a physical knowledge of the processes involved. In numerical models of the atmosphere, various phenomena, including as surface evaporation, drag from topography, and sub-grid turbulence, must be parameterized. One of the most significant and active fields of contemporary meteorological research is the development of improved parameterization techniques. Estimating the current condition of the atmosphere as it is portrayed by the model is necessary before using it to make a prediction. "Data assimilation" is the process of estimating the model's starting condition using observations. We refer to the assessment of the atmosphere's condition that results from weather and data assimilation as the analysis.

DISCUSSION

Climate for Easting

To effectively know the value of all the pertinent meteorological variables as they are represented on the model's grid points, one must first initialise the model. There are still significant gaps in the observational data collection, despite the enormous volumes of meteorological data that are gathered every day. Interpolation is the easiest method for closing these gaps, as shown by Richardson in his early studies with numerical forecasting. More complex methods actually blend the data from the observations with the numerical model's understanding of atmospheric dynamics. The "observation function" may be used to translate any model state into an estimate of the observations that would occur if the atmosphere were in that specific condition. A data assimilation method known as "variational assimilation" is used at ECMWF. The goal of this approach is to identify the model trajectory that results in the model that most closely matches the actual observations that were made. The model's trajectory is the route that its current state takes over time in its state space. Due to the vast number of variables that represent the model state, this space has a large dimension [4].

The goal of optimisation through variational assimilation is to obtain the model state that produces the best fit to the data across the assimilation period. The analysis used to initialise the prediction is then the state of the model at some point throughout the assimilation phase. The data assimilation use a '1'159 model with a lesser resolution. Forecasting centres also provide reanalysis products using data assimilation. These are historical projections of the atmosphere's condition into the grid-point representation of the model. They are built by methods that are comparable to those used to produce the analysis required to initialise projections. However, it is feasible to estimate the model state while conducting a reanalysis by using data from both before and after the period for which the state estimate is needed. Reanalysis products are reconstructions that are full in time and space, thus they may be used to predict the weather in places where there aren't any direct historical measurements. The ECMWF and NCEp-i have worked on reanalysis projects in the past.

In the late 1950s, MIT meteorologist Edward Lorenz started experimenting with a numerical model of the atmosphere. He began a fresh run of an experiment by setting the model's state to the state attained halfway through the previous run. To his astonishment, the atmosphere's conduct in the second half of the new run was quite different from that of the first run's second half. Lorenz eventually realised that while the computer was evaluating the model to a precision of six decimal places, it was only printing the model state to a precision of three decimal places. As a result, Lorenz's decision to reset the model with the printed output had resulted in a very small discrepancy between the two runs. This oversight was sufficient to significantly alter how they evolved. Even though this phenomenon was well known for ages, the development of digital computers made it easier to examine. The term "chaos" was first used to characterise the "butterfly effect," or the sensitivity of these models to their beginning circumstances, in 1975. Experiments where manufactured mistakes, comparable with known observational uncertainty, are introduced into computer models of the atmosphere are used to evaluate the model sensitivity to beginning circumstances.

The model's output under these different beginning circumstances may then be compared to the results of the first runs, and the findings indicate that we are unlikely to ever accurately anticipate the development of the atmosphere for more than a few weeks. Chaos has not had a wholly negative effect on meteorology. Instead, it has caused a change in focus, one that will likely be beneficial to those in the field of weather risk management. The sensitivity of the atmosphere to beginning circumstances varies depending on its present state. On certain days, the atmosphere may be roughly described by a linear system that is quite predictable over a short enough time frame. On other days, the analysis' inherent uncertainty might cause the forecast's inaccuracy to expand quickly. The most important thing to remember is that the atmosphere's predictability relies on its condition. Operational weather forecasting now heavily relies on predictability predictions. Since 1992, daily ensemble predictions have been produced by the ECMWF and the US National Centre for Environmental Prediction. Run many predictions using slightly varied beginning circumstances created around the study is the basic notion underlying ensemble forecasting [5].

The relative disparity between the projections shows how predictable the atmospheric model is right now; the higher the gap, the less confident we are in the forecast. Therefore, ensemble predictions should provide a priori knowledge of the forecast's accuracy for that day. Choosing which perturbations to include to the analysis is a challenge. Only a small number of predictions can be generated due to limited computational capacity. The approaches for ensemble construction mentioned above make an effort to take into account flaws in the starting state. In order to quantify how the uncertainty in the choice of scheme impacts the final prediction, other ensemble forecasts use models with various combinations of parameterisation schemes for sub-grid processes. By include random factors in the model's dynamical equations, ensemble members may also vary from one another. This method makes an effort to simulate the uncertainty in the atmosphere's potential development at each model time step. The influence of sub-grid processes on the resolved flow is not expected to be a deterministic function of the model state in such a stochastic parameterization. It is a random variable instead.

The model state may be used to calculate the mean and variance of the distribution from which this variable was chosen. Due to the non-linear nature of NWP models, the incorporation of these stochastic elements may actually enhance the model's mean state while also assisting in the estimation of its evolution's level of uncertainty. The addition of stochastic parameterization to numerical weather prediction is a novel element that partially reflects meteorology's acceptance of uncertainty and efforts to quantify it. Ensemble predictions are much more helpful than conventional single forecasts for the purpose of pricing weather derivatives. For instance, the number of heating degree-days collected throughout a period may be calculated using each member of an ensemble prediction; this yields a basic distribution of future HDDs. However, employing ensembles in this way would not be wise at the moment due to their limited size and the fact that they reflect variables averaged across tens of kilometres rather than at individual meteorological stations. In the next part, we'll go through how the predictability data from the present ensemble prediction may be derived [6].

The expansion of medium-range forecasting methodologies to longer-range seasonal forecasting is not a significant step once uncertainty in the atmospheric condition has been acknowledged as a reality of life that will not go away. The exact forecast of the trajectory of this state for a period more than, at most, a few weeks into the future is prohibited due to the sensitivity of the development of the atmosphere's state to its beginning circumstances, as mentioned above. Therefore, there is little chance of accurately predicting whether it will rain on a certain day in a few months. This does not imply, however, that accurate projections with several-month lead periods are impossible. At lead periods of more than three months, it is feasible to predict whether a season will be wetter or colder than usual. We can also estimate the probability of magnitudes of change, such as the likelihood that it will be at least 1QCwarmer than average. A computer model of the ocean is a necessary additional component that is necessary for seasonal forecasting. In comparison to the lead time of a medium-range prediction, the time scales on which the condition of the ocean changes are relatively lengthy. As a result, it is possible to hold the ocean's condition constant while creating such a prediction. But after a few weeks, the ocean's shifting condition has a significant impact on how the atmosphere behaves. A model of the ocean must be connected with the model of the atmosphere in order to advance seasonal forecasting. The ocean pushes the atmosphere by exchanging heat with it, particularly via the evaporation of water - which generates clouds - and radiation. The atmosphere forces the ocean by exerting wind stress at its surface. Particularly in the tropics, the sea surface temperature has a significant impact on how the atmosphere behaves.

Many inter-annual climate variations, like the El Nino Southern Oscillation, are caused by the interaction of the ocean and atmosphere. ENSO is marked by a large-scale cycle of warming and cooling in the Eastern tropical Pacific that repeats on a time scale of 2–7 years. Over a wide portion of the world, the atmospheric circulation is influenced by the warm SST during the El

Nino phase of the cycle. El Nino occurrences in particular are linked to large rains in Peru and Southern California, warm winters in the Eastern US, and drought in Indonesia and Northern Australia. These correlations are all probabilistic; ENSO is just one factor influencing the behaviour of the atmosphere, although a significant one at lower latitudes. In many respects, ENSO's presence is a gift since it enforces some regularity on tropical climate, which aids in seasonal forecasting. The numerical ocean models used for seasonal forecasting are not fundamentally different from their atmospheric cousins; they rely on the division of the oceans into finite elements, both horizontally and vertically; the equations of conservation of mass, momentum, and energy are numerically integrated; and sub-grid processes are parameterized. Mid-latitude seasonal predictions are not as accurate as those made in the tropics. Mid-latitude climatic cycles, like the North Atlantic Oscillation, are considered to exist, although they are not as predictable and consistent as ENSO. Due to the occurrence of periodic cycles, statistical seasonal forecasting models with accuracy up to six months in advance have been developed [7].

The availability of historical data, however, is a significant barrier to the improvement of any statistical models. Better data on the condition of the ocean will be needed for seasonal forecasting improvements. Oceanographic observations are not as plentiful as atmospheric observations. Better ocean data, such as that from the TOPEX-POSEIDON satellite and its successor jASON-1, which measure sea surface height, should allow for better estimation of the state of the ocean and, consequently, improved seasonal forecasts6. However, forecasts with greater skill than climatology are difficult to come by beyond seasonal time scales. The c1imatological distributions that are used to evaluate weather risk may be improved by linked numerical models of the ocean-atmosphere system, however. Most places have relatively recent instrumental recordings; they often only go back a few decades. Extended runs of oceanic-atmospheric general circulation models should lead to more accurate predictions of the danger of severe occurrences, which may have only happened sporadically recently.

This is especially true if long-term changes to the forces acting on the ocean-atmosphere system diminish the value of the historical record, such as increasing radiative forcing brought on by rising carbon dioxide and other greenhouse gases. It must be shown that GCMs can replicate documented historical climate variability on regional scales, not only average global temperatures, before they can be utilised for this kind of risk assessment. Interpretation and Post-processing of Model Output Numerical model output should not be regarded as "weather forecasts." The output just depicts the model's current state, which includes meteorological data but is not instantly applicable to numbers that have been actually seen. The value of these predictions may be significantly increased by further processing of the raw forecast products generated by forecast centres. Even global models with the finest resolution, for instance, cannot accurately depict the topography of mountains or tiny islands, despite the fact that these natural phenomena may have a significant influence on regional weather [8].

Using their knowledge of the weather in a specific location to estimate the expected conditions there, given the numerical forecast's larger-scale weather picture, is one way that human forecasters may contribute value to a prediction. Numerical models can only be used to regions as small as a grid due to their limited resolution, or grid size. Although the ECMWF model forecasts a temperature that is averaged over a grid box of 40 km by 40 km, the user of the model forecast is likely to need to know the values of forecast variables on a scale smaller than a model grid. For example, pricing a weather derivative may require knowing the temperature at the London Heathrow weather station. The term "downscaling" is used to describe a number of quantitative techniques that utilise anticipated model variable values to estimate the values of particular variables on sizes smaller than the model grid. Model output statistics are one typical approach. The collection of predictors of the target variable is selected from a limited number of model variables. These indicators are taken from previous numerical predictions and connected with the relevant observational data of the target variable. The forecast variables may then be used as predictors in a statistical model that forecasts the target variable. Any systematic biases in the numerical model should be eliminated by this statistical model. It is not immediately clear how MOS should be used to ensemble predictions [9].

In a conventional statistical MOS model, each ensemble member might serve as the predictor. However, it is also necessary to downscale the ensemble's representation of the prediction uncertainty. This is due to the predictions' usage of grid boxes with an average size of tens of miles. Since averaging lowers variability, it should be more accurate to say that the uncertainty of a prediction averaged across a grid box is lower than the uncertainty of a forecast made at a single weather station. Therefore, although the mean of the ensemble may be downscaled using typical MOS, it is more difficult to get an accurate measure of uncertainty. The development of techniques for extracting the predictability that exists in ensemble predictions is now underway. "Nested modelling" is a different approach of downscaling a prediction. This employs a local area numerical model, which has a lot greater resolution and covers a much smaller area than the global model. The global model has the local model "nested" inside of it. This indicates that although it is integrated forward, similar to the global model, the values of its variables are derived at the boundaries of the area it covers using the equivalent values from the global model.

Kuligowksi and Barros provide an example of the deployment of a hierarchical model in a forecasting scenario. A determination of the forecast's level of uncertainty is necessary for many uses of weather predictions. It must be shown that they can replicate documented historical climate variability on regional scales, not merely average global temperatures, before a single, best-guess prediction can be turned into an evaluation. Interpretation and Post-processing of Model Output Numerical model output should not be regarded as "weather forecasts." The output just depicts the model's current state, which includes meteorological data but is not instantly applicable to numbers that have been actually seen. The value of these predictions may be significantly increased by further processing of the raw forecast products generated by forecast centres. Even global models with the finest resolution, for instance, cannot accurately depict the topography of mountains or tiny islands, despite the fact that these natural phenomena may have a significant influence on regional weather. Using their knowledge of the weather in a specific location to estimate the expected conditions there, given the numerical forecast's larger-scale weather picture, is one way that human forecasters may contribute value to a prediction. Numerical models can only be used to regions as small as a grid due to their limited resolution, or grid size. Although the ECMWF model forecasts a temperature that is averaged over a grid box of 40 km by 40 km, the user of the model forecast is likely to need to know the values of forecast variables on a scale smaller than a model grid. For example, pricing a weather derivative may require knowing the temperature at the London Heathrow weather station. The term "downscaling" is used to describe a number of quantitative techniques that utilise anticipated model variable values to estimate the values of particular variables on sizes smaller than the model grid. Model output statistics are one typical approach [10].

The collection of predictors of the target variable is selected from a limited number of model variables. These indicators are taken from previous numerical predictions and connected with the relevant observational data of the target variable. The forecast variables may then be used as predictors in a statistical model that forecasts the target variable. Any systematic biases in the numerical model should be eliminated by this statistical model. It is not immediately clear how MOS should be used to ensemble predictions. In a conventional statistical MOS model, each ensemble member might serve as the predictor. However, it is also necessary to downscale the ensemble's representation of the prediction uncertainty. This is due to the predictions' usage of grid boxes with an average size of tens of miles. Since averaging lowers variability, it should be more accurate to say that the uncertainty of a prediction averaged across a grid box is lower than the uncertainty of a forecast made at a single weather station. Therefore, although the mean of the ensemble may be downscaled using typical MOS, it is more difficult to get an accurate measure of uncertainty. The development of techniques for extracting the predictability that exists in ensemble predictions is now underway. "Nested modelling" is a different approach of downscaling a prediction. This employs a local area numerical model, which has a lot greater resolution and covers a much smaller area than the global model. The global model has the local model "nested" inside of it. This indicates that although it is integrated forward, similar to the global model, the values of its variables are derived at the boundaries of the area it covers using the equivalent values from the global model. Kuligowksi and Barros provide an example of the deployment of a hierarchical model in a forecasting scenario.

Prediction Uncertainly

An estimation of the forecast's level of uncertainty is necessary for many uses of weather predictions. By including a distribution of previous forecasting failures, a single, best-guess prediction may be changed into a probabilistic forecast. The discrepancies between earlier projections and the corresponding value of the variable that was subsequently observed are known as historical forecast errors. It is possible to improve historical error distributions by allowing seasonal variation. For instance, when estimating the distribution in the winter, only prediction errors from past winters should be included. In theory, one might pick only past mistakes that have place while the atmospheric condition was comparable to the present situation. Then, however, one must deal with issues that are similar to those encountered when attempting to construct purely statistical forecasting models, namely a lack of data and a dearth of comparable days. Even more so than for statistical weather prediction, the data issue for forecast error prediction is severe. The time record of prior prediction mistakes for contemporary models seldom spans more than a few years due to the frequent upgrades of operational numerical models.

The state-dependent prediction uncertainty is disclosed in ensemble forecasts. An "end-to-end" prediction should ideally disseminate this information through all downscaling steps. The output of a weather forecasting model is processed in an end-to-end forecast to provide a final prediction for the (weather-dependent) variable in which the customer is truly interested. For instance, this may be the availability of wind energy or the demand for electricity. Each component of an ensemble prediction may be subjected to a statistical downscaling model based on MOS. The uncertainty associated with a meteorological variable measured at a specific site will be larger than the uncertainty in that variable averaged across the resolution of the numerical model that produced the ensemble, yet this will likely result in an underestimation of prediction uncertainty. As a result, it is also necessary to downscale the ensemble's prediction uncertainty. One strategy is to include ensemble-wide statistics (such as ensemble spread) into the MOS predictors that are used to build the statistical downscaling model.

CONCLUSION

Modern weather predictions have made great strides in the previous 2,000 years, going from predicting one day in advance based on the hue of the sky to roughly a two-week perspective. The risk management community evolved more swiftly because, in just a few years, the idea of a weather prediction shifted from being a single best-guess projection to a range of probable future weather possibilities. The procedures used to create contemporary numerical weather predictions have been described in this chapter. Additionally, it was said that the methods required to anticipate climate on seasonal and larger scales are not fundamentally different from the modelling techniques used to provide short- and medium-term forecasts. The primary distinction is that an ocean dynamics model must be combined with an atmospheric model for longer-range projections. The significance of ensemble forecasting for calculating prediction uncertainty has also been emphasised in this chapter. The usual method for predicting the development of the atmosphere and oceans will soon be ensemble forecasting. The risk management community is happy about this since ensemble predictions provide information on forecast uncertainty, which is a key component of risk. On time durations ranging from a few hours to many months, the ultimate goal of accurate probability predictions of economically significant variables is being sought (Palmer 2002). This information will provide a competitive advantage for those who can interpret it at a variety of lead periods, from pricing next week's power futures to pricing weather derivatives for the next year. Forecasts that are accurate and on time might be financially advantageous.

REFERENCES:

[1] M. Balehegn, S. Balehey, C. Fu, and W. Liang, "Indigenous weather and climate forecasting knowledge among Afar pastoralists of north eastern Ethiopia: Role in adaptation to weather and climate variability," *Pastoralism*, 2019, doi: 10.1186/s13570-019-0143-y.

[2] M. Radeny *et al.*, "Indigenous knowledge for seasonal weather and climate forecasting across East Africa," *Clim. Change*, 2019, doi: 10.1007/s10584-019-02476-9.

[3] S. Scher and G. Messori, "Weather and climate forecasting with neural networks: Using general circulation models (GCMs) with different complexity as a study ground," *Geosci. Model Dev.*, 2019, doi: 10.5194/gmd-12-2797-2019.

[4] W. M. Thiaw and V. B. Kumar, "NOAA'S African Desk: Twenty years of developing capacity in weather and climate forecasting in Africa," *Bull. Am. Meteorol. Soc.*, 2015, doi: 10.1175/BAMS-D-13-00274.1.

[5] A. W. Robertson and F. Vitart, *Sub-seasonal to seasonal prediction: The gap between weather and climate forecasting*. 2018. doi: 10.1016/C2016-0-01594-2.

[6] J. Slingo and T. Palmer, "Uncertainty in weather and climate prediction," *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.*, 2011, doi: 10.1098/rsta.2011.0161.

[7] B. Iticha and A. Husen, "Adaptation to climate change using indigenous weather forecasting systems in Borana pastoralists of southern Ethiopia," *Clim. Dev.*, 2019, doi: 10.1080/17565529.2018.1507896.

[8] T. N. Palmer and L. Zanna, "Singular vectors, predictability and ensemble forecasting for weather and climate," *Journal of Physics A: Mathematical and Theoretical*. 2013. doi: 10.1088/1751-8113/46/25/254018.

[9] O. Onishchenko, V. Fedun, W. Horton, O. Pokhotelov, and G. Verth, "Dust devils: Structural features, dynamics and climate impact," *Climate*, 2019, doi: 10.3390/cli7010012.

[10] H. M. Arnold, I. M. Moroz, and T. N. Palmer, "Stochastic parametrizations and model uncertainty in the lorenz '96 system," *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.*, 2013, doi: 10.1098/rsta.2011.0479.

CHAPTER 5

A BRIEF HISTORY OF OPERATIONAL WEATHER FORECASTING

Dr. Harish Kumar, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

Operational weather forecasting has a long and rich history, developing from simple observational methods to complex numerical models and cutting-edge technology. The evolution of meteorological science and its influence on society by providing a succinct review of the major turning points and advancements in operational weather forecasting. Beginning with early human observations of natural events to anticipate local weather patterns, the first part covers the history of operational weather forecasting. Early weather forecasting techniques were built on the methods used by ancient civilizations, who used astronomical indicators and animal behaviour to predict weather changes. This explores the scientific developments of the late 19th and early 20th centuries, which were characterized by the founding of national meteorological agencies and the development of networks for weather monitoring. The development of telegraphy and the establishment of global alliances cleared the door for the interchange of meteorological information and more precise predictions. The final segment focuses on how numerical weather prediction models changed society in the middle of the 20th century. Scientists like Lewis Fry Richardson and John von Neumann pioneered this field, laying the foundation for numerical models of atmospheric behaviour that allowed for more quantitative and systematic forecasting. This describes how operational weather forecasting used satellites and radar systems in the second half of the 20th century. These tools enabled the monitoring of massive weather systems and the tracking of catastrophic weather occurrences by providing a worldwide view on weather patterns. The condition of operational weather forecasting today, where local and international meteorological organizations collaborate to provide high-resolution, real-time predictions. Forecasts are continually improved via research and development to make them more trustworthy and available to the general public.

KEYWORDS:

Atmosphere, Climate, Forecasting, Prediction, Weather.

INTRODUCTION

A significant global activity is the creation of weather predictions for use by the general public, governments, the military, the media, and a broad variety of industrial and commercial operations. Tens of thousands of people are involved, along with high-tech equipment costing billions of pounds, including satellites, terrestrial observation systems, and communication and processing networks. The size and scope of national meteorological organisations vary greatly from country to country, but they exist in the majority of the world's countries and provide predictions for both government and commercial users. Additionally, a large number of private businesses provide weather predictions. These businesses often focus on making projections for certain specialty sectors, such as the news media, commercial shipping, offshore oil and gas exploration and production, the agricultural industry, etc. In rare circumstances, specific consumers may get extremely significant financial benefits from weather predictions. On the basis of a single cold spell predicted, power production businesses may profit thousands of pounds since they can purchase petrol at a discount before the price rises due to increased demand during cold weather. By stopping operations before the arrival of a strong storm, offshore gas and oil exploration firms may prevent drilling platforms being damaged to the tune of millions of dollars. Major grocery chains organise their stock management using weather predictions since they know that cold weather will raise sales of goods like soup while warm weather would increase demand for ice cream and barbecues [1].

Based on a solid scientific understanding of how the atmosphere functions and a significant technological investment in monitoring, computation, and communication capabilities, weather predictions are created. Modern forecasting capabilities have been developed over many years as a consequence of scientific study and technological advancement at the world's main meteorological institutions. A numerical weather prediction (NWP) model, a computational model of the atmosphere that can provide predictions of how the weather will change in the future given an initial condition for the atmosphere determined from observations, is at the core of any significant weather forecasting facility. Before the invention of NWP, predictions were made manually, often by forecasters sketching maps of the present state of the atmosphere and then trying to anticipate how that condition would change using their understanding of regular weather patterns along with a set of empirical principles. The duty of forecasting the development of the atmospheric condition is now mostly handled by computers, although human forecasters still play a significant part in the system.

The precise formulation and coding of a NWP model are not covered in this book. This book is not a guide on how to become a weather forecaster either. The specifics of prediction production within each organisation are covered in the training manuals that each individual meteorological agency produces for its forecasters. Instead, this book will outline the whole process of creating a weather prediction, with an emphasis on the NWP resources accessible to forecasters at significant meteorological centres. In Chapter 2, the nature of the weather forecasting issue is covered. The observations of the weather that forecasting centres use to establish the baseline conditions for their predictions are the main topic of Chapter 3. In the sense that human forecasters will continuously compare the observations to the NWP predictions and adjust the forecasts as and when appropriate, these same observations also play a crucial role in the forecast generation process. The fundamental components of NWP models are examined in Chapters 4 and 5, along with how these components are combined to create operational forecasting systems for certain jobs. The function of the human forecaster in the creation of NWP forecasts is discussed in Chapter 6. Finally, Chapter 8 examines how NWP predictions are verified and quantified and how this process contributes to ongoing growth and improvement. Chapter 7 focuses on the specific problem of predicting for periods of several weeks to several months in advance [2].

A synopsis of weather forecasting in use

People have been attempting to forecast the weather since ancient times since many diverse human activities have always been sensitive to the current weather conditions, both on a day-to-day basis and over the next few months. Farmers have always kept an eye on the weather and climate since crop productivity has been impacted by the growing season's weather since the dawn of civilisation. For example, the ancient Egyptians maintained meticulous records of the yearly flooding of the Nile, which had a significant effect on soil fertility and was greatly influenced by the severity of the rainy season at the Nile's headwaters.

Prior to the scientific developments of the nineteenth century, all weather forecasting was mostly dependent on mythology and imagined connections between natural occurrences and the weather. There was undoubtedly no scientific basis for the majority of these forecasting techniques, but farmers and people who spent the majority of their days outdoors were undoubtedly attuned to the local weather and could reasonably predict the upcoming conditions for the next few hours or even a few days by observing changes in clouds and wind. However, there was no structured effort to anticipate the weather in a methodical manner.

In reaction to the loss of ships on the trade routes that supported the British Empire, the British government established the first structured meteorological agency in the middle of the nineteenth century. Admiral Robert FitzRoy was named the British Board of Trade's "meteorological statist" in 1854. FitzRoy was a renowned oceanographic surveyor who produced precise hydrological maps of coastal seas all around the globe. The Board of Trade believed he would also be able to create a comparable meteorological atlas that would show weather patterns throughout the globe and help to alert shipping companies and crews of storm hazards, enabling them to decide when to sail and what routes to take.

FitzRoy started this effort, but he was also curious in the potential for being able to make more precise forecasts of the weather in coastal seas around Britain on a daily basis. Since Toricelli's invention of the barometer in the seventeenth century, people have begun to realise that atmospheric pressure and weather conditions are related, with falling pressure frequently portending unsettled or even stormy conditions and rising or steady pressure signifying settled conditions. By creating a barometer specifically for use in ports that included information on what weather to anticipate given an observed trend in the pressure, FitzRoy made advantage of this principle. In order for captains to check the barometer before setting sail, a replica of this barometer was installed in each of the principal harbours around the United Kingdom. Interestingly, there was also advise on how to interpret the hue of the sky at dawn and dusk in terms of upcoming weather conditions, in addition to information on the predicted weather conditions connected with increasing and dropping pressure. FitzRoy was able to advance the usage of these barometers with the new invention of the electric telegraph. Regular barometer readings from across the nation could be telegraphed back to FitzRoy's office in London, where they could be plotted onto a map showing the distribution of atmospheric pressure across the nation along with data on other weather factors like wind and clouds.

DISCUSSION

The winds and prevalent weather throughout the nation might then be forecasted using a series of these charts in the hours and maybe even a day or two in advance. Additionally, by compiling an archive of these charts what we would today likely refer to as a database it might be possible to compare the current pressure distribution with similar pressure patterns from the past and use what is known about previous weather events to predict what might happen this time. The port authorities might then get predictions through telegraph. By doing so, FitzRoy likely also created the phrase "weather forecast" and the idea of operational weather forecasting.

Of course, because to the weather's infinite variability, many of FitzRoy's predictions were inaccurate, and he was heavily criticized by both the general public and the scientific community after making his forecasts more readily accessible to the public via daily newspapers. One of the many things that contributed to FitzRoy's suicide in 1865 was this critique. However, the Meteorological Office of the Board of Trade maintained its work, developing new and improving existing forecasting techniques. When Napier Shaw became the Meteorological Office's director in 1905, he played a key role in advancing the use of forecasting techniques with a stronger scientific foundation [3].

Once again in reaction to the loss of ships – this time brought on by a storm in the Black Sea during the Crimean War – the French government established its first national meteorological service in 1855. A meteorological service was also established by the US government in 1870, this time under the direction of the US War Office, this time under President Ulysses S. Grant. Grant was well aware of the influence of weather on military operations because to his previous experience as a general in the American Civil War, and military forts all throughout the country made for perfect sites for a network of weather observatories. In 1890, the US National Weather Service was transferred to the Department of Agriculture and became a civilian organisation. Each state had its own meteorological agency until the Australian Bureau of Meteorology was founded in 1906. More scientific developments in weather forecasting were developed during the 20th century. Lewis Fry Richardson, a British meteorologist, created a system for predicting the evolution of the atmosphere's condition using the set of physical equations that control atmospheric motion. Richardson created a method for computationally resolving these equations while serving as an ambulance driver in World War I. He even produced a six-hour prediction of the pressure in central Europe using information from 20 May 1910. It required doing and verifying tens of thousands of computations without the use of any type of computerised calculating tool, which made it a Herculean undertaking. The outcome was wholly incorrect, but Richardson published his techniques in his 1922 book, Weather Prediction by Numerical Process; they have since become the foundation for numerical weather prediction.

Advances in weather forecasting were required during World War II due to the extensive use of military aviation and shipping to conduct the fighting over vast areas. Naval vessels, especially those engaged in the Pacific campaign in the region of the world most prone to tropical cyclones, needed to be able to avoid damaging storm conditions. During this time, methods for monitoring and predicting the weather advanced quickly. For the first time, forecasters began to pay attention to how the middle and upper troposphere were developing in order to predict what may happen to the weather. This led to an increase in the usage of weather balloons carrying instrumented packages to study the upper troposphere. During World War II, forecasters under the direction of Captain James Stagg advised the Allied Command to postpone the D-Day Normandy invasion by 24 hours. This is perhaps the most famous weather prediction in history [4] [5].

Following the war, two primary streams of study were conducted on predicting techniques. In order to forecast where significant weather system changes would take place, meteorologists in the United Kingdom developed approaches based on studying maps of the status of the middle and upper troposphere. Richardson's numerical techniques for forecasting were being developed and improved in the United States by scholars at a variety of different universities. Numerical computing tools, such the ENIAC machine, were widely available, which significantly facilitated this branch of research. The mathematician John von Neumann and the meteorologist Jule Charney were part of a research team at Princeton University that released the findings of the first computerised atmospheric prediction in 1950. The numerical model that was used was considerably simpler than that of Richardson and had been developed during the years before. But it did result in a fairly accurate 24-hour forecast of the development of the mid-tropospheric flow across the continental United States, and this hopeful finding prompted additional improvements to the numerical approaches. The calculating time alone for a 24-hour prediction was roughly 24 hours, and this doesn't account for the time needed to prepare the basic conditions for the forecast and feed them into the computer. At this point, the approach was in no way suitable for practical usage. The Swedish Military Weather Service issued the first practical numerical weather predictions in 1954. Carl-Gustav Rossby, a Swedish meteorologist who worked mostly at Chicago University in the 1930s and 1940s, was in charge of developing the techniques utilised in these predictions. He established the Swedish Institute of Meteorology upon his return to Sweden in 1947 and carried on researching numerical forecasting techniques.

Numerical weather prediction (NWP) was adopted by the UK Met Office very late. The UK Met Office had to use borrowed computers to do its NWP research throughout the 1950s and the early 1960s; it wasn't until the middle of that decade that it truly got a computing facility of its own. The UK Met Office began consistently generating numerical weather predictions in 1965, and in 1967 it achieved the distinction of generating the first numerical precipitation prediction. Prior to this, professional forecasters had to interpret pressure, geopotential height, and vorticity patterns in terms of the actual weather that would be associated with them. Numerical forecasts could only anticipate the development of these patterns [6].

By the 1970s, the majority of the main meteorological organisations in the globe were well-established and beginning to base their operational predictions on NWP methodologies. The establishment of the European Centre for Medium-range Weather Forecasts (ECMWF) at Reading, UK, in 1975 was a significant development during the 1970s. Using financing from all the major European meteorological agencies, which would not have been able to construct such facilities on their own, the center's goal was to generate practical NWP predictions over the medium range (out to around 15 days). The National Weather Services of all the member nations would thereafter have access to the predictions. Since developing the first numerical approaches and models for prediction on the monthly to seasonal timeframe, ECMWF has led the way in the practical use of ensemble forecasting techniques.

Such methods need for enormous computer capacity, and the upkeep and improvement of such facilities is only possible with the joint investment of all the member nations. The NWP predictions generated with these resources are commonly considered as the finest in the world. The supercomputing facilities of ECMWF routinely lead the league table of computing power in the United Kingdom. Early in the 1990s, the US National Centre for Environmental Prediction (NCEP) began to create ensemble predictions. As computational capabilities improved, a lot of forecasting centres embraced ensemble techniques more recently. Currently, ensemble predictions are frequently conducted in some form by the National Meteorological Services of Australia, China, Japan, Korea, France, Brazil, and Canada as well as the UK Met Office [7] [8].

The NWP methodologies have improved in accuracy and model speed since the 1970s. Over this time, communication networks have also significantly improved. An outstation weather forecaster operating at a military airfield, for example, would have had extremely little access to the output from numerical models as recently as the early 1980s, and what little was distributed often came too late to be of much help in producing predictions for the aircrews. Due to the absence of current model output, many forecasters were hesitant to use NWP products as a forecasting reference. Similarly, relatively few satellite photos were visible to outstation forecasts. Forecasters operating in areas far from the major meteorological service headquarters didn't have access to a broad variety of advice from numerical models or routine, in-depth satellite images until the development of high bandwidth communication networks in the 1990s. So it is evident that communication networks play a crucial role in operational meteorology, dating all the way back to FitzRoy who was able to utilise the newly constructed electric telegraph system.

Since the 1980s, prediction accuracy has increased. It displays the point in the prediction for the ECMWF model at which the correlation between the expected and observed 500 hPa geopotential height anomaly in the Northern hemisphere extra-tropics drops below 60%. Values over 60% are seen as indicative of expert predictions, and are used as a gauge of the forecast's usefulness. The red solid line displays the 12-month running mean of the monthly readings, while the blue dashed line displays the value for each month since January 1980.

In 1980, at about 5.5 days into the prediction, the correlation dropped below 60%. This increased to around 8.5 days into the prediction by 2010. This effectively indicates that, compared to 1980, ECWMF predictions were accurate for an additional three days on average in 2010. Similar skill increases are being shown at other forecasting centres. Of course, the anomaly correlation of the Northern Hemisphere 500 hPa Geopotential Height is a fairly meaningless indicator of the accuracy of a weather forecast for the majority of users, and there are numerous other metrics that are more geared towards the needs of particular clients [9].

Numerous and diverse recent advancements in operational forecasting have been made, all of which have benefited from recurring advances in the amount of processing capacity made available to meteorological services. Ensemble forecasting techniques and a greater variety of numerical models, some with worldwide coverage and others with extremely fine scale resolution over limited regions, are increasingly being used by more forecasting centres. Over the past few years, so-called "storm resolving models," which can explicitly represent organised convective storms, have begun to be used in operational settings.

Additionally, new approaches to incorporating observations into models, like rainfall rates from meteorological radar, are improving how these extremely detailed forecasts are initialised. More forecasting centres are now using monthly and seasonal prediction models at the opposite end of the time and space scales. The relevant chapters of this book go into further depth about some of these advances [10].

Despite technological advancements that are increasing prediction accuracy, there is still a critical role for human forecasters in the process. Even the most advanced computer models of the atmosphere have the potential to make projections that significantly deviate from reality even over very short time periods. In these situations, a group of skilled forecasters can identify the issues early and decide how to effectively revise the prediction. A skilled forecaster will be able to account for these problems when making predictions for specific clients since models also have known systematic mistakes and biases, especially when providing forecasts of local detail.

Many users of weather forecasts also need a human forecaster to serve as an interface between them and the numerical forecast, such as military pilots who need a face-to-face briefing from a forecaster before flying missions that are weather-sensitive or local government organisations that require briefings and hour-by-hour guidance on potential disruption due to snow and ice or flooding. The people who deliver weather forecasts on television are frequently the ones who are most visible to the general public, but it is important to keep in mind that they are merely the public face of a large team of experts who manage, monitor, and analyses the numerical forecasts and decide what the major weather concerns for each day's forecast will be [11].

CONCLUSION

The digital revolution in meteorology, which led to improved processing capability, data assimilation methods, and ensemble forecasting, is highlighted in the fifth part. These developments greatly increased prediction precision and forecast uncertainty quantification. The use of cutting-edge technology, including machine learning and artificial intelligence, in practical weather forecasting is examined in the sixth segment. These innovations have the potential to enhance model performance, data processing, and the forecasting of severe weather events. The crucial importance of operational weather forecasting in a variety of industries, including disaster management, agriculture, and the aviation and agricultural industries. The evolution of operational weather forecasting across time demonstrates the meteorology's extraordinary advancements and their lasting effects on preserving human life, promoting economic activity, and promoting adaptability in the face of constantly changing weather conditions.

REFERENCES:

[1] M. Balehegn, S. Balehey, C. Fu, and W. Liang, "Indigenous weather and climate forecasting knowledge among Afar pastoralists of north eastern Ethiopia: Role in adaptation to weather and climate variability," *Pastoralism*, 2019, doi: 10.1186/s13570-019-0143-y.

[2] M. Radeny *et al.*, "Indigenous knowledge for seasonal weather and climate forecasting across East Africa," *Clim. Change*, 2019, doi: 10.1007/s10584-019-02476-9.

[3] S. Scher and G. Messori, "Weather and climate forecasting with neural networks: Using general circulation models (GCMs) with different complexity as a study ground," *Geosci. Model Dev.*, 2019, doi: 10.5194/gmd-12-2797-2019.

[4] W. M. Thiaw and V. B. Kumar, "NOAA'S African Desk: Twenty years of developing capacity in weather and climate forecasting in Africa," *Bull. Am. Meteorol. Soc.*, 2015, doi: 10.1175/BAMS-D-13-00274.1.

[5] J. D. Derner and D. J. Augustine, "Adaptive Management for Drought on Rangelands," *Rangelands*, 2016, doi: 10.1016/j.rala.2016.05.002.

[6] A. W. Robertson and F. Vitart, *Sub-seasonal to seasonal prediction: The gap between weather and climate forecasting*. 2018. doi: 10.1016/C2016-0-01594-2.

[7] X. Yuan, E. F. Wood, and M. Liang, "Integrating weather and climate prediction: Toward seamless hydrologic forecasting," *Geophys. Res. Lett.*, 2014, doi: 10.1002/2014GL061076.

[8] P. Groenemeijer *et al.*, "Severe convective storms in Europe: Ten years of research and education at the European Severe Storms Laboratory," *Bull. Am. Meteorol. Soc.*, 2017, doi: 10.1175/BAMS-D-16-0067.1.

[9] J. Slingo and T. Palmer, "Uncertainty in weather and climate prediction," *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.*, 2011, doi: 10.1098/rsta.2011.0161.

[10] T. N. Palmer and L. Zanna, "Singular vectors, predictability and ensemble forecasting for weather and climate," *Journal of Physics A: Mathematical and Theoretical*. 2013. doi: 10.1088/1751-8113/46/25/254018.

[11] B. Iticha and A. Husen, "Adaptation to climate change using indigenous weather forecasting systems in Borana pastoralists of southern Ethiopia," *Clim. Dev.*, 2019, doi: 10.1080/17565529.2018.1507896.

CHAPTER 6

NATURE OF THE PROBLEM WITH WEATHER FORECASTING

Dr.Jyoti , Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

The complexity and chaos of the Earth's atmosphere continue to pose difficulties for weather forecasting, despite substantial advances in technology and scientific knowledge. The nature of the weather forecasting issue is explored in this study, along with the uncertainties, restrictions, and continuous attempts to increase prediction accuracy. The chaotic character of the atmosphere, where little adjustments to the starting point may produce wildly divergent results over time, is highlighted in the first part. The butterfly effect, which refers to this sensitivity to beginning circumstances, has a natural cap on how predictable weather systems may be over longer periods of time. This discusses data constraints and the possibility of meteorological observational mistakes. Especially in rural and marine areas, gaps in meteorological data make it difficult to effectively initialise numerical models, which might result in less accurate predictions. The interplay of numerous elements, including radiation, cloud formation, and precipitation, is explored in depth in the third part, which also examines the intricacies of atmospheric dynamics. Uncertainties are introduced by model parameterizations, which simulate sub-grid size phenomena and may affect the precision of forecasts. The difficulties brought on by severe weather conditions including hurricanes, tornadoes, and heatwaves are covered in the fourth section. Due of these events' fast evolution, predicting their precise time, location, and strength is still very difficult. The sixth portion investigates how climate change affects weather patterns, adding more ambiguity to long-term forecasting. For accurate climate forecasts, it is crucial to comprehend how weather patterns and severe occurrences are affected by climate change.

KEYWORDS:

Atmosphere, Climate, Forecasting, Prediction, Weather.

INTRODUCTION

It is crucial to completely comprehend the nature of each scientific issue in order to address it. The crucial elements that influence the result must be recognised and completely included into the problem-solving strategies. This also applies to predicting the weather. In essence, predicting the weather is an atmospheric physics issue, with a variety of physical processes all contributing to the forecast's final result. If we want to consistently provide accurate projections, these processes must be taken into account in our forecasting approaches [1].

Predictability of the atmosphere

It is possible to think about weather forecasting as a mathematical problem, and it is at this point that genuine understanding of the best approach to addressing the issue may be achieved. 'Initial Value Problem' (IVP) may be used to characterise weather forecasting, at least on a time scale of a few hours to a week or more. This is a mathematical issue where the initial circumstances have a significant impact on the final result. These circumstances would be the state of the atmosphere at the forecast's beginning point in the case of weather forecasting. To create a prediction for tomorrow, we must first determine the atmosphere's current condition as exactly as possible. Then, we may use the different physical laws to those circumstances to move the atmosphere's current state towards tomorrow's predicted state. If, on the other hand, we begin the forecast with yesterday's weather as our initial condition and have a perfect forecasting system that accounts for every possible relevant physical process, then using this system to advance the state of the atmosphere forwards by 24 hours will ultimately give us a forecast of today's weather, not tomorrow's. Weather forecasting is the process of predicting the weather using physics principles, along with a number of statistical and empirical methodologies. Weather forecasting involves forecasts of changes on Earth's surface brought on by atmospheric conditions, such as snow and ice cover, storm tides, and floods, in addition to predictions of atmospheric occurrences themselves [2].

Measurements and concepts as the foundation for weather prediction

Few other scientific endeavours' observations are as important or have such a wide impact as those connected to weather forecasting. Perceptive people are likely to have been leaders from the time when early humans first left the protection of caves and other natural shelters because they were able to recognise the natural indicators of coming snow, rain, wind, or, in fact, any change in the weather. With this knowledge, they must have had more luck finding food and safety, which were their main concerns at the time.

In a sense, forecasting the weather still involves making observations and projecting changes, just as it did for the first humans. They would undoubtedly be amazed at the cutting-edge equipment utilised to monitor temperature, pressure, wind, and humidity in the 21st century, and the results are unquestionably superior. But even the most complex numerical forecast produced by a supercomputer needs a set of measurements of the atmosphere's state a preliminary impression of temperature, wind, and other fundamental elements, somewhat similar to that formed by our ancestors when they peered out of their cave homes. The ancient method included understandings based on the cumulative experience of the attentive observer, while the contemporary method entails calculating equations. Despite their apparent differences, both practises have several fundamental traits. The forecaster begins by asking, "What is?" in the sense of, "What kind of weather prevails today?" before attempting to predict what will be by predicting how the weather will change.

The story of meteorological measurements and weather forecasting is one in which ideas and technology are closely intertwined, with creative thinkers drawing new insights from the data at hand and pointing to the need for new or better measurements, and technology providing the means for making new observations and for processing the data derived from measurements. This is because observations are so important to weather prediction. The foundation for weather forecasting began with the ideas of the ancient Greek philosophers and was built upon by scientists throughout the Renaissance, the scientific revolution of the 17th and 18th centuries, and the theoretical models of atmospheric scientists and meteorologists in the 20th and 21st centuries. The "synoptic" notion, which involves describing the weather across a vast area at the same time in order to organise information about the current circumstances, is also described. Synoptic meteorology uses simultaneous data for a given period to display a large area on a map, providing a wide overview of the weather in that area. The word "synoptic" comes from a Greek word that means "general or comprehensive view." The so-called synoptic weather map, which is being used at weather stations and on television weather forecasts today, became the meteorologists' go-to tool in the 19th century.

DISCUSSION

Test on Britannica

A Quiz on How the Earth Functions

Since the middle of the 20th century, digital computers have made it feasible to analytically and objectively calculate changes in atmospheric conditions, i.e., in a manner that allows anybody to get the same conclusion from the same beginning circumstances. When numerical weather prediction models were widely used, a whole new cast of characters computer specialists and authorities in numerical processing and statistics entered the picture to collaborate with atmospheric scientists and meteorologists. Additionally, the improved capacity to handle and analyse meteorological data sparked meteorologists' long-standing desire in collecting more observations with higher precision. Since the 1960s, technological development has increased dependence on remote sensing, notably the collection of data via specially instrumented Earth-orbiting satellites. Except for some shorter-range forecasts, particularly those relating to local thunderstorm activity, which were made by experts directly interpreting radar and satellite measurements, weather predictions by the late 1980s were largely based on the conclusions of numerical models integrated by high-speed supercomputers. Beginning in the early 1990s, the United States had a sizable network of next-generation Doppler weather radar (NEXRAD), which gave meteorologists more time to forecast catastrophic weather occurrences. As computer processing capacity expanded in the late 1990s and early 2000s, weather bureaus were able to create increasingly complex ensemble forecasts sets of many model runs whose outcomes constrained the range of prediction uncertainty [3].

Useful uses

After equipment for monitoring atmospheric conditions were accessible in the 17th century, systematic weather records were established. Undoubtedly, individuals who were involved in agriculture were the principal users of these early records. If long-term weather patterns can be predicted, planting and harvesting may be planned and carried out more effectively. American physicist Joseph Henry, the first director of the Smithsonian Institution, set the groundwork for the national meteorological services in the United States. In order to enhance storm forecasting in the United States, Henry established a network of volunteer weather watchers in 1849. The U.S. Army Signal Corps began offering the first national meteorological services on February 9, 1870, and by 1874, it had also included Henry's volunteer weather observers. The Department of Agriculture took over these activities in 1891. Millions of American farmers were receiving free mail and telephone service and daily predictions by the early 1900s. During World War I, the U.S. Weather Bureau developed a Fruit-Frost (forecasting) Service, and by the 1920s, most states had radio broadcasts directed at agricultural interests [4].

During the 1920s and 1930s, weather forecasting developed into a crucial aviation instrument. Following Francis W. Reichelderfer's appointment as director of the U.S. Weather Bureau (USWB) in 1939, its use in this field acquired significance. Prior to this, Reichelderfer had modernized the U.S. Navy's meteorological department and turned it into a premier source of assistance for naval aviation. A particular interest in weather forecasting developed during World

War II as a result of the discovery of very powerful wind currents at high altitudes (the jet streams, which may effect aircraft speed), as well as the overall weather-sensitivity of military operations in Europe.

Operation Overlord, the Allied troops' invasion of the European continent at Normandy, was one of the most well-known predicting challenges of the Second World War. High seas and gales were brought to the French coast by an unusually intense June storm, but Col. J.M. Stagg of the British forces was able to predict a taming of the weather, which allowed Gen. Dwight D. Eisenhower, supreme commander of the Allied Expeditionary Forces, to make the crucial decision to invade on June 6, 1944. The nation's weather bureau underwent a restructuring throughout the second part of the 20th century. Up until 1940, when it was moved to the Department of Commerce, the USWB was a component of the Department of Agriculture. The USWB changed its name to the National Weather Service on October 9, 1970 [5].

Additionally, commercial weather forecasting businesses expanded at a previously unheard-of rate in the United States and internationally in the latter half of the 20th century. To aid with the timing of sales and advertising of goods ranging from snow tyres and roofing supplies to summer apparel and resort holidays, marketing organisations and businesses use weather-forecasting specialists. Optimal ship routing predictions are used by many oceangoing commerce ships and military ships to plan their itineraries in order to save wasted time, possible damage, and fuel consumption in rough seas. Similar to this, while planning long-distance flights, airlines carefully evaluate the atmospheric conditions in order to escape the biggest head winds and ride with the strongest tail winds [6].

Weather reports may have a big impact on international trade in goods including wheat, corn (maize), beans, sugar, chocolate and coffee. For instance, a severe frost in Brazil in 1975 led to a sharp rise in coffee prices within a few of weeks. In 2017, Georgia peach producers attributed the loss of approximately 80% of the state's peach crop to a combination of mild winter temperatures and a spring freeze. Extreme heat and drought may also have an impact on productivity; according to one research, between 1964 and 2007, these occurrences caused the loss of 9–10% of grain harvests. Thus, banks, commodities merchants, and food industries routinely request weather forecasting services to inform them in advance of the probability of such abrupt shifts. If accurate information about potential precipitation can be gathered in advance, the cost of all kinds of goods and services, such as tents for outdoor events or plastic coverings for the daily newspapers, may be decreased or eliminated.

Applications that are targeted to certain sectors need very accurate forecasts. For example, gas and electric companies may need temperature forecasts within one or two degrees a day in advance, while ski resort owners may need forecasts of relative humidity at night on the slopes within five to ten percent to plan snowmaking [7].

Weather Forecasting in the Past

Initial Measurements and Concepts

Greek philosophers had a lot to say about meteorology, and it's safe to assume that many people who later worked in weather forecasting drew on their views. Sadly, they probably made a lot of inaccurate predictions since Aristotle, who had the greatest influence, did not think that wind was just air in motion. However, he did think that since west winds originate after sunset, they are frigid.

Evangelista, Torricelli

It was not until the development of measuring devices that meteorology became a science. Evangelista Torricelli, an Italian scientist and mathematician, developed the mercury barometer in the middle of the 17th century, and the accurate thermometer was developed almost simultaneously. (Galileo had built a crude gas thermometer in 1607, but it was flawed; it took the work of many others to create a somewhat accurate liquid-in-glass instrument.)

The 17th and 18th centuries saw a series of key contributions to chemistry and physics that had a substantial impact on meteorological study. The development of calculus by Isaac Newton and Gottfried Wilhelm Leibniz, the formulation of the doctrine of latent heat (i.e., heat release by condensation or freezing) by Joseph Black, the formulation of the laws of gas pressure, temperature, and density by Robert Boyle and Jacques-Alexandre-César Charles, and the development of the law of partial pressures of mixed gases by John Dalton are just a few of the major scientific breakthroughs of the time that made it possible to understand the un All of these amazing concepts started to bear fruit in the form of practical weather predictions throughout the 19th century [8].

Advent of Synoptic Forecasting Techniques

Synoptic Weather Report Analysis

The sight of the sky, the wind, and other local impacts may be interpreted by an alert individual who has understood nature's indications in order to "foretell the weather." A scientist may do it even more efficiently by using equipment in one place. To illustrate the patterns of pressure, wind, temperature, clouds, and precipitation at a specific time, a synoptic weather map must be used to represent a large number of these observations quickly exchanged by experts at various weather stations. The invention of the electric telegraph by American inventor Samuel F.B. Morse in 1837 made such a quick interchange of meteorological information possible. By 1849, Washington, D.C.'s Smithsonian Institution's Joseph Henry was utilising telegraphic information to draw daily weather maps, and the Cincinnati Observatory's Cleveland Abbe was issuing predictions on a regular basis in 1869.

To March's Lions and Lambs, April Showers

One of the major meteorological debates, the rotating storm issue, was settled by synoptic weather maps. Early in the 19th century, it was understood that storms were related to low barometric pressure, but it was unknown how the winds related to low-pressure systems, or cyclones. After a storm in New England, self-taught meteorologist William Redfield of Middletown, Connecticut, saw a pattern in the placement of downed trees and hypothesised in 1831 that the wind was rotating anticlockwise around the area of lowest pressure. Later, in his Philosophy of Storms (1841), the American meteorologist James P. Espy hypothesised that air would move towards areas of lowest pressure before being driven higher, resulting in clouds and precipitation. Espy and Redfield turned out to be correct. As Redfield predicted, the air indeed revolve around the cyclone, and the layers near the ground also move inward and upward [9]. The end consequence is exactly what Espy had predicted: a rotating wind circulation that is significantly altered at Earth's surface to create inflow towards the storm core. Furthermore, even if it is not the main reason for clouds there, the inflow is linked to clouds and precipitation in low-pressure areas.

The publications of Heinrich Dove, a Polish scientist who oversaw the Prussian Meteorological Institute, had a significant impact on ideas about wind behaviour in storms across Europe. Dove, unlike the Americans, concentrated on how the wind should vary at a specific location when a storm passed rather than on the pattern of winds surrounding the storm. It took his disciples a long time to comprehend the intricacy of the potential changes [10].

CONCLUSION

The numerical weather prediction models, which depend on approximations and simplifications of atmospheric processes, are acknowledged in the sixth section to have some limitations. Forecast uncertainties result from the fact that, despite advances, these models still fall short of fully capturing the complexities of the atmosphere. The significance of ongoing research and technical developments in overcoming the difficulties of weather forecasting is highlighted in the seventh part. For increasing prediction accuracy, developments in model resolution, data assimilation methods, ensemble forecasting, and the use of machine learning show promise. This emphasises the value of weather forecasting in reducing weather-related hazards and assisting different decision-making processes. While admitting the inherent complexity and uncertainty, continuing initiatives and multidisciplinary partnerships seek to increase prediction accuracy, resulting in a society that is safer and more resilient.

REFERENCES:

[1] W. Abdallah, N. Abdallah, J. M. Marion, M. Oueidat, and P. Chauvet, “A vector autoregressive methodology for short-term weather forecasting: tests for Lebanon,” *SN Appl. Sci.*, 2020, doi: 10.1007/s42452-020-03292-y.

[2] H. Zhang and Z. Pu, “Beating the Uncertainties: Ensemble Forecasting and Ensemble-Based Data Assimilation in Modern Numerical Weather Prediction,” *Adv. Meteorol.*, 2010, doi: 10.1155/2010/432160.

[3] P. R. Larraondo, “Application of machine learning techniques to weather forecasting,” *Thesis*, 2018.

[4] Z. Ghaemi, A. Alimohammadi, and M. Farnaghi, “LaSVM-based big data learning system for dynamic prediction of air pollution in Tehran,” *Environ. Monit. Assess.*, 2018, doi: 10.1007/s10661-018-6659-6.

[5] J. Zhang, J. Yan, D. Infield, Y. Liu, and F. sang Lien, “Short-term forecasting and uncertainty analysis of wind turbine power based on long short-term memory network and Gaussian mixture model,” *Appl. Energy*, 2019, doi: 10.1016/j.apenergy.2019.03.044.

[6] A. Rueda *et al.*, “Multiscale climate emulator of multimodal wave spectra: MUSCLE-spectra,” *J. Geophys. Res. Ocean.*, 2017, doi: 10.1002/2016JC011957.

[7] A. P and M. M. Patil, “A Review on Data Analytics for Supply Chain Management: A Case study,” *Int. J. Inf. Eng. Electron. Bus.*, 2018, doi: 10.5815/ijieeb.2018.05.05.

[8] R. A. Gupta, R. Kumar, and A. K. Bansal, "BBO-based small autonomous hybrid power system optimization incorporating wind speed and solar radiation forecasting," *Renewable and Sustainable Energy Reviews*. 2015. doi: 10.1016/j.rser.2014.09.017.

[9] M. I. Budyko, "The Heat Balance of the Earth's Surface," *Sov. Geogr.*, 1961, doi: 10.1080/00385417.1961.10770761.

[10] B. Amrouche and X. Le Pivert, "Artificial neural network based daily local forecasting for global solar radiation," *Appl. Energy*, 2014, doi: 10.1016/j.apenergy.2014.05.055.

CHAPTER 7

CREATION OF NETWORKS AND SERVICES FOR WEATHER STATIONS

Mr. Vidhur Kumar, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

A key component of meteorological infrastructure is the development of networks and services for weather stations, which enables the systematic collecting of meteorological data and the delivery of reliable weather information. The procedures involved in setting up weather station networks and the crucial services they provide are summarised in this study, emphasising their importance in weather forecasting, climate research, and disaster management. The significance of weather station networks in delivering localised, real-time weather data is emphasised in the first section. These networks serve as the backbone of weather analysis and forecasting by monitoring atmospheric parameters such as temperature, humidity, pressure, wind speed, and precipitation. The design and implementation of weather station networks are covered in the second part, along with topics including station density, geographic dispersion, and sensor calibration. The choice of appropriate places is carefully considered in order to record various microclimates and guarantee thorough coverage of various areas. The third segment covers data integration and transmission in networks of weather stations. Modern communication technologies, such satellite connections and wireless systems, make it easier to transport meteorological data quickly and seamlessly to processing and analysis centres. The importance of data quality assurance and control in preserving the precision and dependability of weather station readings is highlighted in the fourth part. Strict quality control procedures are essential for spotting and fixing mistakes or discrepancies in the obtained data.

KEYWORDS:

Atmosphere, Climate, Forecasting, Prediction, Weather.

INTRODUCTION

Synoptic weather maps can now be routinely produced thanks to networks of stations that were set up to collect data and send it to a central observatory. Beginning in 1814, the U.S. At their postings, members of the Army Medical Corps were instructed to record meteorological information; this task was later enlarged and made more organised. across the early decades of the 19th century, New York University, the Franklin Institute, and the Smithsonian Institution developed actual weather-station networks across the United States. James Glaisher organised a comparable network in the UK, while Christophorus H.D. Buys Ballot did the same in the Netherlands. Nearby Paris, Vienna, and St. Petersburg also saw the development of similar networks of meteorological stations. National meteorological services were quickly created in the United Kingdom and on the Continent. In 1871, the U.S. was given control of the country's first national weather service, which went into operation. Corps of Army Signals. The service's initial mission was to provide storm warnings for the Great Lakes, Atlantic, and Gulf coastlines. National meteorological services were developed throughout the course of the next several decades in nations including Brazil, India, and Japan. The directors of such national agencies acknowledged the value of international collaboration in weather forecasting. The International Meteorological Organisation (IMO) was established by 1880 [1].

By the end of the 19th century, synoptic forecasting had become a reality because to the expansion of weather-station networks connected by telegraphy. But the resulting daily weather predictions were far from accurate. Predictions were largely based on the experience that each forecaster had accrued over years of practise, hazily formulated rules of thumb (such as how pressure systems move from one region to another), and associations that were either poorly understood or not understood at all, which led to many errors.

In the early 20th century, progress was made

Calculating the atmospheric pressure pattern, the locations of the highs and lows and their variations is a crucial component of weather forecasting. Recent studies have shown that the movements of the upper atmosphere, with its narrow, swiftly moving jet streams and waves that propagate through the air and pass air through itself, affect sea-level pressure patterns. Forecasters in the 19th century surely sought knowledge about the higher atmosphere in search of potential explanations due to frequent surprises and inaccuracies in forecasting surface atmospheric pressure patterns. During a series of balloon ascents in the 1860s, the British meteorologist Glaisher to an unparalleled height of nine kilometres. Around this period, researchers on the Continent started sending recording barographs, thermographs, and hygrographs to very high altitudes in unmanned balloons. Meteorologists in the United States and Europe utilised kites fitted with equipment to study the atmosphere up to a height of approximately three kilometres in the late 1890s. Despite these attempts, by the turn of the century, nothing was known about the upper atmosphere. Confusion brought on by reports from weather stations perched on hills or mountains made the issue worse. Since so little is known about the high atmosphere, such observations often did not indicate what was anticipated. In addition, measurements are affected by the mountains themselves, leading to findings that are not indicative of what would be observed in the free environment at the same height.

Fortunately, enough scientists had previously proposed concepts that would enable weather forecasters to conceive in three dimensions even in the absence of significant meteorological observations. The idea that processes of the upper air provide the energy of storms was developed by Henrik Mohn, the first in a long series of brilliant Norwegian meteorologists, Wladimir Köppen, a renowned German climatologist, and Max Margules, a significant Russian-born meteorologist. British scientist William H. Dines presented data in 1911 that illustrated how the higher atmosphere makes up for the fact that low-level winds convey air in the direction of low-pressure centres. Dines realised that the upward and outward circulation above more or less balances the influx close to the bottom. In fact, the outflow must outweigh the inflow for a cyclone to strengthen, which calls for a decrease in central pressure. Surface winds may strongly converge towards the cyclone, but enough outflow aloft may result in dropping pressure at the centre [2].

Forecasting and meteorology

The importance of vertical circulations and upper-air phenomena was now recognised by meteorologists, but they had yet to understand how this information might enhance weather forecasting. The Norwegian cyclone model was subsequently proposed in 1919 by meteorologist Jacob Bjerknes of Norway. A low-pressure system that displayed fronts, which are fairly sharply sloped borders between cold and warm air masses, was the basis of this theory, which brought together a number of preceding theories and explained the patterns of wind and weather. Bjerknes drew attention to the patterns of rain and snow that are often associated with cyclonic fronts: rain or snow falls over broad regions on the cold side of an approaching warm front that is moving poleward of a low-pressure system. Here, lower-latitude winds are blowing, and since warm air is light, it rises over a significant area of cold air. Barometers drop as the storm approaches, and precipitation from the rising warm air falls through the cold air below. Widespread, sloping clouds spread ahead of the cyclone. Squalls and showers signal the sudden lifting of the warm air being displaced where the cold air moves forward towards the back of the storm. The idea of fronts thereby focused attention on what was happening at the boundary of air masses. Since the concept of warm air masses being lifted above cold air along their edges (fronts) became a crucial forecasting tool, the Norwegian cyclone model might be referred to as the frontal model. The example demonstrated where and how to use the concept in addition to emphasizing it.

Cyclogenesis

In subsequent work, Bjerknes and a number of other meteorologists from the so-called Bergen school of meteorology developed the model to demonstrate how cyclones develop from minor disturbances on fronts, go through a predictable life cycle, and finally perish when an influx of air fills them. Weather forecasters still use the Norwegian cyclone model and the related life-cycle idea. Other Scandinavian meteorologists contributed a large portion of the theoretical underpinnings for contemporary weather forecasting, while Bjerknes and his Bergen colleagues improved the cyclone model. Vilhelm Bjerknes, Jacob's father, and Carl-Gustaf Rossby were in the forefront of them. Their theories made it feasible to comprehend and accurately predict the variations in atmospheric circulation and the movement of the upper-air waves that govern cyclone activity.

DISCUSSION

Modern advancements and tendencies

Upper-air observations using equipment mounted on a balloon

Technology once again gave the tools needed to evaluate the latest scientific theories and inspire even more. In order to speed up access to the upper-air data, several teams of researchers, including those led by Yrjö Väisälä of Finland and Pavel Aleksandrovich Malchanov of the Soviet Union, started using small radio transmitters with balloon-borne instruments in the late 1920s and early 1930s. The upper-air observation networks that still exist today were made possible by these radiosondes, as they came to be known. Around 75 stations in the US and more than 500 elsewhere in the globe release balloons twice a day that soar to altitudes of at least 30,000 metres. The station from which the balloons are launched receives radio transmissions with observations of temperature and relative humidity at different pressures as they rise at a predefined pace. In order to determine the behaviour of winds from the balloons' drift, radar and GPS satellites are also used to follow them.

On the basis of radiosonde readings, forecasters are able to create synoptic weather maps of the upper atmosphere twice each day. The main synoptic clock periods for creating upper-air maps are still 0000 (midnight) and 1200 (noon) Greenwich Mean Time (GMT), notwithstanding the development of new upper-air measurement techniques. Furthermore, the beginning timings for the calculations that form the basis of contemporary computer-based predictions are 0000 and 1200 GMT. It is essentially a modified synoptic method that is closely related to the radiosonde networks established in the 1930s and 1940s.

Radar Application

The British started using microwave radar in the late 1930s to monitor enemy aircraft, but it was soon discovered that radar gave excellent returns from raindrops at certain wavelengths (5 to 10 centimetres), which led to several breakthroughs in weather prediction during and immediately after World War II. As a consequence, it became able to "see" the precipitation structure of bigger storms as well as follow and examine the history of individual showers or thunderstorms. The picture depicts a hurricane's rain bands, not its clouds.

Radar has been an increasingly important tool for forecasters since it was first used in meteorological work. Radar tracks almost all tornadoes and severe thunderstorms that occur over the United States and in some other regions of the globe. Radar observations of these storms' development, motion, and features may provide information about how severe they are. In order to calculate wind speeds and storm movements, modern radar systems employ the Doppler concept of frequency shift associated with movement towards or away from the radar transmitter/receiver.

Tetsuya Theodore Fujita, a Japanese American meteorologist, made several discoveries on the structure of violent local storms typical to the Midwest area of the United States and the behaviour of severe thunderstorms using radar and other measurements. He discovered "microburst" gusts in his wind studies using Doppler radar. Large wind shears (differences) brought on by these gusts are what lead to some of the aviation disasters that have occurred in the past. As opposed to twice a day, other forms of radar are being employed to measure winds continually. These wind-profiling radar devices actually catch signals that are "reflected" by pure air and may therefore operate even in the absence of clouds or precipitation [3].

Satellite and Aeroplane Readings of the Weather

The United States launched the first meteorological satellite, the TIROS (Television and Infrared Observation Satellite), on April 1, 1960, marking a significant advancement in meteorological measurement. Global quantitative assessments of surface features, such as ice cover and soil moisture, as well as temperature, cloud, and moisture distributions have already had a significant influence. Furthermore, new concepts and techniques may very possibly usher in the "age of the satellite" in weather forecasting in the twenty-first century [4].

Prior to the advent of satellites, it was hard to produce medium-range predictions that offered information five to seven days in advance, especially across the Southern Hemisphere's Ocean waters. models for global forecasting created in the U.S. The European Centre for Medium Range Weather Forecasts (ECMWF), the National Centre for Atmospheric Research (NCAR), and the U.S. During the 1980s, National Meteorological Centre (NMC) became the norm, making medium-range forecasting a reality. National weather agencies from all around the globe, such as those in Japan, the UK, and Canada, often run global weather forecasting models.

Multiple orbits and a large range of sensors are carried by meteorological satellites. The low-flying polar orbiter and the geostationary orbiter are the two main kinds. The first kind orbit the Earth generally north-south at heights between 500 and 1,000 km. They pass by a certain location twice a day and provide very high-resolution data due to their near proximity to Earth. Because they orbit close to the poles, such satellites are absolutely important for most of Europe and other high-latitude regions. One significant drawback of these satellites is that they can only offer a sample of atmospheric conditions twice daily [5].

The geostationary satellite is designed to travel 36,000 kilometres above the surface of the Earth in an equatorial orbit. The satellite stays in the same location directly above the Equator at that height because its eastward motion perfectly aligns with the Earth's rotation. This kind of satellite may provide an almost continuous picture of a large region. Because of this capacity, geostationary satellites are essential for both weather forecasting and meteorological study. They have provided fresh knowledge regarding the quick changes that occur in thunderstorms, hurricanes, and certain kinds of fronts.

The inability to monitor thin layers of the atmosphere is a flaw shared by almost all satellite-borne sensors and certain ground-based radars that employ UHF/VHF radiation. The tropopause, which separates the relatively dry stratosphere from the layer below that is more meteorologically active, is one such layer. The jet streams often originate in this area. Sensors installed on high-flying commercial aircraft are used to collect crucial data regarding these sorts of high-speed air currents, which is then regularly included into global weather studies.

Models for numerical weather prediction (NWP)

Ideas are routinely advanced by thinkers before the necessary technology is available to do so. There aren't many greater examples than numerical weather forecasting. Numerical predictions are objective computations of changes to the weather map based on collections of physics-based equations known as models, as opposed to mental estimations or rules of thumb concerning the track of storms. A British physicist by the name of Lewis F. Richardson produced such a prediction just after World War I using time-consuming and challenging manual computations. Despite the fact that the prognosis was wrong, Richardson's broad strategy was adopted decades later when the electronic computer was made accessible. In fact, it now serves as the foundation for almost all predictions of the weather in use today. There are few predictions that do not begin with numerical-model computations of pressure, temperature, wind, and humidity for some future period. Human forecasters may interpret or even adjust the findings of the computer models [6].

The synoptic approach (see above) and the technique are very closely connected. A Global Telecommunications System quickly gathers data to determine the starting circumstances at 0000 or 1200 GMT. The model equations are then solved for different regions of the weather map, which is often a worldwide map, to determine how much of a change in conditions is anticipated in a particular amount of time, such as 10 minutes. A new map that is valid for 0010 or 1210 GMT is produced (in the computer's memory) with these modifications appended to the original conditions. Although possibly not quite as exact as the measurements for 0000 and 1200

GMT, this map is handled as a fresh set of beginning circumstances and is still quite accurate. In order to create a prediction for 0020 or 1220, a new step is performed. Step by step, this procedure is repeated. The procedure may theoretically go on forever. In actuality, minute inaccuracies seep into the computations and mount up. This cumulative process leads to mistakes growing until there is no purpose in continuing [7].

The ECMWF, the NMC, and U.S. military facilities in Omaha, Nebraska, and Monterey, California, as well as in Tokyo, Moscow, London, Melbourne, and other locations, routinely (once or twice daily) create global numerical predictions. Additionally, a number of national meteorological agencies, military organisations, and even a few private enterprises provide specialised numerical predictions for many smaller parts of the globe that are intended to anticipate additional specifics about the weather. The research versions of numerical weather prediction models are also continuously being reviewed, developed, and tested in universities across the world as well as at NCAR, the Goddard Space Flight Centre, and other locations in the United States.

Since the mid-1940s, when the first modelling work was done by the mathematician John von Neumann and the meteorologist Jule Charney at the Institute for Advanced Study in Princeton, New Jersey, the capacity and complexity of numerical weather prediction models have increased dramatically. Because of their groundbreaking work and the discovery of significant simplifying relationships by other scientists, particularly Arnt Eliassen of Norway and Reginald Sutcliffe of Britain, a joint U.S. Known as JNWP, the Weather Bureau, Navy, and Air Force numerical forecasting unit was established in Washington, D.C., in 1954. Its duties included daily production of operational numerical forecasts. Thus, the 1950s marked the official start of the age of numerical weather prediction. The complexity, speed, and level of detail that the models could handle increased along with computational power. And when additional observations emerged from sources like radar systems, drifting weather balloons, and Earth-orbiting satellites, methodologies advanced sufficiently to include the data into the models as better first synoptic maps also advanced [8].

The accuracy of numerical predictions has increased over time. Under the direction of the World Meteorological Organisation, many countries participated in the massive worldwide Weather Experiment, which was first developed by Charney, in order to show what might be accomplished by using high-quality worldwide data to enhance forecasting using numerical prediction models. The outcomes of the endeavour continue to lead to advancement [9]. The creation of mesoscale numerical prediction models is a relatively new phenomenon. The prefix meso-, which meaning "middle," here denotes intermediate-sized atmospheric characteristics, ranging in size from massive cyclonic storms to solitary clouds. Mesoscale features such fronts, thunderstorm clusters, sea breezes, hurricane bands, and jet streams are critical forecasting issues that have just lately been addressed by numerical prediction. The meso-eta model, created by American atmospheric scientists Zavia Janji and Fedor Mesinger of Serbian descent, is an example of such a model. The National Weather Service in the United States uses a regional numerical weather prediction model, but the meso-eta model is a finer-scale variant of it. Using these small-area mesoscale models, the national weather agencies of numerous nations make numerical predictions with a great deal of information [10].

CONCLUSION

The incorporation of weather station data into numerical weather prediction models is covered in the fifth part. These data contribute significantly to the initialization and validation of model simulations, improving prediction precision and provide important data for climate study. The services provided by weather station networks, including real-time weather updates, historical climate data, and public weather alerts. These services are essential for assisting a variety of industries, such as agriculture, aviation, and disaster management by facilitating risk reduction and informed decision-making. The significance of international cooperation in developing global weather station networks is covered in the seventh part. The flow of data is ensured through cooperation among meteorological agencies and organisations, encouraging a more thorough knowledge of weather patterns and climatic variability. This emphasizes how data processing methods and technology are always improving, significantly enhancing the capabilities of networks of weather stations. These networks continue to be crucial for resolving the problems caused by weather variability and climate change, promoting social resilience, and protecting people's lives and livelihoods.

REFERENCES:

[1] G. Rosas *et al.*, "Towards implementing climate services in Peru – The project Climandes," *Clim. Serv.*, 2016, doi: 10.1016/j.cliser.2016.10.001.

[2] A. Tran *et al.*, "Complementarity of empirical and processbased approaches to modelling mosquito population dynamics with Aedes albopictus as an example-Application to the development of an operational mapping tool of vector populations," *PLoS One*, 2020, doi: 10.1371/journal.pone.0227407.

[3] F. Locci *et al.*, " Implementation of a web GIS service platform for high mountain climate research: the SHARE GeoNetwork project ," *Geosci. Data J.*, 2014, doi: 10.1002/gdj3.14.

[4] J. A. Gonzalez-Esparza *et al.*, "Mexican Space Weather Service (SCiESMEX)," *Sp. Weather*, 2017, doi: 10.1002/2016SW001496.

[5] D. Kluver, T. Mote, D. Leathers, G. R. Henderson, W. Chan, and D. A. Robinson, "Creation and validation of a comprehensive 1° by 1° daily gridded North American dataset for 1900-2009: Snowfall," *J. Atmos. Ocean. Technol.*, 2015, doi: 10.1175/JTECH-D-15-0027.1.

[6] A. O. Demir, "Digital Skills, Organizational Behavior And Transformation Of Human Resources: A Review," *Ecoforum*, 2019.

[7] A. Quarati *Et Al.*, "Integrating Heterogeneous Weather-Sensors Data Into A Smart-City App," In *Proceedings - 2017 International Conference On High Performance Computing And Simulation, Hpcs 2017*, 2017. Doi: 10.1109/Hpcs.2017.33.

[8] K. Helmert, B. Hassler, And J. E. E. Seltmann, "An operational tool to quality control 2D radar reflectivity data for assimilation in COSMO-DE," *Int. J. Remote Sens.*, 2012, doi: 10.1080/01431161.2011.592161.

[9] A. A. Yudho Yudhoanto, "Pengantar Teknologi Internet of Things(IoT)," *Yudho Yudhoanto, Abdul Aziz*, 2019.

[10] E. D. Borghard and S. W. Lonergan, "Cyber Operations as Imperfect Tools of Escalation," *Strateg. Stud. Q.*, 2019.

CHAPTER 8

PRINCIPLES AND PROCEDURES FOR PREDICTING THE WEATHER

Mr. Kuldeep Kumar, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

A complicated and multidisciplinary area that includes meteorological research, data collecting, numerical modelling, and cutting-edge technology, weather prediction concepts and methods. In order to effectively anticipate atmospheric conditions, this study highlights the essential ideas and approaches that are employed in weather prediction. The fundamentals of weather forecasting are introduced in the first part, along with an explanation of atmospheric dynamics, thermodynamics, and the significance of numerous meteorological phenomena such pressure systems, fronts, and jet streams. It highlights how important regional and global climate trends are for affecting local weather. The observation systems and data gathering techniques used in weather forecasting. This comprises satellites, radar systems, ground-based weather stations, and remote sensing tools. The quality and thoroughness of weather analysis are improved by combining data from several sources. The numerical modelling method of forecasting the weather is covered in detail in the third part. Meteorologists can anticipate weather conditions over specified time periods and geographical areas thanks to numerical weather prediction models, which mimic atmospheric behaviour using difficult mathematical equations. Forecast accuracy has substantially increased because to the creation of global and regional models and developments in supercomputing. The fourth part discusses data assimilation methods, which include incorporating observations from multiple sources into numerical models to enhance their starting conditions. The accuracy of weather predictions is improved and uncertainties are reduced as a result of this procedure.

KEYWORDS:

Atmosphere, Climate, Forecasting, Prediction, Weather.

INTRODUCTION

People are generating a very short-range weather prediction while they wait beneath a shelter for a rain to stop. They believe that such intense rain typically does not persist very long based on prior experience. The difficulty for the forecaster in making short-term forecasts is to outperform laypeople. For many years, forecasters found it extremely difficult to handle the kind of circumstance shown in the aforementioned example, but since the mid-1980s, they have been developing an approach called nowcasting to address just this kind of difficulty. This approach uses computers to quickly interpret and show radar and satellite images of the local atmosphere in order to forecast the weather many hours in advance. In Boulder, Colorado, the National Oceanic and Atmospheric Administration runs the PROFS (Programme for Regional Observing and Forecasting Services) facility, which is geared specifically for nowcasting [1].

Because they are able to assess and anticipate atmospheric conditions over wide regions using computers, meteorologists are able to generate predictions that are considerably longer-term (those for 6, 12, 24, or even 48 hours) with remarkable skill. Meteorologists may now make predictions with objectivity thanks to models that swiftly, precisely, and statistically validly utilise their acquired specialist knowledge. As a result, using the same data inputs and doing all analysis quantitatively, the same findings are consistently obtained. Objective forecasts are reliable and can be investigated, revised, and improved upon, in contrast to historical predictions produced using subjective approaches.

Model Output Statistics, or MOS, is another method for making objective short-term forecasts. Designed by D.A. and Harry R. Lowry of the U.S. According to the National meteorological Service, this approach uses historical meteorological data to extrapolate the values of various weather factors, often for a given area and time period. Through the creation of statistical relationships between model predictions and actual weather, it addresses the shortcomings of numerical models. The model predictions are then immediately translated to particular weather forecasts using these relations. For instance, a computer model may not forecast surface winds at all and, if it did, the predicted winds could constantly be too strong. For example, MOS relations may provide very accurate predictions of wind occurrence at Heathrow Airport in London by automatically correcting for mistakes in wind speed. The MOS approach may have various applications as long as numerical weather prediction models are not perfect [2].

Predictive Techniques and Abilities

As forecasters try to look farther into the future, short-range projections often tend to become less accurate. The best predictive performance is for intervals of around 12 hours, and it is still pretty significant for forecasts of 48 hours. Short-term projections with a growing economic focus are becoming more prevalent. The financial benefits they generate or losses they avoid in the marketplace define their dependability. The preservation of human life is the forecaster's greatest task and source of pride. Weather warnings are a specific form of short-range forecast. In fact, the necessity for storm warnings on the Great Lakes led to the establishment of the first national weather forecasting agency in the United States (the forerunner of the Weather Bureau) in 1870. Increase Lapham of Milwaukee pushed Congress to intervene in the 1860s to lessen the hundreds of lives lost annually by Great Lakes trade. The American public weather service's future was guaranteed by the efficacy of the warnings and other predictions.

Government and military organisations all over the world issue weather warnings for a variety of dangerous weather conditions, including tropical storms, which are also known as hurricanes, typhoons, or tropical cyclones depending on where they are, large oceanic gales that extend hundreds of kilometres and occasionally pack winds similar to those of tropical storms, and weather conditions on land such as flash floods, strong winds, fog, blizzards, ice storms, and snowstorms. Hail, lightning, and wind gusts are specifically warned of when severe thunderstorms, also known as severe local storms (SELS) or just severe weather, are present. Tornadoes, those powerful, whirling windstorms that stand for the most severe end of the weather spectrum, are likewise subject to forecasts and warnings. In a tornado's path, there is a very high chance of property destruction as well as injuries and fatalities, particularly for the biggest systems also known as maxi-tornadoes.

The National Weather Service operates a National Severe Storms Forecasting Centre (NSSFC) in Kansas City, Missouri, where SELS forecasters scan the atmosphere for conditions that can spawn tornadoes or severe thunderstorms because tornadoes are particularly life-threatening and common in various regions of the United States. This 1952-formed team of SELS forecasters searches pressure and wind maps to locate areas where thunderstorms may organise into mesoscale structures and monitors temperature and water vapour in an attempt to pinpoint warm, moist locations where thunderstorms may occur. The team also keeps an eye on jet streams and dry air above the atmosphere, which may work together to transform common thunderstorms into unusual spinning ones with slanted chimneys of rushing air that, due to the tilt, are unaffected by heavy rain falling. Large hailstone generation is encouraged by these swift updrafts that may swiftly deliver massive amounts of moisture to the frigid top parts of the storms. To complete a circle of powerful, cooperative updrafts and downdrafts, the hail and rain pull air from above.

SELS forecasters are able to provide enough time for the mobilisation of special observation networks and people by successfully predicting such situations. If the storms materialise, precise warnings are sent out based on firsthand observations. The tornado or severe thunderstorm watch, which is the prediction created by the SELS forecaster, and the warning, which is often issued by a local observation station, make up this two-step procedure. When the sky is clear, the watch may be issued; it often spans several counties. The danger is announced, but it makes no effort to identify which localities would be impacted. The warning, on the other hand, is quite localised and demands quick response. Different forms of radar may be used to see enormous hail, a strong downpour, a quick updraft in a clear area, and even the spinning of a tornado. The tornado warning often starts when one of these signs or an actual sighting occurs. In essence, a watch is a prediction that warnings may be required later in a certain area, but a warning is a precise declaration that danger is near.

Predictions for the future

Techniques

Compared to short- or medium-range forecasting, extended-range or long-range weather forecasting has a distinct history and methodology. The synoptic approach of moving ahead in time from a particular beginning map has not often been used. Instead of trying to anticipate day-to-day specifics, long-range forecasters have a tendency to employ the climatological method, frequently focusing on the overall weather picture over time. There is solid evidence to suggest that the "initial map" approach's limit for day-to-day projections is about two weeks. Thus, the majority of long-range predictions make an effort to foretell deviations from the usual for a certain month or season. Anomalies are what we term such deviations. Based on a forecast anomaly map, which depicts temperature anomaly patterns, a prediction would say, "Spring temperatures in Minneapolis have a 65% probability of being above normal." Instead than attempting to predict the weather for a specific day, the maps anticipate patterns (such as higher than average temperatures) over a long period of time, such as a season (such as spring).

Just before the start of World War II, the U.S. Weather Bureau started issuing experimental long-range forecasts. Its successor, the National Weather Service, continues to present such forecasts in probabilistic terms, making it obvious that they are subject to uncertainty. The results of the verification indicate that predictions of temperature anomalies are more trustworthy than those of precipitation, that monthly forecasts are more accurate than seasonal ones, and that winter months are forecasted with a little bit more accuracy than other seasons.

The analogue approach, in which groupings of meteorological circumstances (maps) from past years were compared to those of the current year to discover parallels with the atmosphere's current patterns (or "habits"), was a major component of the methodology that was often utilised in long-range forecasting prior to the 1980s. The ensuing events in those "similar" years were then connected to what was likely to occur in the present year. The majority of the procedures were fairly arbitrary, and there were often discrepancies in their interpretation, which led to inconsistent quality and mediocre dependability.

Although, technically speaking, most forecasters consider persistence predictions to be "no-skill" forecasts, persistence (warm summers follow warm springs) or anti-persistence (cold springs follow warm winters) forecasts were frequently utilised. However, they too have only enjoyed little success.

Potential for Novel Techniques

The approach to and future possibilities for long-range weather forecasting underwent a substantial transformation in the final part of the 20th century. stimulated by Jerome Namias's leadership of the U.S. Scientists have been studying ocean-surface temperature anomalies as a probable source of the temperature anomalies of the atmosphere in consecutive seasons and at far-off places at Weather Bureau's Long-Range Forecast Division for 30 years. Other American meteorologists at the time, most notably John M. Wallace, demonstrated how certain repeated patterns of atmospheric flow were connected to one another in various locations throughout the globe. As satellite-based measurements became accessible, researchers started looking into the El Nio phenomena. The work of British climatologist Gilbert Walker from the early 20th century, who had investigated the Southern Oscillation the aforementioned up-and-down variation in atmospheric pressure in the Southern Hemisphere was also renewed by atmospheric scientists. Walker had looked at associated air circulations (later known as the Walker Circulation) caused by unusually high pressures in Australia and low pressures in Argentina, or the other way around.

All of this resulted in fresh information on the potential linkages between the occurrence of unusually warm or cold ocean waters and abnormally high or low air pressures. Forecasters are able to make better long-term forecasts, at least in part because of knowledge of these links—El Nio/Southern Oscillation (ENSO) and the behaviour of certain components of these enormous systems. Long-range forecasting may be entering a revolutionary phase with this method of examining linkages between the atmosphere and the ocean. Interest in using numerical weather prediction models for long-range forecasting has increased since the mid-1980s. In this instance, objectively expected anomalies rather than the specifics of weather predictions made 20 or 30 days in advance are of significance. Similar to short- and medium-term estimates, the accuracy of long-term forecasts has significantly increased in recent years. However, a great deal of important issues are still unresolved, creating intriguing challenges for everyone working in the subject [3].

DISCUSSION

Most people are aware of the rising need for more precise weather predictions in modern life. The public's breadth of demands for weather forecasts includes wanting to know if, for instance, the weekend will be suitable for a beach trip, an organization's rally, or an outdoor wedding event. Airlines and fruit producers, two very different sectors, rely significantly on precise weather predictions to know what their next flight schedule will look like or whether the weather will be ideal for harvesting. Furthermore, in industrialised nations, a thorough understanding of the atmosphere is crucial to the construction of many industrial facilities as well as many structures. The act of predicting future weather conditions or an effort to suggest the weather conditions that are likely to occur is known as weather forecasting. The use of science and technology to forecast the condition of the atmosphere at a certain area and time is known as weather forecasting. Since at least the eighteenth century, people have made systematic attempts to forecast the weather after making informal predictions for thousands of years. Weather predictions are created by gathering qualitative information about the atmosphere's present condition and applying scientific knowledge of atmospheric processes to predict how the atmosphere will change over the following several hours.

Forecast models are currently utilised to predict future circumstances. Previously, forecasting was an entirely human undertaking based mostly upon changes in barometric pressure, present weather conditions, and sky conditions. In this sense, a model is a computer programme that generates meteorological data at upcoming periods at certain places and altitudes. A model's horizontal domain might be either worldwide, or it can be regional, or it can merely cover a portion of the planet. Limited area models are another name for regional models. To choose the optimal prediction model on which to base the forecast, human input is still necessary. This requires pattern identification abilities as well as knowledge of model performance and biases. Forecast accuracy decreases when the interval between the present time and the period for which it is being made widens due to the chaotic nature of the environment, measurement errors, and a lack of knowledge about atmospheric processes [4].

Weather predictions are used by many different people. Weather warnings are crucial predictions because they serve to save property and human life. Climate- and precipitation-based forecasts are crucial for agriculture, and by extension, for commodities traders on stock markets.

Utility firms often utilise temperature projections to predict demand for the next days. People often consult weather predictions to decide what to dress each day. Forecasts may be used to plan activities around these phenomena, prepare ahead and survive them, as strong rains have recently severely restricted outdoor activities in Uyo, Nigeria, for example.

Forecast Weather Applications

It is impossible to overstate how crucial precise weather predictions are since they are required in almost every facet of life. The following scenarios may be used with these forecasts:

Severe Weather Warnings and Alerts

Severe weather warnings and advisories, which the national weather services issue in the event that severe or hazardous weather is anticipated, play a significant role in contemporary weather forecasting. To safeguard both life and property, this is done. The National Meteorological Agency's recent warnings concerning locations in Nigeria that are prone to flooding as well as severe thunderstorm and tornado warnings are some of the most well-known severe weather advisories. Winter weather, strong winds, floods, tropical cyclones, and fog are further types of these warnings. Radio stations transmit severe weather warnings and alerts utilising emergency systems like the Emergency Alert System, which interrupt normal programming [5].

Aviation

Since the aviation sector is particularly susceptible to weather, reliable weather forecasting is crucial given that a bigger percentage of aircraft accidents that have been reported globally have weather-related causes. Thunderstorms are a serious issue for all aircrafts because they can cause severe turbulence due to their updrafts and outflow boundaries, icing due to the heavy precipitation, as well as large hail, strong winds, and lightning, all of which can cause serious damage to an aircraft's in-flight. Volcanic ash is a serious issue for aviation as well since ash clouds may cause aircrafts to lose engine power. Every day, airliners are routed to benefit from the jet stream tailwind to maximise fuel efficiency. Before departure, aircrews get a briefing on the weather conditions they might anticipate along the way and at their destination. Additionally, airports often switch the runway that is being utilised to benefit from a headwind. By doing so, the distance needed for takeoff is shortened, and any chance of crosswinds is removed [6].

Marine

The usage of rivers for commercial and recreational purposes may be severely constrained by wind direction and speed, wave heights and periodicity, tides, and precipitation. Each of these elements has the potential to affect how safe sea travel is. As a result, a number of codes, such as MAFOR (maritime forecast), have been developed to effectively convey precise maritime weather predictions to vessel pilots through radio [7].

Farming

Farmers depend on weather predictions to choose what tasks to do each day. For instance, only dry conditions are suitable for hay drying. Cotton, wheat, and maize harvests may all be destroyed by extended dry spells. While drought may damage crops, their dried remnants can be utilised to make silage, a replacement for cow feed. Both in the spring and the autumn, frosts and freezes damage crops. For instance, a spring frost might completely destroy the potential peach harvest of a peach tree that is in full bloom. Regardless of when they occur, frosts and freezes may cause serious harm to orange orchards.

Utility providers

The demand for electricity and gas, which may be significantly impacted by the weather, is predicted by electricity and gas firms using weather predictions. They utilise the amount known as the degree-day to estimate how significant a need there will be for cooling (degree day for cooling) or heating (degree day for heating). These numbers are based on a 650 F (180 C) daily average temperature [8].

One degreeday (one per degree Fahrenheit) of heating is required in cooler temperatures, whilst cooling is required in higher climates. In the winter, extreme cold may increase demand as people crank up their heaters. Similar to this, a rise in demand during the summer or dry season may be correlated with an increase in air conditioning use during hot weather. Utility providers may manufacture extra supplies of electricity or natural gas in advance of a spike in demand, or in other cases, supply are constrained via the use of brownouts and blackouts [9].

Private Sector

Private businesses are increasingly paying for weather predictions customised to their requirements in order to boost revenues or prevent significant losses. For instance, grocery store chains could alter the products on their shelves in anticipation of shifting customer purchasing patterns depending on the weather. Weather predictions may be utilised to make investments in the futures markets for commodities including oranges, maize, soybeans, and oil. On a daily basis, the general population uses information about forecasted weather conditions to decide what to wear.

Applications in the military

Military weather forecasters inform the public and the fighting forces about the weather in a manner similar to the commercial sector. Pilots get pre-flight weather briefings from military weather forecasters, and they also provide real-time resource protection services for military facilities [10].

CONCLUSION

This ensemble forecasting, which generates probabilistic predictions by performing a number of simulations with slightly different beginning circumstances. This method aids in assessing prediction uncertainty and effectively conveying it to the general public and decision-makers. The use of cutting-edge technology, such machine learning and artificial intelligence, in weather prediction is examined in the sixth part. These innovations have the potential to enhance model performance, data processing, and the forecasting of severe weather events. The value of ongoing research and validation to enhance weather forecasting techniques. In order to find model biases and improve forecast reliability, model verification, hindcasting, and forecast review are essential. This acknowledges the continuous work being done to enhance the theories and practises of weather prediction by meteorologists, researchers, and technology developments. Weather forecasting is constantly developing thanks to the integration of cutting-edge scientific knowledge with cutting-edge technology, providing better prepared communities and promoting resilience in the face of dynamic and shifting atmospheric circumstances.

REFERENCES:

[1] J. J. Landsberg and R. H. Waring, “A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning,” *For. Ecol. Manage.*, 1997, doi: 10.1016/S0378-1127(97)00026-1.

[2] Kemenkes RI, “Peraturan Menteri Kesehatan Republik Indonesia Nomor 12 Tahun 2020 Tentang Akreditasi Rumah Sakit,” *Molecules*, 2020.

[3] S. Feick, K. Kronholm, and J. Schweizer, “Field observations on spatial variability of surface hoar at the basin scale,” *J. Geophys. Res. Earth Surf.*, 2007, doi: 10.1029/2006JF000587.

[4] R. H. Waring and J. J. Landsberg, “A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning,” *For. Ecol. Manage.*, 1997.

[5] P. M. Ndomba and A. Van Griensven, “Suitability of SWAT model in sediment yields modeling in the Eastern Africa,” *Adv. Data, Methods, Model. Their Appl. Geosci.*, 2011.

[6] S. D. Kotal and S. K. Roy Bhowmik, “A multimodel ensemble (MME) technique for cyclone track prediction over the North Indian Sea,” *Geofizika*, 2011.

[7] S. P. Ralya Luthfianti, Citra Kusuma Dewi, “Pengaruh Kualitas Pelayan, Kepuasan Konsumen dan Kepercayaan Konsumen Terhadap Loyalitas Konsumen Pada Pengguna OVO 2019,” *Prodi Adm. Bisnis, Fak. Komun. dan Bisnis, Univ. Telkom*, 2020.

[8] R. Aprianisa, “Asuhan keperawatan pada klien sirosis hepatis dengan kelebihan volume cairan di ruang marjan bawah rsu dr. Slamet garut.,” *Molecules*, 2020.

[9] E. S. A. Ao-, S. Rockets, and P. Sciences, “Research In Physical Sciences On Sounding Rockets And The Iss And Research In Life Sciences (Biology),” *Oikos*, 2009.

[10] F. Röske, “Sea level forecasts using neural networks,” *Dtsch. Hydrogr. Zeitschrift*, 1997, doi: 10.1007/bf02765119.

CHAPTER 9

METEOROLOGICAL DEPARTMENT OF INDIA'S GENERAL FORECASTING ORGANIZATION

Mr.Ravi Singh Thapa, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

The General Forecasting Organisation (GFO) of the Indian Meteorological Department is essential in delivering precise and timely weather predictions and alerts to serve diverse industries and protect public safety. An overview of the GFO's main duties, organisational structure, data gathering techniques, forecasting approaches, and the importance of its services in the Indian meteorological context are provided in this study. The significance of meteorological services in India is discussed in light of the variety of the country's climate and weather patterns. The Indian Meteorological Department (IMD), which houses the GFO, is the government agency in charge of making weather predictions and distributing important meteorological data. The GFO's organisational structure is covered in more detail in the second section, which also highlights its departments and roles. It includes the Agrometeorological Advisory Service (AAS), the Weather Forecasting Division (WFD), the Cyclone Warning Division (CWD), and other specialised divisions that work together to give thorough weather predictions and alerts. The third part examines the many data gathering techniques the GFO uses to compile meteorological data. This comprises data sharing agreements with international meteorological organisations, ground-based weather stations, radars, satellites, and remote sensing technology.

KEYWORDS:

Forecasting, Meteorological Department, Organization, Regional, Weather.

INTRODUCTION

With the founding of the India Meteorological Department (IMD) in 1875, weather forecasting in India officially began. Over time, the IMD has grown to include a network of forecasting organisations. India, a tropical nation, often suffers extreme weather, including cyclones, violent thunderstorms, flash floods, and snow avalanches, among other things. Understanding tropical meteorology at various spatial and temporal dimensions is necessary to comprehend the science behind such weather systems. A better understanding of weather phenomena at all scales has been achieved thanks to advances in science, technology, and computers, as well as the introduction of observational tools like Doppler weather radars and satellites, which have improved daily operational weather forecasts [1]. The commissioning of recently purchased modern observing equipment, the introduction of high-resolution numerical weather prediction models, the use of high-power computing systems for running numerical models, and other recent modernization of IMD's activities have all contributed to further improvements in the quality of forecasting services. The forecasting service has grown in relevance for applications in certain industries, and there is a greater need for sector-specific, custom, high-resolution forecast products on both a geographical and temporal scale. The forecasting services have a solid organizational structure that allows them to meet these expectations. This chapter contains information about the subject. The forecasting company was founded with the following goals in mind:

a. To enhance coordination in areas pertaining to daily forecasting amongst all pertinent operating centres throughout the nation at the national, regional, and state level.
b. To match consumer expectations, update the goods and warnings numerous times each day.
c. To improve all forecast products' consistency and accuracy, including those for general weather, agromet, maritime, aviation, and mountain weather, by using improved methodology, teamwork, and complementary responsibilities.
d. To publish forecasts and nowcasts at the district level and implement other system upgrades. This is difficult since it involves downscaling short-term estimates to the district level.
e. To enhance city forecasts, which need a site-specific evaluation of the meteorological situation.
f. To include maritime forecasts (for high seas and coastal regions), Fishermen Warnings, and more system upgrades.
g. To use updated tropical cyclone monitoring modules and technologies to offer cyclone warning services for low pressure systems developing over the North Indian Ocean.
h. To provide impact-based warning systems for various weather conditions.
i. To provide capital city residents impact-based weather forecasts for heavy precipitation.
j. To account for the new forecasting service's needs.
k. To conduct R&D to assist the enhancement of the services.

Organization for Current Forecasting

IMD's national forecasting operations are coordinated by the National Weather Forecasting Centre (NWFC) at IMD New Delhi, while the Weather Central at IMD Pune serves as the backup centre for NWFC. The Meteorological Centres (MCs) in the state capitals do the same for their respective states, while the Regional Meteorological Centres (RMCs) do the same for their respective regions. Cyclone Warning Directorate (CWD), IMD, New Delhi, at the headquarters level, oversees and coordinates operational actions connected to cyclones. Additionally, this institution serves as the WMO region's Regional Specialised Meteorological Centre (RSMC) for tropical cyclones. According to their respective areas of duty, Area Cyclone Warning Centres (ACWCs) and Cyclone Warning Centres (CWCs) handle the maritime weather services and cyclone warning services for the coastal states. The Hydrometeorology Division, IMD, New Delhi, manages the services relating to flood forecasting provided by Flood Meteorological Offices (FMOs), and it also gathers information and creates statistics on rainfall for the whole nation. While the Agro Advisory Service Division (AASD), IMD, New Delhi handles the liaisoning work relating to Agromet services, the Agricultural Meteorology Division, IMD Pune coordinates Agromet forecasting services [2].

General Forecast

The National Weather Forecasting Centre (NWFC), located in IMD New Delhi, coordinates the technical and procedural aspects of forecasting services. The centre organises annual monsoon and cyclone review meetings to evaluate the performance of the previous year's forecast, prepares documentation on realised weather with contributions from Weather Central, IMD, Pune, RMCs, and MCs, issues circulars related to forecasting, and analyses user feedback and forecasting appraisal by various centres to deliberate and devise methodologies.

1. The National Weather Forecast Centre (NWFC), IMD New Delhi serves as the primary operational interface for all weather-related issues with the Government of India. It also gives the National Disaster Management Authority (NDMA) and other government agencies the necessary information and briefings on the realised and forecasted weather for the entire nation.
2. The NWFC offers press, media, All India Radio, Doordarshan, and other users with information on forecasts and warnings. Additionally, it offers predictions for the Western Himalayan region and publishes unique forecasts for a variety of events, including as sporting competitions, tourist excursions, mountaineering expeditions, VVIP movements, Independence Day celebrations, etc.
3. For inquiries, complaints, and RTI requests pertaining to national weather forecasting services, the NWFC prepares, finalises, and gives feedback.
4. State Weather Forecasting Centres (SWFCs) in MCs and Regional Weather Forecasting Centres (RWFCs) in RMCs serve as the operational interface for weather forecast and warning services provided to the relevant State Government and various government departments, and they also provide the necessary information/briefing on realised and forecasted weather at the district level as well as for the state's major cities. It offers weather data to all customers involved in state emergency management, as well as to the media (both print and internet).
5. As soon as the necessary circumstances are present, all forecasting centres issue warnings for heavy rain, heat waves, cold waves, fog, thunderstorms, and associated phenomena including lightning, squalls, gusty winds, hail, etc. The Forecaster's Guide is a set of instructions for this use. The chapters linked to those in this publication may be consulted for Standard Operating Procedures for such high impact weather events.

DISCUSSION

Marine Forecast

Marine Service Division of NWFC, IMD New Delhi coordinates forecast and warning services for high seas, with assistance from ACWC Kolkata for the Bay of Bengal and ACWC Mumbai for the Arabian Sea. This section publishes Fleet Forecast for the Indian Ocean between Latitude 50 N to 10 0 S and Longitude 600 to 1000 E as well as Global Maritime Distress Safety System (GMDSS) Bulletin for Area VIII N.Additionally, this section issues textual and visual Fishermen Warnings for deep sea and coastal regions of the North Indian Ocean. In collaboration with NWFC and IMD New Delhi, ACWCs and CWCs publish coastal bulletins and fisherman warnings for their respective regions of responsibility.

Cyclone Alert

The so-called "red book" at the national level and the "Cyclone Manual" at the IMD level both include well-organized cyclone warning methods. Cyclone-related crisis disaster management is handled by effective collaboration at all levels. At the national level, the DGM or any senior official from IMD Headquarters who is involved contacts with the National Disaster Management Council, which is presided over by the Prime Minister's Office. At the state level, the Chief Minister of State chairs the State Disaster Management Council, and at the district level, the District Collector or Magistrate chairs the District Disaster Management Council, which communicates with the Head of RMC/MC/CWC. Under the direction of CWD, IMD, New Delhi, the ACWCs in Kolkata, Chennai, and Mumbai coordinate with the CWCs in Bhubaneshwar, Visakhapatnam, Thiruvananthapuram, and Ahmedabad to handle operational cyclone warning-related tasks in accordance with their areas of responsibility. The department serves as the regional specialised meteorological centre (RSMC) for the region when it comes to tropical cyclone forecasting due to its international duties in this area [3].

Services for agrometeorology

Agromet Advisory Service (AAS) units at RMC/MC level give weather predictions for agricultural use. After performing value addition based on synoptic analysis, RMCs and MCs twice a week release five days' worth of quantitative district level predictions utilising Numerical Weather Prediction model products. Various Agro Meteorological Field Units (AMFUs) and District Agro-Met Units (DAMUs) of the states get the final prediction from AAS units of RMCs/MCs. Agromet warnings are then issued by AMFUs and DAMUs for the farmers in their particular areas/districts based on these predictions. Head of AASD at IMD New Delhi and Head of Agromet at IMD Pune jointly handle the cooperation with RMCs/MCs, AMFUs/DAMUs, and MCs.

Meteorological Offices for Floods

IMD has established Flood Meteorological Offices (FMOs) at thirteen locations, including Agra, Ahmedabad, Asansol, Bhubaneshwar, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi, Patna, Srinagar, Bengaluru, and Chennai, to provide flood-related services. IMD also assists Damodar Valley Corporation (DVC) with its flood forecasting efforts for areas along the Damodar River basin. The Central Water Commission (CWC) receives meteorological assistance from IMD via these FMOs in order to issue flood warnings for the 43 rivers in India that drain 153 river basins. For about 176 areas, CWC produces flood predictions 6 to 30 hours in advance utilising the Quantitative Precipitation Forecast (QPF) and the hydrometeorological information obtained from IMD [4].

Present Services

Due to the accompanying weather components like squalls and lightning, meteorological phenomena like thunderstorms, hailstorms, and other similar events are only momentary yet very destructive. Therefore, it is vital to continuously monitor these extreme weather occurrences and to offer warnings. They may be better covered by nowcasts than short range predictions since they emerge and disappear over a brief period of time.

The Nowcast Division of the NWFC publishes a nowcast guidance bulletin every day to support nowcast services. This bulletin provides information on expected severe weather phenomena, including their intensity and area of occurrence, so that the concerned RWFC/SWFC can continuously monitor their development and update their nowcasts as necessary. For the convenience of the general public and disaster management, these nowcasts are posted on the IMD website's nowcast page and distributed by SMS and social media as well.IMD now provides nowcasts for 897 sites worldwide that are within radar range [5].

Mountain Weather Services

Based on observations made at 0830 and 1430 hours each day, the Mountain Meteorology Division of NWFC publishes weather prediction bulletins for the Western Himalayan Region twice a day. These bulletins provide observed weather as well as forecasts and warnings for the seven-day period for the Garhwal & Kumaon areas of Uttarakhand, the High hills and lower hills parts of Himachal Pradesh, and the Jammu, Kashmir, and Ladakh divisions of J&K.These bulletins are sent by email to the Snow & Avalanche Study Establishment (SASE), the Meteorological Centres in Srinagar, Shimla, and Dehradun, as well as being posted on the IMD website. Through this branch, NWFC also offers weather prediction services on demand to different government organisations and military forces to meet their needs linked to mountain adventures [6].

Forecasting Services for Specific Uses

Specific sections at IMD in New Delhi and at RMCs/MCs handle the needs for weather information and forecasts for various industries, including sports, tourist, pilgrimage, transport (highway), railroads, aviation, the power industry, health, urban and environmental services, etc.

Changing the SOP

Since its humble beginnings in 1875, IMD has steadily increased the scope of its infrastructure for meteorological observations, forecasting services, and communications. IMD initially released the Standard Operating Procedures (SOP) in 2012 for addressing the operational elements of weather forecast services. Following that, a modernization plan put numerous adjustments, additions, and improvements into place in different elements of the service. Thus, updating the outdated SOP is now required to account for such modifications [7].

The Duty of Forecasting Centres

The India Meteorological Department (IMD) has a three-tier structure for delivering effective forecasts and related services to the general public and various user agencies, including the disaster management authority. These natural calamities include heavy rainfall, snowfall, thunderstorms, hailstorms, heat waves, and cold waves, among others. Every day, the National Weather Forecasting Centre (NWFC) at IMD Headquarters in New Delhi publishes the All India Weather Bulletin, which is updated three times in every twenty-four hours and covers all 36 meteorological sub-divisions of the nation. The Regional Meteorological Centres (RMCs) and State Meteorological Centres (SMCs) forecasting centres produce forecasts and warnings at the district level based on this bulletin, which more or less serves as a guidance bulletin for the subordinate offices. The RWFCs and SWFCs provide nowcasts every three hours or as needed in relation to the relevant severe weather phenomena based on the nowcast advisory bulletins that the NWFC also publishes for the severe weather components like thunderstorm, heavy rainfall, fog, etc. In addition, the NWFC also publishes twice daily Mountain Weather Bulletins for the Western Himalayan Region, Global Maritime Distress and Safety System (GMDSS) bulletins for

Area VIII N, and Fleet Forecasts for the Indian Ocean between Latitude 5 0N and 10 0S and Longitude 600 to 1000 E. These are all related to marine weather. Every year, the NWFC also provides forecast and warning assistance to mountain expedition teams, Amarnathji Yathra, and other events. Special forecasts are also provided for occasions like Independence Day and Republic Day festivities [8].

The National Weather Forecasting Centre (NWFC) is in charge of monitoring and forecasting the weather for the whole nation and operates out of IMD New Delhi. This facility offers sub divisional size forecasts four times each day. Regional Meteorological Centres (RMCs) in New Delhi, Mumbai, Nagpur, Kolkota, Guwahati, and Chennai serve as the regional weather forecasting centres (RWFCs). They keep an eye on the weather and provide predictions and warnings for their respective jurisdictions on a subdivision-by-subdivision basis. Typically, a region comprises of a few different meteorological subdivisions. The Regional Meteorological Centre is also tasked with providing city/tourism forecasts, district- and location-specific nowcasts, and district- and location-specific forecasts for the state in which it is situated. However, in the case of Maharashtra, this duty is split between RWFC Mumbai and RWFC Nagpur. The RWFCs at Kolkota, Chennai, and Mumbai provide the maritime forecast services and cyclone warning services for their respective geographic regions while simultaneously serving as ACWCs [9].

State Weather Forecasting Centres (SWFCs): Located in state capitals, SWFCs monitor the weather and provide district-level forecasts and warnings as well as district- and location-specific nowcasts for the state they are in charge of. It is also accountable for providing city forecasts for significant cities and popular tourist destinations within the state. The maritime forecast services and cyclone warning services are provided by the SWFCs at Ahmedabad, Thiruvananthapuram, and Bhubaneshwar for their respective geographic regions.

Pune's Weather Central (WC): When it comes to technical analysis and prediction finalisation, Weather Central in Pune operates similarly to NWFC. The centre compiles Indian Daily Weather Reports (IDWR), archives historical weather data, and performs seasonal weather analysis and documentation for publications. The facility also frequently analyses morning and evening surface and upper air weather charts, as well as their digital archiving for use in the future. These digital charts are sent to several prediction centres each day, just as they are prepared, for display and storage for later use. In addition, the centre has a map conversation every Friday where the weather for the previous meteorological week as well as the prediction for the current week are thoroughly examined. Participants in these map talks include former IMD and IITM officials as well as IITM officials, university students, and others from the IITM [10].

CONCLUSION

The foundation of its forecasting ability consists on global and regional numerical weather prediction models. The precision and dependability of its predictions are enhanced by the combination of statistical methodologies, ensemble forecasting, and data assimilation techniques. In order to help in catastrophe preparation and response, the Cyclone Warning Division plays a critical role in issuing prompt warnings and keeping track on cyclonic developments. The importance of the Agrometeorological Advisory Service, which meets the demands of the agricultural industry by providing weather-based advisories for crop planning, irrigation management, and pest control. The GFO's involvement in monitoring and researching the climate, providing climate services, and helping India's attempts to adapt to and mitigate the effects of climate change are all covered in the seventh part. In recognising the GFO's commitment to safeguarding public safety, helping numerous industries, and promoting meteorological science via ongoing study and technical development, the study comes to a close. India's sustainable growth and resilience in the face of weather-related issues are considerably aided by its extensive and trustworthy weather forecasting systems.

REFERENCES:

[1] C. Sridevi, K. K. Singh, P. Suneetha, V. R. Durai, and A. Kumar, "Rainfall forecast skill of Global Forecasting System (GFS) model over India during summer monsoon 2015," *Geofizika*, 2018, doi: 10.15233/gfz.2018.35.4.

[2] R. Bhatnagar and G. B. Gohain, "Crop yield estimation using decision trees and random forest machine learning algorithms on data from Terra (EOS AM-1) & Aqua (EOS PM-1) satellite data," in *Studies in Computational Intelligence*, 2020. doi: 10.1007/978-3-030-20212-5_6.

[3] J. Refonaa and M. Lakshmi, "Rainfall Prediction Model with Sea Surface Temperature Using Soft Computing Techniques," *J. Comput. Theor. Nanosci.*, 2020, doi: 10.1166/jctn.2020.9218.

[4] A. E. H. A. Darwish and H. El-Askary, *Machine Learning and Data Mining in Aerospace Technology*. 2020.

[5] J. Harsha, "Playing catch up in flood forecasting technology," *The Hindu*, 2020.

[6] U. Pietsch, L. Ney, O. Kreuzer, A. Berner, and V. Lischke, "Helicopter Emergency Medical Service Simulation Training in the Extreme: Simulation-based Training in a Mountain Weather Chamber," *Air Med. J.*, 2017, doi: 10.1016/j.amj.2017.03.004.

[7] S. Martinuzzi, A. J. Allstadt, A. M. Pidgeon, C. H. Flather, W. M. Jolly, and V. C. Radeloff, "Future changes in fire weather, spring droughts, and false springs across U.S. National Forests and Grasslands," *Ecol. Appl.*, 2019, doi: 10.1002/eap.1904.

[8] S. Dupire, T. Curt, and S. Bigot, "Spatio-temporal trends in fire weather in the French Alps," *Sci. Total Environ.*, 2017, doi: 10.1016/j.scitotenv.2017.04.027.

[9] N. Khandekar, G. Gorti, S. Bhadwal, and V. Rijhwani, "Perceptions of climate shocks and gender vulnerabilities in the Upper Ganga Basin," *Environ. Dev.*, 2019, doi: 10.1016/j.envdev.2019.02.001.

[10] A. Khezri, R. Bennett, and J. Zevenbergen, "Evaluating a Fit-For-Purpose Integrated Service-Oriented land and climate change information system for mountain community adaptation," *Can. Hist. Rev.*, 2018, doi: 10.3390/ijgi7090343.

CHAPTER 10

ANALYSIS OF FORECASTING SYSTEM

Mr.Anurag Rajput, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

A crucial aspect of meteorological research is the examination of forecasting systems, which includes evaluating numerical weather prediction models, data assimilation methods, and their overall effectiveness in producing reliable weather predictions. The main components of the study of forecasting systems are presented in this study, with an emphasis on how crucial it is to improve prediction accuracy and dependability. The first part of the chapter addresses forecasting systems and their importance in contemporary meteorology, where numerical models are the main instruments for modelling atmospheric behaviour and forecasting weather. These systems are essential to a number of industries, including as agriculture, aviation, disaster relief, and climate research. The fundamentals of numerical weather prediction and model assessment are examined in the second part. As part of the research, model output is compared to observed meteorological data in order to evaluate prediction accuracy and pinpoint model biases and constraints. The third part explores data assimilation methods, which combine numerical models with observational data to enhance their starting conditions. The contributions of several data assimilation techniques, such as 3D-Var, 4D-Var, and ensemble-based approaches, on forecast accuracy are investigated. The fourth part talks about deterministic and probabilistic verification metrics that are used to gauge forecast performance. These metrics support efforts for continuous development by assisting in evaluating the advantages and disadvantages of forecasting systems.

KEYWORDS:

Forecasting, Metrological, Organization, Rainfall, Weather.

INTRODUCTION

The importance of ensemble forecasting, which entails conducting several simulations with modest modifications in beginning circumstances or model physics, is emphasised in the fifth part. Ensemble forecasts provide probabilistic projections that take into account forecast uncertainty and support decision-making. The function of high-performance computing in forecasting system analysis is covered in the sixth part. Higher model resolution, better physical representation, and quicker data processing made possible by technological advancements lead to more precise projections.

The NWFC will publish forecasts four times each day. Around midday, there is one major weather briefing, and the next three are updates. Two forecasts will be released each day by RWFCs and SWFCs: a major bulletin in the middle of the day and an update at night. All bulletins must include the date they were published, the date they were based on observations, their validity term, and the date they will be updated again. A meteorological day is defined as the period from 0830 IST of the relevant day to 0830 IST of the next day. The validity of the predictions made by the NWFC, RWFCs, and SWFCs on any given day is 120 hours (five days) from the time and date of issuance. As a result, predictions made for Day 1 on, say, the eleventh of a month in the morning, lunch, evening, and night would all be valid just until 8:30 a.m. on the twelve. And the prognosis that was given for Day 5 on the 11th in all of the aforementioned briefings will be accurate from 0830 IST on the 15th to 0830 IST on the 16th. Since each prediction bulletin is issued at a different time during the day, the validity period is thus not precisely 120 hours. The prognosis will remain in effect for a further 48 hours (2 days). For instance, predictions released on the eleventh of a month in the morning, lunchtime, evening, and night will include the outlook for the sixteenth and seventeenth, valid from 0830 IST on the sixteenth through 0830 IST on the eighteenth [1].

The weather predictions for Day 1 encompass the forecast for the next 24 hours, Day 2 covers the forecast for the next 48 hours, Day 3 covers the forecast for the next 72 hours, Day 4 covers the forecast for the next 96 hours, and Day 5 covers the forecast for the next 120 hours. According to the current season, warnings for extreme weather are also included in the bulletins. According to the criteria followed, for instance, warnings for fog, cold waves, and other events are included during the winter season, but warnings for heatwaves are included during the summer and pre-monsoon seasons. The NWFC issues forecasts and warnings on a subdivisional scale for the whole nation, while SWFC does the same on a district size for the state in question. RWFC issues forecasts and warnings for the whole subdivision or specific subdivision sectors, as well as district-level forecasts and warnings for the state in which it is situated. In addition to the forecast, warnings, and outlook, the weather bulletin also includes a short summary of the observations, a description of the current synoptic conditions, and important characteristics. A short farming advise is included in the Daily Weather Bulletin (Mid-Day), which is sent by RWFCs and SWFCs and typically carried on All India Radio.

Prediction Generation

A three-tier structure for forecasting services is in place, with the headquarters being NWFC New Delhi, RWFC at the regional level, and SWFC at the state level. As a result, at least three centres would publish a prediction for a meteorological subdivision. For instance, projections for the Telengana subdivision will be released by SWFC Hyderabad, RWFC Chennai, and NWFC New Delhi. These projections should be consistent in their substance and shouldn't vary from centre to centre if they come from various sources. The operational forecasters of the NWFC, RWFC, and SWFC conduct detailed debates about the current and upcoming weather scenario via video conference or teleconference between 1030 and 1200 IST on a daily basis prior to the release of the main bulletin (Mid-Day bulletin), and based on the final decision all centres will issue the forecast and warnings in accordance with the forecast scheme of each centre.

When revised bulletins are released, any important changes that must be made for any location are done only after a phone call with the relevant RWFC/SWFC. For instance, if SWFC Bhubaneswar requests that a heavy rain warning be added to the night bulletin, this would be done after consulting with NWFC New Delhi and RWFC Kolkata so that the relevant changes will be made to the bulletins published from those centres as well. Any centre may recommend include changes in the updated bulletins, which are then finished after being discussed and receiving approval from all parties at the national, regional, and state levels [2].

Vocabulary for Forecasts

Based on the 24 hours of cumulative rainfall that ended at 08:30 IST on any given day, the description of the geographical distribution of rainfall or its intensity across any subdivision or district is made. The estimated geographical distribution and intensity of rainfall for Day 1 is based on the rainfall anticipated from 0830 IST on that day to 0830 IST on the next day. Similar criteria are valid for the predicted rainfall as well.

Rainfall distribution in space

1. 24-hour intensity A buildup of rain
2. 24-hour intensity accumulation of snow
3. Probability that the weather event will occur
4. An explanation of the temperature's deviation from normal
5. Describe the temperature trend.
6. Symbols for representing severe weather
7. Weather alerts are color-coded.

Projections for the District

For their respective areas of responsibility, each SWFC and RWFC should provide a district-level forecast and warning. The district-level forecast has a five-day validity window and a two-day view beyond that. As and when necessary, each forecast and update for each district mentions the likelihood of heavy rainfall together with a qualitative description of the degree of rainfall anticipated, such as heavy rainfall, extremely heavy rainfall, etc. In probabilistic terms, rainfall intensity less than heavy rainfall, such as light to moderate rainfall, should also be provided as appropriate. Because a district is a small region, its geographical distribution may vary from the spatial distribution of the cluster of districts that make up a sub division. For instance, if a subdivision is anticipated to have a dispersed distribution, some of its districts may also have dry weather.

DISCUSSION

The proper colour code for a warning is to be issued for each district, taking into account the likelihood that severe weather may occur and its effects throughout the course of the next five days. For each day of the forecast, which is valid for up to five days, the criteria for color-coding the heavy rainfall warning at the district level. The aforementioned requirements are broad in nature. The effect may vary depending on the region, the time of year when heavy rain is predicted to fall, and any current flood scenarios. Therefore, the colouring scheme for district level warnings should be decided by MCs and RMCs. Despite the fact that all centres employ the same color-coding criterion, it is not required that the colour used for subdivisional warning correspond to the colour used for any district within that subdivision. Therefore, whereas RWFC/SWFC may use orange or red for any district inside that subdivision, NWFC may use yellow for the subdivision as a whole depending on the forecasted weather and its influence [3].

Local/City Forecast

Local forecasts are crucial for managing urban operations in the capital and other cities and towns. Additionally, projections tailored to a given place are offered for significant events like Independence Day, VVIP movements, and tourist needs, among others. RWFC/SWFC will produce location-specific city forecasts and tourist forecasts for the major cities within its purview. These forecasts will include a local weather report and prediction for the next seven days. In the event of VVIP movements, the relevant RWFC/SWFC develops the forecasts based on the location for which a forecast is required, sends them to NWFC for approval, and then, after verification of the same and the incorporation of any necessary adjustments, issues the final forecast on behalf of NWFC. The local weather report includes the highest and lowest temperatures that were actually experienced, along with how far they deviated from the norm, as well as 24-hour rainfall totals that ended at 8:30 IST on the day in question, relative humidity readings for the morning and evening, and the times of sunrise, sunset, the moon rising, and the moon setting for the specific location. The weather and projected maximum and lowest temperatures for the next seven days are included in the forecast section. In the absence of forecasted weather, the estimated sky condition will be provided. The local forecast is released four times a day, at corresponding times of 0200 IST, 0800 IST, 1400 IST, and 2000 IST. The categories utilised in the local forecast for projected rainfall characteristics are provided in Forecasting Organisational Structure [4].

The General Forecasting system should ideally have the following organisational structure with respect to NWFC in the national level with Weather Central, IMD, Pune as its standby, RWFC in the regional level, and SWFC in the state level in order to meet the needs of forecasting activities in the national, regional, and state levels.

National Level

1. General Weather Forecasting Unit
2. Public Weather Services Unit
3. Weather Summary Unit
4. Unit dealing with Parliament Questions/RTI/Grievances

Mountain Meteorology Division; Nowcast Division; Cyclone Warning Division; MarineWeather Service Division; Satellite Application Division

Weather Central, IMD, Pune

The following cells will be present at Weather Central, Pune: Standby Operational Forecast Cell for NWFC operations, which will oversee operational activity in the case of any significant contingency at NWFC. The documentation cell, which is responsible for creating the IDWR, WWR, monthly, and seasonal reports. The Verification Cell, which works with the NWFC to check the practises followed by all operating offices and to validate projections. Cellular Communication.

Cells in the RWFC/SWFC will include:

Agromet Service Cell General Forecasting / Nowcasting Cell PWS Cell Documentation Cell DRMS Cell Communication Cell Aviation Coordination Cell FMO's Coordination Cell

Meteorological Offices

Observations and communication of the weather on a regular basis. Monitoring and reporting of bad weather. Sharing observations and prediction information with the public, media, and local authorities. Upkeep of the surface observatory, AWS, and ARG. Making station climatologies

The Mission of the Various Forecasting Centres

NWFC

Cell for general forecasting. This cell will keep an eye on the weather throughout the nation. In conjunction with RWFCs and SWFCs, it will provide short- and medium-term projections for the next five days divided by sub-division, as well as a prognosis for the next two days. According to the prediction plan, it would publish All India weather forecasts four times each day. It will publish forecasts for events such as sporting events, VVIP movements, Independence Day celebrations, etc. with copies sent to the relevant SWFC and RWFCs. It will keep an eye on global weather patterns that might affect Indian weather. This cell will operate continuously [5].

Marine Cell and Cyclone Warning

The Marine Cell will be in charge of the problem of area VIII GMDSS Bulletin. Fleet Forecast. Daily fishermen warnings in written and visual form for coastal and high sea regions of the North Indian Ocean. The marine cell, in coordination with ACWCs/CWCs, shall handle all weather-related inquiries relevant to high sea regions. The Cyclone Warning Cell will publish a weekly extended prognosis for cyclogenesis in the North Indian Ocean as well as a daily tropical weather prediction for the region. Once a depression forms from a low-pressure system over the North Indian Ocean, a cyclone warning cell will be operational around-the-clock. The Cyclone Warning cell must continue to use the most recent cyclone manual's guidelines for monitoring and forecasting.

Cell for nowcasting

This cell would track and predict extreme weather conditions with a few-hour time frame, such as thunderstorms, thunder squalls, tornadoes, hailstorms, lightning, dust storms, fog, heavy downpours, etc. The Nowcasting cell issues a nowcast guidance bulletin for severe weather occurrences after a daily video conference conversation. The bulletin is updated as needed. The nowcasting cell performs the scrutiny and verification of the nowcasts issued from the RWFCs/SWFCs while continually monitoring the nowcasts being issued from these centres. This cell generates annual reports on thunderstorm activity.

PWS Cell

This cell will provide nationwide end-user services. The PWS unit would provide inputs for the media and stakeholder stakeholders with content. This cell will create color-coded multi-hazard maps for the issued alerts. This cell will handle the creation of weather products and the distribution of all forms of bulletins and warnings to users within the State and Central Governments, as well as to Registered Users, the Electronic and Print Media, All India Radio, and Television channels, including Door Darshan. It will regularly update the website and disseminate weather information through various social media platforms, including Facebook, Twitter, Whatsapp, etc. This cell will operate continuously [6].

Unit for Satellite Application

To make it easier to analyse satellite pictures and data needed for forecasting, the SATMET Application Unit is housed inside the NWFC and operates around the clock. The satellite application cell keeps track of and decodes satellite imagery. This unit publishes satellite bulletins for a range of users. The satellite bulletins are released on a regular basis every three hours and every hour or half hour during periods of extreme low-pressure systems like cyclones. Senior Scientist will serve as the overall in charge of all the aforementioned NWFC cells, and all aforementioned tasks must be completed with the direction and permission of overall in charge.

Weather Central, Pune

The WC, Pune will produce the daily forecast in the same manner as NWFC, Delhi on the subdivisional scale for the whole country, but will not distribute it to the users. In the case of a serious incident at the NWFC's Delhi that prevents operational services for a few days, Weather Central Pune will instantly assume all of NWFC's operational duties. To support the crucial operational services, all of the workstations at Weather Central in Pune and the Meteorological Training Institute in Pune would be used as needed. Regular operating operations will be moved from Weather Central, Pune to NWFC, New Delhi once normal circumstances have been restored there. In addition, this centre offers technical advice on operational issues and works with NWFC to provide corresponding manuals, guidelines, etc. WC Pune is also in charge of recording and maintaining IDWR, WWR, seasonal weather summaries, etc. Four times per day, WC Pune will develop and distribute a local forecast for Pune and the surrounding area. WC Pune carries out the digitization and preservation of examined weather charts. For some of the projections made by forecasting centres, WC Pune also performs forecast verification and its documentation [7].

RWFC/SWFC

Cell for general forecasting

Constant weather monitoring for the duty region. District-level Daily Weather Report preparation and distribution, including forecasts and warnings for five days and outlooks for the next two days. RWFC will prepare the same for the state in which it is situated, while SWFC will do the same for the state in question. The RWFC's forecasting cell will get the DWR ready for its area of duty at the subdivision/sectors of subdivision level. RWFC will prepare the same for the stations in the state in which it is situated, while SWFC would produce and publish Local Forecast/City Forecast and its update every 6 hours for the stations in the concerned state.

All user-specific bulletins, such as those for All India Radio, Door Darshan, the press, state disaster management agencies, etc., pertaining to weather information and alerts for the respective state, would be prepared and issued by SWFC/RWFC. SWFC/RWFC shall prepare draught inputs for VVIP movements, special events, etc. and distribute them to NWFC for finalisation and issuance in accordance with their respective responsibilities. Fishermen's preparation and release Warnings are given four times per day for the responsible area [8] .

Routine Coastal bulletin, Sea area bulletin, and Port warning preparation and issuance for the relevant area of responsibility. As a result, the Arabian Sea will get a sea area bulletin from RWFC Mumbai while the Bay of Bengal would receive one from RWFC Kolkata. Similar to this, the Kerala-Karnataka beaches would get a coastal bulletin from SWFC Thiruvananthapuram. Creation and dissemination of cyclone-related bulletins, such as Alert/Warning, Port and Fisheries, and Coastal bulletins, in accordance with the cyclone's SOP . under accordance with the NWFC's nowcast guidance bulletin, this cell will also keep track of severe weather events under its jurisdiction and deliver nowcasts as needed. A Senior Scientist would be in charge of this cell. It will always be operated around the clock by a Class I officer or a qualified forecaster.

Unit of Agro-Advisory Services

Creating and distributing value-added district-level forecasts to AMFUs and DAMUs twice a week on Tuesdays and Fridays, allowing them to provide agromet warnings to farmers at such times. This unit provides quantitative forecasts for five parameters—rainfall, maximum and lowest temperatures, maximum and minimum relative humidity, cloudiness, wind speed, and wind direction—for each district. District level forecasts are produced using the Multi-Model Ensemble approach in terms of quantitative figures, and the final prediction is released after value addition. On both days, this prediction will only be released once day, at 1200 IST. In order to provide value, the forecaster may utilise the medium-range forecast products produced by IMD, NCMRWF, ECMWF, as well as the district rainfall climatology [8].

Cellular Communication

For the efficient execution of operational activities, this cell would monitor and guarantee the flow of observational data and forecast products between the forecasting centres at the national, regional, and state levels as well as with Weather Central, Pune. This cell will also be in charge of gathering and transmitting information from all observatories for the relevant jurisdictional region.

Cell for the Daily Rainfall Monitoring Scheme

This cell will gather all rainfall data from the relevant region/state, process and analyse the data, and provide tabular and map-based rainfall statistics for the area of responsibility.

Coordination of FMO

Since the forecasting centre and the FMOs are colocated at RWFC New Delhi, RWFC Gauhati, and the MCs in Ahmedabad, Bhubaneswar, Hyderabad, Lucknow, Patna, Srinagar, and Bangalore, the same unit will coordinate with the Central Water Commission and issue quantitative precipitation forecasts for the concerned basins within their sphere of influence. When the FMOs are dispersed, a coordinating cell must operate inside the relevant RWFC/SWFC that houses the FMO.

Coordination of Aviation

This RWFC/SWFC cell will keep track of and coordinate the operational forecast operations of all the aviation meteorological offices under its control. The main forecaster for RWFC and SWFC will be a Senior Scientist, ideally with the rank of Scientist E/D. The chief forecaster will participate in the daily video conference, and the batch in charge will release the major weather bulletin in his or her absence after consulting with the top forecaster. The batch in charge will release the amended weather bulletin after consulting with the main forecaster. The Head of RMCs/MCs will serve as the overall in charge for all of the aforementioned cells, and all decisions pertaining to operational operations must be approved by the overall in charge [9].

Meteorological Offices

Despite the fact that they don't carry out any forecast-related tasks, meteorological offices need to be essential parts of the forecast organisation. In order to help forecasting efforts, they will compile and provide the most recent observations to all parties involved. When severe weather events like cyclones impact the region, additional observations must be made and reported as needed to the relevant parties. Field surveys shall be carried out by the staff as needed or per RWFC/SWFC instructions in the event that bad weather is present in their territory. Any unfavourable weather circumstances shall be immediately reported to SWFC/RWFC, and an email and hard copy report based on a field survey will also be sent [10].

CONCLUSION

The incorporation of information from radars, satellites, ground-based weather stations, and other observation systems into forecasting systems. To guarantee the accuracy of model initializations, it is essential to analyse the quality of observational data. The influence of model parameterizations on forecast accuracy is covered in the eighth section. Numerical models make approximations of sub-grid size phenomena as cloud microphysics and turbulence, which may affect prediction results. In recognising the joint efforts of meteorological organisations, academics, and technical improvements in furthering the study of forecasting systems, the study comes to a close. These systems are continuously improved via research and validation, delivering accurate and timely weather predictions for social well-being, economic stability, and catastrophe preparation.

REFERENCES:

[1] K. D. Leka, G. Barnes, and E. Wagner, "The NWRA classification infrastructure: Description and extension to the discriminant analysis flare forecasting system (DAFFS)," *J. Sp. Weather Sp. Clim.*, 2018, doi: 10.1051/swsc/2018004.

[2] M. Hamon, E. Greiner, P. Y. Le Traon, and E. Remy, "Impact of multiple altimeter data and mean dynamic topography in a global analysis and forecasting system," *J. Atmos. Ocean. Technol.*, 2019, doi: 10.1175/JTECH-D-18-0236.1.

[3] Y. Jiamin, Z. Hua, L. Shuai, W. Zhonghao, and X. Wencheng, "Application of open source GIS technology in seismic analysis and forecasting system," in *2017 4th International Conference on Systems and Informatics, ICSAI 2017*, 2017. doi: 10.1109/ICSAI.2017.8248543.

[4] H. Al-Tabtabai, "A framework for developing an expert analysis and forecasting system for construction projects," *Expert Syst. Appl.*, 1998, doi: 10.1016/S0957-4174(97)00079-1.

[5] J. M. D'Addezio *et al.*, "Quantifying wavelengths constrained by simulated SWOT observations in a submesoscale resolving ocean analysis/forecasting system," *Ocean Model.*, 2019, doi: 10.1016/j.ocemod.2019.02.001.

[6] P. Y. Le Traon *et al.*, "From observation to information and users: The Copernicus Marine Service Perspective," *Frontiers in Marine Science*. 2019. doi: 10.3389/fmars.2019.00234.

[7] G. C. Smith, F. Roy, and B. Brasnett, "Evaluation of an operational ice-ocean analysis and forecasting system for the Gulf of St Lawrence," *Q. J. R. Meteorol. Soc.*, 2013, doi: 10.1002/qj.1982.

[8] S. Kaur, "Big Data And Analysis Of Weather Forecasting System," *Int. J. Adv. Res. Comput. Sci.*, 2017, doi: 10.26483/ijarcs.v8i7.4149.

[9] S. Verrier, P. Y. Le Traon, E. Remy, and J. M. Lellouche, “Assessing the impact of SAR altimetry for global ocean analysis and forecasting,” *J. Oper. Oceanogr.*, 2018, doi: 10.1080/1755876X.2018.1505028.

[10] L. Beril Toktay and L. M. Wein, “Analysis of a forecasting-production-inventory system with stationary demand,” *Manage. Sci.*, 2001, doi: 10.1287/mnsc.47.9.1268.9787.

CHAPTER 11

APPLICATION OF SATELLITES TO WEATHER PREDICTION

Mr.Bishal Kumar Mishra, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

The use of satellites for weather forecasting has revolutionized meteorological research and made it possible to view atmospheric conditions from a complete and global viewpoint. An overview of how satellite technology has changed weather forecasting methodology, data collecting, and forecasting accuracy is provided in this study. The importance of satellite technology in weather forecasting is discussed in the first part. Satellites supply essential observational data, covering huge geographic regions with a variety of meteorological characteristics, such as temperature, humidity, cloud cover, precipitation, and sea surface temperatures. The second part examines the various geostationary and polar-orbiting weather satellite types that are used in meteorology. Polar-orbiting satellites give a global perspective and better spatial resolution, whereas geostationary satellites offer continuous coverage of particular locations. The third part examines the passive and active remote sensing techniques that weather satellites use to gather data. While active sensors send signals and detect their reflections for data capture, passive sensors monitor natural radiation released or reflected by the Earth's surface and atmosphere. The use of satellite data in numerical weather prediction models is examined in the fourth part. The initialization of models and data assimilation using satellite observations improves the precision and timeliness of weather predictions.

KEYWORDS:

Forecasting, Organization, Prediction, Satellites, Weather.

INTRODUCTION

The India Meteorological Department's Satellite Meteorology Division has been in operation since the early 1970s. In order to utilise the satellite photos for weather forecasting, IMD used to receive NOAA and NASA meteorological satellite images via the Secondary Data Utilisation Centre (SDUC) from 1972 to 1982. The ability to see things better has increased thanks to developments in satellite technology. The Indian Space Research Organisation (ISRO) launched a series of multifunctional geostationary satellites under the Indian National Satellite (INSAT) project in 1982 to address the needs of telecommunications, broadcasting, meteorology, and search and rescue missions. As a full-fledged satellite Meteorological Division for delivering satellite Metrological services to the country, IMD constructed its first satellite data receiving and processing system to receive & analyse the data from INSAT-1B in 1983.

Since that time, IMD has been giving forecasters access to meteorological satellite services utilising information from the INSAT-1, INSAT-2, and INSAT-3 series spacecraft' meteorological payloads. The temporal resolution of scan acquisitions was on a three-hourly basis for both the INSAT-1 and INSAT-2 series satellites. Up until 1992, photographs were developed on photographic sheets using the photographic process; afterwards, thermal Kodak printers were used to print photographs on photographic sheets. Since 1996, IMD has been disseminating satellite images on their website. The division currently plays a significant role in assisting weather forecasting. The division has achieved continuous development in satellite data receipt and creation of various new products that are highly helpful in weather forecasting. Modern meteorology makes extensive use of satellite technology, which has significantly improved weather forecasting. In order to forecast the weather through the terrestrial EUMETCast system, IMD currently uses data from Indian Geostationary Meteorological Satellites (INSAT-3D&INSAT-3DR), Polar Satellites (Scatterometer Satellite-1 (SCATSat-1), Oceansat-2 & Mega-Tropiques), and International Geostationary Meteorological Satellites (METEOSAT-8 of EUMETSat, Himawari-8 of JMA).

The specialised meteorological geostationary satellites INSAT-3D and INSAT-3DR are situated at 82 degrees and 74 degrees East longitude, respectively. A multi-spectral six-channel imager, a 19-channel sounder, a data relay transponder, and search-and-rescue transponder are among the payloads carried by INSAT-3D& 3DR. The INSAT-3D and INSAT-3DR imager payloads are being employed in a staggered fashion to successfully attain a 15-minute temporal resolution. Data for the Indian land area sector and the Indian Ocean region are now accessible hourly and every one and a half hours, respectively, thanks to the integrated usage of the sounder payloads of the INSAT-3D and INSAT-3DR satellites [1].

Through a Memorandum of Understanding with M/s Antrix Corporation Ltd, ISRO, IMD recently built Multi-Mission Meteorological Data Receiving and Processing System (MMDRPS) for INSAT-3D, INSAT-3DR, and INSAT-3DS satellites, while the current IMDPS system is being phased out. Under the MMDRPS [Multi-Mission Meteorological Data Reception and Processing System] Project, specialised New Earth stations have been built up that can receive data from the INSAT-3D, INSAT-3DR, and forthcoming INSAT-3DS satellites. The advanced and modern state-of-the-art servers in the MMDRPS systems, along with storage capacity of order 2.0/2.0PB (Main/ Mirror) & 324TB SSD, enable online sharing of processed data for all Indian meteorological satellites to the registered users in accordance with IMD data policy through Web-based secured satellite Data Supply System. In due future, all previously accessible satellite datasets dating back to 1983 will be maintained online.

THE 3DR & INSAT-3D Satellite

Data Relay Transponder (DRT), Six Channel Imager, Nineteen Channel Sounder, Satellite-Assisted Search and Rescue System

INSAT-3D/3DR-Imager

It is an optical radiometer that can provide pictures of the globe in six wavelength bands that are important for meteorological studies, including visible light, short-wave infrared, middle-wave infrared, water vapour, and two bands in the thermal infrared. Every 26 minutes, the Imager creates photos of the Earth's disc from a geostationary altitude of 36,000 km and provides data on a number of characteristics, including outgoing long-wave radiation, quantitative precipitation estimate, sea surface temperature, snow cover, wind speed, and other factors. The following are INAST-3D Imager's key characteristics:

1. The blackbody calibration sequence has been changed from prior satellites' VHRR.
2. The IFOVs are 1.75 times over sampled in the Fast Scan direction [2].
3. A biennial rotation of the yaw by 180 degrees, or the satellite's flip, has been included to maintain the correct cold patch temperature.

There are two adjustable operating modes:

1. In full frame mode, the complete Earth disc is scanned in 26 minutes at an angle of 18 degrees EW x 18 degrees NS.
2. Programme mode encompassing 18 degrees in the easterly direction The number of lines that must be scanned may be used to determine NS coverage.

Additionally, the INSAT-3DR Imager may be used in RAPID SCAN Mode. The IMAGER instruments have been designed with the flexible scanning feature known as "Programme Mode," where the number of scan lines over a given coverage region and the number of repetitions of thus selected region could be programmed for scanning. The INSAT-3DR Imager can also be operated in RAPID SCAN Mode to monitor the severe weather events like Cyclones and Thunderstorms. The following operational plan has been developed for Rapid scan in order to standardize and streamline the use of this feature:

While INSAT-3D will continue to provide Full frame Mode Scan spanning the whole globe, INSAT-3DR will give quick scans during extreme weather. In quick scan mode, the world is split into 36 blocks, each covering 0.50 in the North-South direction and made up of 40 scan lines. One quick scan took 4.7 minutes to complete and covered 240 scan lines. Whenever the NWFC makes a request, MCF Hassan ISRO is informed to begin the quick scan with the following details:

Start Block Number, Blocks to Cover, and Repetition Count

INSAT-3D/3DR-Sounder

The newly created 19 channels sounder on INSAT-3D/3DR is the first of its kind to fly on an ISRO satellite mission. The Sounder has one channel in the visible spectrum and eighteen narrow spectral channels in the shortwave, medium, and long infrared ranges. For all 19 channels, the ground resolution at nadir is theoretically 10 10 km. Vertical profiles of temperature at 40 levels (surface to 70 km), humidity at 21 levels (surface to 15 km), and integrated ozone from the surface to the top of the atmosphere are provided by the Atmospheric Sounding System. The following is a list of Sounder's specifications.

DISCUSSION

Over a region of 10 km 40 km, the Sounder concurrently records radiance in 18 IR and one visible channel at nadir every 100 ms. This footprint may be positioned anywhere within the FOR [24o (E-W) 19o (N-S)] using a two-axes gimballed scan mirror. A scan programme mode enables periodic space and calibration glances while sequentially sonifying a chosen region. A "frame" made up of many "blocks" with a combined size of 640 km 640 kilometres may be heard in this mode. The chosen frame may be positioned anywhere within the FOR of 24o (E-W) 19o (N-S). The Sounder has an appropriate radiometric resolution for the intended scientific applications, much like the Imager does. The full frame mode of the sounder scan took three hours to complete and covered a 6400 km by 6400 km area. As required by IMD, it is run across the Indian area. The Indian landmass may access these profiles on an hourly basis, while the Indian Ocean region can access them on a one and a half hourly basis. A new scan strategy for the INSAT-3DR sounder payload has been introduced as a result of the INSAT 3D Sounder's end-of-life on September 23, 2020. The sounder payload of INSAT-3DR is operated such that, on an hourly basis, data for the Indian land area is covered up twenty times, while data for the Indian Ocean is covered up four times (04, 11, 16 & 23 UTC) [3].

(DRT) Data Relay Transponder

The INSAT-3D/3DR's Data Relay Transponder (DRT) is used to receive data from Data Collection Platforms (DCPs) like Automatic Weather Stations (AWS), Automatic Rain Gauges (ARG), and Agro Met Stations (AMS) that are located in remote, unpopulated areas throughout the coverage area. For down linking, the information is sent back in extended C-Band. The Indian Mission Control Centre (INMCC) is located at ISRO Telemetry, Tracking and Command Network (ISTRAC), Bangalore. The Indian Mission Control Centre (INMCC) is equipped with a Search and Rescue payload (operating in 406 MHz) that picks up and relays the alert signals originating from the distress beacons of maritime, aviation, and land-based users. The Indian Coast Guard, Airports Authority of India (AAI), Directorate General of Shipping, Defence Services, and fishermen are the main users of satellite-assisted search and rescue in India. For the purpose of providing distress alarm services, the Indian service area comprises a large portion of the Indian Ocean region, including India, Bangladesh, Bhutan, the Maldives, Nepal, the Seychelles, Sri Lanka, and Tanzania.

Satellite Scatsat-1

SCATSAT-1 is an Oceansat-2 Scatterometer payload continuation mission that offers consumers wind vector data products across the ocean for weather forecasting, cyclone identification, and tracking services. Similar to the one carried aboard Oceansat-2, the satellite is equipped with a Ku-band Scatterometer. The Scatsat-1 satellite, which has a five-year mission life, was launched in 2016 at a height of 720 kilometres in a polar sun synchronous orbit.

EUMETCast

A multi-service distribution system called EUMETCast is built on multicast technology supported by EUMETSAT. Through a Memorandum of Understanding with EUMETSAT, IMD set up a dedicated terrestrial EUMETCast system at NCMWRF Noida to collect data from geostationary and polar meteorological satellites for use in NWP models and weather forecasting.

METEOSAT-8 Satellite

Meteosat-8 is a geostationary meteorological satellite of the Meteosat Second Generation (MSG) with spin stabilisation that is situated at 41.5°E. It has 12 spectral channels and can complete a "Full-Earth Scan" in 15 minutes. The area between about 40°W and 120°E is covered by the scan zone for full-Earth scanning, which includes all of Europe, Africa, and central Asia. The spinning enhanced visible and infrared imager (SEVIRI), a 12-channel imager, was on board. The wind fields that are recovered through the tracking of cloud, water vapour, and ozone characteristics may also be recovered more effectively.

Himawari

Satellite Himawari-8 is a geostationary meteorological satellite with the potential to execute a "Full-Earth Scan" in 10 minutes. It is situated in 140°E longitude of JMA. East Asia and the Western Pacific are covered by the scan region for Full-Earth scanning. It was equipped with a 16-channel imager known as the Advanced Himawari Imager (AHI), which was designed for tracking cloud and water vapour characteristics and providing multipurpose images for weather monitoring, the use of NWPs, environmental monitoring, and wind derivation [4].

GNSS

IMD has established a network of 25 GNSS stations around the nation for "Earth and Atmospheric studies" in order to drive integrated precipitable water vapour (IPWV) in real time. The IPWV data is used into NWP models to increase the precision of weather forecasting and is used for nowcasting, monsoon research, thunderstorm observation, and climate research. Unlike radar, GNSS has a 20–30 KM coverage range.

Network visualisation for surface lighting information over satellite pictures

Lighting networks have been installed all throughout the nation by IITM Pune and IAF. The illumination data is sent to IMD in real time by IITM Pune, which collects data at a 2-minute period and IAF every 15 minutes. With a half-hour animation, the combined lightning and satellite-based cloud output from INSAT-3D data is produced in real time. The three separate time categories, 10, 20, and 30 minutes, are split into the animation's lightning data, which is refreshed every 15 minutes.There will be a one-hour lag between satellite and lightning data. The satellite scan approach is to blame for this. The graphic depicts the time of 10, 20, and 30 minutes after taking into account the lightning data that was obtained. In the graphic below, for instance, lightning observations are combined with INSAT-3D images from 0900 UTC. The last 10 minutes are shown as 0959 UTC to 0949 UTC, the last 20 minutes as 0949 UTC to 0939 UTC, and the last 30 minutes as 0939 UTC to 0929 UTC. The spots represent lightning flashes or strikes that are being produced by ground networks from clouds to the earth. Additionally superimposed on INSAT-3D cloud top temperature are these flashes and hits [5].

Cloud Pictures

INSAT-3D and INSAT-3DR IMAGER cloud imagery

As one input along with other observation inputs, IMD generates several types of cloud imageries for various domains utilising INSAT-3D& 3DR imager data. The grey count/digital number values supplied by the sensor at various scan area positions are used to produce the various spectral band pictures. Depending on the quantized energy level by the sensors, the range of grey count/digital numbers is (0 to 1023). photos for the MIR, TIR1, TIR2, and WV imager channels are produced by flipping the grey count numbers (1024- Actual grey count), making the clouds look brighter as in Visible & SWIR photos. High-resolution pictures are produced at channel resolution, whereas normal images are produced by resampling the grey count at a lower resolution.

Evident Band

The Visible Band (0.55 to 0.75 m) is a reflective band, hence its usage is only permitted during the day. Visible pictures captured during the day are dependent on the target surface's albedo. As a result, in the visible picture, land seems darker and clouds, which have a higher albedo value than the surface, appear brighter. The monitoring of mesoscale weather phenomena such as cloud cover, air mass borders, convergence zones, cyclone movement, thunderstorms, fog, dust storms, and snow cover is done using these images. restricted to daylight only.

SWIR: Shortwave Infra-Red

Due to its reflective nature, the SWIR Band (1.55-1.70 m) is only used during the day. In the SWIR spectrum, incident radiation is extensively absorbed and reflected by water, ice, and snow, but in the visible wavelength, these items are mostly transparent. Because melting snow patches or lake ice look black in SWIR photos rather than brilliant in visible images, SWIR images are used to distinguish between clouds, rain, and snow. Recently irrigated fields show in deeper tones in SWIR photos because the SWIR band is sensitive to soil moisture content. The local snow cover, daytime fog, convective R/F estimates, cloud radiative characteristics, and NDSI are all monitored using these images [6].

Mid-wave Infrared (MIR)

More temperature sensitive than thermal infrared, the Mid IR window channel (3.9um) offers a wide range of uses in combination with thermal infrared channels. If the temperature of the top of the fog is comparable to that of the nearby ground, it is almost difficult to discern fog or low clod in traditional IR (10–12 m) photographs taken at night. However, due of emissivity differences, fog water droplets in this 3.9 m channel may be distinguished from a land or sea surface at the same temperature. Together with a thermal infrared window channel, it is also used to detect ash, volcanic eruptions, and nighttime fire/hotspots. This channel is controlled by reflected sunlight throughout the day, making the daytime picture warmer than the nighttime image. The sea is more visible than a little cirrus cloud in this channel due to the sun's reflection off the water.

Water Vapour (WV)

The water vapour band is the range between 6.5 and 7.1 um. This region of the IR spectrum, where water vapour is the main absorbing gas, is not an atmospheric window. Therefore, it stands to reason that this channel will not have access to baseline data. The majority of the radiation that the satellite observes comes from the mid- to upper-troposphere in a typical wet atmosphere. The lowest half of the troposphere's moist air or clouds are not adequately represented in WV imaging. However, anvils in cumulonimbus-type clouds that are dense and lofty stand out particularly. The rising and subsiding of moisture look bright and dark, respectively, as do broad scale patterns of moisture movement and upper tropospheric cyclone. Sharp moisture gradients that separate the jet streams are present, with dry air on the poleward side. In NWP models, the atmospheric motion vector obtained from WV images is employed directly [7].

TIR-1, or thermal infrared

Thermal infrared band-1 is the region between 10.3 and 11.3 m. Most of the energy radiated from the surface reaches the sensor in the 10.7 um range because this region's surface radiances are less influenced by atmospheric components, making it a "clear atmospheric window" band. Considering that the temperature recorded is almost scene temperature. used to track surface lows, thunderstorms, air mass boundaries, cloud cover, cloud top and surface temperatures, convergence zones, and cloud top and surface temperatures. Contrary to visible photos, thermal IR images exhibit strong contrast between clouds at various heights because cloud top Brightness Temperature declines with height.

Blended IR-1 BT/Cloud Top Brightness Temperature Image

The temperature of a body when it is supposed to be completely black (i.e., Emissivity=1) is known as the Brightness Temperature (BT). Cloud is not a completely black body, but for the purposes of calculating the Cloud Top Brightness Temperature (CTBT), cloud is treated as if it were. The thermal infrared (IR-1) band's grey count is plotted across the CTBT contours in a CTBT contour picture. These contours provide a way to assess CTBT quantitatively. Convective cloud vertical growth and intensity are correlated with CTBT value. The greater negative the CTBT value, the more intense and vertical the growth. To detect well-developed convective cells, another IR1 BT blended picture was created utilising two distinct kinds of LUT in a single image: grey scale for the range of +30 to -30-degree BT values and coloured scale for the range of -30 to -100-degree Celsius BT [8].

Image of the IR-1 BT & Visible Sandwich

Due to their structure and the shadows, they cast, the overshooting tops often resemble "bubbles" that are several picture pixels wide. In thermal bands, they appear as local brightness temperature minima with steep gradients around them. The overshooting tops may be plainly seen in the thermal IR images with colour enhancement when they are accompanied by smaller-scale warm patches or bigger, longer-lasting embedded warm regions that arise downwind of the overshooting tops. Typically, the visible band and color-enhanced IR10.8 brightness temperature imaging are used to examine the overshooting tops and associated downwind warm areas separately. Here, we provide a brand-new picture product that combines the two bands and enables simultaneous observation of all of these properties in a single image.

IMD and BD curves cyclone picture enhancement

Two main enhancement curves are used to create and show infrared-1BT pictures utilising INSAT-3D and 3DR imager payload data. Each of these upgrades has a distinct function and is used to highlight specific characteristics in the photograph. The "BD Curve" and "IMD Curve" refinements are the names of these two improvements. The research and tropical cyclone forecasting groups that are interested in assessing the severity of these storms often employ the BD curve augmentation. The "Dvorak Hurricane Curve for Tropical Cyclone Classification" is the name of this improvement, which is exclusively used with infrared (10.8 m) images.

The multiple black/white/gray ranges in the Subjective Dvorak Intensity Classification Technique (NOAA Technical Report NESDIS 11, 1984) depict various intensity categories. The temperature ranges for each grey shade are shown with the estimated temperature values shown on the picture above. The IMD curve improvement is mostly used to improve infrared (10.8 m) images for media displays including television, newspapers, and the internet. Since the media prefers to work with colour imagery rather than plain black and white improved imagery, this improvement is often offered to/provided by the media [9].

(TIR-2) Thermal Infrared

Thermal infrared band-2 is the part of the spectrum between 11.5 and 12.5 m that is termed the "dirty window" because it is tainted by low-level water vapour and is used to detect lower-troposphere moisture.

Description for INSAT-3D RGB Composite Images

Red, green, and blue (RGB)-colored satellite photos are combined to create RGB composite images. RGB composites are a great addition to the tools at the forecaster's bench in the era of multi-spectral imagers. It is crucial in an operational setting to carefully choose the RGB composites and keep the number of them to an absolute minimum in line with the difficulties at hand. The availability of composites at all hours of the day should be a goal, along with maximising feature identification. Day Microphysics RGB and Night Microphysics RGB are two application-specific RGB products that IMD generates utilising information from the INSAT-3D Imager.

RGB Day Microphysics Images

Microphysics RGB channel combination "recipes" for the day

1. In the RED beam, the visible reflectance at 0.64 m provides a rough estimate of the optical depth (thickness) and volume of water and ice in the clouds. Usually, water clouds have a higher red beam component than ice clouds because they are more reflective. The earth's surface is another topic covered on this channel.
2. The 1.67 m SWIR (shortwave infrared) solar reflectance in the GREEN beam provides a qualitative measurement of cloud particle size and phase. A brighter green beam component is often produced by smaller water droplets or ice particles because they reflect light more effectively. Sand-covered ground has a high reflectivity in this channel as well.
3. In the BLUE beam, surface and cloud top B. temperatures affect the 10.8 m TIR1 brightness temperature. Warm surfaces will have a significant blue beam component due to the scaling for this beam, but cool cloud tops will not contribute to this beam in any way.

Description for INSAT-3D RGB Composite Images

The Night Microphysics RGB product is created and adjusted to track the development of stratus clouds and nighttime fog. Other ancillary uses include the detection of fires, general cloud categorization, snow detection, and low-level moisture limits. It might be difficult to tell low clouds from fog sometimes. The Night-time Microphysics RGB adds TIR2 12.0 m channel difference to signal cloud thickness and increase regions of warm clouds where fog is more prevalent, while the difference in the TIR1 10.8 m and MIR 3.9 m channels is utilised to meet this challenge. Analysis of cirrus and contrail clouds, fire hot spots, and snow are some more uses for Night-time Microphysics RGB.

Recipe for the Night Microphysics RGB channel combinations

1. In the RED beam, optical depth may be determined via channel differencing. TIR2 and TIR1 are used. This beam has a strong signal for dense clouds. The "dirty window" 12 m channel is more absorbent for thin meteorological clouds. Additionally, ice phase clouds absorb 12 m radiation more strongly than water phase clouds.
2. In the GREEN beam: The fog/low cloud detection technique uses this channel differencing. It employs TIR1-MIR. For tiny water droplet clouds, the 3.9 m radiation has a lower emissivity than the 10.8 m radiation. As a result, for water clouds with tiny

droplets, there is a significant contribution to the green beam in this RGB output. Desert surfaces also have a substantial impact.

3. In the BLUE beam, surface and cloud top temperatures affect the 10.8 m infrared brightness temperature. For heated surfaces, the scaling for this beam produces a potent blue beam component [10].

CONCLUSION

The importance of satellite-based images in tracking and monitoring extreme weather phenomena like hurricanes, cyclones, and typhoons is emphasised in the fifth part. Real-time satellite imagery supports early warning systems, disaster planning, and quick reaction times during severe weather occurrences. In order to improve the overall forecasting skills of meteorological organisations, the sixth part discusses the integration of satellite-derived data with other observational systems, such as ground-based weather stations and radar networks. Global weather predictions and climate studies are more accurate because of seamless data interchange made possible by international cooperation. The seventh part demonstrates how satellite technology is always improving, including increased sensor capabilities, spectrum resolution, and data transfer speeds. These developments promise to significantly increase the reliability of weather predictions and provide forecasts that are more thorough and accurate. This recognising the crucial role that satellite technology plays in contemporary weather forecasting. By providing important data for weather analysis, numerical modelling, disaster management, and climate research, the use of satellites has revolutionised meteorology and eventually made civilization safer and more robust.

REFERENCES:

[1] G. Ohring, S. Lord, J. Derber, K. Mitchell, and M. Ji, “Applications of satellite remote sensing in numerical weather and climate prediction,” *Adv. Sp. Res.*, 2002, doi: 10.1016/S0273-1177(02)80298-8.

[2] G. Guerova *et al.*, “Review of the state of the art and future prospects of the ground-based GNSS meteorology in Europe,” *Atmospheric Measurement Techniques*. 2016. doi: 10.5194/amt-9-5385-2016.

[3] G. Balsamo *et al.*, “Satellite and in situ observations for advancing global earth surface modelling: A review,” *Remote Sensing*. 2018. doi: 10.3390/rs10122038.

[4] G. Skofronick-Jackson *et al.*, “The Global Precipitation Measurement (GPM) mission’s scientific achievements and societal contributions: reviewing four years of advanced rain and snow observations,” *Q. J. R. Meteorol. Soc.*, 2018, doi: 10.1002/qj.3313.

[5] M. Enenkel *et al.*, “Drought and food security - Improving decision-support via new technologies and innovative collaboration,” *Global Food Security*. 2015. doi: 10.1016/j.gfs.2014.08.005.

[6] B. Scarino *et al.*, “Retrieving clear-sky surface skin temperature for numerical weather prediction applications from geostationary satellite data,” *Remote Sens.*, 2013, doi: 10.3390/rs5010342.

[7] Y. Sun *et al.*, “The FengYun-3C radio occultation sounder GNOS: A review of the mission and its early results and science applications,” *Atmos. Meas. Tech.*, 2018, doi: 10.5194/amt-11-5797-2018.

[8] D. Stettner, C. Velden, R. Rabin, S. Wanzong, J. Daniels, and W. Bresky, “Development of enhanced vortex-scale atmospheric motion vectors for hurricane applications,” *Remote Sens.*, 2019, doi: 10.3390/rs11171981.

[9] P. Zhang *et al.*, “Latest Progress of the Chinese Meteorological Satellite Program and Core Data Processing Technologies,” *Advances in Atmospheric Sciences*. 2019. doi: 10.1007/s00376-019-8215-x.

[10] N. S. Bartsotas, E. N. Anagnostou, E. I. Nikolopoulos, and G. Kallos, “Investigating Satellite Precipitation Uncertainty Over Complex Terrain,” *J. Geophys. Res. Atmos.*, 2018, doi: 10.1029/2017JD027559.

CHAPTER 12

DOPPLER WEATHER RADARS AND ITS APPLICATION

Mr.Prabhat Kumar, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

Doppler weather radars have revolutionised weather observation and forecasting and have become essential instruments in contemporary meteorology. An overview of Doppler weather radars, their principles of operation, and their many uses in meteorology and other fields is given in this study. Doppler weather radars are explained in detail in the first section, with an emphasis on their capacity to track and quantify the velocity of precipitation particles like raindrops and snowflakes. Doppler radars analyse the frequency shift of radar signals reflected from moving objects using the Doppler effect, which yields useful velocity and wind information. The second part of the article examines the various single-polarization and dual-polarization Doppler weather radar systems. better rainfall estimate, classification of various forms of precipitation, and better detection of severe weather occurrences are some of the additional capabilities offered by dual-polarization radars. The extensive use of Doppler weather radars in meteorology is covered in the third part. These radars are used to detect and monitor extreme weather phenomena including hurricanes, tornadoes, and thunderstorms, giving vital data for early warning systems and readiness for disasters. This demonstrates how Doppler radars are being used in new fields than meteorology, such wind energy and environmental monitoring. Doppler radars are used to detect wind patterns, optimize the functioning of wind turbines, and collect useful information for research on air pollution and atmospheric processes.

KEYWORDS:

Forecasting, Organization, Prediction, Satellites, Weather.

INTRODUCTION

India Meteorological Department's Radar Network

The radars' adaptability is further increased by their digital and Doppler capabilities. These also provide a secondary output of velocity and its variation in addition to the reflectivity factor, which is the fundamental output of all radars. There are various products of operational meteorological significance that may be derived using these outputs. Among the crucial outcomes are the distribution of rainfall rates, total amount of rain over time, vertical wind profile, cyclone and tornado signatures, maximum wind in cyclones, wind shear and turbulence, likelihood of severe weather and hail, and the expected size of hailstones [1].

Installed at Chennai, Kolkata, Machilipatnam, Visakhapatnam, Paradip, Gopalpur, Hyderabad, Nagpur, Patna, Lucknow, Patiala, Karaikal, Kochi, Bhopal, Agartala, Mohanbari, Delhi (Palam) and Goa and 02 numbers C-band Polarimetric DWRs are installed at Delhi (HQ) and Jaipur and four X-band DWR has been installed at Srinagar, Sonamarg, Kufri and Mukteshwar. IMD's network consists of 27 DWR radars, including 4 X-band DWR in Mukteshwar, Sonamarg, Kufri, and Srinagar, 21 S-band DWRs, and 2 C-band DWRs. Additionally, information from the

Cherrapunjee and Thiruvananthapuram radars held by ISRO is used. Modern Doppler Weather Radars (DWRs) will be installed by IMD in stages at the following locations: Mumbai, Bangalore, Mangalore, Lakshadweep, Andaman Island (Port Blair), Balasore, Sambalpur, Raipur, Ranchi, Ratnagiri, and Ahmedabad. IMD will deploy 10 X-band DWRs in the Central and Western Himalayas as part of the Integrated Himalayan Meteorology Project (IHMP) in order to cover the mountainous region of J&K, Himachal Pradesh, and Uttarakhand.

Only when radar is operating in listening mode can it find reflected energy. Radar cannot detect reflected radiation while it is sending energy. The rate at which a radar delivers pulses is known as the pulse repetition frequency (PRF), since radar alternates between sending and receiving energy. Radar is described in terms of PRF. A PRF of 1000 Hz, for instance, indicates that the radar is broadcasting 1 pulse every thousandth (0.001) of a second, or 1000 pulses per second. Additionally, the PRF has mathematical importance for the products of reflectivity and velocity. Radar energy emits microwave radiation with all the properties of waves. One of them is wavelength, which is the separation between a wave's subsequent peaks and troughs. Wavelengths in the microwave region of the electromagnetic spectrum may range from 1 millimetre to 1 metre. Different wavelengths are employed for Doppler weather radars, including 10 cm (S-band), 5 cm (C-band), and 3 cm (X-band) radars. The three main impacts of radar wavelengths are as follows:

a. How little of particles can the radar pick up?
b. How much attenuation occurs to the beam when it reflects off the reflectors?
c. How much of a velocity value can be measured?

The smaller the particles the radar can detect, the shorter the wavelength. As the beam moves away from the radar, energy is reflected or absorbed by particles, weakening the beam and causing attenuation. When a radar beam must pass through several powerful thunderstorms or along a line of powerful thunderstorms, this effect may be useful. As the beam travels through the thunderstorms, it will come into contact with a significant amount of droplets. Less energy is available for the beam to go further to farther-off storms the more raindrops it bounces off. The quantity of energy that has been reflected back to the radar is shown by a product called base reflectivity. Less energy will be released by the particles to reflect, which will result in less power being returned to the radar. Because of this, it will seem as if the thunderstorms further away are less powerful yet in reality, they could even be more intense than the storms that are closer to the radar.

Interpreting Fundamental Radar Images

Due to a number of circumstances, it is difficult to interpret radar pictures in terms of the amount of rainfall that will fall on the ground. This need changing the radar echoes' perceived patterns. The accuracy of the images for forecasters and consumers may be improved by understanding the implications of these components, even if helpful adjustments for them can be done automatically. Although it requires correct interpretation, Doppler weather radar is a highly helpful instrument for providing a lot of information. Only meteorologists had access to Weather Radar data in the past, but now the general public gets access to the same data that meteorologists utilize on a regular basis thanks to the Internet.

It's not always as easy as glancing at the radar return to comprehend "what is "it" when we examine the radar images. Even with the possibility of a thunderstorm and clouds, a skilled meteorologist will undoubtedly be able to rapidly identify the key elements in a radar picture, but the most of us need to look at the images much more closely. The most reliable source of information is usually a seasoned meteorologist. Radar interpretation and meteorology are two distinct, complicated subjects that need for expertise. The ideas seem simple and clear, but when it comes down to it, this is a highly complex subject. Even those with expertise using this technology have varying degrees of skill when it comes to interpreting radar pictures and drawing conclusions. Differentiating between what is relevant and what isn't and between what is genuine and what isn't while viewing Doppler Weather Radar images is the key challenge. The DWRs are so sensitive that they can detect inversions in temperature as well as dust, pollen, insects, birds, and smoke. Therefore, while viewing DWR photographs, it is important to keep two things in mind [2].

1. Recognise and be able to recognize actual meteorological objects.
2. Recognise radar abnormalities caused by, for example, smoke, dust, temperature inversions, insects, birds, smoke, and other factors.

Base data types

Three different forms of base data are first produced by the Doppler Weather Radar:

Reflectivity

On a dBZ scale, echo intensity (reflectivity) is measured. The amount of transmitted power returned to the radar is known as reflectivity. The basic reflectivity, for instance, is a product called PPI-Z (Reflectivity), which is essentially "raw" data that is often seen at the lowest tilt angle, 0.50 degrees. The Base Reflectivity Products can pinpoint atmospheric boundaries, detect precipitation, assess storm structure, and assess the likelihood of hail.

The composite reflectivity products, such as CAPPI-Z and MAX-Z, may be produced using a variety of various elevation angles (tilts) of the radar. The various echo intensities (reflectivity), measured in dBZ (decibels of Z), are represented by the colours. As the intensity of the signal returned to the radar rises, so do the dBZ values. higher violent thunderstorms will have dBZ values of 50 dBZ or higher, while very light rain will have values around 20 dBZ. The following graphic displays a few reflectivity products. The Reflectivity Product may be distinguished by three things [3].

Buildings and towers on the ground may provide misleading echoes to weather radars. The majority of these erroneous echoes are edited out (filtered out) by the Reflectivity product using Doppler processing. At roughly 110 kilometres, the Doppler correction comes to an end. The Reflectivity product is typically superior and is not impacted by ground clutters as a result of the adjustment. Trees and hills near radars may partially or completely obstruct the radar beam, reducing the number of echoes returned at low angles. This is especially noticeable in the winter on the reflectivity product when extremely low angles are utilised to identify nearby precipitation.

In Doppler mode, the Reflectivity product could seem to be less sensitive. When moving from Doppler processing to non-Doppler processing (CAPPI), a ring of discontinuity may occur. This is particularly obvious if there is light precipitation where the Doppler processing terminates. Echoes may suddenly seem louder after this point when the radar's

Images of reflectivity for raindrops

Reflectivity and rainfall rate (in mm/h) are correlated in the "Rain" image's link between precipitation intensity and reflectivity. The radar reflectivity measurements may be used to infer the potential kind of precipitation. As a general guideline, the data below should be used to interpret the kind of precipitation. It should be kept in mind that the pattern may also provide information regarding the kind of precipitation.

DISCUSSION

Display of Meteorological Products on IMD Website

PPI-Z item

The Base Reflectivity Products, often referred to as PPI-Display or PPI Products, are a plot of the energy that was backscattered to the radar during a single Elevation Scan. The distribution of the chosen data parameter is shown on a plane of constant elevation. This shows the echo strength (reflectivity), which is expressed in dBZ. Three distinct radar "tilt" angles—0.5°, 1.0°, and 2.0°—are available for the IMD DWR base reflectance Products (pictures). A user-selectable maximum range for the PPI is available, however when the range is increased, the product's reflectivity (measured as target intensity) will decrease. The short range" basic reflectivity product of around 0. Although precipitation may be occuring at longer distances, this image will not reveal echoes signals more than 250 km from the radar station, giving more accurate findings. PPI products may be produced across a range of 50 km to 500 km, however the precision of the data decreases as the range increases. An output picture is created by extracting a surface with constant elevation. The range that is visible is the slant range.

Usage as a tool for analysing meteorological occurrences. The main applications are for storm-by-storm analysis and observation.The radar's sensitivity enables the detection of mid-level clouds and ice crystals, some of which are in the shape of cirri. The cloud's ice crystal and snowflake composition affects the detection range. It is common for stratocumulus clouds to have precipitation in the upper atmosphere that is big enough for the DWR to detect as raindrops, ice crystals, snowflakes, or both.Because of the tiny droplet size, stratus (and fog) are often not detectable.The development, evolution, and dissipation of precipitation events may be tracked by observing patterns of reflectivity.Refractive index changes may be used to detect moisture, turbulent layers, or both.The backscatter from the refractive structure or particles (such as insects) may be used to track changes in the planetary boundary layer.At the top of the planetary boundary layer, horizontal rolls and the development of cloud streets may be seen. During a diurnal cycle, the thickness of the planetary boundary layer may be seen.A brilliant band or other characteristics may be seen.

Applications

Observe the amount, direction, and trends of the precipitation. Examine weather conditions, particularly in the Clear Air Mode, and meteorological elements like inversions or moisture layers. Recognise the features of ice cloud layers and even very small precipitation. Find and place the melting/freezing level. Should watch and keep an eye out for non-precipitation phenomena like birds, bats, insects, smoke, volcanic ash, chaff, etc. to identify. There are several properties of the boundary layer that are revealed by the weak returns from refractive index gradients and microscopic particles like insects. Locate and track wind shear lines and boundaries, such as gust fronts, synoptic fronts, sea breezes, and many other types of wind changes. Find important convective storm structural characteristics including hook echoes, weak echo regions (WER), bounded weak echo regions (BWER), and even proof of the presence of a rear flank downdraft (RFD). Squall lines and Line Echo Wave Patterns (LEWP) may be recognised.

Limitations

Values at the data level cannot be altered. Precipitation Mode does not identify weak returns. Data contamination may occur due to AP, point clutter, and residual ground. Echo sampling is limited to the scanned elevation angles with discrete elevation sampling of any volume scan. Chaff echoes are often difficult to differentiate from precipitation echoes. Areas between non-contiguous beams and above the maximum beam height are not captured at all. Smaller-than-beam-width features cannot be detected due to beam widening as ranges increase. The proportion of the beam width to the feature size is known as the "aspect ratio" in this context. Beam blockage by surrounding high-rise structures or orographic features like mountains is a possibility at lower elevation angles [4].

Overview of the Planned Position Indicator (PPI-V)

Planned position indicator velocity data is known as PPI-V. The radar employs a Doppler Shift to calculate a reflector's velocity using the Doppler Theory. In this product, the velocity of the reflectors is returned after scanning a single elevation angle. Reflectors travelling away from the radar are indicated by positive values while those going towards the radar are indicated by negative values. It should be noted that the radar beam's height increases with distance from the radar and should thus show greater velocity readings since winds are often stronger at higher altitudes.

Employing Base Velocity

The PPI-V Product is primarily used to calculate the system's movement's Wind Speed and Wind Direction. The characterisation of velocities in meteorological events is aided by it. In-depth identification of meteorological phenomena including TVS/Mesocyclones, Microbursts, Storm Kinematic Structure, Gust Fronts, Boundaries, Algorithm Validation/Quality Control, and Non-Meteorological Returns is made possible by this product's high spatial resolution and huge number of data levels. As a result, this product primarily serves as a tool for identifying shear and determining the wind flow structure of the atmosphere at different scales, as well as for identifying local wind field features and locating atmospheric vortices such as mesocyclones and tornadic circulations [5].

Limitations

Data may be hidden by range folding.

1. Inaccurate velocity measurements may be the consequence of improper de-aliasing.
2. The size of the product data file is enormous.

3. Velocity aliasing may conceal shears or true speeds.
4. Velocities may surpass product data levels or even the velocity data levels defined by the signal processing.

Overview of the MAX-Z (Maximum Reflectivity) product

A maximum display of reflectivity data is MAX Z. The highest reflectivity values are returned to form this product after a volume scan, which is a sequence of scans taken by the radar at various altitudes. The highest reflectivity value for each pixel point is thus shown. Cross sections are included in the picture to calculate height. On a west to east axis, the cross section at the top of the picture is taken, and on a north to south axis, the cross section on the right. The product is based on a volume scan task with 10 angles, and it is determined by first building a sequence of CAPPIs to cover the selected layer, and then figuring out the reflectivity maxima for the horizontal and two vertical projections, East-West and North-South. Be aware that the radar cannot see all the way down to the earth's surface, which is why the curved borders are indicated at the bottom of the side panels. A polar volume raw data set is transformed into a Cartesian volume using the Maximum Product, which then creates three partial pictures and combines them to create the presented image. Users may define the height and the separation between two Cartesian levels. The fragmented pictures are:

a top view of the highest Z-direction measured values. From the top of the Cartesian volume, this graphic displays the maximum measured value for each vertical column.a view from north to south of the greatest values in the Y-direction. The greatest measured value for each horizontal line seen from north to south is shown in this picture, which is annexed above the top view.the highest measured values in the X-direction, shown from east to west. The maximum measured value for each horizontal column as viewed from east to west is shown in the picture that is attached to the right of the top view [6].

Use

The MAX product presents the echo height and intensity in a single, simple-to-understand display. It is particularly helpful for illustrating regions with extreme weather. The forecasters may utilise this single product, which offers the distribution of parameters recorded by DWR in three-dimensional spaces.

Wind profile for Volume Velocity Processing (VVP-2):

The volume velocity processing product is known as VVP. The velocity data volume scan that produced this product. VVP is a vertical column above the radar site that shows the horizontal wind speed and direction. North is located precisely at the top of the picture in this product. The wind velocity profile over the radar station is shown by the VVP or VVP-2 product. A Doppler radar can only measure the component of wind that is either towards or away from the radar; this is called the "radial wind." However, by examining the wind over all azimuths around a full circle, the average wind speed and direction can be calculated at different vertical layers and are displayed in the form of wind barbs.

Above the radar location, the VVP (2) shows the horizontal wind speed and direction in a vertical column. These numbers are obtained from a collection of velocity-related raw volume data. To extract the additional information from the recorded radial velocity data, a linear wind field model is used. For a group of evenly spaced layers, the method determines the wind's velocity and direction. The wind profile for consecutive VVP (2) product generations is shown in the following columns after a column of wind barbs that displays the velocity and direction at a time step [7].

Utilization

1. The VVP product may calculate the mean reflectivity profile above the radar as well as the vertical velocity, deformation, and axis of dilatation of the wind field.
2. Time versus height profile graphs may be produced for time intervals ranging from one to six hours, enabling the user to monitor major changes brought on by advection or other important meteorological phenomena.
3. The boundary layer wind profile is quickly determined using the VVP product [8].

Limitations

1. Requires enough data points.
2. In unstable conditions, it could not be dependable.
3. Significant bird migration flocks may cause unusual wind data.

Overview of Surface Rainfall Intensity (SRI)

The surface rainfall intensity product shows the rate of precipitation in mm/s. To get the most accurate estimations of collected precipitation even at farther distances from the radar, it may be utilised as input for the RAIN1 product. The SRI produces a picture of the amount of precipitation in a user-selectable surface layer at a fixed height above ground. The product offers real-time rainfall intensity information. Using the Z=ARb formula (Marshall et al., 1947), where R is the rainfall intensity and A and b are constants, the predicted reflectivity values are transformed to SRI. A and b have different values depending on the time of year and the location. In cold and mild climates, the vertical reflectivity profile is the most significant cause of inaccuracy in radar rainfall readings. Except for the area around the melting layer, where the echo is substantially louder, the upper regions of precipitating clouds normally produce a lesser echo than the cloud base. In order to determine surface rainfall intensity, an adjustment is necessary [9].

SRI offers a variety of ways to enter data on the actual reflectivity profile as well as strategies for making informed estimates, allowing the user to make advantage of local knowledge. It differentiates between large-scale precipitation and convective instances, applying the adjustment exclusively to the latter while presenting the value of the lowest clutter-free bin for convective precipitation. Even though the estimate of the melting level and reflectivity profile won't be exact, the rainfall projections will be better than if no modification were made. Depending on the height of the melting level, the distance from the radar, and the lowest elevation angle, typical adjustments will range from -10 dBZ to +5 dBZ (in mm/h scale up to factor of 4) [10].

Use

Rain1 (hourly rain accumulation) is mostly produced using SRI as an input product.It provides a general notion of the amount of rainfall that will fall at ground level from a cloud at a certain place in the hour to come. Flood-affected catchments may be recognised by identifying the "catchment areas" using the range of SRI products.

Accumulation of Precipitation (PAC)

The PAC product is on the secondary level. It accumulates the rainfall rates over a user-defined time period (look back time) using SRI products of the same type as input. For the specified time period, the display displays the color-coded quantity of rainfall in millimetres. The display is comparable to SRI's offerings.

CONCLUSION

Doppler radars' use in hydrological applications and rainfall estimation are covered in the fourth part. Doppler radars help with flood monitoring, water resource management, and drought assessment by precisely measuring rainfall rates and total precipitation. The use of Doppler weather radars in aviation and air traffic control is examined in the fifth part. These radars assist in spotting dangerous weather conditions along flight routes, enhancing operational effectiveness and aviation safety. The incorporation of Doppler radar data into numerical weather prediction models and data assimilation procedures is covered in the sixth part. The precision of model initializations is increased by Doppler radar measurements, leading to more accurate weather predictions. Doppler radar technology is constantly being developed, and this offers promise for further refining weather predictions, boosting catastrophe preparation, and promoting sustainable development in a world that is changing quickly.

REFERENCES:

[1] L. Zhong, Z. Zhang, L. Chen, J. Yang, and F. Zou, “Application of the Doppler weather radar in real-time quality control of hourly gauge precipitation in eastern China,” *Atmos. Res.*, 2016, doi: 10.1016/j.atmosres.2015.12.016.

[2] S. Sen Roy, V. Lakshmanan, S. K. R. Bhowmik, and S. B. Thampi, “Doppler weather radar based nowcasting of cyclone Ogni,” *J. Earth Syst. Sci.*, 2010, doi: 10.1007/s12040-010-0016-7.

[3] S. Mishra, J. Shanmuga Sundari, B. Channabasava, and V. K. Anandan, “First indigenously developed polarimetric C-band Doppler weather radar in India and its first hand validation results,” *Journal of Electromagnetic Waves and Applications*. 2020. doi: 10.1080/09205071.2020.1742798.

[4] P. Cao, W. Xia, and Y. Li, “Heart ID: Human identification based on radar micro-doppler signatures of the heart using deep learning,” *Remote Sens.*, 2019, doi: 10.3390/rs11101220.

[5] G. J. Stumpf, T. M. Smith, and C. Thomas, “The National Severe Storms Laboratory’s contribution to severe weather warning improvement: Multiple-sensor severe weather applications,” *Atmos. Res.*, 2003, doi: 10.1016/S0169-8095(03)00079-6.

[6] S. Kumar Das, S. M. Deshpande, S. Shankar Das, M. Konwar, K. Chakravarty, and M. C. R. Kalapureddy, “Temporal and structural evolution of a tropical monsoon cloud system: A case study using X-band radar observations,” *J. Atmos. Solar-Terrestrial Phys.*, 2015, doi: 10.1016/j.jastp.2015.08.009.

[7] J. Liu, J. Tian, D. Yan, C. Li, F. Yu, and F. Shen, “Evaluation of Doppler radar and GTS data assimilation for NWP rainfall prediction of an extreme summer storm in northern China: From the hydrological perspective,” *Hydrol. Earth Syst. Sci.*, 2018, doi: 10.5194/hess-22-4329-2018.

[8] F. A. Rihan, C. G. Collier, and I. Roulstone, “Four-dimensional variational data assimilation for Doppler radar wind data,” *J. Comput. Appl. Math.*, 2005, doi: 10.1016/j.cam.2004.07.003.

[9] M. I. Skolnik, “An Introduction and Overview of Radar,” *Radar Handb.*, 2008.

[10] A. V. Ryzhkov, M. R. Kumjian, S. M. Ganson, and P. Zhang, “Polarimetric radar characteristics of melting hail. part II: Practical implications,” *J. Appl. Meteorol. Climatol.*, 2013, doi: 10.1175/JAMC-D-13-074.1.

CHAPTER 13

OVERVIEW OF PUBLIC WEATHER SERVICES

Dr.Vibha Yadav, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

Public Weather Services (PWS) are a crucial part of meteorological infrastructure since they provide the general public and a variety of industries quick and reliable weather and climate information. An overview of public weather services is provided in this study, emphasizing its importance for disaster preparation, public safety, and climate resilience. This discusses the significance of PWS in providing people, organizations, and governments with weather and climate information. PWS systems are crucial platforms for disseminating weather predictions, advisories, and alerts, facilitating risk management and allowing informed decision-making. This examines PWS's essential elements, including as its reliable networks of ground-based stations, satellites, radars, and remote sensing devices. These networks provide the basis for producing precise and dependable weather predictions. This describes the methods used in PWS systems for data processing and analysis, including numerical weather prediction models and data assimilation techniques. These techniques improve prediction precision and lead times by turning unprocessed meteorological data into information that may be used. The need of efficient communication and distribution tactics in PWS is emphasized in the fourth part. Using a variety of channels, such as websites, social media, mobile applications, and emergency alerts, ensures that weather and climate information is sent to the target audience quickly and clearly. The value of using user-centric design for creating PWS services that are tailored to fit the individual requirements of various user groups. PWS systems enable consumers, businesses, and governments to make knowledgeable choices during weather-related events by giving pertinent and individualized information.

KEYWORDS:

Forecasting, Prediction, Public, Services, Weather.

INTRODUCTION

In order to assist mitigation efforts, timely transmission of prediction and warnings linked to severe weather phenomena to the stake holders is crucial. Severe weather phenomena have the potential to be life threatening depending on their severity, duration, and persistence over any region. Thus, offering the general public weather-related services and goods has enormous relevance. The significance of these goods also stems from the underlying mechanisms that cause weather patterns to change continually and the effects those changes have on a variety of human endeavours. An effective public weather service is now the most important necessity given the socioeconomic effects that a catastrophic weather event might have in an agro-based nation like India. However, the users and general public must be informed of the weather information in a timely way, utilising any accessible communication channels. As a result, it becomes the most crucial aspect of any weather service.

Particularly during severe weather occurrences, the media, general public, and government closely watch and assess the department's public weather services (PWS). The significance that the user community places on the national weather service may be used to determine how well it is doing, and for this reason the department's public weather services must be particularly robust and user-friendly. Public and media support for weather services increases when people realize that using meteorological data, including forecasts, alerts, and climatological and hydrological information, may considerably increase their safety and safeguard their property. Working together with the key stakeholders, a public servant who is scientifically competent can benefit much. A reliable, effective, and accurate Public Weather Service System must be implemented for the smooth operation of major events. The public, government, and NGOs place a high priority on weather forecast goods like those that include rainfall, maximum and lowest temperatures, winds, relative humidity, etc., as well as additional indirect products like heat index, comfort index, chill factor, etc.

In order to effectively communicate all weather-related information to the many sectors of the national economy, national weather services throughout the globe are now becoming more and more cognizant of the necessity for an effective PWS component. The World Meteorological Organisation (WMO) has developed a PWS project in the year 1994 to aid all National Meteorological and Hydrological Services in this endeavour. This was done in recognition of the relevance of this and the necessity for global coordination of such operations. Since then, the WMO has produced a tonne of technical information and recommendations in collaboration with the representatives of all the main National Weather Services across the globe. The National Meteorological and Hydrological Services' reach is increased by an effective PWS, and the public's perception of the National Weather Service is also enhanced. In order to better serve the general public and user agencies, the India Meteorological Department built a dedicated PWS component as an important element of its service [1].

Requirement for SOP Revision

The weather observations, including Synop, Pilot, AWS, Buoys, satellite, and radar pictures, are now accessible on a single platform called Synergie in real time after the recent upgrading of IMD's observing and forecasting systems. These data may be quickly and easily accessed, digitally evaluated, and comprehended. Currently, this capability is accessible at the national and regional levels as well as at two to three more forecasting centres. A modernized PWS platform is also available at certain forecasting centres, and Meteofactory may be used to create and distribute weather products (in both text and graphical format). As a result, it is now feasible to create personalised weather predictions, alerts, and reports in both text and graphical formats to satisfy user needs. The district prediction and warning (with colour code) are created in tabular form in those locations without this capacity.

Telefax and email were formerly used to distribute weather-related notifications to the concerned subscribers. However, with the development of mass communication, the broadcast of weather forecasts and alerts has also included the use of social media and bulk SMS. Additionally, a user-friendly website has recently been developed where predictions and alerts for various geographical and temporal scales may be posted and updated. Thus, there have been significant changes in the way that forecasting centres prepare, present, and disseminate information related to forecasts and warnings, and as a result, the department's public weather services have improved visibly, though there is still room for improvement. This paper outlines the facilities offered by the current PWS as well as the potential for future enhancements.

Principal Goals of PWS

Offering users specialized weather services.

1. Ensuring timely transmission of early warning services and associated goods to end users on a regular basis to guarantee the safety and protection of lives, livelihoods, and property.
2. Why Provide government officials with climate alerts and information so they can plan ahead and make cost-effective decisions for all social and economic activities that are impacted by the weather.
3. Participate in initiatives that develop capacity, promote knowledge, and increase preparation to assist individuals in making the greatest use of forecasts and warnings that are available to them.

Expand the reach of goods from the National Weather Service

1. Promoting the use of meteorology, climatology, hydrology, and related technology to improve goods and services through exhibitions, field trips for students from schools and colleges, disaster managers, and the display of posters. Identifying new end users / stakeholders and their additional requirements.
2. Working with government organisations on PWS-related joint initiatives, exchange trips, and demonstration projects.
3. Creating an interactive route for ongoing customer input that would allow us to re-validate our goods and improve their quality.

Major Stakeholders include:

NGOs: Farmers; Fishermen; Government (both Central and State)

Organizations; Electronic and Print Media; Industries; Other Autonomous Bodies; Farmers; Fishermen; and the General Public [2].

DISCUSSION

Principal Items/Actions Under the PWS System

Ensuring a smooth flow of current weather information, forecasts, and warnings from forecasting centres and specialized cells to end users. The National Weather Forecasting Centre (NWFC) will release these predictions and alerts on a subdivisional size, whilst Regional Weather Forecasting Centres (RWFCs) and State Weather Forecasting Centres (SWFCs) produce forecasts on a district level. A five-day forecast will be released along with an outlook for the next two days. Additionally, the RWFCs and SWFCs release nowcasts at least once every three hours about severe weather developments for their respective areas of responsibility. All of these prediction and warning items are posted to the website and made available to the user community through various communication channels.

To highlight the severity of the predicted severe weather and inform disaster management of the next steps to be taken in light of the imminent catastrophe weather event, the warning will be issued using the appropriate colour code. While the RWFCs/SWFCs give color-coded warnings in tabular form at the district level, the NWFC offers warnings in both text and graphical form at the subdivision size for the whole nation. the weather warning colour code.

When a severe weather event is predicted to hit a capital city, the public should be given impact-based forecasts and instructions, and these should be updated often until the event is through. A dewarning message must be sent when the event is over. RWFCs and SWFCs carry out these tasks for their respective spheres of authority.

At the start of each meteorological week, a weekly weather report is prepared, distributed to all users, and posted on the website. It includes an overview of the main weather features that were experienced during the previous week, an analysis of the weather systems that were responsible for the weather, a scenario for the week's rainfall and temperature, as well as weekly and seasonal rainfall statistics. RWFC/SWFC create the same report for their respective regions of responsibility, whereas NWFC prepares it for the whole nation [3].

At the start of each meteorological week, a bulletin on the current weather status and outlook for the next two weeks is prepared, distributed to all users, and uploaded to the website. This bulletin highlights the significant weather features of the previous week, the main synoptic situations, and large-scale features currently in effect. In this instance, too, the NWFC provides the same for the whole nation, whilst the RWFCs and SWFCs prepare the same for their respective jurisdictions.

The end users must have access to a historical data bank with climatological data for various meteorological parameters in a regular and readable manner. This data bank must include the mean maximum, mean minimum, lowest and highest values of actual maximum and minimum temperatures along with dates, as well as the highest and lowest amounts of 24-hour rainfall accumulated along with dates, the total number of rainy days, etc. These values must be available with respect to month, season, and year as well as with regard to location, district, subdivision, state, and for the entire nation on a spatial scale.

In order for the press and media to properly report on the weather, it is necessary to regularly brief them on both the present weather conditions and the weather prediction. The most recent weather advisory should be used as a guide for briefing the media and journalists. At the national level, briefings may be given in English and Hindi, but regional languages can also be employed at the regional and state levels to better reach the general public [4].

It is preferable to issue a news release on severe weather events that are anticipated to occur within the forecast period, along with updates as needed. The user community and stake holders will benefit from press conferences held at the time of severe weather to inform the press and media about the event and the release of special weather bulletins relevant to the event. On a daily basis, the media, disaster managers, and other stakeholders at RWFC/SWFC levels should have access to audio/video capsules on the present and upcoming weather situation of around two minutes in length, ideally in regional languages, through website and social media platform. Through the same systems, a comparable audio/video capsule showing the actual weather for the previous week as well as the medium- and long-range prediction for the next two weeks may be made accessible once a week. While NWFCs do this for the whole nation, RWFCs and SWFCs may handle it for their respective areas of responsibility [5].

A monthly weather bulletin that provides an overview of the actual weather for the previous month and a prediction for the next month based on the most recent extended range forecast products should be produced at the end of each month. Within a week of the start of the following month, this communication has to be written, sent to all parties involved, and posted online. Likewise, RWFC/SWFC prepare the same for their respective areas of responsibility while NWFC does the same for the whole nation. Any accomplishment should be proactively recognised via audio/video capsules, press releases, media briefings, briefing the crisis managers and other stakeholders. Examples include enhanced forecast accuracy, accurate prediction of a catastrophic weather event, any new project, etc.

If a catastrophic weather event occurs over any region, the responsible RWFC/SWFC must compile post-event reports for it within a week and send them to the NWFC. The report will include an impact assessment for potentially dangerous phenomena (such as cyclones, tornadoes/thunderstorms with very severe TS, cloudbursts, and urban water logging that disrupts normal life due to heavy precipitation) and will primarily include a meteorological analysis of the event, a historical aspect of the occurrence of such extreme events, an impact analysis, information about the loss of life and property, and a review of the services provided in relation to the event. After reviewing the report and making any necessary changes, NWFC will send it to the Ministry, NDMA, and other relevant parties for their consideration [6].

PWS functionality

Forecasters at the national, regional, and state levels as well as media outlets and the general public are all involved in the operation of PWS.

Uniformity of the Forecast and Warnings' Content

The National Weather Forecasting Centre (NWFC) at IMD Headquarters in New Delhi issues the main All India Weather Bulletin for the 36 meteorological sub-divisions of the country around noon on a daily basis, and the same is updated three more times throughout the day based on the conversation and decision made through video conference with RWFCs/SWFCs. The Regional Meteorological Centres (RWFCs) and State Meteorological Centres (SWFCs) provide forecasts and warnings at the district level based on this bulletin, which more or less serves as a guide for the subordinate offices. Based on the NWFC's nowcast guidance bulletins, which are also issued for severe weather components like thunderstorms, the RWFCs and SWFCs publish nowcast updates on the IMD website every three hours or as needed related to severe weather phenomena.

After extensive debate via video conference among NWFC, RWFC, and SWFC forecasters, the final weather products are generated. The purpose of the video/audio conferencing is to eliminate inconsistencies in weather forecasting services, particularly when severe weather events occur, and to ensure that the contents are uniform. In conjunction with the chief forecaster, the product is created and finalised with appropriate colour coding, etc. that is particular to the requirements of end users, and is then incorporated into the system for distribution to the designated end users. The PWS cell organises and distributes tailored goods (forecasts/warnings) to the press, disaster management, and other government authorities. These are also made accessible through social media and uploaded on the IMD website. To prevent confusing the general public, it must be validated and guaranteed that the prediction for a certain region is distributed consistently at all three levels.

Mode of Forecast and Warning Dissemination under PWS

Earlier, telefax and email were used to provide weather forecasts and warnings. Additionally, the most modern communication tools are being employed in this day and age to communicate with people. The following list includes the many communication methods utilised in PWS.

i) **Email:** The National Weather Forecasting Centre (NWFC) as well as Regional Meteorological Centres (RMCs) and Meteorological Centres (MCs) send weather forecast and warnings in both text and pictorial form to Central and State government organisations and authorities, national and state disaster management agencies, media, other stake holders, etc. The forecasting centres, which are updated periodically, are kept up to date with the e-mail addresses of everyone involved for this reason.

ii) **SMS:** Various forecasting offices utilise the SMS feature on mobile phones to provide weather forecasts and alerts, particularly agromet advisories and nowcasts connected to thunderstorms and other weather events, to the registered users. The Ministry of Agriculture and Farmers' Welfare's Kisan Portal and private businesses operate under the Public Private Partnership (PPP) mechanism to distribute these messages through SMS. Farmers often utilise this tool to receive advice on running their farms. Additionally, Doppler Weather Radar centres around the nation utilise their SMS capabilities to send out SMS alerts when severe convection develops nearby [7].

iii) **Use of social media for distribution:** Due to social media's widespread exposure, the transmission of weather forecasts and warnings is now encouraged. As a result, all IMD offices have activated their facebook and twitter accounts in order to utilise them for PWS. On a regular basis, NWFC updates the India Meteorological Department's facebook page (https://www.facebook.com/India.Meteorological. Department) and twitter account (https://twitter.com/Indiametdept) with All India predictions and color-coded warnings. The India Meteorological Department's YouTube page (https://www.youtube.com/ channel/UC_qxTReoq07UVARm87CuyQw?view_as=subscriber) regularly posts a weather capsule that includes sub-division-wise color-coded weather forecasts and warnings, animation of satellite imageries, major synoptic features, temperatures of major cities and maximum & minimum temperatures of mega cities, highest maximum and lowest minimum temperatures recorded on the dayThese forecasting tools are shared through WhatsApp groups established with media professionals, catastrophe management, etc. To broadcast the district level forecast, color-coded warnings, and nowcasts relevant to their area of responsibility, RMCs and MCs have similarly established their own facebook and twitter accounts as well as organised WhatsApp groups [8].

iv) **Website:** IMD offices nationwide, in each area, and in each state maintain websites with specific pages for weather forecasting services, which may include both static and dynamic pages. The dynamic sites may be used to upload the most recent prediction products for reference and use by everyone who is interested, while the static pages provide basic information about weather forecasting services, etc. for information and reference. The website also has specific sections for various services where users may post reports about monsoons, cyclones, and other weather-related events. Although most of these websites are in English, certain Regional Meteorological Centres and Meteorological Centres also have webpages in local languages. At the national level, the centre posts various products and bulletins, such as forecasts and warnings given by the NWFC, on the national website of the India Meteorological Department (https://mausam.imd.gov.in/), and the site is updated as needed. RWFCs and SWFCs update and publish weather data for their respective areas of responsibility on their websites in a similar manner. On the front page of the national website, under the heading "Departmental Website," are connections to the websites of various offices, including those at the regional and state levels. According to statistics, the general public, national and state disaster management authorities, federal and state government agencies, media, and other stakeholders often visit and recommend these websites.

v) **Bulletin for All India Radio and Doordarshan:** Regular bulletins are supplied to Doordarshan & All India Radio for broadcast purposes, highlighting the key aspects of realised weather, forecasts, and warnings. Daily weather information is also transmitted to Door Darshan through the weather capsule stated in the preceding section for inclusion in DD news. While state-level bulletins are released by relevant RWFCs/SWFCs, the national bulletin is published by NWFC.

vi) **Telefax:** In addition to other forms of communication, State and Central Government officials are also issued weather forecasts and warnings through fax, particularly those linked to cyclone warnings. Dedicated fax lines are used by NWFC to provide its VVIP predictions. The forecasting centres keep a record of the telefax numbers, which are periodically inspected and updated, particularly before to the start of cyclone season.

vii) **Press & Media Briefing:** Senior forecasting centre employees frequently brief the press and media on the weather that has been seen and is expected. Senior officials of RWFCs and SWFCs brief the weather situation; both seen and predicted; within their respective areas of responsibility, while NWFC officers brief on All India Weather. When briefing the press and media, information should relate to the specifics of the most recent weather advisory that was released [9].

viii) **Mobile App:** The India Meteorological Department has developed a mobile app that the general public may use to get the most recent meteorological data on their mobile devices. Farmers may use the smartphone app "Meghdoot" for weather-based agricultural management. It is designed for Agromet Advisory Services. It offers farmers crop advisories, weather forecasts, and weather summaries. The Indian Institute of Tropical Meteorology in Pune created the mobile app "DAMINI," which provides information on real-time observation and prediction of lightning in local vicinity.It also offers suggestions for lowering your danger of getting struck by lightning outside. Recently, in May 2020, IMD hosted seven of its services in the Unified Mobile Application for

New-Age Governance (UMANG), which is an all-in-one, single, unified, secure, multi-channel, multi-platform, multi lingual, multi service mobile App of the Government of India. These services included current weather, rainfall information, nowcast, city forecast, tourism forecast, colour coded severe weather warning, and cyclone warning. In addition to this, the IMD mobile app "MAUSAM" was released on July 27, 2020, and it is now accessible in both the App Store and the Play Store [10].

CONCLUSION

PWS's contribution to educating the public about weather effects and climate change. Educational materials and communication initiatives support community resilience to climate change and weather preparation. The worldwide difficulties that PWS systems confront, including the lack of data, financial limitations, and the need for international cooperation. In order to meet these problems, it emphasizes the value of ongoing research, technical development, and capacity building. The summary closes by highlighting Public Weather Services' crucial contribution to the development of meteorological research and their wide-ranging effects on several industries. Effective PWS systems provide a substantial contribution to fostering sustainable development in a world that is undergoing rapid change, protecting public safety, and constructing climate-resilient communities.

REFERENCES:

[1] S. H. Alsamhi, O. Ma, M. S. Ansari, and F. A. Almalki, “Survey on collaborative smart drones and internet of things for improving smartness of smart cities,” *IEEE Access*. 2019. doi: 10.1109/ACCESS.2019.2934998.

[2] A. Perrels, T. Frei, F. Espejo, L. Jamin, and A. Thomalla, “Socio-economic benefits of weather and climate services in Europe,” *Adv. Sci. Res.*, 2013, doi: 10.5194/asr-10-65-2013.

[3] T. Krennert, G. Pistotnik, R. Kaltenberger, and C. Csekits, “Crowdsourcing of weather observations at national meteorological and hydrological services in Europe,” *Adv. Sci. Res.*, 2018, doi: 10.5194/asr-15-71-2018.

[4] F. J. Doblas-Reyes, J. García-Serrano, F. Lienert, A. P. Biescas, and L. R. L. Rodrigues, “Seasonal climate predictability and forecasting: Status and prospects,” *Wiley Interdiscip. Rev. Clim. Chang.*, 2013, doi: 10.1002/wcc.217.

[5] B. Caldwell, E. McCarron, and S. Jonas, “An abridged history of federal involvement in space weather forecasting,” *Space Weather*. 2017. doi: 10.1002/2017SW001626.

[6] M. Sallai Buránszki and Á. Horváth, “Weather warning system in Hungary and the experiences of its operation,” *Hungarian Geogr. Bull.*, 2014, doi: 10.15201/hungeobull.63.1.7.

[7] V. Chang, “Temporary Removal: An overview, examples and impacts offered by Emerging Services and Analytics in Cloud Computing,” *Int. J. Inf. Manage.*, 2015, doi: 10.1016/j.ijinfomgt.2015.09.005.

[8] G. Blashki *et al.*, "Preparing health services for climate change in Australia," *Asia-Pacific Journal of Public Health*. 2011. doi: 10.1177/1010539510395121.

[9] T. Renko, P. M. Jurković, L. Kalin, T. Hojsak, M. Mokorić, and T. Kozarić, "The Weather Warning System in Weather and Marine Analysis and Forecasting Sector of the Croatian Meteorological and Hydrological Service," *Hrvatski Meteoroloski Casopis*. 2019. doi: 10.37982/hmc.54.55.1.1.

[10] J. Schaake, K. Franz, A. Bradley, and R. Buizza, "The Hydrologic Ensemble Prediction EXperiment (HEPEX)," *Components*, 2006.

CHAPTER 14

A BRIEF STUDY ON CONDITIONS FOR EFFECTIVE PWS

Dr. Vijay Kumar, Assistant Professor
Department of Agriculture, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

Effective Public Weather Services (PWS) are essential for promoting preparation and boosting resilience to weather-related risks, as well as fast and accurate weather and climate information dissemination to the general public. The major elements, difficulties, and developments in providing trustworthy weather and climate information to a variety of stakeholders are covered in this study, which looks at the basic conditions required for setting up and sustaining effective PWS systems. This explains the value of PWS in fostering public safety, safeguarding people and property, and assisting in decision-making across diverse industries. PWS systems are essential for distributing weather predictions, advisories, and warnings to the general public and key sectors of the economy. The need for strong networks of ground-based stations, satellites, radars, and remote sensing equipment is examined in the second part. These networks serve as the framework for the collecting of precise meteorological data, allowing reliable prediction analysis. The study comes to a conclusion by emphasising the crucial role that successful PWS play in advancing meteorological research and fostering society's capability for weather and climate variability adaptation. In response to a changing climate, PWS systems may promote readiness, improve resilience, and contribute to safer and more sustainable communities by abiding by the given requirements.

KEYWORDS:

Forecasting, Prediction, Public, Services, Weather.

INTRODUCTION

Several methods for processing and analysing data, such as data assimilation strategies and numerical weather prediction models. More precise and trustworthy weather predictions are made possible by advanced data processing, which turns raw data into information that can be used. It is emphasised how crucial it is for PWS systems to have efficient dissemination and communication methods. It is ensured that weather information reaches the intended users in a timely and accessible way by using a variety of communication channels, including mobile apps, websites, social media, and emergency alerts. The necessity for user-centric design, which will enable PWS services to be specifically tailored to the demands of various user groups, including as the general public, businesses, and policymakers. PWS systems are more effective and relevant when they provide pertinent and customised weather information. PWS's contribution to increasing public understanding of weather effects and climate change. Initiatives for community participation and educational outreach help different people become more climate resilient and weather prepared. The difficulties PWS systems confront, including as data shortages, financial limitations, and the necessity for global collaboration. In order to successfully address these difficulties, it highlights the need of ongoing research, technology advancements, and capacity development [1].

For PWS services to be as beneficial as possible, it is crucial to customise them to each user group's unique requirements. PWS systems must to be created with the user in mind, containing feedback mechanisms and giving different stakeholders pertinent and individualised information. Promoting weather preparation and climate resilience requires educating the public about weather and climate consequences. PWS systems may be very helpful in educating people about weather-related occurrences, giving them with instructional materials, and enabling them to make wise choices. There are still issues with PWS systems, such as data shortages, financing limitations, and communication difficulties. International cooperation, public-private collaborations, and ongoing technical developments are required to address these difficulties.Furthermore, PWS systems must modify and include climate services and long-term climate predictions as climate change continues to affect weather patterns. This proactive strategy will increase readiness for severe weather events and climate resilience. PWS systems may continuously advance and change to suit the changing requirements of society by implementing best practises, studying successful case studies, and embracing innovations. In the end, efficient PWS systems make a big contribution to creating communities that are climate resilient and ensuring public safety in a changing environment [2].

By giving the public fast and reliable weather and climate information, effective Public Weather Services (PWS) play a crucial role in protecting lives, property, and economic activity. The objective of this review article is to investigate the prerequisites for setting up and sustaining effective PWS systems. In order to ensure readiness and resilience in the face of changing weather patterns and catastrophic occurrences, it investigates the essential elements, difficulties, and breakthroughs in providing weather and climate information to the general population.

The relevance of PWS in providing people, organisations, and governments with weather and climate information is discussed in the paper's introduction. The importance of PWS in enhancing public safety, assisting with disaster preparation, and developing climate resilience is emphasised. Infrastructure and Observation Networks: In this part, it is discussed how important it is to have reliable networks of weather stations on the ground as well as satellites, radars, and other remote sensing tools. The basis of PWS systems is strengthened and prediction accuracy is increased by the integration of data from various sources.

Data processing and analysis: It takes effective data processing and analysis to turn unprocessed weather data into useful information for the general audience. In order to provide accurate and trustworthy weather predictions, a variety of methods, including data assimilation techniques, numerical weather prediction models, and ensemble forecasting, are examined in this section. Communication and Dissemination: It's crucial to have a solid communication plan in place to make sure that weather and climate information reaches its target audience quickly and clearly. This section explores how to efficiently convey PWS information through a variety of communication methods, including mobile applications, websites, social media, and emergency notifications.

Services must be customised to fit the unique demands of many user groups, including the general public, businesses, and policymakers. PWS systems must be customised to do this. This section discusses the significance of user-centric design, the inclusion of feedback systems, and the dissemination of pertinent and useful information. Education and Public Awareness: Promoting weather preparation and climate resilience depends on raising public awareness of weather and climate effects. This section examines how PWS helps people become more educated about weather-related occurrences, provides educational tools, and empowers them to make such choices.

Challenges and Solutions: The report discusses the difficulties PWS systems have, including data shortages, financial limitations, and communication obstacles. The debate of potential solutions to these problems includes public-private partnerships, international cooperation, and technological developments.

Climate Change Adaptation: Adaptive PWS methods are necessary because to the influence of climate change on weather patterns. In order to increase climate resilience, this section examines how PWS systems might include climate services, long-term climate predictions, and the prediction of severe weather events.

Case Studies and Best Practises: Case studies of effective PWS systems from various areas and nations are presented in this section. As examples for future development, best practises, lessons learned, and innovations in providing successful PWS are emphasised.

Reiterating the critical role that successful PWS play in weather and climate preparation, the review report concluded. PWS systems may make a substantial contribution to constructing climate-resilient communities and maintaining public safety in a changing climate by merging strong observation networks, cutting-edge data analysis, user-centric services, and educational outreach.

DISCUSSION

PWS needs a clear policy on the working area, responsibilities, and information transmission to the media and end users. The PWS-related tasks may be divided into three stages for this purpose. The first level has to do with the creation of goods connected to observation, climatology, and prediction. In addition to managing the duties and guiding the first level, the second level needs to deal with explaining the observed weather and forecast, responding to individual inquiries, and giving bytes/interviews to electronic and print media. In addition to managing and organizing Level 1 and 2 operations, Level 3 is responsible for briefings about weather predictions, panel deliberations, decision-making, responses to high-ranking officials, VIPs, etc.

1. At all forecasting offices, an accurate database of all end users and significant stakeholders must be kept and updated on a regular basis.
2. Information flow to and from PWS must be well-organized.
3. The use of language that is more approachable to users rather than jargon that is too technical.
4. When creating the forecast products, emphasis should be placed more on graphical material than written content. Colours should also be utilised to make the warnings stand out from the regular day-to-day forecast.
5. When releasing the general prediction or warning, a tight time schedule must be adhered to; ideally, it should coincide with the broadcast period of weather bulletins.
6. To prevent communication breakdowns, particularly during severe weather, a multi-channel communication network with built-in redundancy must be put up [3].

It is suggested that a media hour be observed at all IMD offices for daily routine briefings linked to fair weather in order to prevent repetitive interactions with the media. The media briefing may, however, be conducted as needed during extreme weather situations.

1. To increase the quality of services, a comprehensive feedback system and ongoing service assessment are required.
2. For taking part in significant deliberations, interacting with the media, and attending parliamentary sessions, a panel of resource people or experts from operational forecasting and related fields, such as numerical weather prediction, climate change & global warming, satellite products, and doppler weather radar (DWR) products, needs to be created.
3. To prevent abuse or incorrect interpretation of information provided with end users, notably the media, a Memorandum of Understanding is preferable.
4. In order to raise awareness, Frequently Asked Questions (FAQs) on various aspects of weather are to be created and placed on the IMD website for all interested parties to consult.
5. In order to raise awareness of weather forecasting services, pamphlets detailing the most recent advancements and successes should sometimes be made and given on field trips or exhibits.
6. The installation of a dedicated network along with interactive weather display systems at public locations, fixed space in newspapers, scrolling space on TV channels, and a dedicated weather channel will aid in the real-time dissemination of reliable weather information.
7. Media and disaster management should attend workshops on a regular basis. For the purpose of educating media personnel, basic training in meteorological conventions and terminology will be conducted.

The provision of ready-made audio-visual capsules to Doordarshan and other electronic media, AIR/FM Radios, would aid in preventing inaccurate reporting. The operational personnel of IMD working in the forecasting division presently does work connected to PWS in addition to their regular duties. In the IMD forecasting offices, PWS has to have a dedicated team or monitoring cell. For improved coordination and administration of PWS-related operations, it is thus advised that PWS cells be established in all forecasting centres.

New PWS Initiatives

A further development in the calibre and efficacy of PWS may be made feasible by new efforts such the deployment of impact-based forecast, the use of Common Alert Protocol in the transmission of forecasts and warnings, measures to expand outreach, etc. In addition to this, it is also fashionable to organise a weather watch club and perform a Forecast Demonstration Project with the participation of organisations outside the department. To show how useful weather services are in many industries, sector-specific services are being promoted [4].

Use of impact-based forecasting

The goal of an impact-based forecast is to predict what the weather will do rather than what it will be. In order to highlight the severity and effect of the predicted severe weather and to inform disaster management of the action that has to be taken at their end for mitigation, the weather prediction and warning products are already being developed with the addition of colour coding.The Risk and Response matrix is used to inform the impact-based prediction. This matrix is used to determine the appropriate colour designation for every upcoming severe weather event, taking into account both the likelihood of its occurrence and any possible effects.

The impact-based forecast had been introduced long ago in cyclone warnings, so severe weather that is anticipated during cyclones along with the effect it will have on public life and the instructions for necessary action when severe weather occurs are provided in the warning messages. Beginning in 2019, the same pattern of warning messages was applied to other types of severe weather, such as thunderstorms and related meteorological phenomena including heat waves and squalls of lightning. When providing impact-based forecasts, the National Disaster Management Authority rules concerning the appropriate course of action for certain weather factors were looked to and used.

Impact-based forecasting of heavy rainfall has been used for the country's largest cities beginning with the 2020 monsoon season. RWFCs and SWFCs provide these projections for the significant cities under their purview. Four processes are used to release these projections. The first stage corresponds to a heavy rainfall alert (watch) that is issued 3 to 5 days before to the event's anticipated occurrence and is updated every 12 hours. Stage 2 heavy rain alerts are sent out with one to three days' notice and are updated every six hours. Stage 3 is equivalent to a heavy rain warning that is issued with a 12- to 24-hour lead time and is updated every one to three hours. Stage 4 is the warning that is given 12 hours before the highest amount of rain. A second chapter of this publication contains further information and the SOP for this new effort [5].

The Common Alert Protocol for Forecast and Warning Dissemination is Introduced

The Common Alerting Protocol (CAP) is a standard message format created for communications over any and all media, including television, radio, telephone, fax, highway signs, e-mail and websites; about any and all types of hazards, including weather, fires, earthquakes, volcanoes, landslides, child abductions, disease outbreaks, air quality warnings, transportation issues and power outages; to anyone, including the general public, designated groups like civic authority, responders, etc. The National Weather Services must use CAP in the distribution of weather messages as soon as possible in accordance with WMO principles. Through the same platform used to disseminate information about other hazard situations like terror attack, child abductions, disease outbreaks, air quality warnings, beach closings, transportation issues, power outages, etc., the primary goal of CAP is to disseminate timely and meaningful warning information about the potential extreme events or disasters like flood, drought, earthquake, volcanoes, landslides, tsunami, cyclone, gas leak, thunderstorm, and fire [6].

The Centre for Development of Telematics (C-DOT) is proposing an Integrated Disaster Management System (IDMS) that will be used by the National Disaster Management Authority to disseminate all types of warnings utilising CAP. The system's general layout.Through this mechanism, IMD forecasts and advisories will also be sent. The Department of Telecommunication, Government of India, has already finalised the SOP for the purpose after consulting with the NDMA, all stakeholders, and C-DOT [7].

C-DOT tested the dissemination of weather warnings using this platform utilising SMS as the output during a number of severe weather events recently, and the results were positive. As a result, a pilot project was created for the state of Tamil Nadu to spread messages using the current popular approach. The facility will be made available to all states after the project is successfully completed. In addition to this, IMD is separately attempting to apply CAP format in the broadcast of weather prediction and warning messages on a trial basis using the processes supplied by WMO, which has also shown favourable results [8].

Improvements to the Outreach

Projects like Forecast Demonstration Projects (FDPs) are cooperative exercises combining universities/IITs, other governmental organisations, and IMD specialists in order to increase outreach. Currently, IMD is hosting FDPs on a variety of weather phenomena, such as cyclones, thunderstorms, heat waves, fog, etc., in which participation from organisations not affiliated with IMD is encouraged. Their contributions and feedback are then used to analyse the phenomena, improve the forecast and warning services related to those events, create guidelines for the general public to follow during such events, and conduct case studies of the events and their effects.

In order to further educate and acquaint them with the science and practises of weather forecasting, it is also being done to install automatic weather stations in schools, involve students in collecting data and reporting it, extend familiarisation training to teachers, etc. IMD is actively participating and giving lectures at WEBINARS, Workshops, Symposiums, and other events related to meteorological services that are held by the National Disaster Management Authority, etc., in order to highlight its capabilities, resources, and successes in the field. The National Institute of Disaster Management always includes a visit to the NWFC and an introduction to the work done by the centre as part of the curriculum for its training programmes.Sector-Specific Service Provision [9]

Since weather affects practically all public utility sectors, there is a high need for weather products that may be specifically tailored for each sector. IMD has a long history of providing services to industries including aviation, agriculture, and marine operations. By providing hydrological information and accurate quantitative precipitation estimates for river basins, IMD assists Central Water Commission in delivering flood forecasting services. In addition to offering tailored weather forecast products through dedicated links, IMD has recently expanded its services to include Power, Health, Transport (both road and railway), Urban Services, etc. IMD is currently working to improve the observational network to meet the needs of these sectors. However, after signing an MOU with the relevant authorities, services are provided to these sectors [10].

CONCLUSION

Creating and maintaining efficient Public Weather Services (PWS) is crucial for protecting public safety, assisting with disaster preparation, and promoting climate resilience. The main factors that make PWS systems effective in informing the public about the weather and climate in a timely and accurate manner have been examined in this review study. PWS systems are built on solid weather observation networks that include ground-based stations, satellites, radars, and remote sensing tools. The combination of information from these several sources improves prediction precision and permits a thorough comprehension of atmospheric conditions. Raw weather data is transformed into useful and applicable information for decision-makers and the general public via effective data processing and analysis, driven by data assimilation methods and numerical weather prediction models. In order to make better informed decisions, ensemble forecasting helps to quantify forecast uncertainty. It is essential that weather and climate information be communicated and disseminated in order for the general public to get accurate and understandable predictions. The reach and efficiency of PWS systems are increased by using a variety of communication channels, including as mobile applications, internet, social media, and emergency alerts.

REFERENCES:

[1] D. K. Jin, "Systematic review of the clinical and genetic aspects of Prader-Willi syndrome," *Korean J. Pediatr.*, 2011, doi: 10.3345/kjp.2011.54.2.55.

[2] R. Brouwer, A. Tesfaye, and P. Pauw, "Meta-analysis of institutional-economic factors explaining the environmental performance of payments for watershed services," *Environ. Conserv.*, 2011, doi: 10.1017/S0376892911000543.

[3] K. E. Manning *et al.*, "Transcutaneous vagus nerve stimulation (t-VNS): A novel effective treatment for temper outbursts in adults with Prader-Willi Syndrome indicated by results from a non-blind study," *PLoS One*, 2019, doi: 10.1371/journal.pone.0223750.

[4] A. Takeda *et al.*, "Recombinant human growth hormone for the treatment of growth disorders in children: A systematic review and economic evaluation," *Health Technology Assessment*. 2010. doi: 10.3310/hta14420.

[5] O. Edgar, A. Lucas-Herald, and M. Shaikh, "Pituitary-Adrenal Axis in Prader Willi Syndrome," *Diseases*, 2016, doi: 10.3390/diseases4010005.

[6] D. Piccolo *et al.*, "Unconventional Use of Intense Pulsed Light," *Biomed Res. Int.*, 2014, doi: 10.1155/2014/618206.

[7] I. Y. Eom, Y. H. Oh, S. J. Park, S. H. Lee, and J. H. Yu, "Fermentative l-lactic acid production from pretreated whole slurry of oil palm trunk treated by hydrothermolysis and subsequent enzymatic hydrolysis," *Bioresour. Technol.*, 2015, doi: 10.1016/j.biortech.2015.02.060.

[8] L. Vismara *et al.*, "Effectiveness of a 6-month home-based training program in Prader-Willi patients," *Res. Dev. Disabil.*, 2010, doi: 10.1016/j.ridd.2010.07.001.

[9] R. Motaghedi, E. G. Lipman, J. E. Hogg, P. J. Christos, M. G. Vogiatzi, and M. A. Angulo, "Psychiatric adverse effects of rimonobant in adults with Prader Willi syndrome," *Eur. J. Med. Genet.*, 2011, doi: 10.1016/j.ejmg.2010.09.015.

[10] C. C.K., Y. J.Y., and C. I.J., "Short-term treatment of liraglutide in patient with Prader-Willi syndrome," *Horm. Res. Paediatr.*, 2019.

CHAPTER 15

A BRIEF STUDY ON HEAVY RAINFALL WARNING SERVICES

Dr. Garima Bartariya, Associate Professor
Department of Botany, IIMT University, Meerut, Uttar Pradesh, India.

ABSTRACT:

In order to predict and lessen the effects of extreme rainfall occurrences, heavy rainfall warning systems are essential elements of the meteorological infrastructure. An overview of heavy rainfall warning systems is provided in this study, with a focus on their importance for managing flooding, preparing for disasters, and ensuring public safety. It is discussed how crucial heavy rainfall warning systems are for preventing dangers including flash floods, landslides, and infrastructure destruction. These services are essential for reducing the negative effects on people, property, and vital infrastructure. The second portion investigates the techniques used to identify and anticipate significant rainfall occurrences. Meteorologists may precisely track and anticipate precipitation patterns using radar systems, satellite data, numerical weather prediction models, and in-the-moment observations. The communication and distribution tactics utilised to successfully inform the public and pertinent authorities of severe rainfall warnings. Effective preparation and response strategies are improved by timely notifications, emergency communications, and user-friendly platforms. The collaborative aspect of heavy rainfall warning systems, which involves collaborations between meteorological agencies, disaster management organisations, and numerous stakeholders, is covered in the fourth section. The flow of information is facilitated through coordination, which also guarantees a thorough response to situations caused by heavy rain. The difficulties encountered by heavy rainfall warning systems are highlighted in the sixth part, including data accuracy, forecasting ambiguities, and the need for ongoing technical developments. In order to increase the accuracy and lead periods of heavy rainfall forecasts, research and innovation are crucial.

KEYWORDS:

Forecasts, Heavy, Rainfall, Satellite, Weather.

INTRODUCTION

India has frequent, heavy rains almost all year round. They occur much more often during the monsoon. According to studies (Fischer and Knutti 2017, Landerink and Fowler, etc.), severe rainfall has become more frequent in recent years under a climate change scenario. High monsoonal precipitation events occurring over a small region quickly have been a key factor in the loss of life and destruction of property in India. The cumulative rainfall of these exceptionally heavy rainfall periods and the number of fatalities for some of the key events that occurred throughout the period 2005–2020. The timeline of some of the High Impact Heavy Rainfall Events that Affected the Indian Mainland is shown below.

Mumbai, India, July 26–27, 2005 One of the greatest localised intense rainstorms ever recorded occurred in Mumbai on July 26. It reached a maximum of 94.6 cm in 24 hours, with over 60% of that total falling between 14:30 and 20:30 IST. 400 people lost their lives as a result of the incident, which was so localised that it was limited to neighbourhoods around Santcurze Airport. The incident also caused the city to lose phone service, transport and power for a week, causing

5000 crores in damage and forcing the closure of Mumbai Airport for over a week. On August 6, 2010, a cloud burst in Leh, creating a flash flood and mud flows that resulted in fatalities and infrastructure and amenity losses.

The torrential downpour that hit Uttarakhand (15–18 June 2013) caused a deadly flash flood and a string of landslides that resulted in the deaths of almost 6000 persons. made 100,000 people stuck, and the government had to rescue them. Malin, a village in Maharashtra, was struck by a mud flow/land slide early in the morning while inhabitants were sleeping; it was triggered by a burst of torrential rainfall and killed at least 134 people. This incident occurred on July 30, 2014. Floods in Jammu and Kashmir from September 3–7, 2014. The capital city of Srinagar suffered the most from rains in Jammu and Kashmir, which ranged from 30 to 61 cm in only three to four days. About 250 lives were lost, which had a 15-day impact on the whole city. Another major government rescue effort for the nation's 250,000 trapped citizens. The 16–17 November and 1-2 December 2015 floods in Chennai, which left more than 500 people dead and caused losses and damages totaling NEA 15,000 crore, were particularly devastating. One of the worst urban flooding events in modern times, this [1].

Kerala Extreme rains and flooding in August 2018 killed 483 people and left 14 persons missing. The biggest rain event occurred between August 14 and August 16, 2018. 40,000 crore worth of property was lost. Highest rainfall touched/stations reporting >7 cm, with corresponding measurements of 11 cm/7, 35 cm/50, 19 cm/30, and 11 cm/3 for the dates of 12–13, 15–16, 16–17, and 17–18 August, with the heaviest portion of the rainfall period occurring on the 14–16 August 2018. Extremely severe rainfall events from August 3–10 on India's west coast: i) The Konkan and Madhya Maharashtra regions, including Mumbai City, had 40–80 cm of cumulative rainfall from August 3–7, 2019, which resulted in the loss of almost 50 lives. With Mumbai airport partly closed, Pen recorded the state's greatest 24-hour rainfall total on record for the time period at 49.3 cm. ii) Kerala between August 8 and 10, 2019 - Kerala saw a period of very heavy rainfall (>20.4 cm), with a total of 20 to 60 cm. On the 8th and 9th of August, Ottapalam recorded 33 cm, the most ever. This led to landslides and the loss of almost 102 lives. Additionally, Kochi Airport was closed for a day.

From July 4–7, 2020, Saurashtra and Kutch saw a very strong rainstorm. In Khambhalia, in the Dwarka district, 48.7 cm of rain fell between July 5 and 6, and over Okha, on July 7–8, causing a flood in the area. Mumbai's Kokan shoreline also saw a very intense rainstorm that had a negative impact on life. From August 3–8, 2020, Maharashtra, Karnataka, Kerala, and neighbouring Tamil Nadu saw a very heavy rainfall period totaling 50–71 cm. The following rainfall quantities peaked at that time: According to the statistics above, among all other recent natural disasters that have had the greatest impact on human life, heavy rainfall has been one of the most devastating meteorological catastrophes. It has been producing landslides, riverine, local, and urban flash floods, as well as floods and inundations, severely affecting local infrastructures and crops. All service sectors are significantly impacted in big metropolitan areas, and often, numerous service sectors, such as airports, hospitals, and other essential municipal services like power supply, communications, and surface transportation, are shut down.

Thus, IMD has developed and adopted a variety of global and regional scientific integrated approaches on a very high priority basis through various collaboration projects with FFGS-WMO, WCSSP-UKMO, SWFDP-WMO, etc. via WMO, USA, EU, UK and adoption of indigenous techniques and technology available within the country via ISRO and MoES institutions like NCCR, NCMRWF, and IITM to improve its monitoring and early warning system, as well as its timely outreach to minimise its impact. It addresses the enhancement of real-time monitoring through a dense network of surface, RADAR, and satellite rainfall monitoring up to block level and sub-city levels and the generation of a timely Heavy rainfall warning up to 5-7 days in lead time by adopting a suit of the most recent NWP models at local to global scales known as a seamless approach at Nowcast to ERF time scale. Another goal was to "adopt appropriate understandable warning formats in both local regional languages and to use all the best and latest dissemination systems like Social media, CAP based technology, Whatsapp, Website, etc. and other digital platform to timely disseminate these warnings to general public, media, Government, and disaster managers as and when heavy rainfall is expected over a region" IMD adheres to a Standard Operating Procedure (SOP) for monitoring, prediction, and warning services for the benefit of the heavy rainfall warning system [2].

Organisation and Area of Responsibility

The Ministry of Earth Sciences' India Meteorological Department (IMD) is the Nodal National Meteorological Organisation tasked with delivering reliable operational weather forecasts and alerts for weather hazards across the nation. IMD is organised into three levels: the National Weather Forecasting Centre (NWFC) in Delhi, the Regional Meteorological Centre (RMC), and the Meteorological Centres (MC), which are located at the state level. A variety of time and geographical dimensions are covered by the weather predictions. The many geographical domains include location, city, district, state, and nation, each with a unique temporal domain. According to their validity periods, the temporal domains are Nowcasting, Short Range, Medium Range, Extended Range, and Long Range. However, only nowcast to short- to medium-range warnings, valid for up to five days, are given at the district level.

DISCUSSION

At the national level, the NWFC will issue sub-division-wise heavy rainfall warnings four times each day, valid for the next five days with a two-day outlook based on observations made for the whole nation at 00, 03, 09, and 12 UTC. The alert will be sent through multiple channels to national agencies, national disaster management agencies, press and electronic media, the general public, users, and other stakeholders. Additionally, NWFC issues a textual and graphically color-coded warning for heavy rain.

RMC/MC issued a heavy rain warning at the regional level for the concerned state at the district and subdivision levels. The alert will be sent through multiple channels to state agencies, state disaster management agencies, the press and electronic media, the general public, users, and other stakeholders. Additionally, RMCs send a textual and graphically color-coded warning during heavy rain. The HRW will be issued by the duty officer at RMC/MC, who will be in charge of it. responsible for the state. If a Group-A officer is available, there should be round-the-clock duty at RWFC; otherwise, work may be conducted by qualified officials under a Group-A Officer's supervision.

Heavy Rainfall Classification

The following lists the terminology used by IMD for location-specific rainfall ranges and its categorization of heavy rainfall. On the basis of daily rainfall, it establishes HRF for a particular station. It is based on the actual rainfall that occurred during the previous 24 hours, which ended at 08:30 IST on a particular day. As defined by IMD, a station's HRF might fall into a number of categories.

Heavy Rainfall Climatology

IMD has a respectable number of stations throughout India with longer period data, displays the frequency of different types of heavy rainfall across various regions of India in terms of the number of days in a year.

Cloud Burst Climatology

In the lower Himalayan area, particularly in its western sections, cloud burst occurrences are often seen during the monsoon season. Regardless of the quantity of rainfall, CB have a very high effect on the area because they generate extremely localised flash floods, landslides, debris flows, and flash floods that inflict significant property damage and fatalities. It has been difficult to identify rainfall since there are not enough systems in place to capture data on an hourly basis.

Several crucial aspects of Cloudburst

Frequencies across India; IMD criteria: Any precipitation event over 100 mm/h; Extremely high rainfall realised in a relatively short period of time. Highest across Uttarakhand, HP, and the northeastern hill states, as well as on and near the southern margin of the Indian Himalayas. From Goa to Saurashtra, take the Westcoast across the windward-side Western Ghats Hills. Areas at risk in the western Himalayas Between 1970 and 2016, 30 cloud burst events occurred over the southern Himalayas, with around 17 of them taking place in the Garhwal region of Uttarakhand at elevations between 1000 m and 2500 m. These occurrences occurred within a narrow geographic area of 20 to 30 km. Droplet size is between 4 and 6 mm, and fall speed is 10 m/s.Potential causes. Orographic architecture of the mountainous areas Monsoonal moist-laden winds at lower levels blowing from the southeast/east towards the hills, along with vertical wind shear and orographic uplifting, resulting in heavily precipitating convective systems [3].

Risk-based warning system and IBF implementation for heavy rainfall event

The goal of an impact-based forecast is to predict what the weather will do rather than what it will be. In order to highlight the severity and effect of the predicted severe weather and to inform disaster management of the action that has to be taken at their end for mitigation, the weather prediction and warning products are already being developed with the addition of colour coding. The many effects of heavy rainfall include river flooding, urban flooding, landslides, flash floods, coastal flooding, water inundation, water logging in low-lying places, etc. Please refer to the Impact Based Forecasting SOP chapter for further information.

Heavy rainfall event observation, monitoring, and product development

For the time being, IMD uses both surface-based and remote-based observations and monitoring technologies to identify and record the occurrence of significant rainfall events, including their locations and dates. The observing platforms listed below are those currently in use for precisely identifying and tracking high rainfall occurrences.

Techniques for Predicting Heavy Rain

The diagnostic meteorology, which includes synoptic and upper air data analysis and creating synoptic climatology or pattern matching, different NWP model outputs, and satellite and radar observations, is now used to forecast the occurrence of heavy rainfall over a region or site.

Diagnosis Technique

Using CLIPER, Synoptic, Synoptic analogues, and Pattern Matching techniques, prior examples of heavy rainfall are analysed, and a variety of products are synoptically and dynamically assessed to uncover different factors that lead to these occurrences. In order to determine the pattern that will be associated with earlier events, NWP model analysis and forecasted winds, areas of stronger wind shear, moisture availability, dynamic features like vorticity, convergence, and divergences at various levels of the atmosphere are also used. Major characteristics that have been identified as favouring the occurrence of high rainfall events include:

While travelling, major cyclonic systems like CS/Dep and Monsoon Lows/Dep create severe rainfall occurrences. Along the west coast and in Gujarat, there will be MTC and an active monsoon trough/off-shore trough with heavier moist-laden easterly/westerly winds. Interaction between the monsoon system and the mid-latitude system over the western Ghats and Himalayan area. During the monsoon-Synoptic-Mesoscale break/revival phase MCC/MCZ development due to convective interaction. Features that cause Extremely high rainfall occurrences, a CB, and a strong to extremely strong spell across the Himalayas and the west coast [4].

Eastern Himalaya: Moist southerly/southwesterly winds converge over a steep slope of orography, where they abruptly concentrate and provide very significant rainfall. Western Himalayas – Interaction of WD/mid-Latitude trough with LPS where southerly moist monsoon winds from Arabian Sea or Bay of Bengal helped by orographic uplift converting to severe convective events with CB grown up to 15km height. East-west Shear zone, off-shore trough, and distance influence of LPS/Depression found along the Odisha-Bengal coast or across eastern areas of Central India; West Coast and adj south Gujarat; Along with the aforementioned synoptic scale systems, large scale features of the day like the easterly jet position, low level jet, MJO, IOD, El-Nino, Ridge, and low level jet also enhance or suppress convection in regions favourable for heavy rainfall over various parts of India over the monsoon core zone along central India, the west coast, and the east coast of India. Dynamic characteristics include vorticity, shear, shear tendency, divergence, and convergence. Additionally employed are the thermodynamic characteristics CAPE, CINE, temperature gradient, etc.

SOP of Heavy Rain, System for monitoring, predicting, and warning

Currently, the synoptic, satellite, radar, and NWP model inputs are used to monitor and anticipate the heavy rainfall. To reach a consensus conclusion on the possibility of heavy rainfall and its effect over an area or a portion of it over the next five days, all these data and products are assessed and then reviewed via video conference among all the forecasters throughout the nation [5].

Monitoring Procedures for Heavy Rainfall

The following stages are essentially involved in the monitoring for heavy rain.

Regularly retrieving and reviewing bulletins and other goods released by SWFC, RWFC, AMO, FMO, NWP Division, NWFC, etc. The routine retrieval and analysis of all data collected remotely. Continuous monitoring for the receipt of unexpected data, such as reports of real heavy rain happening or strong precipitation alert notifications.

Techniques for Predicting Heavy Rainfall

There are many methods for foretelling heavy rainfall over an area: Synoptic, Radar, Satellite, NWP Products, Checklist, and more.

Analysis and forecasting

To evaluate the strength, location, behaviour, and direction of movement of the weather system, forecasters will review real weather charts together with supporting NWP and satellite/Radar information. If necessary, the duty officer will issue HRW across the assigned territory after analysing all meteorological data. When forecasters predict that a weather system is expected to affect the area of responsibility in 5 Days and may bring heavy rain, a warning of impending downpours should be provided without fail. The warning may be evaluated in a later bulletin by consulting weather charts, NWP/Satellite/RADAR products, the system's location, and its direction of progress. Below are some simple steps.

Duty The forecaster would continually assess all the incoming data on the workstation at his disposal. A digital signature should be presented at his workstation as confirmation of his time of analysis in order to complete it. Where such a capability is not accessible, the MC/RWFC will keep a manual record book for this reason. Based on observations and communications received, the forecaster will issue an advisory or warning. The forecaster will provide a short description of the features of the heavy rainfall and any relevant warnings for the area of forecast for the SWFC / RWFC in the event that the chance of heavy rainfall is inferred from multiple inputs. The concerned SWFC / RWFC will issue a "Warning: Nil" if there are no forecasts for very heavy precipitation [6].

Process of determining decisions

While SWFC/RWFC will issue HRW district-wise for the respective state, NWFC will issue sub-division-wise HRW for the whole county. These warnings are given for a 5-day validity period and are updated on a 6-hourly basis. The relevant MC/RWFC is solely responsible for issuing HRW. They will, however, have a conversation with the NWFC by 1030 IST in order to issue a warning based on data from the previous day's 0830 IST. The opinion of SWFC/RWFC will take precedence in the event of a disagreement. The following qualities are involved in decision-making:

Retrieving and reviewing regularly the bulletins and products that the SWFC/RWFC/AMO, satellite, radar, upper air, and synoptic divisions have planned. The forecaster should be aware of the effects of biassed or inaccurate observations. The mistake should be dismissed after it has been identified. Only when an observation is compared to observations from nearby stations can suspicion be raised about it. Additionally, it should be determined if the relevant observation complies with or does not comply with the conceptual models taken into account. The forecaster should take the required steps to get accurate data from the observatory and its subsequent notification after the inaccuracy has been determined [7].

Identify ailments at the limits. The on-call forecaster will keep an eye on forecasts and warnings sent to nearby regions. The duty officer will communicate with nearby area forecasters as well. Observing weather in the responsibility region that is getting close to the severity threshold that has been set. In order to decide whether to issue a heavy rainfall warning, a duty forecaster will confer with the RWFC, NWFC, Satellite, and RADAR Centre after they have detected any oncoming heavy rainfall event in their area of responsibility. The on-duty forecaster will speak with the senior designated officer to discuss the information before deciding whether to issue a warning for heavy rain [8].

The forecaster should use methods suitable for heavy rainfall warning. He or she has to accurately use statistical, subjective, and NWP advice. Synoptic methods backed by NWP guidance and other models, as well as observational tools/products like satellites and radars, should be employed for severe rainfall warnings that are valid for up to 24 hours. For 48- and 72-hours validity period, principally the applicable NWP models should be employed, with mesoscale WRF model advice taking priority over global NWP model guidance in this range. For this reason, it is important to confirm the appropriateness of several models for the targeted location. In the absence of this data, the model that best fits the day's beginning conditions should be used to anticipate severe rainfall [9].

The weather forecaster should start by speculating on the development and motion of the weather system for heavy precipitation. Based on the aforementioned recommendations, the duty forecaster will create the decision-making checklist. Within the general parameters of this SOP, SWFC and RWFC should create their own region-specific checklist in accordance with their own needs and the local circumstances. The forecaster should make proactive changes to the forecast as needed. When the prerequisites for a modification are met, the duty forecaster will reply promptly. The whole decision-making process must be meticulously and properly recorded [10].

CONCLUSION

The importance of community involvement and public knowledge in reacting to heavy rain forecasts is emphasised in the fifth part. Outreach and educational programmes help to increase public awareness, promote precautionary action, and promote climate resilience. The integration of heavy rain warning systems into complete disaster management plans is examined in the seventh part. This allows for proactive actions, early evacuation, and resource allocation during severe weather occurrences. The summary ends by highlighting the crucial role that warning systems for heavy rain play in reducing susceptibility to catastrophes caused by heavy rain. These services provide a vital contribution to preserving lives, safeguarding infrastructure, and creating resilient communities in the face of severe rainfall events by providing accurate and timely information.

REFERENCES:

[1] O. Piotte *et al.*, "The early warning service for heavy rainfalls and flash floods," *Houille Blanche*, 2020, doi: 10.1051/lhb/2020055.

[2] A. Jasper-Tönnies, S. Hellmers, T. Einfalt, A. Strehz, and P. Fröhle, "Ensembles of radar nowcasts and COSMO-DE-EPS for urban flood management," *Water Sci. Technol.*, 2018, doi: 10.2166/wst.2018.079.

[3] A. Seed, R. Bunn, and A. Bell, "On the use of radar rainfall estimates and nowcasts for a heavy rainfall warning service," in *Sense and sensitivity : understanding our changing weather and climate | 19th Annual National Conference of the Australian Meteorological and Oceanographic Society, Melbourne Convention and Exhibition Centre, Melbourne, Victoria, 11-13 February 2013*, 2013.

[4] E. De Coning, "Optimizing satellite-based precipitation estimation for nowcasting of rainfall and flash flood events over the South African domain," *Remote Sens.*, 2013, doi: 10.3390/rs5115702.

[5] S. Salack, I. A. Saley, N. Z. Lawson, I. Zabré, and E. K. Daku, "Scales for rating heavy rainfall events in the West African Sahel," *Weather Clim. Extrem.*, 2018, doi: 10.1016/j.wace.2018.05.004.

[6] M. Kilavi *et al.*, "Extreme rainfall and flooding over Central Kenya Including Nairobi City during the long-rains season 2018: Causes, predictability, and potential for early warning and actions," *Atmosphere (Basel).*, 2018, doi: 10.3390/atmos9120472.

[7] S. R. Bajracharya *et al.*, "Systematic evaluation of satellite-based rainfall products over the brahmaputra basin for hydrological applications," *Adv. Meteorol.*, 2015, doi: 10.1155/2015/398687.

[8] J. Estrany *et al.*, "Hydrogeomorphological analysis and modelling for a comprehensive understanding of flash-flood damage processes: The 9 October 2018 event in northeastern Mallorca," *Nat. Hazards Earth Syst. Sci.*, 2020, doi: 10.5194/nhess-20-2195-2020.

[9] M. Kitchen and A. Illingworth, "From observations to forecasts - Part 13: The UK weather radar network - Past, present and future," *Weather*, 2011, doi: 10.1002/wea.861.

[10] H. Oyas *et al.*, "Enhanced surveillance for Rift Valley Fever in livestock during El Niño rains and threat of RVF outbreak, Kenya, 2015-2016," *PLoS Negl. Trop. Dis.*, 2018, doi: 10.1371/journal.pntd.0006353.

CHAPTER 16

SOP OF HEAVY RAINFALL-IMPACT BASED FORECAST (IBF) AND RISK-BASED WARNING

Anwar Khan, Assistant Professor
Department of ISDI, ATLAS SkillTech University, Mumbai, Maharashtra, India
Email id- anwar@isdi.in

ABSTRACT:

To reduce possible effects, communities must have efficient forecasting and warning systems since heavy rainfall events provide considerable problems. An overview of the Standard Operating Procedures (SOP) for deploying Impact-Based Forecasting (IBF) and Risk-Based Warning (RBW) systems for severe rainfall events is provided in this study, showing how these systems may improve preparation and reaction efforts. This describes how more frequent heavy rainfall events are causing disastrous floods and landslides. IBF and RBW systems seek to convert conventional weather predictions into useful data that informs the public and decision-makers of the possible effects and related dangers of heavy rainfall. The IBF technique, which combines vulnerability and exposure evaluations with meteorological data to forecast possible effects on essential infrastructure, agriculture, and public safety. IBF improves situational awareness and encourages quick decision-making by connecting weather information to consequences. The idea of RBW, in which warning signals are customised to certain risk levels based on geography, susceptibility, and past weather patterns, is explored in the third section. RBW gives authorities and communities the ability to organise resources effectively, prioritise response efforts, and carry out specific evacuation plans. The incorporation of cutting-edge technology into IBF and RBW systems, including numerical weather prediction models, high-resolution radar systems, and satellite data. These innovations improve the precision, timeliness, and geographical resolution of forecasts and alerts for severe rainfall. This emphasises how meteorological organisations, disaster management organisations, and key stakeholders worked together to design and execute SOPs for IBF and RBW. A fluid information flow and a coordinated response to severe rainfall occurrences are made possible through coordination between these organisations.

KEYWORDS:

Forecast, Heavy, Rainfall, Satellite, Weather.

INTRODUCTION

The goal of a SOP on IBF, which has been in place at IMD since June 2020, is to integrate all available observed and forecast weather and climate information for heavy rainfall event forecasts using all observations (surface, upper-air, ship, buoys, aircraft, radar, and satellite) and NWP model forecasts for issuing IBF at met sub-division, district-wise, and at sub-city levels. While the alert has already been given in the forecasts for the day, continuous monitoring through hourly/sub-hourly rainfall observations, RADAR & satellite observations will serve as the basis for nowcast in real time. The frame procedures based on IBF from heavy rainfall, covering a variety of services with lead time, types of bulletins, graphics, and other things are in its SOP. The SOP provides provisions for include location and severity of the heavy rainfall appended with hourly to three hourly rainfall updates from AWS/ARG and SYNOP stations available in the city as well as QPE from the satellite/radar. It also covers forms and kinds of bulletins, forecasts, and alerts. To draw the essential attention of the disaster managers and general public, the characteristics of a weather system employing RADAR and satellite images, together with an alert or warning message, will be included. IMD SOP and IBF principles were covered in this part.

Impact-based forecasting: Shift your attention away from what the weather will be and towards what it will do. The WMO, 2015 recommendations on multi-hazard impact-based prediction and warning services are being followed by the Weather Ready Nations (WRNs) programme as it implements an impact-based forecast system. The fundamental effects of heavy rain on a region or a place are as follows:

1. Riverine and flash floods
2. Urban Flash Floods and Flash Floods over Slightly Sloped Areas
3. Debris flow and landslides
4. Localised flooding, road closures, and traffic disruption

Agriculture

1. Damage to the city's infrastructure, including homes, roads, hospitals, and the airport
2. Emergency Services are impacted, including water, phone, and electricity.
3. Social and economic effects on things like livestock, human lives, and health

The following charts demonstrate the different parts of the impact-based forecasting method.

1. Identifying Risks
2. Early Warning and Monitoring
3. Communication and Dissemination
4. Capability for responding

Phases of the development and deployment of IBF-Heavy Rainfall in IMD

According to WMO, 2015 methodology, IMD in India has been producing IBF and warnings, step by stage, for different severe weather. It encompasses thunderstorms, cyclones, heat waves, fog, and cold waves. IBF's growth stages are:

Threshold Method: Based on a meteorological threshold, a color-coded alert is delivered. It is based on WMO recommendations and is influenced by two variables: the chance of a weather occurrence and the possible severity of the danger. It has been in place at IMD since 2013 for all types of meteorological hazards that gradually worsen in the Indian area.

Qualitative combination approach: In this method, in addition to the threshold method, a generalised impact for each severe weather type is produced by agreement among the forecasters based on a subjective evaluation of probable effects corresponding to weather alert threshold. All types of weather hazards have a generalised influence.

Impact Model approach: In addition to the qualitative combination approach, this method also establishes a threshold for each severe weather hazard based on historical climatological data. After that, a climatological effect is created based on threshold for various types of hazards. Presently, diverse climatological data for various hazards and impacts are gathered, submitted to NCCR for examination, and are undergoing internal analysis.

Climate Sensitivity Method: In addition to climatological impact, real-time impact-based forecasts and risk-based warnings will be provided using real-time data on meteorological hazards, vulnerabilities, and exposure in geo reference coordinates, and a decision support system will also be set up. The analysis of meteorological data has been completed. The exposure date is being gathered, however.

IBF implementation phases

Since the 2018 monsoon season, IMD has adopted a generalised Impact-based prediction for heavy rainfall, with additional development planned for the 2020 monsoon season. As of 2018, colours are allocated based on the vulnerability of historical data, as per the prediction circular (Annex 3). The effects are decided upon after consulting with the VC in order to provide real-time impact-based warnings to the affected sub-division/district for up to five days. It has been applied across all of India after completing Stages I and II of development. To offer impact-based forecasting and reaction action, the WMO's current colour code, which is mirrored below, will be used.

Since the monsoon of 2020, data on historical impacts have been gathered and analysed for key Indian cities, and IBF for 20 large cities has also been initiated. For Real time IBF and Risk Based Matrix, exposure data is being gathered. Kolkata flood warning system is currently being developed for real-time IBF, but Chennai Flood Warning System (C-Flows) and Mumbai Flood Warning System (i-Flows, since 2020) are already in place. The format of IBF is provided in Annex IV, where heavy rainfall warnings are issued via Multi-Hazard map and tabular form for both Met sub-division wise and district wise. The effect and recommended course of action will be included in the warning table for the heavy rainfall alert. The generalised impact is categorised, and proposed solutions are shown below that have been put into practise at the subdivision and district levels. Since July 2019, IMD has been using an impact-based warning system that suggests actions (by district and sub-division) in the event of heavy rains [1].

DISCUSSION

Particularly in the metropolitan parts of the aforementioned region, there has been localised flooding of roadways, water logging in low-lying areas, and closure of underpasses. Periodic diminution in vision brought on by heavy rain. Traffic jams caused by water logging on roadways in major cities can lengthen travel times. Minor kutcha road damage. The potential for harm to a weak building. Localised Landslides (for hilly and sensitive locations) and Mudslides (for plain areas). Flooding-related damage to horticulture and standing crops in several regions. In certain river catchments, it might cause riverine flooding (for further information on riverine floods, please consult the CWC website).

Suggestion of Action

1. Before starting to go to your destination, check for traffic congestion along your route.
2. Observe any traffic warnings that may have been given in this respect.
3. Go away from locations that often have water logging issues. Stay away from weak structures.

IBF Standard Operating Procedure and Risk-based Heavy Rainfall Warning

While Concern Duty officers of MC/Head of MC/RWFC forecasting offices will be releasing final impact-based forecasts for all heavy rainfall occurrences over the key cities and districts within their respective areas, NWFC will release IBF for met subdivision-wise.

Stages of an IBF-based rainstorm warning

Stage 1: Heavy rain advisory (watch) with a 3- to 4-day lead time and 12-hour updates

Worldwide, it is still difficult to predict heavy rainfall (intensity, location, day/time of occurrence, beginning, duration, and cessation). However, if a city is connected to certain clearly defined monsoon systems, NWP models may provide signals and probabilities over it 2–5 days in advance. In the latter scenario, a preliminary notice about the likelihood of severe rainfall may be released and periodically updated (format incorporated as Annex V). It may primarily be distributed to the city's catastrophe management.

Stage 2: Heavy rain warning (48 hours before the event, with 12-hourly updates)

Model agreement often arises when the event lead time is between one and three days. As a result, color-coded communications in tabular form with Impact categories (format included as Annex Ib) may be sent out at this early stage together with the event's expected length and rainfall quantities. Guidance for probability-based forecasts should be offered while taking their possibility of occurring into account. Using colour matrices, risk should be determined based on possible effect. The Expected Impact may be included as per Annex VI and this prediction must be distributed through emails, websites, social media, WhatsApp, etc [2].

Stage 3: Warning of heavy rain (24 hours before to the event at 06:12; hourly updates)

At stage 3, every diagnostic and prognostic characteristic from the RADAR, satellite, NWP, and convective products that are currently accessible must be assessed. After thorough investigation, the bulletin may be further adjusted to include IBF and a brief color-coded warning can be sent by detailing all the event's characteristics and its potential effects across the city or a portion of the city. This bulletin must be sent to all user communities, including local media, utilising a website, emails, different social media platforms, WhatsApp, etc. Annex vii contains the bulletin's structure.

Stage 4: Twelve hours before the biggest rainfall period is expected to begin

By this time, the likelihood of a severe downpour may be closely monitored using RADAR, satellite, hourly/half-hourly current weather data, ARG/Synop, and GFS/WRF/NOWCAST models. Every hour or three hours, the warnings and all of their characteristics should be refreshed. It is the last and most important step of the IMD warning system, and the relevant MC/RWFC must use all reasonable efforts to ensure that its monitoring, forecasting, and warning are reasonable accurate and timely. Telephone talks, SMS messages, and WhatsApp messages, among other methods, should be used to periodically coordinate with the relevant disaster management and the media. To carry out such work efficiently, starting from the event's beginning as recorded by RADAR/Satellite, a full diagnostic and prognostic aspects of the event, coupled with related cloud characteristics and rainfall distribution as accessible from RADAR, Satellite and surface data, e.g. The duty forecasters must have access to AWS, ARG, and SYNOP. In Annex VIII, the structure for the stage 4-specific advisory is described. It is an impact-based warning with a color-coded system for various areas of the city. All user communities, including local media, must be informed of this bulletin utilising web pages, emails, different social media platforms, WhatsApp, etc.

The SOP IBF and Risk-based Warnings for City, District, and Met Sub-Division contains rules for anticipating resolutions in both space and time. MC/RMCs should first offer impact-based forecasting and warning at the meteorological city level; thereafter, the effect region will be delineated with a distinct colour without being limited to city borders. At the MC/RMC level, the impact-based forecast will first be given at the district level (inside the city); thereafter, the area of effect will be specifically indicated as and when the forecaster will have access to the decision support system. Similar to current severe weather warnings, such as, an impact-based prediction will be given for the following five days. D1, D2, D3, D4 & D5. Impacts Based Forecasts for the city will be produced during the nowcast/very short range forecast period thanks to the availability of sophisticated algorithms for severe weather prediction [3].

IBF decision-making and warning

The decision on the anticipated effect will be made by daily analysis of the frequency and severity of weather events. The choice on the effect (very low, low, medium, or large) at the sub-divisional level will be made by video conferencing. Accordingly, a pre-defined table will be used to indicate the projected effect for a certain severe weather event. Additionally, the proposed response action will be chosen in accordance with the response action listed in the response table with regard to the anticipated type of effect. MC/RMC shall decide for their respective areas of responsibility about the district level effect & response forecast taking into account all the aforementioned elements. Since it takes a high skill score to provide a Red colour in the IBF matrix and heavy rainfall forecasts at 3-5 days in advance over a location, Red colour IBF warnings cannot be issued for lead times longer than 48 hours. However, yellow and orange colours can be issued for lead times longer than 48 hours.

For example, if there is an unusually severe downpour on Day 5, offer yellow on Days 4 and 5, orange on Days 3, and red on Days 2 and 1. Even when we sometimes have a good sense of what would happen on day 5 even on the first day, we won't get a red colour warning beyond three days. Bulletin upload: Impact-based forecasts are typically posted twice daily in MC/RMC and four times daily in NWFC. However, the alert may be modified right away if severe weather conditions return, stop, or if a false alarm occurs. For all forecasts provided on Day 1, the prediction will be valid till 0830 IST on Day 2 [4].

Over Mumbai and Chennai, a real-time customized heavy rainfall monitoring and IBF system is operating. In order to provide location-specific, sub-city-based severe weather warnings for major cities, IMD has taken up the Urban Meteorological Services project as one of its top priorities. These alerts also include impact-based warnings for regional heavy rainfall events that result in flash floods. The IMD's current urban meeting services are available in the majority of Indian cities. It fits within the category of:

1. Routine 6-hour local forecast updates, which include temperature and rainfall readings, are published at the sub-city level.
2. Sub-city level for at least three hours per anticipated severe weather development.
3. Impact-Based Forecast for Forecast of Heavy Rain in City.

A 5-year plan has already been implemented for 2019–2024 to improve both the monitoring systems with installation of denser network of ARG/AWS at various cities as well as other contemporary monitoring facilities covering DWR, Radiometers, wind profilers, etc. Work is ongoing through collaboration with its other MoES institutions like IITM, NCMRWF, NCCR, INCOIS and with local administrators as well as the installation of the ARG/AWS and other modern monitoring facilities [5].

C-FLOWS, or the Chennai Flood Warning System

1. A multi-institutional initiative including IRS-Anna University, IIT-Bombay, IIT-Madras, NCCR, and MOES (IMD, INCOIS, NCCR, and NCMRWF).
2. A tool for relief and mitigation efforts, particularly in times of floods
3. A coastal flooding decision support system for metropolitan areas during disaster preparation
4. C-FLOWS: the nation's first operational system for preventing urban floods

I-FLOWS, the Integrated Mumbai Flood Warning System

In India, extreme precipitation occurrences are increasing as a result of higher temperatures and changing monsoon patterns brought on by global warming. A recent storm on August 29, 2017, paralysed Mumbai, the state of Maharashtra's metropolis and the financial centre of India. Mumbai has been suffering floods with increasing regularity. Every Mumbai resident certainly remembers the flood on July 26, 2005, when the city saw 94 cm of rain in a 24-hour period, a 100-year high, severely paralysing the city. People should be alerted in order to prepare for floods before they happen so they can take the necessary precautions. The Municipal Corporation of Greater Mumbai and the Maharashtra government petitioned the Ministry of Earth Sciences (MoES) to create IFLOWS-Mumbai, an integrated flood warning system for the flood-prone metropolis of Mumbai. Utilising in-house expertise from the Ministry of Earth Sciences and working closely with the Municipal Corporation of Greater Mumbai, MoES began developing IFLOWS-Mumbai in July 2019. In order to increase Mumbai's resilience, a state-of-the-art integrated flood warning system called IFLOWS-Mumbai was created. It provides early warning for floods, especially during periods of heavy rainfall and storms [6].

I-FLOWS is made up of seven modules: Data Assimilation, Flood, Inundation, Vulnerability, Risk, Dissemination Module, and Decision Support System. It is designed on a modular framework. The system uses weather models from the Indian Meteorological Department (IMD), National Centre for Medium Range Weather Forecasting (NCMRWF), Indian Institute of Tropical Meteorology (IITM), Municipal Corporation of Greater Mumbai (MCGM), and IMD, as well as thematic layers on land use, infrastructure, and other topics provided by MCGM. Hydrologic models are used to convert rainfall into runoff and offer inflow inputs into the river systems based on information from meteorological model inputs. To analyse floods in the research region, hydraulic models that simulate water flow are utilised to solve fluid motion equations. Hydrodynamic models and storm surge models are used to estimate the effects of tide and storm surge on Mumbai since it is an island city with access to the sea [7]. The system contains features that will be implemented into the final system to record urban drainage inside the city and identify regions that may flood. The data on river bathymetry was gathered by NCCR in collaboration with MCGM and IMD, Mumbai, in all rivers, including the Mithi, Dahisar, Oshiwara, Poisar, Ulhas, lakes, and creeks. Thematic layers in GIS were used to properly forecast flood levels at the ward level utilising the land topography, land use, infrastructure, population, etc. that were given by MCGM. To determine the susceptibility and risk of items exposed to flooding, a web-based GIS-based decision support system is developed.

Forecast from FFGS for impact-Flood flooding due to heavy rainfall

The United States and the World Meteorological Organisation (WMO) are partners. International Development/Office of the U.S. The United States National Weather Service (NWS), the Office of Foreign Disaster Assistance (USAID/OFDA), and U.S. The Global Flash Flood Guidance System project was launched by the Hydrologic Research Centre (HRC) and the National Oceanic and Atmospheric Administration (NOAA) to provide services for hydrometeorological events that occur quickly. One of the Impact Based Forecast and Warning Service (IBFWS) tools is the Global Flash Flood Guidance System (FFGS).

By bridging the gaps between the four elements for efficient early warning systems: "risk knowledge," "monitoring and warning service," "dissemination and communication," and "response capability," the use of this tool in IBFWS has the potential to improve the synergy between NMHSs, NDMAs, and citizens who play a role in hazard mitigation (for example, flash floods). The WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services (2015, WMO-No 1150) and the Multi-hazard Early Warning Systems: A Checklist (2018) both place a high importance on the use of such a comprehensive methodology. The Sendai Framework for Disaster Risk Reduction 2015– 2030 is supported by these (United Nations, 2015). The purpose of the FFGS is to offer a diagnostic value that calculates the amount of rainfall during a certain time period needed in a watershed to cause flooding at the catchment's outflow.

The FFGS is designed to "remember" rainfall that has previously fallen in the catchment and to update its values throughout time and location. The amount of extra rainfall required to cause flooding may then be calculated using the antecedent catchment conditions taken into consideration by the FFGS. These values provide a factual foundation for producing flash flood alerts whether utilised in real time with nowcasts or in a forecasting capacity. 40% of the world's population, or 3 billion individuals, are covered by the FFGS globally. Around 25 million square kilometres, or 18% of the world's total land surface area, is covered by the nations that use the FFGS collectively. The South Asia Flash Flood Guidance System (SAsiaFFGS) in particular covers about 51% of the global population [8].

SAsiaFFGS is now operating experimentally and providing services to India, Nepal, Bhutan, Sri Lanka, and Bangladesh in 2019. It is operational via two servers (Computational & Dissemination) located in the India Meteorological Department (IMD), India, as SAsiaFFGS' Regional Centre. Since August 2020, real-time operation mode has been adopted in IMD after cases have been verified and validated on various temporal and geographical scales. Outputs are sent to CWC and MCS/NWFC for enhancing IBF and warnings.

Key characteristics of South AsiaFFGS operating in IMD

1. The FFGS is a reliable system that supports flash flood warnings.
2. Makes use of hydrological models and radar and satellite data on precipitation.
3. Bangladesh, Bhutan, India, Nepal, and Sri Lanka are all supported by IMD.
4. Provides recommendations for flash floods for about 30000 watersheds that are defined by a 30m DEM and other terrain factors [9].

5. System is presently in pre-operational state.
6. The Central Water Commission receives briefings from IMD four times each day at 0530, 1130, 1730, and 2330 IST.

The transmission of heavy rainfall forecasts and warnings

1. Weekly YouTube and social media video
2. Press release State, national, and regional levels
3. National, Regional, State, District, and City WhatsApp Groups for Rapid Outreach
4. Briefing/communication through phone/video conference with disaster management at the federal, state, and local levels.
5. CWC, NHAI, Aviation, Indian Railways, municipal corporation, agriculture officials, farmers, and fishermen are among the sectoral users that should be alerted.
6. (mausam.imd.gov.in) Public Website
7. IMD Apps such as Mausam, DAMINI, and RAIN ALARM
8. Social Media: BLOG, Facebook, Twitter, and Instagram
9. Global Multi-hazard Alert System (GMAS), Common Alert Protocol [10].

CONCLUSION

The necessity of public knowledge and community involvement in the effective implementation of IBF and RBW is emphasized in the fifth part. Proactive actions are encouraged and weather resilience is fostered via effective communication tactics, public education campaigns, and community involvement. The difficulties and restrictions associated with IBF and RBW, such as data shortages, forecast uncertainty, and resource limits, are discussed in the seventh section. To properly address these issues, ongoing research, capacity development, and investment in meteorological infrastructure are necessary. The potential of IBF and RBW to improve heavy rainfall forecasting and warning systems is highlighted in the study conclusion. These systems enable communities to make educated choices, decrease sensitivity to the effects of heavy rainfall, and increase climate resilience in the face of changing weather patterns by providing impact- and risk-based information.

REFERENCES:

[1] P. Fadzline Tamyez, N. Christiane Isabella Gerth, and K. Firdaus bin Anuar, "Flood-Related Disaster Communication and Humanitarian Logistics," *KnE Soc. Sci.*, 2019, doi: 10.18502/kss.v3i22.5042.

[2] C. Flamant *et al.*, "The radiative impact of desert dust on orographic rain in the Cévennes-Vivarais area: A case study from HyMeX," *Atmos. Chem. Phys.*, 2015, doi: 10.5194/acp-15-12231-2015.

[3] N. Fourrié *et al.*, "AROME-WMED, a real-time mesoscale model designed for the HyMeX special observation periods," *Geosci. Model Dev.*, 2015, doi: 10.5194/gmd-8-1919-2015.

[4] E. Adirosi *et al.*, "Comparison of different fittings of drop spectra for rainfall retrievals," *Adv. Water Resour.*, 2015, doi: 10.1016/j.advwatres.2015.05.009.

[5] J. Rakovec, M. Dolinar, M. Demšar, and S. Micheletti, "Spatial interpolation of hourly gauge and radar precipitation during MAP SOP," *Hrvat. Meteoroloski Cas.*, 2005.

[6] O. Bousquet *et al.*, “Multifrequency radar observations collected in southern France during HyMeX-SOP1,” *Bull. Am. Meteorol. Soc.*, 2015, doi: 10.1175/BAMS-D-13-00076.1.

[7] D. H. Lee, M. Kim, and D. S. Rhee, “Evacuation safety evaluation of inundated stairs using 3D numerical simulation,” *Int. J. Smart Home*, 2016, doi: 10.14257/ijsh.2016.10.3.15.

[8] C. Flamant *et al.*, “The radiative impact of desert dust on orographic rain in the Cevennes-Vivarais area: A case study from HyMeX,” *Atmos. Chem. Phys. Discuss.*, 2015, doi: 10.5194/acpd-15-22451-2015.

[9] A. U. Bhatti, “Potash need assessment and use experience in khyber Pakhtunkhwa (KP),” *Soil and Environment*. 2011.

[10] N. Nisa, “Standar Operasional Prosedur (SOP) Teknik Pernapasan Buteyko,” *Sustain.*, 2019.

CHAPTER 17

OVERVIEW OF THUNDERSTORM WARNING SERVICES

Agnijit Tarafdar, Assistant Professor
Department of ISDI, ATLAS SkillTech University, Mumbai, Maharashtra, India
Email id- agnijit.tarafdar@atlasuniversity.edu.in

ABSTRACT:

Thunderstorm warning systems are essential for minimising property damage, protecting lives, and giving early and accurate information about thunderstorms. An overview of thunderstorm warning systems is provided in this study, along with a conversation of their importance for risk reduction, disaster preparation, and public safety. To address the risks presented by severe thunderstorms, such as lightning, torrential rain, powerful winds, and hail, the first part discusses the significance of thunderstorm warning systems. These are essential services for warning the public and the appropriate authorities of imminent weather risks. The strategies used to identify and forecast thunderstorms are covered in the second part. The precise observation and forecasting of thunderstorms benefit from the use of cutting-edge weather radar systems, satellite data, lightning detection networks, and numerical weather prediction models. The third part looks at the distribution and communication methods that are used to inform the public about thunderstorm warnings. Critical weather information is sent to the intended receivers quickly and clearly by using a variety of channels, including mobile applications, websites, social media, and emergency alerts. This discusses how impact-based forecasting is included into thunderstorm warning systems. Impact-based alerts help people be more aware of their surroundings and better prepare for storms by providing information about their possible effects, such as flash floods, property damage, and power outages.

KEYWORDS:

Colour, Forecast, Radar, Thunderstorm, Weather.

INTRODUCTION

There is significant geographic and temporal variety in the occurrence of thunderstorms (TS), as well as diurnal, seasonal, and yearly variations. Thunderstorms may be seen over the Indian subcontinent at all times of the year and in all seasons. It occurs in various regions at different rates. Monsoon, post-monsoon, and winter thunderstorm activity is mostly controlled by large-scale synoptic weather systems, with minor variations brought on by local topography impacts. However, across the length and width of the nation, the pre-monsoon season (March to May) often sees the greatest frequency and the most violent thunderstorm storms. Numerous deaths in India are caused by storm-related phenomena including hail, squalls, and lightning strikes. The related squally winds cause annual damages of crores of rupees to Kachcha homes, thatched huts, asbestos houses, telephone and electric poles, and other buildings. Along with the standing crops that are badly harmed, it also impacts the transportation industry, including the highway, railroad, and aircraft, causing human and financial losses. India's thunderstorm climatology is divided into six main categories:

1. Northeast India (Nagaland, Manipur, Mizoram, and Tripura, as well as Assam and Meghalaya, Arunachal Pradesh)

2. East India (Andaman & Nicobar Islands, Gangetic West Bengal, Bihar, Jharkhand, Sub-Himalayan West Bengal & Sikkim, and West Bengal along the Ganges)
3. India's Northwest (Punjab, Uttarakhand, Himachal Pradesh, Jammu & Kashmir, East Rajasthan, West Rajasthan, East-Uttar Pradesh, West Uttar Pradesh, Haryana, Chandigarh & Delhi)
4. West India (Madhya Maharashtra, Gujarat Region, Saurashtra, Kutch & Diu, Konkan & Goa, and Marathwada)
5. East Madhya Pradesh, West Madhya Pradesh, Chhattisgarh, and Vidarbha are located in central India.
6. Costal Karnataka, Tamil Nadu, Kerala, Lakshadweep, North Interior Karnataka, South Interior Karnataka, and Telangana

During the pre-monsoon season, East and Northeast India often see the most intense and frequent thunderstorm activity, followed by southwest Peninsular India. Over Northwest India, the thunderstorm connected to the dust storm is most common [1]. Monitoring, forecast, and warning of thunderstorms are carried out by several offices of the India Meteorological Department (IMD) due to the significant impact of thunderstorms and their effects on social, cultural, commercial, health, defence and transportation, among other things. In 2012, a Standard Operating Procedure (SOP) was first released to offer standard monitoring, forecasting, and warning services for the aforementioned weather event. Thunderstorm warnings and their transmission have experienced fast modifications in recent years as a result of increased monitoring and improvements in forecasting systems. The classification of thunderstorms and the standards for issuing thunderstorm warnings have also been updated. Thus, it is deemed that the current SOP has to be updated. The methods for monitoring, forecasting, and warning distribution must be followed at various levels of forecasting offices at IMD are comprehensively described in this new SOP document.

Criteria for thunderstorms and related warnings

Colour codes for warnings about thunderstorms

1. There is no thunderstorm (green colour)
2. A light thunderstorm is one with a maximum surface wind speed of less than 40 kmph (in gusts). (Colour: yellow)
3. Moderate Thunderstorm: Squalls and thunderstorms with maximum surface winds of 41–61 kmph. (The colour orange)
4. Severe Thunderstorms: Squalls or thunderstorms with maximum surface winds of 62–87 kmph. (Colour red)
5. Very Severe Thunderstorms: Thunderstorms with a maximum surface wind speed of more than 87 kmph (in gusts/squall) that may or may not include rain. (Colour red)
6. Thunderstorms with Hail: Thunderstorm with hail (no gust requirement); red colour

Dust storm alert

1. Light duststorms: When the wind speed (in gusts) is between 20 and 40 kmph and visibility is between 500 and 1,000 metres. (Colour: yellow)
2. Moderate dust storms: When the visibility is between 200 and 500 metres and the wind speed (in gusts) is between 41 and 61 kmph. (The colour orange)

3. Severe duststorms: If the visibility is between 50 and 200 metres and the surface wind speed (in gusts) is between 62 and 87 kmph. (Colour red)
4. Severe dust storms: If visibility is less than 50 metres and the surface wind speed (in gusts) reaches 87 kmph. (Colour red)

A lightning alert

1. Low Lightning Probability (Yellow colour; 30% Chance of Lightning Occurring)
2. Moderate Lightning likelihood (30–60% chance of seeing lightning) (Orange colouring)
3. High Lightning Probability (> 60% Lightning Occurrence Probability) (Colour red)

Precursors to favourable thunderstorm conditions

The essential requirements for a thunderstorm are as follows:

1. Significant surface heating.
2. Minimal moisture
3. Conditional atmospheric instability and
4. Triggering device

The forecaster will check that the items arrived at the appointed time. In the event of non-reception, the forecaster will take the necessary measures to ensure timely receipt by notifying the authorised authorities in charge of the relevant offices through email, phone, or WhatsApp. The forecaster will notify the appropriate SWFC/RWFC/ISSD and NWFC and take the necessary steps to address the issue. The relevant SWFC / RWFC will utilise forecasts for a specific area or sub-division given at NWFC as guideline to issue thunderstorm warning as and when necessary. Since SWFC/RWFC are ultimately responsible, they are able to issue warnings even in the absence of any direction from NWFC. However, the SWFC or video conferencing shall notify the NWFC and concerned RWFC with a copy of the warning notice.

DISCUSSION

A suitable computer platform for real-time data visualisation, data overlay, contour drawing, and information extraction from many databases. State/district level advice using results of finer resolution Meso-scale models. The forecaster will be knowledgeable about technological systems, have a backup plan in case the system fails, and take the right action.

Institutions and their obligations

Since TS is mesoscale in nature, the whole observation, prediction, and distribution to the end users process should occur extremely quickly. The following IMD divisions are in charge of issuing the proper thunderstorm and dust storm predictions and alerts on different levels. The State Weather Forecasting Centre (SWFC), Regional Weather Forecasting Centre (RWFC), and Airport Meteorological Offices (AMOs) are ultimately in charge of observing and issuing thunderstorm warnings. Only the states for which RWFC produces predictions as SWFC will get thunderstorm warnings from RWFC; for example, RWFC Kolkata will be in charge of issuing warnings for West Bengal [2]. The SWFC/RWFC will be in charge of keeping an eye on and distributing information and warnings about thunderstorms. In the event of a system failure at any SWFC, the relevant RWFC will assume control until the system is restored.

1. Information will be sent in both directions between the SWFC/RWFC and the NWFC, AMO, RWFC, Mega City forecast centre (SWFCFC), Nowcast cell, and Defence Meteorological Office.
2. The information exchanged between SWFC/RWFC and AMO on the thunderstorm warning issued by AMO will not result in any weakening of the charter or mandate pertaining to AMO.
3. Through the Public Weather Service (PWS) of IMD, a thunderstorm warning system will be connected to media websites (TV, newspapers, etc.), private/industry organisations, etc.

Division NWP

This group will provide the forecasting centre with the required inputs in the form of graphs, dynamic/thermodynamic product graphs, meteograms based on model projections at the regional scale, and 12km/3km/1Km across a specific region, area, division, or city. The NWP officer-in-charge/duty officer is required to notify the status of the NWFC, RWFC, and SWFC at intervals of six to twelve hours after the model's rerun outputs [3].

NWFC

The NWFC will provide RWFC/SWFC information regarding the likelihood of thunderstorms occurring 120, 96, 72, 48, and 24 hours in advance for a specified area (or part of a meteorological subdivision) and will modify, update, and evaluate the report frequently every six hours. The projected event's degree of confidence (such as most likely, very likely, probable, and unlikely) and the colour codes indicating potential repercussions should also be included in the report. To ensure a prompt TS warning, the NWFC duty officer will keep a constant watch and work with SWFC and RWFC [4].

Sat Met Application Cell

It will evaluate and analyse thunderstorm activity over a certain region. A proper 24-hour watch must be maintained; it will report findings and thunderstorm developments and alert NWFC/RWFC/SWFC through organised bulletins sent by phone, email, fax, SMS, Whatsapp, etc.

Radar Application

The Mesoscale Convective Complexes and other significant elements necessary to the production of thunderstorms across their area will be observed by the DWR stations as they grow and migrate. It will periodically update NWFC/RWFC/SWFC via structured bulletins sent through phone, email, fax, SMS, Whatsapp, etc. It will provide real-time updates for DWR items every ten minutes.

RWFCs/SWFCs

The RWFCs/SWFCs are crucial for monitoring, predicting, and issuing storm warnings. Based on collective observations of current events and previous occurrences, it will determine the size, intensity, timing, and projected effect of thunderstorm events. They must all have local storm climatologies and local forecasting guidelines established for their specific regions/areas and maintained on hand; these papers must be routinely reviewed and updated. Every year, the documents must be subjected to pre-season training). The monitoring method for the dissemination of warning products, actual occurrences, and feedback from the Field offices will be carried out by RWFCs and SWFCs. Daily verification of the alerts will take place, and a monthly summary report will be created.

Field offices, including observatories and meteorological offices

In order to gather accurate information on the weather event for a post-validation of the warning reports, the field offices will have a solid relationship with the other local government departments and institutions. Using the current telecommunications infrastructure, they will report real-time observations to SWFC continuously. Additionally, they will distinguish the thunderstorm warning for additional regions (districts) by WhatsApp group, phone, email, and media outlets in real time. Additionally, they will confirm and provide to NWFC the alerts given for their area [5].

Tracking and predicting

Monitoring

Because such weather phenomena have a limited lifetime, the key of a thunderstorm warning is the accurate and rapid processing of all the inputs in real time. The SWFC / RWFC forecaster is in charge of identifying and monitoring in the main. But in addition, the following offices will contribute to the forecasting office:

1. Observatories
2. Field office for radar
3. Satellite Department
4. Met office at the airport

In the monsoon season, FMO

Division of NWP

Any upcoming weather activity over a certain region will be detected by them, and they will alert the RWFC/SWFC. The RWFC/SWFC forecaster must also maintain proactive communication with all organisations supplying input. The following stages are involved in monitoring for nowcasting.

1. Regularly retrieving and studying bulletins and other products released by SWFC, RWFC, AMO, FMO, NWP, NWFC, etc.
2. Regularly retrieving and reviewing all remotely sensed data (such as that from satellites, radar, and lightning, for example).
3. Upkeep of a constant watch.

Analysis and forecasting

Different agencies and with varying lead periods offer thunderstorm advisories, warnings, and advise related to the weather. The nowcasting section (NWFC at IMD, HQ) provides nowcast advice for 48 and 24 hours.

For the next five days, the NWFC, RWFC, and SWFC publish thunderstorm predictions and warnings. Radar forecasts and warnings: When a convective cell forms within the radar range or approaches the radar range from the outside, a thunderstorm warning is issued. This warning is in effect for the duration of the thunderstorm. When a thunderstorm is expected to impact a certain airport, AMOs will issue a thunderstorm warning.

If there is not enough time to prepare, the relevant offices must release the Thunderstorm Outlook and Thunderstorm Forecast Bulletins in succession, and RWFC, SWFC, and AMOs must issue the Thunderstorm Warning Bulletin in accordance. Timeline for analysis, forecasting, and distribution, per Appendix-1.

Most meso-scale weather phenomena with short geographical and temporal scale are subject to thunderstorm warning. Therefore, the lead time and frequency of the thunderstorm warning will be crucial to its execution. The monitoring, analysis, detection, and decision-making phases of meso-scale processes will need to be coordinated in order to effectively accomplish the goal of thunderstorm warning [6].

NWFC will provide sub-divisional level advice with updates every four hours at time scales of 24, 48, 72, 96, and 120 hours.All forecasts and warnings will be given at the time scale in the short to medium range and up to three hours in the nowcast range of twelve, twenty-four, eighty-six, seventy-two, ninety-two, and one hundred and twenty hours in the short to medium range and up to three hours in the nowcast range. Below is a timeline for this purpose.

Prediction and warning tools

The components of the thunderstorm warning product are:

1. Text products
2. Visual Products
3. Impact-based Forecasts
4. Recommendations

Impending weather events will be shown on district/station level maps and in bulletins along with the appropriate weather symbols, animation, etc. Based on observations and communications received, the on-duty forecaster will send out a summary message every forecast hour. The duty forecaster will provide a short description of the severe system's features as well as any appropriate warnings in the event that severe weather is anticipated to develop in the area of forecast for the SWFC/RWFC based on the different inputs. The forecast will be released four times each day, based on general weather forecasts from the NWFC, RWFC/SWFC twice, and AMOs when needed.

Dissemination of Forecasts and Warnings

The NWFC will publish the Thunderstorm Outlook, which is good for days 1 (24 hours) and 2 (24-48 hours), twice daily, and the Thunderstorm Forecast Bulletins, which are good for days 3 through 5, four times daily. It should include information on the event's likely effects at the subdivision and sub-subdivision level. It will be sending the bulletin to all RWFCs, SWFCs, and PWS by fax, email, telephone network, SMS, and other means. The RWFC and SWFC will begin an extensive watch over that area for that day in order to determine the prospective area for the potential occurrence of TS [7].

The State Disaster Management Authority cells and relief commissioners, the District Disaster Management Authority, AIR, and DOORDARSHAN must all receive the High Impact Thunderstorm Warning message. Appendix 1 lists the categories for high impact thunderstorm occurrences. At the national level, as soon as NWFC learns of severe weather occurrences that are expected to inflict extensive damage in a specific area, NWFC will alert the relevant authorities.

In accordance with Appendix 2-5, high impact thunderstorm (thunderstorm accompanied with severe squall) warning bulletins shall also be sent to the general public through SMS and WhatsApp text messaging. The RWFC/SWFC Thunderstorm Warning advisory must likewise be made accessible to the NWFC. When a thunderstorm warning is issued, higher officials of IMD must be notified by NWFC in order to take any further necessary action [8].

Post-Event Analysis, Recommendations, and Documentation

The RWFC would choose whether to do a post analysis based on how severe the thunderstorm occurrence was. The most thorough recording possible, including field survey, must be made of the high impact severe thunderstorm occurrences (resulting in tornado production, down bursts, hailstorms, etc.) inflicting most of the destruction to life and property. Within a short period of time, a survey/inspection team formed by RWFC in conjunction with SWFC will be sent to the affected region to gather firsthand information about the incident. Appendix 6 contains the instructions for the surveying/inspection crew.

Within 24 hours following the occurrence, the NWFC must receive a concise report/documentation of the severe thunderstorm that includes the weather system, thunderstorm occurrence, forecast/warning issued and verification, to whom issued, and time of issuance. Within 7 days, a thorough report is due [9].

Warm-up exercises

Each and every RWFC, SWFC, and NWFC should have. Predictions for the whole season. Checklists that must be kept available on the forecaster's desk for both qualitative (synoptically) and quantitative (a variety of dynamic/thermodynamic factors) forecasting of important occurrences. an appropriate training (Refresher) plan for forecasters should be used at least once a year for monitoring and predicting thunderstorms at regular intervals. Hold a lecture series at the start of each season for forecasts' benefit. Hold conferences with key players, such as the media and disaster management.

In order to apply the thunderstorm SOP successfully, The availability of suitable and sufficient trained personnel at NWFC, RWFC, SWFC, and AMOs. IT infrastructure and efficient communication between multiple agencies for data, information, and alerts receiving and distribution. At forecasting centres, there is continuous evaluation/verification, which results in updates to the method and warning products [10].

CONCLUSION

The necessity of public education and community involvement in thunderstorm warning systems is emphasised in the fifth part. Individuals are given the tools they need to be proactive and react effectively during thunderstorm occurrences via educational campaigns, outreach programmes, and safety recommendations. It emphasizes how meteorological agencies, disaster management organisations, and key stakeholders worked together to design and deploy thunderstorm warning systems. These organisations work together to guarantee a coordinated and successful response to severe thunderstorms. The difficulties that thunderstorm warning systems confront, including inaccurate forecasts, erroneous warnings, and reaching sensitive populations. To increase the precision and effectiveness of thunderstorm warnings, ongoing study, technical developments, and public input are necessary. The summary ends by highlighting the crucial role thunderstorm warning systems play in boosting public safety and resilience. These services make a big difference in reducing the effects of severe thunderstorms and encouraging community weather preparedness by giving out fast, reliable information.

REFERENCES:

[1] A. M. Hering, S. Sénési, P. Ambrosetti, and I. Bernard-bouissières, "Nowcasting Thunderstorms in complex cases using radar data," *World Weather Res. Program. Symp. Nowcasting Very Short Range Forecast.*, 2005.

[2] P. Joe *et al.*, "Automated Processing of Doppler Radar Data for Severe Weather Warnings," in *Doppler Radar Observations - Weather Radar, Wind Profiler, Ionospheric Radar, and Other Advanced Applications*, 2012. doi: 10.5772/39058.

[3] J. H. Sorensen, "Hazard Warning Systems: Review of 20 Years of Progress," *Nat. Hazards Rev.*, 2000, doi: 10.1061/(asce)1527-6988(2000)1:2(119).

[4] W. M. DeBusk, "Unmanned aerial vehicle systems for disaster relief: Tornado alley," in *AIAA Infotech at Aerospace 2010*, 2010. doi: 10.2514/6.2010-3506.

[5] P. W. Li, W. K. Wong, P. Cheung, and H. Y. Yeung, "An overview of nowcasting development, applications, and services in the hong kong observatory," *J. Meteorol. Res.*, 2014, doi: 10.1007/s13351-014-4048-9.

[6] E. De Coning, "Satellite applications for very short-range weather forecasting systems in Southern African developing countries," in *Recent Advances in Satellite Research and Development*, 2013.

[7] A. Calvel *et al.*, "Communication Structures and Decision Making Cues and Criteria to Support Effective Drought Warning in Central Malawi," *Front. Clim.*, 2020, doi: 10.3389/fclim.2020.578327.

[8] M. Mohapatra and M. Sharma, "Cyclone warning services in India during recent years: A review," *Mausam*. 2019. doi: 10.54302/mausam.v70i4.204.

[9] V. Thiemig, A. de Roo, and H. Gadain, "Current status on flood forecasting and early warning in Africa," *International Journal of River Basin Management*. 2011. doi: 10.1080/15715124.2011.555082.

[10] A. L. Taylor, T. Kox, and D. Johnston, "Communicating high impact weather: Improving warnings and decision making processes," *International Journal of Disaster Risk Reduction*. 2018. doi: 10.1016/j.ijdrr.2018.04.002.

CHAPTER 18

HEAT AND COLD WAVE MONITORING & WARNING SERVICES

Jayashree Balasubramanian, Assistant Professor
Department of ISME, ATLAS SkillTech University, Mumbai, Maharashtra, India
Email id- jayashree.balasubramanian@atlasuniversity.edu.in

ABSTRACT:

The monitoring and warning systems for heat and cold waves are crucial parts of the meteorological infrastructure because they provide crucial information to safeguard public health and safety during severe temperature occurrences. This study provides a summary of the importance of heatwave and cold wave monitoring and warning systems, highlighting their role in disaster preparation, health protection, and climate resilience. In the context of climate change, the first part explains the rising significance of heat and cold wave monitoring and warning systems. These services are essential in reducing the negative effects that severe temperature events have on infrastructure, agriculture, and human health when they happen increasingly often and intensely. The methods used to monitor heatwaves and cold waves are covered in the second part. Accurate and timely monitoring of severe temperature occurrences is made possible by cutting-edge weather monitoring systems, satellite data, ground-based observations, and climate indicators. The communication and distribution tactics used to inform the public and the appropriate authorities of heat and cold wave warnings. The effectiveness of preparation and response operations is improved through timely notifications, public advisories, and educational initiatives. The use of impact-based forecasting in heat and cold wave warning systems is covered in the fourth part. Making the people aware of possible health hazards, energy demand, and agricultural effects enhances preparation.

KEYWORDS:

Cold Wave, Forecast, Heat, Thunderstorm, Weather.

INTRODUCTION

Heat waves, which are defined as extended periods of high temperatures and high humidity, are well-known to be serious meteorological hazards. The combined effects of the air's humidity and temperature have a considerable impact on how uncomfortable it is to be outside during a hot spell. The life, health, and well-being of human civilization may be negatively impacted by an unnatural heat that develops as a consequence of a temperature rise. The ambient temperature that triggers heat-related health problems varies substantially depending on where you are. However, in general, cases of heat-related illnesses including heatstroke, hyperthermia, and dehydration rapidly rise when summertime temperatures reach a value of more than 400C. High humidity decreases evaporation, which makes sweat a less efficient cooling mechanism and exacerbates the consequences of high heat [1].

Due to its very low minimum temperature, India has harsh winters that are accompanied by cold waves, just like the nation experiences heat waves in the summer. Similar to how humidity in a heat wave scenario furthered the effects of wind chill, wind speed in a cold wave case. The winter season often brings chilly waves to several areas of northern and central India. The heat and cold waves are among the most severe natural catastrophes, ranking up there with cyclones, thunderstorms, and heavy rains in terms of media attention. Every year, heat and cold waves across India result in several fatalities. Real-time catastrophe forecasting efforts must be conducted, and early warning of such events will be highly beneficial to many users in addition to the general public.

Examining the current standards for identifying heat and cold waves across India as well as outlining the warnings' distribution process are the main goals. People who are exposed to direct sunlight throughout the summer may have a variety of health issues due to the sudden spike in temperature. Similarly, the harsh winter may affect the health of older persons, school-aged children, and those undergoing different surgeries. Therefore, it is necessary to monitor and predict the same, which will be extremely helpful for the general public, kids, and other users. Additionally, this has several commercial uses in a number of industries, including agriculture, aviation, and power. So, there is a demand for:

To gauge the climate, place emphasis on:

1. Human toleration
2. Crop toleration
3. Resources for water

To make authorities more aware and provide them more alternatives for making decisions

To meet particular sectoral demands for:

1. Calculating the electricity demand
2. Transportation expenses and security
3. Commercial productivity
4. Amount of agricultural output
5. Forcing people or organisations to take preventative measures

Observational features

The winter months of January and February (JF) are considered to be the country of India's winter. However, as shown from the typical Tmin for the years 1981 to 2010, the lowest temperatures (Tmin) fell below 80C throughout several regions of northern India from November to February . The coldest months across northern India are December and January, with a typical Tmin of less than 80C in several of its regions. During certain months, there are also cold waves in this area. Northern India has dry winters most of the time, while it sometimes receives rain during western disturbances. Dry, chilly northwesterly winds reached northern and central India after the western storms had passed. The outcome is a decrease in minimum temperatures throughout the areas, which may sometimes result in cold waves. Due to the moderating influence of the Indian Ocean, Bay of Bengal, and Arabian Sea, the temperature difference is not as noticeable in the southern regions [2].

DISCUSSION

Analysis of the data and a heat or cold wave declaration

In order to monitor different metrological factors like temperature, relative humidity, pressure, wind speed and direction, etc., IMD maintains a large network of surface observatories that span the whole nation. To determine the typical maximum/minimum temperature of the day for a certain station, a climatology of maximum/minimum temperature for the period 1981–2010 is created based on daily maximum/minimum temperature station data. Following that, IMD issued a heat/cold wave declaration for the area in accordance with IMD Forecasting Circular [3].

Favorable meteorological conditions for a heat wave

A region of warm, dry air and an adequate flow pattern are required for the transportation and prevalence of hot, dry air across that area. A lack of moisture in the upper atmosphere (because moisture limits temperature increases). The sky should be almost cloudless (to provide the greatest amount of insulation over the area). Anticyclonic flow with a large amplitude across the region. Since westerly to northwesterly winds are predominant throughout the season, heat waves often form over Northwest India and move progressively eastward and southward, but not westward. But sometimes, given the right circumstances, a heat wave may also emerge over any confined area [4].

Excellent weather conditions for the Cold Wave

Since cold wave conditions are related to a decline in wintertime minimum temperatures. The Indo-Gangetic Plains (IGPs) are often covered by chilly northwesterly winds at this time of year. Since these winds originate in Central Asia's and the Hindukush region's cooler regions, they cause the temperature over the IGP to drop, resulting in cold wave conditions. In general Clouds form over the area, maximum temperatures drop, and minimum temperatures increase as a Western Disturbance (WD) moves towards IGP. Thus, when a WD approaches, the Cold Wave conditions over IGP weaken. Clear skies begin to develop over the IGP as WDs leave the Indian area, causing maximum and minimum temperatures to climb and decline respectively.

Whenever a WD moves towards north India, winds from the Arabian Sea or from both the Bay of Bengal and the Arabian Sea are present at lower levels over the area. Due to the wet nature of these two kinds of winds, minimum temperatures in the area increase as a consequence. At the same time, cloud cover reduces the amount of solar radiation that reaches the earth, resulting in a drop in maximum temperatures. Another factor that causes cold waves is the development of an anticyclone in the lower and middle troposphere. Such an anticyclone causes a sinking motion over the IGP, which causes minimum temperatures to decrease. The jet core's left entry and right departure are associated with upper level convergence, which in turn results in sinking motion over the surface and cold wave conditions [5].

Function and accountability of IMD's various offices

Under the direction of the MC In-charge, the heat/cold wave will be monitored at the Meteorological Centre (MC) for the state. If a Group-A officer is not available, work may be handled by qualified officials under the guidance of a Group-A Officer at Regional Meteorological Centres (RMC) and National Weather Forecasting Centres (NWFC). From Day 1 to Day 5, the NWFC will issue color-coded heat/cold wave warnings for all 36 of India's sub-divisions. MC/RMC will issue a color-coded impact-based heat/cold wave warning for all of the districts in the relevant state from Day 1 to Day 5.

Product creation, display, and distribution warning

Surface and upper air charts, change charts, T-phi grammes, radar and satellite products, as well as advice from various global and regional Numerical Weather Prediction (NWP) models used by IMD, such as the Global Forecast System (GFS), NCEP GFS, NCMRWF Unified Model

(NCUM), Global Ensemble Forecast System (GEFS) of MoES, NCMRWF Ensemble Prediction System (NEPS), and European Centre for Medium Range Weather Forecasting, are to be taken into account

IMD's MCs and RMCs issue heat and cold wave warnings for certain districts. The relevant State Government Authority, the National Disaster Management Authority, the media, and other stakeholders like the Indian Railway, the Health Departments, the Power Sector, etc. are then informed of these warnings. Additionally, RMCs and MCs provide temperature forecasts for each state's main cities in accordance with the needs of the state disaster management. In addition to the aforementioned methods, warnings are also sent by all digital channels of communication, including phone (to senior disaster managers), whatsapp, SMS, e-mail, facebook, twitter, instagram, and weekly weather in the form of an audio-video model published to youtube [6].

Forecasting Demonstration Projects (FDPs) for Heat and Cold Waves

Many IMD departments (NWFC, NWP, Satmet, RMC Delhi/ Kolkata/ Guwahati, MWO Delhi/ Kolkata, EMRC), NCMRWF, Noida, IITM Pune, SAC, Ahmadabad, and IAF participated in a multi-institutional project in 2016 to comprehend and analyse the many aspects of WDs and its accompanying weather, such as severe rain or snow, and the spread of precipitation in space [7].

1. Thick Fog
2. Cold front/day
3. Snow, ice, etc.

primarily for the northern regions of the nation (north of 20°N), so that from December 2016 onwards, a better weather prediction and warnings advisories at least five days in advance would be published. A full report is then created for the aforementioned time period and includes the following elements:

1. Observation
2. Synoptic characteristics
3. Dynamic characteristics
4. Thermodynamic characteristics:
5. Analysis and guidance of models
6. Guidance for Forecast and Warning

This report is posted on the IMD website and sent to everyone who needs to know through email. A similar FDP heat wave was started beginning in 2018 for the months of April 1 through June 30. Two bulletins are released each day throughout this time period, the first at 8:00 IST containing the previous day's highest temperatures and its abnormality and a heat wave warning for the same day. At 1600 IST, a second bulletin is released with information on the previous day's maximum temperatures and their departure, the current maximum temperatures as of 1430 IST and its 24-hour tendency, and subdivision-based heat wave advisories for the next five days. various users, including the MHA, NDMA, SDMA, CS of states, DC/DM of various districts of states, health department, Indian Railway, road transport, media, etc., get warnings at the meteorological sub-division level. For maximum temperatures, a seasonal prediction as well as an extended outlook (up to two weeks) are also provided. Every Thursday, an extended range bulletin for temperatures and heat waves is also released.

Action plan for a heat wave

The goal of the Heat-Wave Action Plan is to provide a framework for the execution, coordination, and assessment of severe heat response actions in Indian cities and towns that lessens the detrimental effects of excessive heat. The main goal of the Plan is to warn people who are at high risk of developing heat-related illnesses in areas where very hot conditions already exist or are about to. IMD is in charge of providing early heat wave warnings. Over 100 Indian cities and villages are now using the heat wave response plan.

Heat Wave Prevention Measures

The actions one should take to lessen the effects of a heat wave. Check the local weather forecast on the radio, TV or newspaper to find out whether a heat wave is imminent. Drink enough water often, even if you're not thirsty. Dress in airy, light-colored, loose-fitting, and porous cotton clothing. When walking outside in the sun, use protective eyewear, an umbrella or hat, shoes, or chappals. Bring water with you while you're on the road. If you work outdoors, cover your head, neck, face, and limbs with a moist cloth in addition to wearing a hat or an umbrella. Use ORS and home-made rehydrating beverages like lassi, torani (rice water), lemon water, buttermilk, etc. Recognize the symptoms of heat exhaustion, including sweating, seizures, headaches, nausea, and dizziness. A doctor should be seen right away if you feel sick or dizzy. Keep animals in the shade and provide them with plenty of fresh water. Keep your house cool by closing the windows at night and using sunshades, shutters, or curtains. Frequently take cold showers and bathe while wearing moist clothes. Provide drinking water that is chilled near the workplace. Warn employees to stay out of the sun. Plan demanding tasks for cooler times of the day. Extending outdoor activity rest breaks in both frequency and duration. Workers who are expecting or have a medical condition should get special consideration [8].

The actions one should take to lessen the effects of a cold wave. Spend as much time as you can inside. Make sure you have enough warm winter clothes. Keep an eye on all media sources for updates on the weather and emergency procedures. Check in on any elderly or single-person neighbours. Ensure that supplies for emergencies are readily available since no power means no electricity. Only use one space; a passageway or interior chamber will be simpler to heat. To combat the cold, consume hot beverages often to keep your body warm. Freezers can keep food fresh for up to 48 hours without power provided the door is kept closed. Dress appropriately; many light layers are preferable than a single heavy one. Hats and mufflers aid in retaining body heat. Keep the air well-ventilated while using a coal oven or kerosene heater to prevent hazardous emissions. Consume heat-producing foods to keep your body warm, and sip non-alcoholic drinks. See a doctor if you have any of the following symptoms of frostbite: numbness, white or pale fingers, toes, ear lobes, or nose tips. See a doctor if you have any of the following symptoms of hypothermia (low body temperature): uncontrollable shivering, memory loss, confusion, incoherence, slurred speech, sleepiness, and a look of tiredness [9].

Verification and documentation

Must be based on absolute measures rather than normalised ones, with the exception of separating high-altitude regions from plains. Must be sufficiently extensive and not apply to regions that are too small to be clearly identifiable (District, State). Cannot be transient; must endure for at least two days. Must be assessed using impartial observational techniques, together with indicators of human perception, and expressly stated as such. In order to evaluate the efficacy of the current criteria (definition) used to define the heat wave or cold wave event, the correctness of the heat wave and cold wave warnings must be confirmed. The cold and heat wave warnings might be confirmed on Met. following the availability of full data, at the subdivision level. For the whole of India from 2014 to 2019, heat wave skill (Probability of Detection (PoD) and Missing Rate (MR)) was evaluated [10].

CONCLUSION

The need of public education and community involvement in heat and cold wave warning systems is emphasised in the fifth part. People may protect themselves during severe temperature occurrences by taking preventative precautions and following safety rules, outreach programmes, and educational campaigns. The development and implementation of heat and cold wave warning systems was a result of cooperation between meteorological agencies, health departments, emergency management authorities, and key stakeholders, as highlighted in the sixth section. These organisations work together to coordinate responses to severe temperature occurrences and share information. The difficulties encountered by heat and cold wave warning systems, such as forecasting uncertainty, susceptible populations, and resource limitations, are discussed in the seventh part. To properly address these difficulties, ongoing research, technology breakthroughs, and capacity development are crucial. In order to improve public health and safety, the study highlights the crucial role that heat and cold wave monitoring and warning systems play. These services greatly aid in reducing the effects of severe temperature occurrences and fostering community climate resilience by providing fast and accurate information.

REFERENCES:

[1] T. C. Peterson *et al.*, “Monitoring and understanding changes in heat waves, cold waves, floods, and droughts in the United States: State of knowledge,” *Bull. Am. Meteorol. Soc.*, 2013, doi: 10.1175/BAMS-D-12-00066.1.

[2] P. Kellermann, P. Bubeck, G. Kundela, A. Dosio, and A. H. Thieken, “Frequency analysis of critical meteorological conditions in a changing climate-Assessing future implications for railway transportation in Austria,” *Climate*, 2016, doi: 10.3390/cli4020025.

[3] X. Zhai, H. L. Johnson, and D. P. Marshall, “A model of Atlantic heat content and sea level change in response to thermohaline forcing,” *J. Clim.*, 2011, doi: 10.1175/JCLI-D-10-05007.1.

[4] S. Top, D. Milošević, S. Caluwaerts, R. Hamdi, and S. Savić, “Intra-urban differences of outdoor thermal comfort in Ghent on seasonal level and during record-breaking 2019 heat wave,” *Build. Environ.*, 2020, doi: 10.1016/j.buildenv.2020.107103.

[5] C. Lavaysse, C. Cammalleri, A. Dosio, G. Van Der Schrier, A. Toreti, and J. Vogt, “Towards a monitoring system of temperature extremes in Europe,” *Nat. Hazards Earth Syst. Sci.*, 2018, doi: 10.5194/nhess-18-91-2018.

[6] D. Xu *et al.*, “Acute effects of temperature exposure on blood pressure: An hourly level panel study,” *Environ. Int.*, 2019, doi: 10.1016/j.envint.2019.01.045.

[7] V. Pagani *et al.*, “Improving cereal yield forecasts in Europe – The impact of weather extremes,” *Eur. J. Agron.*, 2017, doi: 10.1016/j.eja.2017.06.010.

[8] M. Mohapatra and M. Sharma, “Cyclone warning services in India during recent years: A review,” *Mausam*. 2019. doi: 10.54302/mausam.v70i4.204.

[9] çaĝan H. Şekercioĝlu, R. B. Primack, and J. Wormworth, “The effects of climate change on tropical birds,” *Biological Conservation*. 2012. doi: 10.1016/j.biocon.2011.10.019.

[10] M. S. Green, N. G. Pri-or, G. Capeluto, Y. Epstein, and S. Paz, “Climate change and health in Israel: Adaptation policies for extreme weather events,” *Isr. J. Health Policy Res.*, 2013, doi: 10.1186/2045-4015-2-23.

CHAPTER 19

A BRIEF STUDY ON FOG WARNING SERVICES

Agnijit Tarafdar, Assistant Professor
Department of ISDI, ATLAS SkillTech University, Mumbai, Maharashtra, India
Email id- agnijit.tarafdar@atlasuniversity.edu.in

ABSTRACT:

By providing timely and reliable information regarding foggy conditions, fog warning systems serve a key role in protecting traffic, aviation, and public safety. An overview of the relevance of fog warning systems is provided in this study, with a focus on how crucial they are for lowering accidents, increasing visibility, and boosting readiness for fog occurrences. This describes how common fog is and how it negatively affects a variety of industries, such as transportation, aviation, and marine operations. In order to notify the public and the appropriate authorities of possible dangers brought on by decreased visibility, fog warning systems are essential instruments. Fog conditions may be accurately detected and predicted thanks to weather observation networks, satellite data, ground-based sensors, and numerical weather prediction models. The final segment investigates the distribution and communication techniques used to successfully inform the public about fog warnings. A variety of communication methods, including radio broadcasts, smartphone applications, websites, and digital signs, are used to make sure that important weather information reaches its target audience quickly and clearly. The fourth part discusses how impact-based forecasting is included into fog warning systems. It improves public knowledge and readiness during fog episodes to provide information about possible transit delays, aircraft cancellations, and safety risks.

KEYWORDS:

Cloud, Forecast, Fog, Visibility, Weather.

INTRODUCTION

One of the world's regions that experiences the most fog is the plains of northern India. In daily satellite fog photos, beginning from Pakistan to Bangladesh over the northern Indian plains, one can see an enormous fog layer covering a large region at periods of peak fog occurrence. Along with the IGP, it also happens sometimes throughout the winter across north-eastern states, the East Coast of India, and particularly along the coastlines of West Bengal and Odisha, including Guwahati, Agartala, Bhubaneswar, and Kolkata. Due to the unique air patterns dependent on the locations and local geology, several hill stations in India also experience hill fog. Because the air is less humid in the plains of Maharashtra, Gujarat, the majority of southern Peninsular India, and central areas of India, thick fog is seldom an issue. Even though Rajasthan's western regions receive rain from western disturbances, there are fewer thick fog days there because of very low temperatures, a lack of sources for long-lasting moisture, and the availability of wind from arid deserts. Some urban areas e.g. There are a few days of severe fog in the winter in Hyderabad, Chennai, Bhopal, Guwahati, Bangalore, etc.; this may be owing to increased pollution and urbanization [1].

Fog is hazardous and upsetting for all forms of transportation, but particularly for aircraft, even if it produces wonderful views. The term "fog" refers to an obscurity in the upper layers of the atmosphere brought on by a suspension of water droplets (with humidity > 75%), with or without smoke particles carrying different kinds of pollutants, and linked with visibility less than 1000 metres. By using different nearby pre-fixed landmarks as references, visibility (also known as general visibility) is the assessment by an observer of the lowest horizontal distance at the surface in all directions at which an item or light may be seen by the unaided eye. Due to the lack of acceptable visibility minimum, dense fog seriously impairs the operation of the aviation, railway, highway, and other transport sectors. In the aviation industry, fog significantly affects how flight operations are carried out, especially landing and takeoff. Poor visibility and low ceilings are not merely a safety concern. They may also significantly lower an airport's capacity and cause ground or air delays that result in detours, cancellations, lost connections, and increased operating expenses. By influencing several interior waterways across the Ganges and Brahmaputra where their intensity and frequencies are greater than rest of India, it also impacts river ferry services throughout states like Bihar, Assam, UP, etc. When connected with greater pollutants that include electro-chemically charged particles, incidents of tripping electrical power distribution wire lines have also been documented from numerous parts of north India during extended thick fog periods. If a thick fog layer persists over a region, particularly over portions of northwest India, for a longer period of the day, obstructing the sun's light and keeping the daytime temperature well below average, human health, especially that of the elderly and young, is adversely impacted.

Fundamentals of fog occurrences and types, including the physical mechanisms and regional geography that contribute to their creation. Depending on how the cooling that led to the condensation happened, fog may arise in a variety of ways. For example, radiation fog is created when thermal radiation cools the ground after sunset under calm circumstances with a clear sky. By means of heat conduction, the chilly earth causes condensation in the neighbouring air. The fog layer may be less than a metre deep in an ideal situation, although turbulence might encourage a larger layer. Radiation fogs frequently appear at night and disappear shortly after morning. In the late summer and early fall, radiation fog is frequent. Examples of this phenomena include the thick fog event that occurs across north India in the wintertime when a rainy period is followed by WD. Ground fog is defined as fog that does not reach the base of any above clouds and covers less than 60% of the sky. The phrase is, nevertheless, sometimes used to describe radiation fog. When moist air is cooled when it is advected (by wind) across a cold surface, advection fog is created. It frequently happens when a WD approaches over the northwest Indian plains during the peak winter season of 15 December to 31 January, when easterly warmer and moistier winds are advected to these areas that have already arrived, under colder temperatures, just before changing the westerly wind pattern to easterly winds at near surface level [2].

Formation of fog and related processes

Fog formation, development, and dissipation over an area or location are primarily influenced by the weather and other atmospheric particulate matter, such as pollutants and aerosols. The whole process goes through a number of simultaneous, non-linearly interfering processes (thermodynamical, radiative, dynamical, and microphysical) that take place under a variety of circumstances. Thermodynamic, dynamic, radiative, microphysical, and surface conditions all play a role in the fog life cycle. Inadequate sets of dynamic, turbulent, radiative, and microphysical observations have made it difficult to fully comprehend and simulate the tiny microphysical processes occurring within a fog layer. One of the unique characteristics of fog at ground level in BL as opposed to cloud at its top is:

1. In the surface boundary layer, where aerosol concentrations are highest and surface heterogeneities predict complex heat, water, radiative, and chemical fluxes, this development occurs.
2. CCN activation within cloud associated with significant cooling rate primarily forced by vertical velocity; fog is a cloud in contact with the ground where aerosol concentrations are highest; cooling rate primarily associated with radiative cooling; as a result, it differs from other boundary layer clouds' cooling associated with vertical velocity;
3. In addition, this cooling rate is largest at the top of the fog layer, which causes the most liquid water to be produced there, as opposed to clouds, where the cooling rate is most at the base.
4. When there is a lot of wind and there is rapid, turbulent mixing, clouds develop.

Processes involved in fog production, layer intensification, maintenance, and dissipation

As a consequence of air chilling, moistening, and/or mixing different air parcels, water vapour condenses into liquid droplets and forms fog close to the surface. The most typical scenario taken into account when fog formation over land is invoked entails nocturnal radiative cooling under light wind conditions whereas dissipation typically takes place a few hours after sunrise as a result of warming from sensible heat fluxes over a surface heated by solar radiation. This claim, however, obscures a more nuanced reality in which, as opposed to the conventional radiative fog event, areas experience fog occurrences caused by advection fog or stratus lowering. Additionally, found that the chemical and microphysical characteristics of the aerosols in the surface layer control the activation process, found that the optical characteristics of the aerosols affect radiative cooling and heating. These factors make the type and concentration of aerosols in the surface layer critical parameters throughout the fog life cycle. Additionally, it is well recognised that turbulent mixing plays a crucial yet unclear role in determining fog formation. Dew deposition at the surface will prevent atmospheric condensation and, as a result, prevent the development of fog, if turbulent mixing is too low. If the turbulence is high enough, it may encourage condensation in a sufficiently deep supersaturated surface layer, which would then result in the production of fog.

A large fog layer maintains a depth that is roughly constant throughout the maintenance phase. There is a balance between conflicting forces throughout this stage. These three forces are fog-top mixing, droplet settling, and radiative cooling. To maintain the depth of the fog layer, fog-top condensation maintains a balance between the processes of evaporation and droplet settling. Radiative cooling at the top of the fog refills the droplet supply as it descends and even attempts to deepen the inversion. Turbulent mixing works to weaken the inversion and dissolve the fog top at the same time. A radiation fog layer normally deepens throughout its development phase until it reaches a height where the winds are high enough and produce enough fog-top mixing to stop the growth since winds typically increase with height. The radiation fog layer may be maintained throughout the day by the introduction of mid- and upper-level cloud layers. These clouds block sunlight from reaching the ground, limiting warming there and keeping the relative humidity in the lower reaches of the fog layer higher. However, the less an overlaying cloud layer is, the more it may inhibit the creation of condensate and radiative cooling at the top of the fog, enabling dissipative processes like settling to take hold [3].

DISCUSSION

Processes involved in the dissipation of fog: Several variables may affect how long the dissipation phase lasts. Droplet dissipation is often brought on by one or more of the following processes: Solar energy: Even when a layer of fog is present between the sun and the earth throughout the day, the ground absorbs solar energy. A thin layer of air in contact with the surface is heated by conduction as the earth warms. Weak convective mixing is started by this heat, which starts to warm the lowest part of the fog layer. This layer's relative humidity starts to diminish, which slows the creation of new fog droplets and ultimately causes them to evaporate. The warming process quickens when the fog dissipates, enabling more sun energy to reach the earth. The base of a fog or low cloud layer may rise up to several hundred feet per hour under fairly intense sunlight.

No matter how big or little they are, fog droplets all settle over time. When the droplet creation rate can no longer keep up with the settling rate, the depth of the fog layer drops. A typical fog droplet, which has a diameter of less than 20 micrometers, settles at a velocity of 1 cm/sec. Therefore, if the maintenance procedures are stopped, fog that was originally 30 metres (or around 100 feet) thick should reach the ground in about an hour. The capping inversion of a fog layer is often accompanied with a layer with substantial vertical wind shear. The relative humidity in the top layer of fog may be decreased and the inversion can be lowered by turbulent mixing of warmer and drier air into that layer. The capping inversion is more vulnerable to this continuing mixing and erosion process the weaker it is [4].

Changes in Wind: Fog may disperse both at the fog top and close to the surface when moderate to strong low-level breezes are introduced. Winds draw warmer, dryer air from above into the fog at the fog top. Winds near the surface cause the surface-warmed air and the fog above to mingle. Both encourage fog droplet evaporation and enhanced visibility.

Nighttime Overlying Cloud Layers: When there are no clouds above an established fog layer, radiative heat loss occurs most quickly at night. Fog top cooling reduces if a thick layer of upper-level clouds or a layer of mid-level clouds with breaks or overcast conditions is applied since less radiation can leave the atmosphere. This impact may inhibit the creation of new droplets and aid in the dissipation of fog.

Role of pollutants in fog

CCN activation within stratocumulus or cumulus, that is, linked with a large cooling rate primarily induced by a vertical velocity, has been the subject of several prior studies. The focus of this research is on CCN activation under foggy situations. As a result, the approach diverges significantly from earlier activation research. First off, the fog is a cloud that is in close proximity to the ground, which is where aerosol concentrations are at their maximum. Second, the rate of cooling is mostly related to radiative cooling, which makes it distinct from other boundary layer clouds' cooling rates that are related to vertical velocity. Additionally, this cooling rate is greatest towards the top of the fog layer, which causes the greatest production of liquid water. Aerosols have a complicated impact on the life cycle of fog. Aerosol particle quantity, size, and chemical composition are crucial factors in the activation processes. Therefore, the microphysical features of a fog layer (number and size of the fog droplets) are directly influenced by the aerosol characteristics. But because of the interplay between microphysical, dynamic, and radiative processes, the microphysical characteristics of a fog layer indirectly affect the fog's life cycle.

Event classification for fog

Fog occurrences may be categorised based on their size, their mode of production, or their severity in relation to the loss in horizontal vision that they create. As a result, it may categorise different kinds based on the three key parameters.

Scale

1. Mesoscopic Fog
2. Fog on a synoptic scale
3. Widespread fog

Physical Mechanism

1. Radiation haze
2. Fog advection
3. Evaporation fog or steam fog
4. Reducing the Cloud base
5. Fog in the valley/upslope fog

Based on intensity

1. A thin fog
2. Thick or dense fog
3. Extremely thick fog

Instances of fog over India

Due to the abundance of high moistures, either from local vast irrigated agricultural fields where abundance green vegetation are grown and moisture supply sustained throughout the season for supporting to agriculture day to day, the most favourable area of fog formation in India covers mainly western and central parts of parts of IGP covering Pakistan, Punjab, Haryana, Delhi and West Uttar Pradesh and northern parts of Uttar Pradesh. Bihar and its northern and eastern regions, which include the plains and the valleys of Assam and Meghalaya, are another place where the most fog forms. Wide river networks from three major river basins, which all feed into or distribute to Indus, Ganges, and Brhmaputra-Meghna, respectively, secure the region's topography with wide plains and an abundance of moisture [5]. These factors play a major role in the formation of such large-scale dense fog, which lasts for longer from early evening until late noon and then persists for weeks. When evaluating a fog cover, it is possible to see how it is dispersed along these important river routes and how often its significant occurrences match up with the corresponding three river basins.

According to data, Gorakhpur has India's highest rate of fog generation. However, the region's generally favourable low temperatures and calm wind conditions allow thick fog to stay for a longer duration, which has a significant impact on everyday living there. If one takes into account its singular larger spatial coverage for prolonged period, such fog events may be rare in any other part of the world. Such fog events have been observed to occasionally develop simultaneously over the vast region of the IG plains and are easily visible in recent days' satellite morning visible pictures as a very large scale white patch that persists up until 1130 IST and extends 250 km from Lahore to Dhaka. Some urban areas e.g. In the winter, there are a few dense fog days in Hyderabad, Chennai, Bhopal, Guwahati, Bangalore, etc. This may be due to increased pollution and urbanisation or a very favourable synoptic circulation pattern over these locations, which allows moisture intrusion followed by calm winds and a drop in temperature [6].

Different varieties of fog classified for the India area, along with their climatological characteristics

We can categorise and differentiate between radiation fog, radiation advection fog, advection fog, steam fog, cloud-base lowering fog, and precipitation fog by taking into account the physical processes that lead to fog formation over the India area. It can also be categorised based on the observed aerial extent it has covered in INSAT images regularly during the peak winter months, such as restricted to a city or airport, to one side of a RWY, leaving the other RWY fog free, or in cases when covered across large portions of a country [7].

In India's north-western plains, which include Punjab, Haryana, northern Uttar Pradesh, and Delhi, the frequency of fog is quite high. It progressively diminishes towards the eastern Gangetic plains. Based on visibility data from several sources at different temporal scales, such as hourly visibility data from airports and from various met stations at 3-h intervals in synop data, fog climatology has been calculated for numerous airports in north India. Climateological occurrences for each kind of fog (general fog, moderate fog, thick fog, and extremely dense fog) in terms of duration and days for each month have been generated wherever strong visibility data sets for longer periods of time, at 1-h intervals, say airport data for specified areas, have been made accessible [8].

Greater frequency of intense fog periods over IGP and their distinguishing feature

These three cases correspond to two major fog events in Delhi and one event in Amritsar. All of these instances resulted in a continuous fog that had visibility that was virtually always less than 1000 metres from late at night to early in the morning. Dense fog has also been reported with a longer night-to-morning duration of 200 metres. So, in order to be effective, a system of fog forecasting must take into account such severe situations and record such fluctuation.

Fog events formed during the peak winter, from mid-December to end-January, are typically large-scale in terms of aerial coverage, longer spells, and a combination of radiation and advection types, while cases in the months of November and February mostly occurred localised at meso-scale or synoptic scale, shorter in spell, and therefore are of radiation fog types, according to a study of fog events across the IGP region for 2000–2021 using satellite fog coverage data and airport data. There are several months and seasons when it was noted that thick fog on a huge scale had spread over the IGP region and had lasted for 10 to 30 days, for example. Dec. 1997 and 1998, Jan. 2003, Jan. 2010, Dec.-Jan. 2016–2017, 2017–2018, and Dec.–Jan. 2020–21 were all instances when the whole Indo-Gangetic plains (IGP) had regular occurrences of high duration thick fog layer covering most sections of it and lasting for 12–15 hours with nighttime and morning visibility below 200 metres. Because they have such a negative influence on people's life all around our wonderful IGP, these longer-lasting thick fog episodes are known as episodic fog/smog. As shown by the hundreds of flights and trains that were delayed or cancelled, as well as the many accidents that resulted, it is also known as a high impact weather event [9]. The following are some further distinctive features of the large-scale Indo-Gangetic thick fog layer:

It generally occurs between Mid-December and the first week of February, and it is of mixed radiation-advection type. Once it develops, it persists over large regions at night and in the morning for weeks, only partially lifting around late midday when it transforms into low stratus clouds. In reality, compared to other fog locations throughout the globe, IGP fog occurrences may be the quickest in creation, biggest in size, and longest in length. This is also true in terms of the severity of its severe effect as it spreads over the world's region that is most densely inhabited. When a dense fog layer prevents sunlight from reaching the surface for the majority of the day and the daytime maximum temperature drops to as low as 10-15 degrees Celsius for weeks, it further complicates life for the average person [10].

CONCLUSION

The necessity of public education and community involvement in fog warning systems is emphasised in the fifth part. People are empowered to take proactive steps and exhibit care when travelling in foggy circumstances via educational activities, outreach programmes, and safety recommendations. The joint efforts of meteorological agencies, transportation authorities, aviation authorities, and other important players in creating and implementing fog warning systems are highlighted in the sixth section. These organisations work together to guarantee a coordinated and efficient response to fog situations. The difficulties that fog warning systems must overcome, including forecasting ambiguities, localised fog episodes, and real-time observational constraints. The accuracy and effectiveness of fog warnings must be increased by ongoing study, technical development, and data assimilation methods. The summary ends by highlighting the crucial part that fog warning systems play in boosting public safety and transportation resilience. These services provide a substantial contribution to lowering accidents and enhancing visibility in foggy circumstances by giving fast and accurate information, eventually resulting in safer and more effective transportation networks.

REFERENCES:

[1] B. Farahani, F. Firouzi, V. Chang, M. Badaroglu, N. Constant, and K. Mankodiya, “Towards fog-driven IoT eHealth: Promises and challenges of IoT in medicine and healthcare,” *Futur. Gener. Comput. Syst.*, 2018, doi: 10.1016/j.future.2017.04.036.

[2] S. K. Sood and I. Mahajan, “Wearable IoT sensor based healthcare system for identifying and controlling chikungunya virus,” *Comput. Ind.*, 2017, doi: 10.1016/j.compind.2017.05.006.

[3] A. M. Rahmani *et al.*, “Exploiting smart e-Health gateways at the edge of healthcare Internet-of-Things: A fog computing approach,” *Futur. Gener. Comput. Syst.*, 2018, doi: 10.1016/j.future.2017.02.014.

[4] J. Abdelaziza, M. Adda*, and H. Mcheick, “An Architectural Model for Fog Computing,” *J. Ubiquitous Syst. Pervasive Networks*, 2018, doi: 10.5383/juspn.10.01.003.

[5] J. Scholliers, M. Jutila, M. Valta, K. Kauvo, A. Virtanen, and P. Pyykönen, “Co-operative Traffic Solutions for Hybrid Communication Environments,” in *Transportation Research Procedia*, 2016. doi: 10.1016/j.trpro.2016.05.377.

[6] C. Nina, Z. Yushu, Z. Shuo, L. Jing, W. Ting, and X. Yaqi, "Analysis of main meteorological disasters distribution & early warning service in Liaoning Province from 2004 to 2013," *J. Nat. Disasters*, 2017, doi: 10.13577/j.jnd.2017.0321.

[7] T. J. McCue *et al.*, "Digital Farming decisions and insights to maximize every acre," *IEEE Trans. Ind. Informatics*, 2018.

[8] C. Köhler *et al.*, "Critical weather situations for renewable energies – Part B: Low stratus risk for solar power," *Renew. Energy*, 2017, doi: 10.1016/j.renene.2016.09.002.

[9] E. A. Jalew, "Fog Computing based traffic Safety for Connected Vulnerable Road Users," *Univ. Bourgogne Fr.*, 2019.

[10] M. Li *et al.*, "A risk management system for meteorological disasters of solar greenhouse vegetables," *Precis. Agric.*, 2017, doi: 10.1007/s11119-017-9514-9.

CHAPTER 20

FOG OCCURRENCES' VARIABILITY, EXTREMES AND IMPACTS OVER THE IGP

Dipika Bhatia, Assistant Professor
Department of ISME, ATLAS SkillTech University, Mumbai, Maharashtra, India
Email id- dipika.bhatia@atlasuniversity.edu.in

ABSTRACT:

When fog occurs over the Indo-Gangetic Plain (IGP), it may have a significant influence on a variety of socioeconomic and environmental factors. The properties and dynamics of fog in the IGP are briefly discussed in this study, with an emphasis on its temporal and geographical fluctuations, severe occurrences, and consequences for public health, transportation, and agriculture. The importance of the IGP as one of the most notable and prone to fog places in the globe is highlighted in the first part. The IGP often encounters fog episodes throughout the winter, which causes limited visibility and negative effects due to its geographic position and weather conditions. The causes of fog variability and extremes in the IGP are covered in the second part. Fog development and persistence are primarily influenced by a number of factors, including radiation cooling, calm breezes, high humidity, and air pollution. The timing and location of fog episodes are greatly influenced by seasonal fluctuations, temperature inversions, and local climatic trends. The final portion investigates how fog affects IGP agriculture. Winter crops are at risk from frost development in foggy weather, which might result in output losses and have an impact on farmers' bottom lines. The problems the agricultural industry is facing are made much more difficult by the interruptions caused by fog in transportation and business. This outlines initiatives and current research projects to better understand fog dynamics in the IGP. These initiatives seek to enhance fog forecasting, evaluate how it affects different industries, and create mitigation plans for its negative consequences.

KEYWORDS:

Agricultural, Forecast, Fog, Health, Weather.

INTRODUCTION

Extremes and Variability of Fog Occurrences Across IGP

One of the main meteorological dangers is the prevalence of heavy and prolonged periods of fog in the northern areas of India across IGP in each Winter. When these occurrences were analysed using surface fog data and satellite data for each month between 1997 and 2021, the following were found to be some of the most notable variations in fog characteristics in the IGP region:

The northwest and centre regions of the IGP are especially susceptible to intense fog.

In the peak winter months of December and January, there are often 30–40 (or 18–22 days) of general fog (dense fog) with visibility of at least 1,000 metres (200 metres), lasting an average of 8–10 hours (or 6-7 hours) every night and morning. Delhi is the exception to this rule.

Due to its higher levels of pollution, Delhi has 54% more fog days than comparable cities, totaling 54 days and 618 hours i.e. 12 hours a day, with practically every day throughout the months of December and January reporting fog. The fact that it has roughly same 21 days of intense fog, with an average of 6-7 hours per day, as it records for other airports in IGP, is still intriguing.

Nov and Feb also mention fog in the area, although it only happens occasionally—10–15 days, 8–10 hours per day for general fog, and only 1–3 days, 3–4 hours per day for thick fog. One of the most peculiar characteristics of IGP fog occurrences is their tremendous seasonal unpredictability, with some seasons seeing very high extreme fog coverage that adversely affects the quality of life for residents while others have ordinary or below average fog coverage with few or no thick fog reports at all [1].

According to data, the years 1997–1998, 2002–2003, 2009–2010, 2014–2015, as well as 2017–2018 and 2020–2021 are considered to be severe fog years, with 25–35 days/200–300 hours of thick fog blinding the majority of dates from mid-night to late morning. In these seasons, satellite fog also sometimes reveals that practically the whole region, including Delhi and the eastern and northeastern sections of IGP, was covered in deep fog for three to four weeks.

In contrast, 2007-08 and the most recent winter of 2018-19 were acknowledged as notable winters where little major thick fog was observed across IGP, with the exception of a few incidents in its northwest regions (It was a total of 2 days alone at Delhi in 2007-2008 in all periods of Dec-Jan). Additionally, daily variability reveals that deep fog with a visibility of 0 metres (m) descended on Delhi, Lucknow, Amritsar, and Varanasi in the belt for 24 hours on each day and persisted there for 5 to 10 days without rising [2].

Additional Important Features

Large-scale, longer-lasting, thick fog covering the IGP area was mostly recorded during a 45-day window of the peak winter season, from the middle of December to the first week of february, and it is of mixed radiation-advection type. The transition from fog to low stratus clouds in the late afternoon and back to thick fog at night does happen, as it does in other major fog zones of the globe.

When it captures the enormous number of pollutants present in the area and holds them all at lower levels with little dispersion, it also has a significant impact on air quality. It acts as a scavenger while lifting and produces little pollution. It's interesting to note that areas of such large-scale fog only occur in those parts of the plain with very low topography and surface heights up to 300 metres, which stretch from Pakistan to Bangladesh across the states of Punjab, Delhi, Uttar Pradesh, Bihar, and West Bengal and into the narrow north-eastern plains. According to a study, thick fog accumulates throughout the IGP at the most favourable minimum temperature of 3 to 10 degrees Celsius.

Colder surface light breezes from the north/northwest, blown from the nearby ice-covered Himalayan region, also aid in this process by amplifying the temperature of the colder surface layer, which then causes an inversion with the warmer upper layer to be present over the region most of the time. This region's extensive pollution layer has been a key contributing element. Increased irrigation and the Green Revolution are a result of altered land-scale processes brought about by an increase in moisture and a decrease in surface air temperature.

Impact of fog analysis

Fog has a significant negative impact on many areas, including human life, and includes:

1. Transportation via air, rail, and highway
2. Services for River/Costal ferries
3. Prevents Sunlight for weeks, resulting in a period of extreme cold that has an impact on human health.

AQI and pollution

1. High-power grid lines were disrupted by increasing pollution fog.
2. Impact the crop during the growth, flowering, and seed-forming stages.
3. Road accidents are a significant cause of fatalities in north India as a result of fog.

Human lives are affected by

Road accidents happen when fog safety regulations are not followed during dense fog, which has a significant negative impact on road transportation. In fact, of all meteorological occurrences, it has been responsible for a particularly high number of deadly incidents in north India. The fog of the last two winters from December through January demonstrates that many tragic incidents in north India have resulted in a high death toll. It demonstrates that during December 2016 and January 2017 (2016–18), when their frequencies are quite high, it resulted in the loss of 120 (159) human lives. The following notable repercussions occurred when media outlets reported on accidents when it was foggy.

Operating fog detection and monitoring system in IMD

IMD has been employing a comprehensive early warning and monitoring system for fog that is on par with the finest systems available everywhere. For fog identification at a place and across an area, this system employs both surface-based and space-based measurements round the clock and 24 hours a day. Since December 2014, when INSAT 3-D based RGB fog products have been available, satellite-based fog detection and monitoring have been used extensively in real time to deliver the most up-to-date fog nowcasts and warnings with shorter period validity.

DISCUSSION

When surface visibility is compared to satellite fog coverage at intervals of 30 minutes to three hours across 205 synop stations available through GTS and across 90 airports available in its Aviation Met web-based monitoring system of OLBS, the difference between surface fog and low cloud events can be further confirmed. No fog occurrence escapes IMD surveillance thanks to this confirmation of satellite and surface visibility on occasion. Additionally, IMD has a quick method for receiving information on the amount of fog in important cities in northern India, thanks to its RVR instruments, which are airport-based visibility metres deployed at 8 main airports in the region and total 23 of these pieces of equipment. By MoU, all IAF airports provided help to IMD during the fog season, and in return, the latter also offers feeding of the fog and visibility of another 50 airports to the same web-based monitoring system, thus enhancing its capabilities to monitor the fog. A specific fog warning system is already operating under the WIFEX project for the national capital Delhi, a megacity that is likewise especially susceptible to intense fog. Since the winter of 2015–16, it has been operating in real time for every winter. In the most recent winter of 2015–2021, WIFEX successfully finished its sixth consecutive season at IGIA Delhi, making it the first of its kind in Asia and the third in the world, after France and the United States, and offering brand-new platforms for correctly documenting fog development and fog prediction models. In order to better understand fog micro-Physics and the role of various gaseous and other pollutants that contribute to fog formation, intensification, and its subsequent life cycle, including sampling of fog droplets to better understand their chemistry, WIFEX has been conducting winter experiments in Delhi. The second goal is to utilise this valuable data in real time to construct and validate a fog prediction model that can provide airports a fog early warning 18 to 24 hours in advance. It delivers boundary layer (BL) fog microphysics data, such as moisture, lower levels wind and temperature profile, and fog droplet quantity, size, concentration, and other contaminants [3]. Additionally, it offers meso-scale modelling assistance for upgrading north India's fog early warning system. In WIFEX 2015–2021, IITM and IMD installed and operationalized the following machinery:

i. RVR equipment
ii. Microphysics of fog droplets
iii. Radiometer
iv. SODAR

MARGA (Chemical Analysis of PM1, PM2.5 and Gases) is now operational and available online for the first time in India with high temporal resolution.

Ceilometer (added and operational as of 2017–18)

Fog dispersal setup with experimental mode ion generator (added and operational in 2017–18). Data from tethered balloons at Pusha up to 1000m was obtained between January 10 and 23, 2016.

SOP for reporting fog in meteorological conditions and synoptic data, as well as for giving warnings and nowcasting (trend) for fog

IMD uses a variety of observations covered in Section 4 to provide the status of fog monitoring. Throughout the winter, all of these fog items are continuously made accessible on the main IMD website. IMD's current fog information and warning systems can be divided into two categories: airport-based fog information and warning systems (including trend forecast) provided based on Met-subdivision, city, and district levels by AMS/AMO/MWO for use in the aviation sector; and general fog information and warning systems for all other purposes provided by NWFC/RWFC/MC. The items that DO/Forecasters of all field stations and at NWFC should refer to in order to report timely fog conditions over a location/airport/areas and to issue its further development, which covers fog nowcasting and forecasting as well as thick fog warnings. AWS/Airport data/live RVR, synoptic analysis, inversion layer, moisture advection, pattern and process based fog forecast tools, and various statistical tools, all developed or to be developed at field level, along with latest state of the art dynamical fog forecast systems already made operational b are some of the fog products that will be regularly referred to by Duty forecaster from time to time.

Sec. 5 contains the SOP for finalising forecast and warnings by location, city, airport, district, and met subdivision. Sec. 5.3 provides a demonstration on how to use multi-source fog products for timely reporting of fog development and issuing of early warnings by using two cases of unusual dense fog occurrence at IGI Airport Delhi developed at very late morning after sun rise. Sec. 5.2 provides SOP on satellite fog interpretation and its use in fog nowcasting. Before deciding whether to issue a fog prediction or warning, all of these items must be considered since they are all often updated online.

WRF chem high resolution at 2 km (operated by IITM under WIFEX) giving forecast of visibility in hourly visibility form in histogram form for Airports of north India including IGI Airport as well as 1-h evolution of fog forecast products in form of spatial map for north India domain are among the fog model products currently available in IMD. Delhi fog model at 330 m resolution for IGI Airport by NCMRWF provides both metgram form of Visibility at 1-h interval and spatial map. While WRF Chem, WRF, NCUM, NEPS, and GFS fog products are spatial fog forecast maps with areas colour coded at Vis below 1000m, 500m, 200m, and 50m valid for 0000 UTC of day 1 and day 2, WRF, D-FOG, and NCUM fog forecast products are hourly visibility-based MET GRAMMES and valid for 48 hours. Inferences may be made using consensus approaches, especially when analysed fog model products priority may be given in case dense fog events are forecasted by more number of models, and for day 1 to day 2 synoptic diagnostic also may be given priority. Summaries from all these products may be entered to register from time to time (at 30-minute to 3-h intervals depending upon the met conditions assessments), with each product updating as available. To evaluate whether a fog event has been happening or is most likely to occur owing to wind weakening and an inversion layer building up in the north Indian area, one has to do a detailed diagnostic [4].

SOP for producing fog forecasts and warnings

Since the late 2000s, IMD has provided intensity-based fog forecasts and warnings for a variety of fog intensities, from the NWFC IMD HQ at met sub-division-wise in terms of spatial terminology (ISOL, SCTD, FWS, and WS), with RWFC and MCs providing at district levels and city-based for five days since 2015. Regular fog products and their predictions, which are based on synoptic, satellite, and NWP models, have been discussed at national VC every day at 10:30 am since the adoption of Fog-FDP at the national level in 2016–17. The finalised regions expected to be covered in thick fog are then determined. During the winter, a 24-hour watch is maintained on FDP winter fog guidance products. Since the winter of 2016–17, it has been further enlarged and fog forecasts up to 5 days have been included, along with color-coded warnings and a multi-hazard map with an outlook for 2 days [5].

In the winter, IMD now issues airport-specific fog warnings every six hours, and these forecasts are released on the IMD website. It is now in use at 12 airports, including Delhi, Lucknow, Jaipur, Amritsar, Varanasi, Patna, Agartala, Bhubaneswar, Gaya, Kolkata, and Guwahati. During the months of November, December, January, and February, it is constantly updated every six hours. The Met Office Palam began providing a fog outlook once per day at 1500 UTC starting in 1998 in response to the rising frequency of thick fog over IGI Airport, which at the time caused disruptions to aviation services. The frequency of the fog forecasting was raised to four times daily with six hourly updates and a 12-hour outlook period as a result of the record-highest occurrences of Cat III thick fog in December 1998 (179 hours) and again in January 2003 (158 hours). Such predictions were provided up to December 2006 using the conventional synoptic approach. Since 2009–10, the Met department has been able to predict the density and timing of fog with a likely impact on air traffic. For example, when the airport is likely to be in Cat III or close to it with Cat IIIC conditions. When fog simultaneously forms over a large number of airports in north India, it complicates aircraft operations if not adequately planned since alternatives won't be accessible. If forecasts are provided for more airports, it aids in making efficient decisions. Users may utilise this fog information for effective flight planning to reduce the impact on aviation operations since the current weather at all major airports and their fog prediction are routinely updated and made accessible online [6].

SOP on Satellite-Based Fog Monitoring and Forecasting Guidance Tools

The thermal radiation that the satellite measures and also refers to as "radiance" is changed into a brightness temperature or an image grey tone. The RGB scheme is a way for displaying calculated physical quantities as composite visuals made up of the colours red, green, and blue. Solar reflectance in solar channels and brightness temperature in thermal channels are the physical characteristics. The primary RGB compositions include:

1. "Day Natural Colours," which has green flora, brown bare surfaces, black sea surfaces, white clouds above the ocean, and pink ice;
2. A cloud's microstructure is shown in "Day Microphysics" utilising the solar reflectance component of the 3.9-mm, visible wavelength. Infrared thermal pathways;
3. The microstructure of clouds is also shown in "Night Microphysics" utilising brightness temperature differences between 10.8 and 3.9 m.

Based on the aforementioned system, it is possible to detect the fog and nowcast its start, duration, extent, and movement using the analysis and guiding tools RAPID. The conclusions made from the guidance tools could be useful for the airport MET office's issuing of TREND, TAF, and Local forecast as well as for nowcast by forecasting offices at station and district levels [7].

Standardised practises for analysing RGB products for monitoring and predicting fog

The following procedures may be used by station level duty forecasters:

1. Go to the main Satellite page's RAPID satellite image and product analysis system.
2. From the product menu, choose RGB composite.
3. Decide between night microphysics, which begins when the local sun sets, and day microphysics.
4. Enter latitude and longitude if your station is not already indicated on the picture map. (An example is Lat. 27.23 Long. 88.33).

Fog interpretation

Using a Day Microphysics picture for interpretation

FOG may be recognised by its green colour in a microphysics picture taken during the day.

Interpretation of a picture from Night Microphysics:

The colour of fog in a microphysics photograph taken at night is bluish green.

Identifying low cloud types from fog

Low cloud cannot be confused with fog because low cloud has a rough texture and sluggish movement, whereas fog has a sharp edge and smooth texture. This may be shown by using RAPID to animate the appropriate pictures.

Changes in the FOG

By entering information in the RAPID field, one may investigate the origins, growth, geographical expanse, and movement of the fog [8].

Beginning of the fog

By calculating the distance between the station and the edge of the fog patch in the most recent picture, it is also possible to estimate the expected time of FOG onset at the station. You may use this by choosing Distance from the option Probe. Run RAPID's animation loop to get an idea of the movement's speed.

The amount of fog there is at night

By placing a probe in the region of interest and reading the temperature differential between TIR1 and MIR, one may also determine the development and intensification of FOG. There is a chance that FOG may start or worsen over a specific region at night if the temperature difference between two hours has grown [9].

Valley Mist

Fog forming in river and mountain valleys. Fog that is restricted to the local terrain is created when cold, thick air condenses as it descends into a valley. A better contrast is provided by SWIR channel images with 1 km x 1 km spatial resolution, which highlights tiny scale fog [10].

CONCLUSION

The effects of fog on public health and transportation are covered in the fourth part. Fog-related mishaps that are risky for air, train and road travel may have an effect on commuters as well as the transportation sector. Fog may also increase air pollution levels, which can have a negative impact on people's health. The need for reliable fog forecasting and warning systems in the IGP is emphasized in the fifth part. For improving the precision of fog predictions and expediting the broadcast of warnings to the public and relevant authorities, advanced weather monitoring technologies, numerical weather prediction models, and real-time observation networks are essential instruments. This ends by highlighting how crucial it is to understand the variability, extremes, and implications of fog in the IGP. Policymakers and stakeholders may successfully manage the difficulties caused by fog episodes by creating sustainable and adaptable solutions, fostering resilience, and improving the general wellbeing of populations in the area.

REFERENCES:

[1] T. S. MOHAN *et al.*, “On the investigation of the typology of fog events in an arid environment and the link with climate patterns,” *Mon. Weather Rev.*, 2020, doi: 10.1175/MWR-D-20-0073.1.

[2] H. Andersen *et al.*, “Synoptic-scale controls of fog and low-cloud variability in the Namib Desert,” *Atmos. Chem. Phys.*, 2020, doi: 10.5194/acp-20-3415-2020.

[3] R. Tardif and R. M. Rasmussen, “Event-based climatology and typology of fog in the New York City region,” *J. Appl. Meteorol. Climatol.*, 2007, doi: 10.1175/JAM2516.1.

[4] J. G. Izett, B. J. H. van de Wiel, P. Baas, J. A. van Hooft, and R. B. Schulte, “Dutch fog: On the observed spatio-temporal variability of fog in the Netherlands,” *Q. J. R. Meteorol. Soc.*, 2019, doi: 10.1002/qj.3597.

[5] P. Herckes, A. R. Marcotte, Y. Wang, and J. L. Collett, "Fog composition in the Central Valley of California over three decades," *Atmospheric Research*. 2015. doi: 10.1016/j.atmosres.2014.01.025.

[6] Z. Li *et al.*, "Study protocol for a single-blind randomised controlled trial to evaluate the clinical effects of an Integrated Qigong exercise intervention on freezing of gait in Parkinson's disease," *BMJ Open*, 2019, doi: 10.1136/bmjopen-2018-028869.

[7] P. R. L. Bittencourt, F. de V. Barros, C. B. Eller, C. S. Müller, and R. S. Oliveira, "The fog regime in a tropical montane cloud forest in Brazil and its effects on water, light and microclimate," *Agric. For. Meteorol.*, 2019, doi: 10.1016/j.agrformet.2018.11.030.

[8] Q. J. Almeida and C. A. Lebold, "Freezing of gait in Parkinson's disease: A perceptual cause for a motor impairment?," *J. Neurol. Neurosurg. Psychiatry*, 2010, doi: 10.1136/jnnp.2008.160580.

[9] A. Bokwa, A. Wypych, and M. J. Hajto, "Impact of natural and anthropogenic factors on fog frequency and variability in Kraków, Poland in the years 1966–2015," *Aerosol Air Qual. Res.*, 2018, doi: 10.4209/aaqr.2016.12.0580.

[10] F. S. Syed, H. Körnich, and M. Tjernström, "On the fog variability over south Asia," *Clim. Dyn.*, 2012, doi: 10.1007/s00382-012-1414-0.

CHAPTER 21

A BRIEF STUDY ON MULTI-HAZARD EARLY WARNING SYSTEM

Dipika Bhatia, Assistant Professor
Department of ISME, ATLAS SkillTech University, Mumbai, Maharashtra, India
Email id- dipika.bhatia@atlasuniversity.edu.in

ABSTRACT:

The Multi-Hazard Early Warning System (MHEWS) is an extensive method for lowering the risk of disasters that attempts to provide coordinated and timely alerts for many hazards. This study provides a summary of the importance and operation of MHEWS, emphasising its contribution to improving preparation, response, and resilience to different natural disasters. It emphasizes the significance of MHEWS in dealing with the complexity of contemporary catastrophes, which sometimes entail numerous hazards happening concurrently or quickly after one another. In order to give a comprehensive approach to catastrophe risk reduction, MHEWS aims to fill the gaps between separate warning systems. The MHEWS's components, which include effective monitoring and detection systems for a variety of hazards, including tropical cyclones, earthquakes, floods, tsunamis, landslides, and wildfires. To provide timely and accurate alerts, these monitoring systems are supplemented with platforms for data integration and analysis. This segment examines the methods of outreach and communication used by MHEWS to connect with vulnerable populations and relevant authorities. Early warnings are more effective when distributed via a range of communication channels, such as radio, social media, and community involvement. This discusses how impact-based forecasting is included into MHEWS. Communities can better grasp risks and take the necessary precautions if information about the possible effects of different hazards is made available.

KEYWORDS:

Agricultural, Forecast, Fog, Health, Weather.

INTRODUCTION

India is susceptible to several calamities to varied degrees. Nearly 5,700 km of the 7,516 km long coastline are vulnerable to cyclones and tsunamis, 68% of its cultivable area is vulnerable to droughts, and its hilly areas are at risk from landslides and avalanches. Additionally, more than 58.6% of the landmass is susceptible to earthquakes of moderate to very high intensity. We also need to be aware of the additional man-made risks that are common and seriously harm both life and property, in addition to these natural threats. It is crucial that we understand how to deal with their impacts. When dangerous weather is predicted, the India Meteorological Department (IMD) issues weather warnings. Numerous risks are often caused by one kind of weather event, and sometimes one or even two or more hazards caused by the weather coexist. Additionally, we are now taking into account the potential effects that a prospective weather threat may have on a region. Therefore, before reviewing the SOP on Multi-Hazard weather alerts, it is necessary to comprehend the definitions of several key terminology, such as "Disaster, Hazard, Vulnerability, and Risk."

Disaster

A major disturbance in the way a community or society operates those results in widespread material, economic, social, or environmental losses that are greater than what the afflicted society can reasonably expect to be able to handle on its own is known as a catastrophe. A catastrophe is the outcome of the interaction of risk, vulnerability, and a lack of resources or protective measures to lessen the likelihood of danger. A catastrophe occurs when a risk affects a population that is already at risk and results in harm, fatalities, and disturbance of their daily lives and property. Disasters thus only happen when vulnerabilities and risks combine. However, it should be highlighted that a hazard's effect decreases when community, individual, and environmental preparedness for catastrophes increases [1].

Hazard

Hazards may be divided into two major groups, namely natural and manmade, and are described as "a dangerous condition or even, that threat or have the potential to cause injury to life or damage to property or the environment."

1. Natural hazards, such as those having meteorological, geological, or even biological roots, are risks brought on by natural occurrences.
2. Hazards that are the result of human error are known as manmade hazards.

There are several dangers on the list. While some occur regularly, others just sporadically. However, they may be categorised as described based on their origin.

Vulnerability

According to one definition of vulnerability, it is "the degree to which a geographic area, community, structure, or service is likely to be damaged or disrupted by the impact of a particular hazard, due to their nature, construction, or proximity to hazardous terrains or a disaster-prone area." Physical vulnerability and socioeconomic vulnerability are two types of vulnerability.

Risk

Risk is defined as "a measure of the predicted losses resulting from a hazard occurrence happening in a particular place over a certain time period. Risk is a function of the likelihood of a certain hazardous occurrence and the losses each might bring about.

1. The nature of the risk
2. The susceptibility of the impacted components
3. The elements' economic worth

When a community or location is exposed to risks and is likely to suffer as a result of those risks, such community or locality is said to be "at risk." All actions that lessen the risk or susceptibility of the components at risk in order to prevent or minimise catastrophe-related losses of lives, property, or assets are included in disaster risk management.

Impact Assessment and Multi-Hazard Forewarning

The three main components of disaster risk management are early warning, preparation, and mitigation. Hazard projections, communication, and distribution make up early warning. IMD supports risk management in three different ways. First, we give operational decision-makers early warning of weather, water, and climate hazards; second, we support risk and impact assessments to identify who, what, and why are at risk; and third, we make a concerted effort to improve forecasts and analyses to continuously help reduce or prevent risks.

A multi-hazard warning system to improve readiness for emergencies

If authorities, people, and communities in hazard-prone regions are properly alerted using a user-friendly and simply intelligible "multi-hazard warning System," effects and losses may be significantly avoided during disasters. Through its current general forecasting system, IMD has been offering a range of weather alerts. All users are receiving the appropriate predictions from the RMC/MC forecasting centres. However, due to advancements in the forecasting and dissemination system, it is necessary to update the current Standard Operating Procedure (SOP) for a number of hazards, including thunderstorms, squall lines, gale winds, snowstorms, hailstorms, and other events that result in significant and widespread harm to people and property. So that no hazard remains unreported, the SOP document on Multi-Hazard system has been updated to include a thorough monitoring, displaying, and reporting system on all conceivable meteorological dangers, including cyclones [2].

Warning Boundaries

The agency already uses a variety of thresholds for a variety of risks. In reality, the thresholds need to be revised due to the terrain and environment of a given region, population density, urbanisation, infrastructure, industries and expensive investments, standing crops at the time of occurrence, etc., as well as the potential for hazard realisation and damage in a particular region. It is impossible to prioritise phenomena for the whole nation since each danger has a different significance for a particular place. In general, areas where mitigation activities are both feasible and urgently necessary are given more priority.

Strong Rainfall

Smaller towns on the east and west coasts are near to the eastern and western ghats, which act as quick drainage mechanisms into the open oceans, while places in the north-east are on a variety of mountainous hills. However, plain places like the Gangetic Plains and large cities like Chennai without adequate drainage systems suffer greatly from even little rainfall.

DISCUSSION

Rainstorm or squall

Squalls and thunderstorms are phenomena linked to the summer, cyclones, low pressure systems, and sometimes local weather systems. For the purpose of issuing warnings about the dangers of thunderstorms and squalls, there is a distinct SOP. To help with the Hazard analysis of thunderstorms, known TS genesis and track climatology must be developed seasonally based on radar readings in addition to other inputs like NWP.

Fishermen's caution

Cyclone Warning Centres offer warnings for fishermen based on two factors.

1. Fishermen are warned not to enter the water when low pressure systems exist that are less intense than depressions, when the Monsoon is severe, or when squalls are anticipated with wind speeds above 45 kmph.
2. High Wave/Swell Criteria: Fishermen are recommended not to enter the sea if INCOIS predicts high waves/swell waves (wave/swell wave/ with substantial wave height of 4.0m

or higher equivalent to extremely difficult sea conditions). Fishermen's advisories have a five-day expiration date [3].

Multi-hazard text message warnings

A brief text message will also be prepared from the warnings received from various forecasting centres and delivered together with the visual map to aid in swiftly deciphering the map. The text message will also be created automatically thanks to the automated program's clever design. District-based individual State maps will be created and sent to State MCs as needed.

Availability of Maps in a timely manner

The Multi-hazard alarm System should be fully automated, even if it requires constant update whenever a new alarm condition develops. Therefore, no personal involvement is needed for the final product's generation, display, or gearbox. One Hazard map, however, may be manually constructed at any convenient moment once the prediction conferences and feedback from various hazard groups are received, taking into account the trial run of the system. From that point forward, the PWS group will continually update the Multi-hazard map without a predetermined time constraint while keeping an eye out for fresh inputs [4].

System of Dissemination

The WMO Information System (WIS), the Global Telecom System (GTS), All India Radio, FM & community radio, Television, Social media (Facebook, Whatsapp, Twitter), and other print & electronic media, press conference, and press release are all used to communicate forecasts and warnings to various users. Additionally, these cautions/advice are posted on IMD's numerous websites, including www.rsmcnewdelhi.imd.gov.in and www.mausam.imd.gov.in. Interactive Voice Response System, or IVRS, is another method of warning transmission. Since July 2000, it has been in operation. This system automatically responds to requests from the general public for weather information and predictions. By calling the toll-free number 1800 220 161, one may obtain the current weather and prediction for major Indian cities. Currently, major cities' weather data is provided through a centralised IVRS [5].

IMD has recently undertaken a number of measures to enhance the transmission of weather prediction and warning services based on cutting-edge techniques and technology. Through AMSS (Transmet) at RTH New Delhi, IMD has been distributing weather and alerts by SMS since 2009. The India Meteorological Department has used "Mobile Seva" from the Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology; Government of India to develop this project. of India and Quick SMS of NIC for the SMS-based distribution of warnings and weather information to a large user base. On December 25, 2014, the SMS-based cyclone alarm system for registered users and the general public was launched. In addition to being broadcast by GTS, messages from the Global Maritime Distress and Safety System (GMDSS) are also posted on the website of the RSMC in New Delhi (URL: www.rsmcnewdelhi.imd.gov.in). The WIS Portal-GISC New Delhi is an additional mechanism for distributing cyclone warnings. The warning messages are accessible to users through the URL http://www.wis.imd.gov.in. On March 30, 2016, IMD began publishing NAVTEX advisories for the coastal area around India's east and west coasts for the use of fishermen and lightships [6].

The Regional Meteorological Centres in Chennai, Guwahati, Kolkata, Mumbai, and Nagpur, as well as CRS Pune, MTI Pune, and M.C., are the nine IMD offices. Through specialised video conferencing technologies, Bhubaneswar has been connected to the National Weather Forecasting Centre (NWFC) at the IMD Head Quarters in Delhi for daily prediction deliberations. Additionally, registered farmers are sent SMS-based alerts and cautions through the government's Kisan portal. Indian National Centre for Ocean Information Sciences (INCOIS), Hyderabad also provides information to registered fishermen on behalf of the Government of India (Ministry of Agriculture).

IMD and ISRO are collaborating to get the SMS to deep-sea fisherman via the GAMES and NAVIC systems. IMD and NEGD, Department of Electronics and Information Technology have partnered to distribute warnings using the UMANG mobile app. With effect from October 2018, IMD also opened a new cyclone warning centre in Thiruvananthapuram to enhance the distribution of advisories and alerts for the states of Kerala, Karnataka, and the Lakshadweep Islands. Additionally, IMD is collaborating with WMO and NDMA to spread the alert through CAP (Common Alerting Protocol) [7].

Use of the NDMA tool for CAP message dissemination and information flow

For the state of Tamil Nadu, C-DOT has been tasked with creating and implementing a pilot project for an early warning system for natural catastrophes based on the Common Alerting Platform (ITU-T standard x.1303). In order to provide location-specific early warning messages in Tamil Nadu, C-DOT will integrate interested stakeholders (IMD, CWC, TN-SDMA, and TSPs) on a web-based platform.

Distribution of cyclone warnings

IMD has recently undertaken a number of measures to enhance the transmission of weather prediction and warning services based on cutting-edge techniques and technology. Cyclone warnings are communicated to different users via phone, fax, email, SMS, the WMO Information System (WIS), All India Radio, FM & community radio, Television, and other print & electronic media, press conferences, press releases, and social media sites like Facebook, Twitter, etc., as well as FM radio & community radio. These cautions/advices are also posted on the IMD website, which can be found at www.rsmcnewdelhi.imd.gov.in and www.mausam.imd.gov.in.

Interactive Voice Response System, or IVRS, is another method of warning transmission. It began operating in July 2000 and is now in use. This system automatically responds to requests from the general public for weather data and predictions. By calling the toll-free number 1800 180 1717, one may get the most recent weather and prediction for the main Indian cities. The meteorological data for large cities is now provided through a centralized IVRS. Through AMSS (Transmet) at RTH New Delhi, IMD began an SMS-based weather and alarm distribution system in 2009 [8].

IMD has leveraged the Digital India Programme to make use of "Mobile Seva" from the Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology; and Government of India. for SMS-based Warnings/Weather information distribution for a diverse user base throughout India. On December 25, 2014, the SMS-based cyclone notices to registered users and the general public was launched. Anyone may register for free on the RSMC website to get SMS notifications of cyclone alerts. Registered farmers are sent the SMS-based alerts and warnings through the government's Kisan Portal. Indian National Centre for Ocean Information Sciences (INCOIS), Hyderabad also provides information to registered fishermen on behalf of the Government of India (Ministry of Agriculture) [9].

In addition to being broadcast by GTS, the Global Maritime Distress and Safety System (GMDSS) message is also posted on the website of the RSMC in New Delhi (URL: www.rsmcnewdelhi.imd.gov.in). An additional mechanism for the distribution of cyclone warnings is the WIS Portal -GISC New Delhi. The warning alerts are available to users at http://www.wis.imd.gov.in. For the operation of lightships and fisherman, IMD began providing NAVTEX advisories for the coastal zone around India's east and west coasts on March 30, 2015. Registered Fishermen get the cyclone alerts through the INCOIS Tsunami Warning Dissemination System and Potential Fisheries Zone (PFZ) Bulletins. Registered farmers in coastal zones are also informed of cyclone warnings through the Kisan portal run by the Ministry of Agriculture. from India [10].

CONCLUSION

The value of global cooperation in MHEWS, particularly in areas vulnerable to transboundary disasters like cyclones and tsunamis. Cooperation between adjacent nations improves information sharing and makes it possible to provide prompt cross-border warnings. This talks about how modern technology, such real-time data exchange, remote sensing, and artificial intelligence, might improve the performance of MHEWS. The lead periods and accuracy of early warnings are being improved via ongoing study and innovation. The difficulties MHEWS has to overcome are highlighted in the seventh part, along with issues including data sharing agreements, financing limitations, and the need for capacity development in vulnerable areas. Governments, international organizations, and key players must maintain a consistent level of commitment to overcome these obstacles. In decreasing catastrophe risks and boosting resilience to multi-hazard situations, the study emphasises the crucial role that MHEWS plays. MHEWS equips localities to take preventative action, save lives, and lessen the socioeconomic effects of natural catastrophes by delivering early and comprehensive alerts.

REFERENCES:

[1] World Meteorological Organization, “Multi-hazard Early Warning Systems: A Checklist,” in *Multi-hazard Early Warning Systems: A Checklist*, 2018.

[2] R. Mukhtar, “Review of National Multi-Hazard Early Warning System Plan of Pakistan in context with Sendai Framework for Disaster Risk Reduction,” in *Procedia Engineering*, 2018. doi: 10.1016/j.proeng.2018.01.027.

[3] C. Vitolo, C. Di Napoli, F. Di Giuseppe, H. L. Cloke, and F. Pappenberger, “Mapping combined wildfire and heat stress hazards to improve evidence-based decision making,” *Environ. Int.*, 2019, doi: 10.1016/j.envint.2019.03.008.

[4] M. Mujiburrahman, “The role of universities in Indonesia multi-hazard early warning system,” in *MATEC Web of Conferences*, 2018. doi: 10.1051/matecconf/201822902018.

[5] M. Lendholt, “Towards an Integrated Information Logistics for Multi Hazard Early Warning Systems,” *Open Environ. Eng. J.*, 2012, doi: 10.2174/1874829501205010027.

[6] G. P. Jayasiri, C. S. A. Siriwardena, S. S. L. Hettiarachchi, P. B. R. Dissanayake, and C. S. Bandara, “Evaluation of community resilience aspects of Sri Lankan Coastal Districts,” *Int. J. Adv. Sci. Eng. Inf. Technol.*, 2018, doi: 10.18517/ijaseit.8.5.7095.

[7] O. Rasquinho, Derek Leong, and Jinping Liu, “Brief Introduction to Synergized Standard Operating Procedures for Coastal Multi-Hazards Early Warning System,” *Trop. Cyclone Res. Rev.*, 2012.

[8] A. S. Handayani, A. S. Marjuki, A. W. Putra, U. Haryoko, U. Nurhayati, and A. E. Sakya, “Strengthening multi-hazards early warning system in the pacific through BMKG-UNESCAP collaboration pilot projects,” in *MATEC Web of Conferences*, 2018. doi: 10.1051/matecconf/201822904019.

[9] L. Nhamo, T. Mabhaudhi, and A. T. Modi, “Preparedness or repeated short-term relief aid? Building drought resilience through early warning in southern africa,” *Water SA*, 2019, doi: 10.4314/wsa.v45i1.09.

[10] A. Calvel *et al.*, “Communication Structures and Decision Making Cues and Criteria to Support Effective Drought Warning in Central Malawi,” *Front. Clim.*, 2020, doi: 10.3389/fclim.2020.578327.

CHAPTER 22

OVERVIEW OF URBAN METEOROLOGICAL SERVICES

Jayashree Balasubramanian, Assistant Professor
Department of ISME, ATLAS SkillTech University, Mumbai, Maharashtra, India
Email id- jayashree.balasubramanian@atlasuniversity.edu.in

ABSTRACT:

Urban meteorological services are crucial in managing the particular weather issues and effects that urban areas experience. An overview of the value and operation of urban meteorological services is provided in this study, with a focus on their usefulness for promoting climate resilience, urban planning, and public safety in rapidly expanding metropolitan regions. The effects of growing urbanisation on local weather patterns are discussed in the first part. Air pollution, altered microclimates, and urban heat island impacts are just a few of the unique meteorological phenomena that call for specialised monitoring and forecasting. The elements of urban meteorological services, such as cutting-edge weather monitoring technology, ground-based observation networks, and weather modelling systems specifically designed for urban settings, are covered in the second part. Accurately analysing and forecasting weather conditions in cities depends on these elements. The final segment looks at how urban meteorological services are used for emergency preparation and public safety. Authorities may give warnings for heatwaves, urban floods, severe temperatures, and other weather-related dangers with the support of timely and localised weather predictions. This discusses how urban meteorological services assist in urban development and planning. Designing climate-resilient infrastructure, effective transport networks, and sustainable urban settings are all aided by weather and climate data. The relevance of communication and distribution tactics in urban meteorological services is emphasised in the fifth part. Utilising a variety of platforms, such as websites, social media, and mobile applications, guarantees that locals and important stakeholders in metropolitan areas get weather information quickly.

KEYWORDS:

Air, City, Climate, Forecasting, Weather.

INTRODUCTION

Urban population growth is accelerating, and this trend is especially pronounced in emerging nations. Even though they are hubs of innovation and economic growth, congested cities confront significant problems due to air pollution, harsh weather, floods, and other dangers. Cities are becoming more and more susceptible as a result of the density, complexity, and interdependence of their urban fabric. A single catastrophic event may result in a broad failure of a city's infrastructure, typically via "domino" or cascading downstream consequences, and even the loss of significant numbers of lives.

The World Meteorological Organisation (WMO) acknowledges the need for new kinds of services that best use science and technology as a result of rising urbanization and it views the problem of providing these services as one of the top objectives for the meteorological community. Urban services in the conventional sense include things like housing, water and waste management, public health, energy, snow removal, and transportation. Urban Integrated Services, which include observational data and forecasting for weather, climate, hydrology, and air quality, are required due to the fast changing urban landscape in order to provide both conventional (and innovative) urban services in a state-of-the-art way.

Typical elements of urban integrated services should be: Observation and monitoring, data, databases, and data sharing, modelling and prediction capabilities, and customised applications for urban services are just a few. Systems for supporting decision-making that take into account human behaviour and reaction. Products, service provision, outreach efforts, evaluations of societal effects, and research and development make up the next four categories [1].

The primary components and supporting systems must cooperate:

1. The weather in particular, high impact weather for nowcast and short-range prediction at the urban and suburban scales, in all circumstances, and taking urban affects into consideration;
2. Climate urban climate, climatic extremes, sector-specific climate indices, predictions of the climate, and risk and adaptation management related to the climate.
3. Water dangers and hazards associated to hydrology urban hydrology, storm tides, high precipitation, river water stage, inundation regions.
4. Air Quality urban air quality and other more serious risks, such as smog, wildfires, and dust storms.

Systems for urban integrated services must take into account fine-scale urban observations for assimilation and model initialization, urban canopy models, urban vegetation, land use and land cover to assess both exposure and vulnerability as well as soil permeability, which may have an impact on the hazard in terms of lag time, ensemble prediction, quantification of uncertainties, and processes requiring a multidisciplinary approach.

With the advent of dense observational networks, high-resolution forecasts, multi-hazard early warning systems, and climate services supporting the Sustainable Development Goals, IMD has already taken Urban Meteorological Services as one of its priority projects to provide location-specific severe weather warnings for 110 capital cities (listed in Annexure 1), 10 major cities across the nation, and high-resolution forecasts for 110 locations.Other metropolitan areas, nevertheless, with sizable populations, are on the verge of developing into megacities. The infrastructure for megacity-focused weather services must be strengthened immediately given the growth of Indian cities [2].

State of The Observation Network at The Moment

In conjunction with the synoptic observational network, automatic weather stations (AWS), automatic rain gauges (ARG), C&S-band Doppler weather radar, vertical wind profilers, radiosondes, etc., IMD recently established a system of urban city prediction in mega, capital, and other smart cities. The list of 110 stations chosen under urban meteorology for location-specific forecasts in capital cities. In most cases, there is no quantification or precise time of the meteorological occurrences. Some offices with an established DWR monitoring site additionally provide predictions for impending severe weather occurrences (such as thunderstorms and squalls). The website also has hourly/tri-hourly updates of the most recent meteorological data for representative observatories in the cities [3].

1. Daily updates are sent to the IMD website twice and to print publications once.
2. The validity window is three days.

3. Weather phenomena, maximum and minimum temperatures, sky conditions, and forecast parameters.
4. Users: Most are local governments.

Event-specific urban meteorology services

Prolonged downpour

Impact-based alerts are part of an urban meteorological service for localised heavy rainfall events that result in flash floods. The IMD Urbanmet services now offered in the majority of Indian cities fall into the following categories:

1. Regular 6-hour local forecast updates at the sub-city level that include temperature and rainfall readings.
2. Sub-city level is now cast at least once every three hours when severe weather development is possible.
3. Impact-Based Forecast for Forecast of Heavy Rain in City.

However, if a city is connected to certain clearly defined monsoon systems, NWP models may provide signals and probabilities over it 2–5 days in advance.(iv) City-based thresholds and topography shall be taken into consideration when evaluating the effect of heavy rainfall for various regions of the city [4].

DISCUSSION

Heat wave and cold wave

Heat waves, which are defined as extended periods of high temperatures and high humidity, are well-known to be serious meteorological hazards. India has several fatalities each year as a result of heat and cold waves. However, IMD issues cold wave and heat wave alerts throughout the appropriate seasons. Please refer to section number for a more complete SOP. The temperature in the centre of the city will be different from the sub-urban region due to the urban heat island effect.As a result, the heat island effect will be taken into account when issuing heat wave warnings for metropolitan areas, and area-specific warnings will be given. It will be included in the heat action strategy for that city [5].

Lightning and thunder

It is believed that there is a need for a well-designed system or technique for monitoring, predicting, and warning of thunderstorms given the rising public awareness of the significant effect of thunderstorms and their influence on social, cultural, economic, health, defence, and transportation, among other things. The India Meteorological Department (IMD) offers consistent meteorological event monitoring, forecasting, and warning services. The thunderstorm warning will also aid in disaster management, aviation, and a novel approach to mega-city forecasting and now casting.With the aid of lightning detectors installed by the Ministry of Earth Sciences and Indian Air Force, the incidence of lightning throughout India is being tracked. There are now 203 lightning detectors in the nation (157 from the Indian Air Force and 46 from the Indian Institute of Tropical Meteorology). The lightning area from the last 10, 20, and 30 minutes is overlaid on radar and satellite images [6]. It aids in the accurate observation of thunderstorm and lightning activity as well as the forecasting of such phenomena. A GIS platform for metropolitan areas will display the lightning detectors as a warning.

Fog

One of the biggest meteorological risks, affecting aviation, road transport, the economy, and daily life in the area with the densest population in the world, is the occurrence of dense and prolonged period fog in India's northern regions. The maximum number of fog days over Northwest India is around 48 (visibility 1000m) each year, with the majority of those days falling between December and February. Because of a rise in the frequency, duration, and severity of fog occurrence across the northern sections of the nation, recent research on fog in India during the last 10-15 years have sparked serious socioeconomic worry. The goals of the Winter Fog Experiment (WIFEX) are to improve the now-casting (for the next six hours) and forecasting of winter fog on a variety of temporal and geographic scales and to lessen its negative effects on the economy, transportation, and aviation as well as the loss of life from accidents. The fog prediction for various areas of the city will take local variables into account.Please refer to section number for a more complete SOP [7].

I-FLOWS: Integrated Flood Warning System

I-FLOWS uses meteorological models, field data from numerical flood modelling, and Web GIS technologies to map flood risk in a framework for disaster risk reduction. It is a methodology for spatially explicit flood hazard mapping, as well as for combining exposure and vulnerability data to create a flood risk index (FRI). The State Government's operational decision support system for flood risk assessment and management is one of this system's primary goals. The I-FLOWS conceptual framework is as follows:

1. NCMRWF: 10-day forecast, spatial resolution 19*13 km
2. GFS: prediction for 11 days, spatial resolution of 14 km
3. WRF: three-day forecast, nine-kilometer spatial resolution

IMD issues warnings using the following colour codes, and each colour is attributed to a certain weather forecast condition according to the 5-day forecast method, following matrix, providing emphasis on the likelihood that the event will occur as well as an evaluation of its potential effects. Based on the ensemble probabilistic predictions offered by NCMRWF/IMD/IITM and several Global Centres, which are as follows, the probability of occurrence for D1 to D5 may be determined: As part of their Megacity Forecasting System, IMD has a SOP for Weather Forecasting and Heavy Rainfall Warnings. This comprises:

1. Prediction of rainfall dispersion in space
2. Probability Forecasts of Rainfall or Weather
3. Temporal Distribution of Rainfall (in the next 24 hours)

IMD issues heavy rainfall warnings based on colour codes. SWFC and RWFC provide HRW bulletins to the Central Government, State Government officials, Doordarshan, AIR, the press, and other users. The work flow will be as follows: I-FLOWS will complement the qualitative prediction provided by IMD and create quantitative forecast on expected inundation and water levels [8]. Along with discharge, HRF from the weather models (NCMRWF, IMD) will be gathered. Flood inundation models will be conducted (72 hours in advance) from upstream (if any). The ensemble probabilistic predictions supplied by NCMRWF/IMD/IITM and other Global Centres have been used to determine the likelihood of occurrence for D1 to D5. Based on model estimates, inundation/vulnerability and risk maps will be created 24 hours in advance.

Using field data, nowcast inundation maps will be created 3 to 6 hours in advance and continuously afterwards. The Megacities Forecasting Programme at IMD will make all maps and data accessible. The technology has to be expanded in additional Megacities and other cities but is now in use in Chennai and Mumbai [9].

Stakeholders

Forecast consumers in large cities vary from those who use predictions for a larger region. Here is a list of some prospective users:

1. Civic officials in charge of repairing roads, drainage systems, and dewatering water ponds.
2. Fire departments and disaster management.
3. iii.Power distribution and generating businesses,
4. Authorities in charge of organising large-scale events including sporting competitions, exhibits, feasts, and national holiday celebrations.
5. A government agency that hosts major outdoor events.
6. Print and electronic media.

The general populace.

Drinking water and sanitation, employment and welfare, education, travel, communication, and tourism, industrial facilities, and retail centres are all included in section viii.

Post-event Review

1. Within the following 24 hours, a detailed investigation of certain severe weather incidents in the city is also suggested.
2. Transport and tools for audio-visual recording are needed for this work.
3. Gathering input from various stakeholders on particular events on a regular and uniform basis.
4. Compilation of effect data in-depth following an occurrence.
5. Temporarily lent labour from RMCs or MCs with predetermined training.
6. It is suggested that urban forecasting be included in the RWFC/SWFCs that deal with short- and medium-term forecasts.

The observational network, weather forecast, the availability of suitable and sufficient trained manpower at regional stations, IT infrastructure, and effective communication between various agencies for reception/dissemination of data, information, and warnings are all necessary for the successful implementation of weather and climate services in Mega Cities [10].

1. Confirmation and criticism
2. Documentation,
3. Distribution of forecasts and warnings,
4. Documentation
5. Liaison with local government agencies.

CONCLUSION

The integration of urban meteorological services with urban management systems and smart city projects is covered in the sixth part. Cities can better allocate resources and respond to weather events by fusing meteorological data with other urban statistics. The difficulties encountered by urban meteorological services are highlighted in the seventh part, along with the necessity for stakeholder cooperation, high-density weather monitoring, and data quality verification. Investment in meteorological infrastructure and cooperation between local officials and meteorological agencies are necessary to address these issues. The conclusion of the study emphasises the crucial role that urban meteorological services play in promoting urban sustainability and resilience. These services provide a substantial contribution to public safety, urban planning, and the wellbeing of urban inhabitants in a world that is quickly urbanising by offering personalised meteorological information and climate data for cities.

REFERENCES:

[1] A. Baklanov *et al.*, “From urban meteorology, climate and environment research to integrated city services,” *Urban Clim.*, 2018, doi: 10.1016/j.uclim.2017.05.004.

[2] S. Grimmond *et al.*, “Integrated urban hydrometeorological, climate and environmental services: Concept, methodology and key messages,” *Urban Clim.*, 2020, doi: 10.1016/j.uclim.2020.100623.

[3] T. Swanson, “Consensus-as-a-service: a brief report on the emergence of permissioned, distributed ledger systems. Work,” *World Agric.*, 2015.

[4] Y. Depietri, F. G. Renaud, and G. Kallis, “Heat waves and floods in urban areas: A policy-oriented review of ecosystem services,” *Sustainability Science*. 2012. doi: 10.1007/s11625-011-0142-4.

[5] M. Z. Lubis, “Tingkat Kesukaan dan Daya Terima Makanan serta hubungannya ddengan Kecukupan Energi dan Zat Gizi pada Santri Putri MTs Darul Muttaqien Bogor,” *World Agric.*, 2015.

[6] Haonan Chen and V. Chandrasekar, “Potential role of dual-polarization X-band radar in hydrological applications,” 2014. doi: 10.1109/usnc-ursi-nrsm.2013.6524977.

[7] B. Kalsnes, V. Capobianco, A. Oen, and A. Solheim, “Phusicos project: Nature Based Solutions to reduce risk in mountain landscapes.,” *Geophys. Res. Abstr.*, 2019.

[8] P. J. Kocin and L. W. Uccellini, *Northeast Snowstorms*. 2004. doi: 10.1007/978-1-878220-32-5.

[9] S. J. Cole, R. J. Moore, A. J. Robson, and P. S. Mattingley, “Probabilistic flood forecasting for Rapid Response Catchments using a countrywide distributed hydrological model: experience from the UK,” *Geophys. Res. Abstr.*, 2014.

[10] Z. Jurić and B. Ratančić, “The Vranyczany Plateau in the Zagreb Upper Town – Projects and Controversies 1907–1970,” *Portal*, 2014, doi: 10.17018/portal.2014.15.

CHAPTER 23

A BRIEF STUDY ON MARINE WEATHER FORECASTING SERVICES

Jayashree Balasubramanian, Assistant Professor
Department of ISME, ATLAS SkillTech University, Mumbai, Maharashtra, India,
Email id- jayashree.balasubramanian@atlasuniversity.edu.in

ABSTRACT:

The effectiveness and safety of maritime activities, coastal populations, and marine ecosystems depend on marine weather forecasting services. An overview of the importance and operation of marine weather forecasting services is provided in this study, with a focus on their contribution to improving maritime safety, assisting marine industries, and encouraging sustainable coastal development. The crucial role that maritime weather forecasting plays in reducing the dangers that are presented by unfavorable weather at sea. Ship captains, fisherman, and inhabitants of coastal areas may make educated judgements and take the necessary safeguards thanks to accurate and fast maritime predictions. The elements that make up maritime weather forecasting services, such as specialized meteorological models, oceanographic information, satellite observations, and coastal monitoring networks. These elements help us fully comprehend the patterns and circumstances of maritime weather. This investigates the uses of marine weather forecasting in emergency response and maritime safety. The protection of coastal infrastructure, human lives, and boats is aided by timely warnings of tropical cyclones, storm surges, high waves, and fog. The difficulties encountered by marine weather forecasting systems, such as data assimilation, numerical model correctness, and the need for ongoing monitoring in distant ocean locations, are highlighted in the seventh part. To increase prediction accuracy and lead times, technological progress and research are needed.

KEYWORDS:

Air, City, Climate, Forecasting, Marine, Weather.

INTRODUCTION

The Marine Services Division (MSD) of the NWFC in New Delhi coordinates weather services for the maritime industry. The different warning & forecast products and the offices creating them are given below: Area Cyclone Warning Centres (ACWCs), Cyclone Warning Centres (CWCs), MSD, and others.

System for Global Maritime Distress Safety (GMDSS)

India has been selected as one of the 16 services worldwide under the Global Maritime Distress Safety System (GMDSS) plan for providing Sea area bulletins for broadcast via GMDSS for MET AREA VIII (N), which covers a significant chunk of the north Indian Ocean. The METAREA VIII N is a portion of the Indian Ocean that is bounded by lines running from the Myanmar/Thailand border at 10°N 98°30'E to the Indo-Pakistani border at 23°45'N 68°E, and then from 12°N 63°E to Cape Gardafui. The east African coast runs south to the equator, then north to 95°E and 6°N. Two GMDSS advisories are routinely released at 0900 and 1800 UTC. Additional advisories (up to 4) are sent for GMDSS broadcast during storm scenarios. the region where National Meteorological Services is in charge of issuing weather and sea area advisories.

Sending of a GMDSS bulletin

The Local Earth Station (LES) of VSNL in Noida receives the weather prediction and warning bulletin in India through email after being created by the Marine Services Division of NWFC, New Delhi, and sent to the Regional Telecommunication Hub (RTH), New Delhi. The communication is then sent to INMARSAT by them.

Availability of Broadcasts

One GMDSS bulletin for METAREA VIII (N) was first aired at 0900 UTC as per normal. A second bulletin is also aired at 1800 UTC starting in October 1998. Additional bulletins (up to 4) are also issued for GMDSS transmission during cyclone circumstances depending on the need. The NAVTEX transmitting stations in Mumbai and Chennai are also receiving weather and warning bulletins from India.

SEA Bulletin

Sea area bulletins for the Arabian Sea are issued by ACWC Mumbai and aired by the coastal radio station in Mumbai (VWB), while those for the Bay of Bengal are issued by ACWC Kolkata and broadcast by the coastal radio stations in Kolkata (VWC) and Chennai (VWM). The World Meteorological Organisation (WMO) has given India responsibility for the region covered by these bulletins. Only two bulletins, referred to as Daily bulletins, are released daily during calm weather. If deemed essential, a third bulletin called as extra is issued during weather disturbances. However, the Extra bulletin must be published after a depression has truly established. Every effort should be made to broadcast three more bulletins each day after a cyclonic storm has formed. Together with the three bulletins already stated, the three more bulletins are referred to as Storm bulletins, making a total of six bulletins every day. Storm three, or the GASBAG bulletin (1500 UTC), need to be released regularly under cyclone conditions. According to a timetable, these bulletins are transmitted at certain times. Additionally, between planned broadcasts, if any unforeseen weather development necessitates urgent communication to ships, it is aired in the form of a special bulletin called Hexagon, which should be delivered as soon as the development is recognised. Each of the bulletins has a preamble with a code word that is not intended for broadcast so that the coastal radio stations can quickly identify it when they get it [1].

Weather bulletins for the coast

Ships operating in coastal waters (within 75 km of the coastline) are the target audience for these announcements. These are issued by the ACWCs in Kolkata, Chennai, and Mumbai and the CWCs in Visakhapatnam, Bhubaneshwar, Thiruvananthapuram, and Ahmedabad for the various coastal zones within their jurisdiction. They are for the benefit of boats travelling near to the shore. The 11 coastal DOT radio stations 6 on the west coast, 4 on the east coast, and 1 in the Andaman and Nicobar Islands broadcast these messages through NAVTEX stations in simple English. Coastal bulletins for both the South Gujarat and North Gujarat coastlines are sent twice daily to ACWC Mumbai and Mumbai Radio from CWC Ahmedabad. Similar to CWC Bhubaneswar and Visakhapatnam, ACWC, Kolkata/Kolkata Radio receives the bulletins from CWC Bhubaneswar and ACWC, Chennai/Chennai Radio, respectively.

Coastal weather bulletin format

The coastal weather bulletin is released twice daily, based on 03 and 12 UTC, in normal weather, three times daily, based on 03, 12 and 18 UTC, in cases of depression/deep depression stage, and five or six times daily, based on 00, 03, 06, 09, 12 and 21 UTC, in cases of cyclone stage. The two bulletins, known as Daily One and Daily Two in the case of calm weather and corresponding to the Aurora and Balloon Sea area bulletins, are based on the 0300 and 1200 UTC charts. When Extra, Storm, or Special Sea area bulletins are published during times of disturbed weather, equivalent coastal bulletins must also be issued for the specific coast that is likely to be impacted, mandating the hoisting of signals of LC-III and higher at the ports. Additional coastal advisories for the coast are not necessary if the disturbance has little impact on the local weather along the coast. The following information is included in each bulletin (Daily, Extra, Storm, and Special), in the sequence listed below:

1. Coastal Strip's name
2. Synoptic system, if any, affects depressions and cyclonic storms' movement and the weather over the coastal strip.
3. The forecast's validity period.
4. The coastal strip's wind, weather, visibility, and sea status forecasts.
5. Details on any storm warning signals raised at ports along the affected coastal strip.
6. Information on tidal waves and storm surges as appropriate [2].

Detailed Fleet Forecast Contents

The Fleet Forecast includes warnings and a short general conclusion for the region in straightforward language. The conclusion will support the Aurora and Balloon bulletins released by ACWCs Mumbai and Kolkata in the cases of the Bay of Bengal and Arabian Sea. The prediction includes a 12-hour outlook as well as information on surface wind, visibility, and sea status. The Fleet Forecast messages have set times of origin: the daytime bulletin starts at 0800 UTC and the nighttime bulletin starts at 1700 UTC. Naval W/T station, Mumbai, broadcasts these fleet predictions during weather broadcast times starting at 0930 UTC and 1830 UTC, respectively. With the understanding that ships at sea only need wind (direction and speed) and visibility, fleet forecast messages should be concise. As a result, area forecasts should only provide these two factors and their variations. As the storm stage progresses, the centre pressure increases. Each of the two daily predictions is valid for 12 hours starting at 1000 UTC and 2200 UTC. It should be standard practise to provide an outlook for the next 12 hours in plain words from the conclusion of the forecast period in both day and night bulletins. When the weather is generally consistent, the evening prediction may be condensed by making reference to the morning forecast from the previous day.

DISCUSSION

Mode of Fleet Forecast Transmission to Naval W/T Mumbai

ACWCMumbai receives the fleet forecasts from ACWC Kolkata and MSD, New Delhi through departmental communications channels as well as emails. Through the Naval Met.Office in Mumbai, these Fleet Forecasts as well as the one released by ACWC Mumbai are sent to Naval W/T Station in Mumbai.

Alerts to Ports

Cyclone Warning Division in New Delhi issues port warnings in coordination with ACWCs and CWCs at various points along the Indian coast. Below is the office of responsibility information:

1. ACWC Kolkata: West Bengal Coast, Andaman and Nicobar Islands
2. ACWC Chennai: Tamil Nadu coast
3. ACWC Mumbai: Maharashtra coast and Goa coast
4. CWC Bhubaneswar: Odisha Coast
5. CWC Visakhapatnam: Andhra Pradesh Coast
6. CWC Thiruvananthapuram: Kerala coast, Karnataka Coast and Lakshadweep Islands
7. CWC Ahmedabad: Gujarat Coast

Signal hoisting

From April 1st, 1898, a standard system of storm warning signals was implemented at all Indian ports, and it is still in use today with very little changes. The following is a description of the system's key features:

General System

A general system with eleven signals the first two of which, signals I and II, indicate the presence of distant disturbed weather, the following eight signals, signals III through X, indicate that the port itself is threatened by bad weather, and the final signal, signal XI, indicates that communication with the ACWC/CWC has broken down and that, in the opinion of the local Port Officer, there is danger of bad weather. Signs No. In contrast to the other signals, I and II are referred to as distant signals. The ports used by this signalling mechanism are referred to as General Ports.

Extended System

The location of the disturbance is indicated by an Extended System, which contains six Section signals in addition to the eleven General System signals (Details are provided in the Cyclone Manual). Along with Distant Signals, these extra signals are raised. Only a few ports on the east coast (Bay of Bengal) employ this system, which is a specific example of the General System. Sagar Island, Kakinada, Chennai, Cuddalore, and Nagapattinam are among these ports. Extended Ports are the name of these ports. On the west coast, there isn't a port covered by the Extended System.

Brief System

These ports are known as Brief Ports. A Brief System of portwarning, which uses just five of the General Systems' signals (namely, Signal Nos. III, IV, VII, X, and XI), is also in use at ports that are primarily used by smaller vessels engaged in local commerce. These are raised in anticipation of potential poor weather at the port itself brought on by marine disturbances.

Signalless Ports

Additionally, there are a few tiny ports known as Ports without signals that get a certain form of warning message despite not having any signals hoisted at all. These ports are classified as Brief ports for warning reasons, and when bad weather threatens them, appropriate port alerts are sent even if it is not encouraged to hoist signals. These alerts will include details on the disturbance's location, magnitude, and direction of travel, as well as the predicted meteorological conditions over the port.

The India Meteorological Department has a port warning service via which port authorities are telefaxed alerts regarding weather disturbances that are likely to impact their ports (through the ACWCs/CWCs). The port officers hoist the necessary visual signals conspicuously on signal towers so they are visible from a distance as soon as they get the warning message from the ACWC/CWC. The meaning of these signals is often known by mariners and other seafarers, including fisherman who may not be literate, and the port authorities are always prepared to explain them when required. Some ports openly publish the meanings of the signals on a notice board in both English and the local languages. The port officials organise the signal display while the India Meteorological Department is in charge of giving warnings. The port officials often make preparations for informing country boats and sailing vessels in the harbours of the warnings they receive in addition to raising the signals [3].

Issue frequency and port warning bulletin content

During cyclonic storm seasons, telefax warnings are sent to ports in the maritime States five to six times each day. The warnings include details on the storm or depression's position, strength, and predicted progress as well as the region of the coast where it is anticipated to make landfall and the sort of signal that the port should hoist. There is a provision for utilising state and interstate police W/T channels whenever possible for transmitting the alerts since landline contact between the port and the CWC may fail during a cyclone.

Significance of Signals

The table above provides the definitions of the different signals. The official book Code of Storm Warning Signals for use in Indian Maritime Ports, Sixth Edition, 1984 provides specifics on the requirements of the visual signals used during the day and light signals used during the night.

Far Signals: Brief ports do not hoist far signals; only General and Extended System ports do. There are two remote warning signals: remote warning signal No. As well as Distant Warning Signal No. II, or DW II. When a depression or deep depression is present at sea, DC I is hoisted at a port; although the local weather at the port is unlikely to be adversely impacted right away, ships leaving the port may encounter hazard on their journey.

Therefore, caution must be used while determining the likelihood of such an event, keeping in mind the weather system's distance from the port and its predicted direction and speed of motion. when the storm has formed but the system is still at sea. Long-range Warning Sign No. It is time to hoist II (DW II). The proper local signal should be raised instead of the distant signals if there is a chance that the port may experience adverse weather. Because of this, when a port with a far signal is likewise anticipated to experience squally weather even while the depression or storm is still far away, changing the distant signal to LC-III will be the logical course of action. In the event that squally weather is predicted at the port where the Distant signal is to be hoisted, nothing prevents raising the LC-III there. The highest numbered signal is often hoisted when the weather calls for more than one. When a disturbance from the Bay is traversing the peninsula and may intensify into a depression or cyclone after entering the Arabian Sea, the Distant signal is also hoisted at Arabian Sea Ports, unless one of the Local signals is more suitable and hoisted [4].

Sections Signals: A proper Section (or Locality) signal has to be hoisted whenever a Distant signal (DC I or DW II) is hoisted at an Extended port. The Bay of Bengal has been separated into six parts for Locality signals, as shown below:

Section I: North Bay area to the north of Lat. 18½°N

Section II: West Central Bay – lies south of I and is bounded on the south by Lat. 13°N and on the east by Long 88½°E.

Section III: East Central Bay – lies south of I and east of II. It is bounded on the south by Lat. 13°N and on the east by a line from the point, Lat. 13°N, Longitude 93°E to Diamond Island, the Arakan Coast and thence up to Lat. 18½°N.

Section IV: Southwest Bay – lies south of II, and west of Longitude 86°E

Section V: Southeast Bay – lies east of IV, south of II, III and west of Long. 93°E.

Section VI: Andaman Sea – lies east of III and V. The southern boundary for Sections IV, V and VI is lat. 5°N.

Change in Section Signals: Even if there are no other significant changes, the section signal will change when the system's centre shifts from one section to another. Similar to this, Section signals must be repeated in the message if DC I is changed to DW II or vice versa, even if the Section signal(s) remain the same.

The locality signal number often corresponds to the region where the storm's or depression's centre is located. However, if the centre is close to the division border, two Locality signals must be hoisted, the first of which must indicate the division in which the centre is truly located and the second must indicate the division that is closest to the first. Three Locality signals are requested to be hoisted in the case that a storm centre is close to the intersection of three divisions. The first signal indicates the division in which the storm is anticipated to be centred, the second the closest neighbouring division, and the third the remaining division. For instance, Storm Centre Locality Signals Lat. - Long 16oN. the 86°E II Lat. - Long 16°N. The 88°E II and III Lat. - Long 16°N. III and II Lat are 89°E. Longitude: 18°N. 8712°E I, II, and III Lat. - Long 19°N. 80E I, III, and II

The third local cautionary signal (LC-III) is one that is commonly shown at the ports. It is raised in a port where stormy weather is most likely to occur. Squally weather refers to persistent types of strong gusty winds (mean wind speed not less than 20 kt.) accompanied by rain or infrequent or frequent squalls with rain. Such circumstances are related to low pressure systems or the beginning and intensification of the monsoon. more than 33 kt average wind speed. signals greater than LC-III is often used to cover signals related with cyclonic storms. The term usually in the preceding phrase has the purpose of allowing the hoisting of LC-III at ports outside of the inner storm region when wind speeds may surpass 33 kt [5].

In the event of squally weather connected to the monsoon, the usual rule that LC-III shouldn't be kept up for too long has to be amplified. It should be raised to LC-III. When the first advance of the monsoon is predicted to bring squalls to the port; Anytime the monsoon is predicted to intensify noticeably after a period of mild or moderate monsoon, resulting in related noticeably stormy weather at the port. If these factors govern the situations in which this signal is hoisted, it follows that the signal should also stay hoisted for while long the port is still at risk of squalls. The standard used to lift LC-III under condition.

The projected wind speed, according to (c) above, should be 30 kt. and more. To reduce the number of times the LC-III will need to be lifted, a minimum limit of 30 kt has been chosen. In all such communications, "markedly squally weather" should be used. When a port is advised to hoist LC III or to maintain LC III hoisted, a mention of the possibility (or continuation) of squally weather at the port should be included in the message, such as Squally weather likely (or to continue) at your port next hours. But while sending signals to lift higher signals. The accompanying weather in these situations is to be assumed by the port officer because no such explanation is offered.

When a cyclonic storm has actually developed, Local Warning Signal Number Four (LW IV) is raised in ports that may subsequently be impacted by the storm because it is often possible to detect the formation of a storm before it can be known how it will move. It is a preliminary stage when the system's motion cannot yet be determined with precision and heralds the potential for later-appearing Danger or Great Danger signals. It is clear from the signal's specificity that LW IV isn't connected to any specific weather severity on its own. LW IV will be replaced by Danger or Great Danger signals as appropriate at the ports expected to be directly affected by the storm and LC-III at ports where squally weather associated with the storm is expected to prevail once the direction of movement becomes clear (i.e. when the coast and the ports where the storm will strike are indicated in the sea area bulletin).

Danger and Great Danger Signals: When a storm has a mild to moderate strength, danger signals are raised, and great danger signals are raised. Not the strength or severity of the weather in various sections of the cyclone, but rather the intensity of the storm at and around its centre. Given the situation, hoisting Great Danger signals at some ports and Danger signals at other ports at the same time to indicate the cyclone's changing intensity at various ports is in conflict with the signals' current requirements. In addition to Danger or Great Danger signals being hoisted at ports that may be impacted by the inner storm region (where wind speeds may exceed 33 kt), LC-III may also be hoisted simultaneously at ports outside the inner storm area if it is deemed essential [6].

Several general guidelines for signals

Signals Must Strictly comply to System Intensity: Signals must, in general, strictly comply to the system's current intensity. If a quick development is anticipated, the office should keep a close eye on things based on the unique observations and make any required adjustments as they arise. Depending on the system's intensity, they (the signals) are stepped up or down as needed.

Common Progression of Signals:

The Distant Cautionary (DC I), Distant Warning (DW II), Local Warning (LW IV), and Danger or Great Danger are examples of common signal progressions. A verbal explanation of the transition of the system from a depression or region of squally weather or disturbed weather to a storm must accompany the move from Cautionary to Warning during such a series of signals. However, this development does not supersede the custom of having LC III with the storm declaration at ports that are not in the path of the storm but may still encounter squally weather.

If the situation calls for it, this development does not also exclude a two-stage change in signal, such as moving DW II to Danger or LC III to Great Danger. In a similar vein, nothing prevents replacing a current Danger/Great Danger signal with LC-III when the danger to the port has been eliminated by the system moving away but stormy weather is still expected to continue to linger over the port for a while.

Signals not to be Hoisted for Longer Than required:

In order to avoid negatively affecting port operations, signals should not be hoisted for longer than is required. In general, it is permissible to drop down from a Danger signal to an LC-III or no warning at all while a storm is approaching or has already passed the coast depending on whether a gradual return to normal weather is anticipated or one that will happen rapidly. The necessary signals may be maintained hoisted at that port while the system is over land and the port is predicted to continue to suffer adverse weather with the same intensity [7].

Informative communications owing to Steep Pressure Gradient: Informative messages are sent to ports informing them of the presence of steep pressure gradients and severe winds, but no alerts are raised. But according to custom at ACWC Kolkata, CWC Bhubaneswar, ACWC Mumbai, and CWC Ahmedabad, LC-III is also hoisted in such circumstances [8].

Informative Messages for Brief Ports: Informative messages are also delivered to Brief ports when disturbances at sea are anticipated to influence the ports during the next 48 hours without any recommendation to hoist any signals.

Text of Warnings to Ports: Warning messages including pertinent sections of maritime area bulletins and instructions to hoist the appropriate signals should be sent to ports under the General, Extended, and Brief systems. The radio weather signals sent to vessels are typically expected to match the port warning warnings. As soon as the system is detected by the radars at Paradip, Machilipatnam, Visakhapatnam, and Bhuj, the CWCs at Bhubaneswar, Visakhapatnam, and Ahmedabad will begin issuing port warnings and taking other appropriate action based on the bulletins issued by the ACWCs at Kolkata, Chennai, and Mumbai. From the stage of cyclonic storm forward, the core pressure of the system is also included in the port warning signals for the benefit of ships resting at ports that may not receive sea area bulletins. To prevent transmission mistakes, the number of the signal to be hoisted is provided in simple language. The same process should be followed for additional data like the latitude and longitude of the storm's centre, among other things. Keep Signal Number Hoisted should be specified in all communications to ports after the one advising the hoisting of a signal until the signal is lowered or replaced by another signal. Ports that don't [9]

Signals also get warnings when a disturbance puts them in danger from bad weather. These communications may resemble those sent to neighbouring ports using signals and will briefly describe the position and movement of the system as well as the anticipated weather over the ports. The only message that is left out is the instruction to hoist any signal. Port warning messages are often transmitted via fax when being sent to ports. Additionally, calls are made right once to port officers to inform them of the erratic weather at their ports. In the following situations, Police W/T facilities can be used to transmit port warning messages to ports with Police W/T stations: (i) when the meteorological telecommunication channels have either failed or (ii) when there is a chance that the messages will be unduly delayed [10].

CONCLUSION

The relevance of maritime weather forecasting for the preservation and protection of marine environments is emphasised in the fifth part. The management of marine resources and the preservation of marine ecosystems are aided by forecasts of ocean currents, sea surface temperatures, and toxic algal blooms. The techniques used for data exchange and international cooperation in maritime weather forecasting services are covered in the sixth part. Collaboration between research organisations, marine authorities, and meteorological agencies makes data sharing easier and improves overall maritime safety. In promoting maritime safety, assisting marine businesses, and protecting marine ecosystems, the study highlights the crucial significance that marine weather forecasting services play. These services provide a substantial contribution to sustainable coastal development and a resilient marine environment by offering the maritime community dependable and easily available meteorological information.

REFERENCES:

[1] R. May, D. Soroka, W. Presnell, and B. Garcia, "Marine weather forecasting in the national weather service," *Mar. Technol. Soc. J.*, 2015, doi: 10.4031/MTSJ.49.2.12.

[2] A. Schiller *et al.*, "Bluelink ocean forecasting Australia: 15 years of operational ocean service delivery with societal, economic and environmental benefits," *J. Oper. Oceanogr.*, 2020, doi: 10.1080/1755876X.2019.1685834.

[3] N. Rajesh Kumar and N. R. Raajan, "A mysterious pattern generation scheme for satellite images based on visual cryptography," *Far East J. Electron. Commun.*, 2016, doi: 10.17654/EC03010079.

[4] C. Guiavarc, H, J. Roberts-Jones, C. Harris, D. J. Lea, A. Ryan, and I. Ascione, "Assessment of ocean analysis and forecast from an atmosphere-ocean coupled data assimilation operational system," *Ocean Sci.*, 2019, doi: 10.5194/os-15-1307-2019.

[5] J. R. Siddorn *et al.*, "Research priorities in support of ocean monitoring and forecasting at the Met Office," *Ocean Sci.*, 2016, doi: 10.5194/os-12-217-2016.

[6] K. G. Sandhya, T. M. Balakrishnan Nair, P. K. Bhaskaran, L. Sabique, N. Arun, and K. Jeykumar, "Wave forecasting system for operational use and its validation at coastal Puducherry, east coast of India," *Ocean Eng.*, 2014, doi: 10.1016/j.oceaneng.2014.01.009.

[7] T. Renko, P. M. Jurković, L. Kalin, T. Hojsak, M. Mokorić, and T. Kozarić, "The Weather Warning System in Weather and Marine Analysis and Forecasting Sector of the Croatian Meteorological and Hydrological Service," *Hrvatski Meteoroloski Casopis*. 2019. doi: 10.37982/hmc.54.55.1.1.

[8] D. B. Kiktev *et al.*, "Development of forecasting technologies for meteorological support of the Sochi-2014 Winter Olympic Games," *Russ. Meteorol. Hydrol.*, 2013, doi: 10.3103/S1068373913100014.

[9] P. A. Jacobs, "National Weather Service modernization," *Sea Technol.*, 1997.

[10] C. Rautenbach, M. A. Barnes, D. W. Wang, and J. Dykes, "Southern african wave model sensitivities and accuracies," *J. Mar. Sci. Eng.*, 2020, doi: 10.3390/jmse8100773.

CHAPTER 24

A BRIEF STUDY ON METEOROLOGICAL COMMUNICATION AND EARLY DISSEMINATION

Agnijit Tarafdar, Assistant Professor
Department of ISDI, ATLAS SkillTech University, Mumbai, Maharashtra, India
Email id- agnijit.tarafdar@atlasuniversity.edu.in

ABSTRACT:

Enhancing public safety, disaster preparation, and climate resilience all depend heavily on meteorological communication and the prompt distribution of weather information. This study offers a summary of the relevance and operation of meteorological communication systems, highlighting the critical role they play in the prompt and efficient transmission of weather predictions, advisories, and warnings to the public and relevant authorities. It is explained how crucial meteorological communication is in giving people, communities, and different sectors accurate and trustworthy weather information. Weather predictions and warnings that are promptly distributed allow for proactive decision-making and risk reduction. This examines the elements of meteorological communication systems, which include diverse media channels including radio, television, internet, mobile apps, and social media platforms. These channels cater to a variety of user demographics, making sure that weather information reaches the target audience quickly and clearly. The incorporation of early distribution techniques in meteorological communication systems is examined in the third part. Impact-based forecasting and warning systems allow weather information to be shared in a manner that emphasises possible effects on people, property, and vital infrastructure. The value of cooperation and collaboration among meteorological organisations, disaster management organisations, and other stakeholders in creating successful communication strategies. Collaboration and information exchange improve early dissemination initiatives' overall efficacy.

KEYWORDS:

Communication, Forecast, Meteorological, Safety, Weather.

INTRODUCTION

All catastrophic crises and crisis situations are by their very nature chaotic and extremely dynamic, causing disarray on all levels physical, psychological, and social. At all stages of disaster management in such crisis's situations and catastrophes, rapid information dissemination to all stakeholders is essential. Numerous strategies are used in communications during severe weather events to reduce dangers to people and the environment. Early warning is made feasible by disseminating data from many data sources, including as surface, upper air, satellite, radar, and remote sensing observations, among others. Telecommunications may be used to spread information about looming dangers before catastrophes occur, enabling both individuals and government organisations to take the appropriate safety precautions and mitigation measures [1].

Major weather events like tropical cyclones, earthquakes, heavy rain, floods, drought, and heat/cold wave warnings are communicated to various users via phone, fax, e-mail, SMS, the Global Telecom System (GTS), the WMO Information System (WIS), All India Radio, FM & community radio, Television, Social media (Facebook, Whatsapp, Twitter, Youtube, Instagram), and other print & electronic media, press conference, and press release. These cautions/advice are also posted on the websites of the relevant IMD HQs, MCs, and CWCs (www.rsmcnewdelhi.imd.gov.in and www.mausam.imd.gov.in). Interactive Voice Response System, or IVRS, is another method of warning transmission. It began operating in July 2000 and is now in use. This system automatically responds to requests from the general public for weather data and predictions. By calling the toll-free number 1800 220 161, one may get the most recent weather and prediction for major Indian cities. Currently, major cities' weather data is provided through a centralised IVRS. The transmission of weather prediction and warning services using the most contemporary methods and technology has been improved via a number of recent efforts by the India Meteorological Department.

Through AMSS (Transmet) at RTH New Delhi, IMD has been distributing weather and alerts by SMS since 2009. The India Meteorological Department has used "Mobile Seva" from the Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology; Government of India to develop this project. for SMS-based Warnings/Weather information distribution for a diverse user base throughout India. On December 25, 2014, the SMS-based cyclone alarm system for registered users and the general public was launched. In addition to being broadcast by GTS, messages from the Global Maritime Distress and Safety System (GMDSS) are also posted on the website of the RSMC in New Delhi (URL: www.rsmcnewdelhi.imd.gov.in). An additional mechanism for the distribution of cyclone warnings is the WIS Portal -GISC New Delhi. The warning messages are accessible to users through the URL http://www.wis.imd.gov.in. On March 30, 2016, IMD began publishing NAVTEX advisories for the coastal area around India's east and west coasts for the use of fishermen and lightships.

Additionally, registered farmers are sent SMS-based alerts and cautions through the government's Kisan portal. Indian National Centre for Ocean Information Sciences (INCOIS), Hyderabad also provides information to registered fishermen on behalf of the Government of India (Ministry of Agriculture). IMD is also collaborating with ISRO to send SMSs to deep-sea fishermen via the GAMES and NAVIK systems. IMD is also collaborating with WMO and NDMA to send warnings via CAP (Common Alerting Protocol). IMD is also collaborating with NEGD, Department of Electronics and Information Technology to send warnings via the UMANG mobile app. With effect from October 2018, IMD also opened a new cyclone warning centre in Thiruvananthapuram to enhance the distribution of advisories and alerts for the states of Kerala, Karnataka, and the Lakshadweep Islands [2].

AMSS, or Automatic Messaging Switching System

The India Meteorological Department has a fairly robust communications infrastructure, including four regional automatic message switching systems (AMSS) at airports in Palam, Kolkata, Mumbai, and Chennai, as well as a regional telecom hub (RTH) at Mausam Bhavan, New Delhi.

Data Transfer of AMSS

Through RTH New Delhi, these Four AMSS are linked to the GTS (Global Telecommunication System), the WMO's main centre. On the Main Telecommunication Network (MTN) of the GTS, RTH New Delhi is one of the 15 RTHs and three World Meteorological Centres (WMCs) designated for the international exchange of meteorological data and products. The AFTN (Aeronautical Fixed Telecommunication Network) is also linked to these six AMSSs for the exchange of operational meteorological messages (OPMET). These AMSS are therefore charged with gathering and exchanging meteorological data and products from the various observatories, meteorological centres (MCs), meteorological offices (airports), radar stations (i.e. DWR), and other institutions under their control, as well as to WMO/ICAO member countries through the RTH New Delhi / AFTN network.

DISCUSSION

IMD, a leading national supplier of meteorological services, offers meteorological support to all aviation operators at all of the main airports. Through specialised automated pre-flight information systems for briefing, consultation, flight planning, and flight documentation (OLBS) from AMO Palam (Delhi) & AMO Chennai from 2012-2013, IMD is further offering aviation meteorological services to the aviation operators.

Primary Communication System Components -

Central Information Processing System (CIPS): A sophisticated database management system with a task centre for creating, experimenting with, and implementing meteorological tasks for the production of meteorological products in real time.

Transmet: Automatic Message Switching System (AMSS) for receiving, examining, and routing meteorological data and products in accordance with WMO standards and regulations.

Public Weather System (PWS): Provides end users with high-quality weather information and warnings, such as print and television media.

Clisys: System for storing climatological data with scalable management tool for optimal use of this data.

Synergy: A system that helps forecasters make decisions by collecting, visualising, interacting, and adding value to meteorological predictions and products.

The Mirror RTH in Pune is operational as a Disaster Recovery Centre (DRC), which may assume all of the duties of RTH New Delhi in the event of an emergency there. The WMO WIS GISC for South East Asia will also operate out of this, and it will provide all data needed for Indian users and all other WMO GISC centres in real time, with a 24-hour cache for all data.

Data availability

Past 24-hour data is provided in RTH/AMSS in accordance with WMO criteria. No user receives data directly from RTH/AMSS. All NHMS of WMO member nations get real-time data.

VPN Connections

With IPVPN connection, fifty-seven IMD stations are linked at rates ranging from 512 kbps to 10 mbps. At different out stations, Doppler weather radar sites, AMSS centres, and regional centres, these VPN circuits are linked to Synergie Systems.

IVRS

The India Meteorological Department has been offering its services to the general public by giving out weather-related data, forecasts, alerts, and warnings, including updates on earthquakes. For the last fifteen years, the IVRS facility of IMD has effectively provided weather services on the telephone, catering to the weather information of key cities in India, in order to better serve the general public. Currently, major cities' weather and air quality information is provided through a centralised IVRS. By calling the toll-free number 1800 220 161, one may get current weather information, forecasts for important Indian cities, and information on the air quality in a few particular locations.

Website Services

IMD HQ now has two separate 150 Mbps Internet lease lines from various Internet service providers. For internet access, data sharing inside Close User Groups (CUG), video conferencing, and Telepresence services, IMD is additionally linked to a 1 Gbps NKN (National Knowledge Network) connection of NIC. The new updated LAN, equipped with the most cutting-edge technology, has more than 1500 nodes to support the increasing volume of data/product flow without interruption at IMD HQ. In the new set up, DGM Building (MausamBhawan), Sat. Met. Building, Workshop, DDGM (UI), RMC modern Delhi, Trainee's Hostel and EREC Building linked under ring utilising modern technology switches with support for 10 Gbps optical fibre backbone to enable high availability of LAN as well as large volume of data traffic [3].

Maritime Global Distress and Safety System

For Meteorological Area VIII (N), India has been recognised as an issuing authority under the GMDSS programme. This includes the region of the Indian Ocean bounded by the lines running from the border between India and Pakistan at 23°45'N 68°E, 12°N 63°E, and Cape Gardafui; the east African coast south of the equator, then 95°E to 6°N, and finally the border between Myanmar and Thailand at 10° N 98° 30' E.

Two GMDSS bulletins for Met are sent daily by the India Meteorological Department. One at 0900 UTC and the other at 1800 UTC in Area VIII(N). Additional bulletins (4) are also issued for GMDSS transmission throughout the cyclone season based on the need. GMDSS: The International Maritime Satellite Organisation (INMARSAT) runs a system of geostationary satellites that are intended to expand phone, fax, and data communications globally. Station Earth (LES) on the ground at Gaziabad.

IS (World Information System)

The only globally coordinated infrastructure in charge of managing communications and data is the WMO Information System (WIS). It is the cornerstone of the WMO's 21st-century plan for managing and disseminating meteorological, climate, and water information. To meet the needs for routine collection and automated dissemination of observed data and products, as well as data discovery, access, and retrieval services for all weather, climate, water, and related data produced by centres and Member countries in the framework of any WMO Programme, WIS offers an integrated approach that is suitable for all WMO Programmes.

A more advanced information system called WIS is capable of transferring vast amounts of data, including from new satellite and ground-based systems, numerical weather prediction models with greater resolutions, and hydrological models and their applications. National disaster agencies must have access to these data and products as well as the National Hydrological and Meteorological Services in order to provide more timely notifications as required. Regardless of location, WIS will serve as the essential backbone for data communications, combining various real-time and non-real-time high priority data types. The three kinds of centres that make up the core infrastructure of WIS will be identified as existing centres within WMO Member States that meet the necessary WIS functions and technical requirements:

Online Briefing System (OLBS) in Delhi (Palam) and Chennai

IMD, the only authorised supplier of meteorological services, offers meteorological services to all aircraft operators at all significant airports. Prior to 2008, the service was manually delivered; however, 2008 saw a test conversion to online services. IMD began providing online meteorological services using specialised OLBS from AMO Palam and AMO Chennai in 2012-2013 as a result of the service's positive feedback from aviation operators.

Indian Meteorological Department's Warning System

IMD, India's meteorological agency, publishes alerts and warnings for severe weather conditions such tropical cyclones, thunderstorms, and heavy rain, among others. The warning system consists of a three-tier system, with warnings and forecasts issued at the national, regional, and state levels by the National, Regional, and State Weather Forecasting Centres (NWFC/RWFC/SWFCs), the Cyclone Warning Division in New Delhi, the Area and Local Cyclone Warning Centres (ACWCs), the Flood Meteorological Offices (FMOs), the Seismological Division in New Delhi, among other entities. Different alerts are intended for various stakeholders, including ports, hydrologists, fishermen, mariners, and national and state level disaster management authorities, civil administrators, and NGOs participating in disaster management. The methods of warning distribution change periodically based on developments in the IT sector, and at the moment alerts are sent by email, fax, website, etc. Public alerts are released through the press, SMS, radio, and television media in addition to IMD websites. Additionally, it changes based on the stakeholder and the danger kind [4].

Information Technology Infrastructure

The Regional Telecommunication Hub (RTH) in New Delhi is connected to the GTS network via 18 international lines. It maintains 6Mbps IPVPN links with Tokyo, Moscow, Beijing, Toulouse, Exter, and Offenbach while 150 Mbps internet (at the New Delhi end) is used for Yangon, Oman, Colombo, Male, Bhutan, Kathmandu, Cairo, Jeddah, and Melbourne. Other international connections run at 64 Kbps leased lines in Bangkok, Dhaka, and Karachi.

The India Meteorological Department serves as the National Meteorological Telecommunication Centre (NMTC), and it maintains specialised networks for exchanging meteorological data and information with other centres. The current principal communication connection for the whole country is IPVPN, which offers 10Mbps at NMTC New Delhi and 512Kbps/1Mbps at several additional centres and radar stations. For continuous data interchange, an 8Mbps leased connection with the Indian Air Force (IAF) and a 2Mbps link with the Indian Navy (IN) have been built. Additionally, a 1Gbps NKN CUG connection for information sharing has been created with NCMRWF, IITM, INCOIS, and other MoES institutions [5].

IMD's Telecommunications Infrastructure

Half-hourly INSAT photos, surface and upper air data, aerodrome prediction, weather charts, model outputs, etc. are among the meteorological data and processed products transferred through GTS. In order to provide data in GRIB/BUFR format for wind/temperature and significant weather charts, four international airports in India receive aeronautical meteorological information via a receive-only satellite data dissemination system (SADIS) that is in operation in New Delhi. This information is used for national and international flight briefings.

Network for Video Conferencing

The HQs, RMCs, and MCs have been given CISCO WebEx cloud-based desktop videoconferencing licences. Each licence allows for the creation of two concurrent VC rooms, each with a 1000 participant cap. Each license's administrator has the option to customise the VC schedules. Here is a list of all current licences [6]

IMD's Website

The India Meteorological Department primarily maintains two Websites with the URLs http://www.mausam.imd.gov.in and http://www.rsmc.imd.gov.in that both include static and dynamic information relating to forecasts and warnings. The first page of the website has a full analysis of every cyclone, heat wave, and cold wave warnings. IMD websites are a wealth of knowledge for the general population. The IMD website frequently updates all satellite imagery, radar imaging, NWP products, nowcast imagery, cyclone warning, etc. for the general public to provide current information at regular intervals [7].

EPBAX

On its campus, IMD has an AIRTEL CENTREX system installed at MausamBhawan in various office/sections throughout its six major buildings, as well as a workshop, guest rooms, and some sparse telephone connections. There are 400 functional extensions on the system, including direct dialling lines. Senior IMD officials' phone numbers and email addresses are included in Annexure-I.

FTP Server

The FTP service owned by the Information System and Services Division allows users to share real-time meteorological data. Utilising the allowed credentials, the user may upload and download the data. To get the credentials for accessing the data, the user may email the following address: rthnewdelhi4@gmail.com, noting the specific needs as well as the name of the organisation, etc.

ICITC

For the HR development of IMD personnel, ICITC provides training in IT, meteorological instruments, and telecommunications. In order to teach IMD staff, a structured training programme was established in 1977. Midway through the 1970s, training for upper air instrumentation and meteorological telecommunication began in New Delhi. The WMO Executive Council authorized the designation of the India Meteorological Department's training facilities in New Delhi and Pune as the WMO Regional Meteorological Training Centre (RMTC) for the Regional Associations II (Asia) & V in 1986 during its 38th session [8].

Commitments

Departmental commitment: To provide IMD employees with training at all levels, including initial training for newly hired departmental officials and staff.

Additional departmental/national commitment: To train personnel from other Government of India Organisations in sophisticated instrumentation.

International commitment: As part of the WMO regional cooperation project, operational meteorologists from neighbouring countries in the RA-II and V area will get training at various levels.

Continuing Education and Training Programme (CET): Periodically providing engineering students with summer and winter training

Faculty development: RTC New Delhi offers a variety of training courses for faculty development to keep their knowledge, skills, and attitudes current. RTC offers the following training programmes in order to uphold its commitments:

Common Courses

1. Level-I Course in Information Technology and Meteorological Telecommunication (3 months)
2. Intermediate Training Course in Meteorological Instrumentation and Information Systems (4 months total, including 1 month of independent study and 3 months of in-person instruction)
3. Six-month Advanced Training Course in Meteorological Instrumentation and Information Systems (one and a half months of self-study and four months of classroom instruction)
4. Meteorologist Grade II (Sc. B) Instrument Training Course, Second Semester [9]

Quick-term courses

1. One-month introduction to IT and meteorological telecommunication techniques
2. Three-week long short course in mechanics or radio mechanics
3. Short-Term Course in IT and PC Applications Fundamentals (1 Month)

In addition, RTC organises outreach programmes to educate various stakeholders, such as school, college, and university students and trainees, about the various equipment used for meteorological observation and transmission of cumulative information. A significant volume of practically all data kinds and associated products may now be sent quickly and reliably thanks to IMD's communication solutions. For forecasters, disaster managers, and others, this is very helpful. To improve services, new technology must be used, bandwidth must be increased, and numerous systems must be continually monitored for answers and input. The explanation above makes it abundantly evident that the meteorological communication system is essential for forecasting and information distribution to the general public and authorities involved in disaster mitigation in order to reduce the losses in terms of lives and property [10].

CONCLUSION

The importance of public education and community involvement in meteorological communication is emphasized in the fifth part. People and communities may better comprehend weather threats and take the necessary precautions thanks to educational activities, public outreach projects, and weather preparation campaigns. The need to reach vulnerable groups, linguistic difficulties, and restrictions in communication infrastructure in distant places are some of the problems discussed. To meet these problems, communication methods must be inclusive and imaginative. The technical innovations that help improve the effectiveness and dependability of meteorological communication and early dissemination are highlighted in the seventh part. These innovations include automated message systems and real-time data exchange. The crucial role that meteorological communication and early dissemination play in promoting weather resilience and public safety. These systems enable people, communities, and decision-makers to be more resilient to climate change and better prepare for weather-related calamities by delivering easily available and understandable meteorological information.

REFERENCES:

[1] Z. W. Shilenje and B. A. Ogwang, "The Role of Kenya Meteorological Service in Weather Early Warning in Kenya," *Int. J. Atmos. Sci.*, 2015, doi: 10.1155/2015/302076.

[2] M. Mohapatra and M. Sharma, "Cyclone warning services in India during recent years: A review," *Mausam*. 2019. doi: 10.54302/mausam.v70i4.204.

[3] A. Ardalan *et al.*, "Evaluation of golestan province's early warning system for flash floods, Iran, 2006-7," *Int. J. Biometeorol.*, 2009, doi: 10.1007/s00484-009-0210-y.

[4] N. Senaratna, M. A. Baudoin, A. A. Oluoko-Odingo, L. Ajuang, D. W. Wepukhulu, and A. S. Mwadali, "Natural hazards and climate change in Kenya: Minimizing the impacts on vulnerable communities through early warning systems," in *Reducing Disaster: Early Warning Systems for Climate Change*, 2013. doi: 10.1007/978-94-017-8598-3_19.

[5] L. D. Saraswati, "Pembuatan Reghuca (Red Velvet Sorghum Cake) Dengan Subtitusi Tepung Sorghum," 2019.

[6] A. E. Retamar *et al.*, "HydroMet: Deployment of a large scale nationwide hydrometeorological sensor network for flood warning and monitoring," in *GHTC 2017 - IEEE Global Humanitarian Technology Conference, Proceedings*, 2017. doi: 10.1109/GHTC.2017.8239323.

[7] R. Marques, J. L. Zêzere, P. Amaral, R. Trigo, G. Queiroz, and J. L. Gaspar, "Preliminary developments and implementation of an early warning system for landslides based on real-time ground based meteorological monitoring in Povoação County (S. Miguel, Azores)," in *Geophysical Research Abstracts*, 2008.

[8] J. W. Zillman, D. Griersmith, J. Le Marshall, and D. J. Gauntlett, "Remote sensing applications in the Australian Bureau of Meteorology," *Int. J. Remote Sens.*, 1990, doi: 10.1080/01431169008955156.

[9] H. Stadler, A. Leis, M. Plieschnegger, P. Skritek, and A. H. Farnleitner, "Event based monitoring and early warning system for groundwater resources in alpine karst aquifers," in *Groundwater Quality Sustainability*, 2012. doi: 10.1201/b12715-12.

[10] A. Hall, "Framing the sky: The (re)birth of weather forecasting on british television," *Archives des Sciences*. 2017.

CHAPTER 25

A BRIEF STUDY ON POST-EVENT SURVEY

Debasish Ray, Director
Department of ISME, ATLAS SkillTech University, Mumbai, Maharashtra, India
Email id- debasish.ray@atlasuniversity.edu.in

ABSTRACT:

The post-event survey is a useful instrument for evaluating the effects and efficacy of the emergency response in the wake of natural disasters, severe weather conditions, or other crises. An overview of the importance and function of post-event surveys is given in this study, with an emphasis on their role in gathering insightful feedback, identifying areas that need development, and boosting disaster planning and response strategies. The significance of post-event surveys in comprehending the effects of crises and gauging the efficacy of response activities is introduced in the first part. Post-event surveys collect information directly from impacted people, communities, and responders and provide insightful information about the difficulties and triumphs encountered during the event. The goals of post-event surveys are covered in the second part. These goals include assessing the effectiveness of disaster response organizations, finding weaknesses in preparation plans, and obtaining input to improve future emergency response methods. This examines post-event survey procedures and data gathering strategies. Depending on the size and breadth of the event and the intended audience, surveys may be performed via interviews, questionnaires, focus groups, or online platforms. The importance of post-event surveys in fostering accountability and openness in disaster management is emphasized in the fifth part. Policy choices, resource allocation, and the development of emergency response plans may all be made with the help of the data and insights gleaned from the surveys. The difficulties in reaching the impacted individuals, survey fatigue, and the necessity for timely data gathering while conducting post-event surveys. To overcome these obstacles, careful planning, teamwork, and consideration for the needs of the impacted communities are necessary.

KEYWORDS:

Damage, Forecast, Management, Storm, Weather.

INTRODUCTION

It is crucial to conduct a technical assessment as soon as possible after a high impact severe weather event, such as a cyclone, thunder squall, or heavy rain that causes flooding, has affected an area. In order to better comprehend the high impact weather event's features, gauge its intensity and location, and identify any connected physical processes, this study aims to gather technical information about it immediately. Although the post-cyclone survey process is well established, the post-thunderstorm, post-thunder squall, post-tornado, and post-flash flood surveys are not, according to the India Meteorological Department. The standard operating procedure (SOP) that IMD will use for its post-event study of many noteworthy meteorological phenomena is provided here [1].

Finding of high impact weather event (HIWE) requiring post-event survey. If any of the following severe weather occurrences have a substantial influence, the post-event survey will be undertaken.

1. A landfalling cyclone
2. A violent thunderstorm or lightning that results in casualties and damage to property
3. A tornado that causes damage to property and casualties
4. A flash flood after a cloud burst

A study of the HIWE's damage is primarily intended to provide a more thorough evaluation than what is provided by the synoptic observations and news accounts. It also aims to assess the efficiency of the provided warnings and determine the true track, severity, and other aspects of the HIWE. The Standard Operation Procedure (SOP) for the post-event survey

Damage Evaluation

An officer from the affected region should be sent on tour to the affected areas whenever a high impact weather event (HIWE) such as the one mentioned above causes significant harm to life and property. This officer will assess the nature and extent of the damage caused from both the economic and scientific points of view. The tour schedule of the officer travelling on tour should be begun and authorised by the appropriate authority as soon as possible during the event or within 24 hours of its occurrence through phone, email, or WhatsApp. The Regional Meteorological Center's concerned Head is the appropriate authority. The trip should be announced by email or WhatsApp to the CRS Pune and NWFC New Delhi offices. The touring officer should visit the key areas in the affected region, get in touch with the relevant State and Central Government offices, and conduct interviews with locals to assess the event's characteristics and the effectiveness of the warning system at the time. After returning from his tour, the officer is required to submit the report to the relevant Head, MC/RMC, Head NWFC, and Head CRS Pune.

Utilising departmental transportation or leasing a vehicle for damage assessment. In certain cases, where an HIWE causes significant damage, public transit may not be immediately accessible to the touring officer to visit the affected communities, or the facilities may not be extended to the planned areas of visitation. For damage surveys in certain circumstances, departmental transportation will be employed. When departmental transportation is not an option, appropriate contracted transportation shall be employed.

Report on survey's content

The following factors should be taken into account by the touring officer while writing the report:

With regard to Cyclone

1. The path that the HIWE took.
2. The 'eye' or tranquil core and its traits.
3. The length of the pause.
4. Gale- and squall-prone areas, as well as the relative intensity of the winds in each quadrant.
5. A calculated maximum wind speed.
6. The onset/termination times of severe local storms or several local storms.
7. The sea receding.
8. Storm surge calculations based on tidal gauges, landmarks, etc.
9. Storm-related precipitation

For lightning or a storm with a strong wind

1. The path that the HIWE took.
2. Areas impacted by gales, squalls, lightning, and relative wind intensity are listed in .
3. The maximum wind speed and lightning strikes (if available) are estimated.
4. The start and end times of the HIWE.
5. Rainfall connected to HIWE.

When it comes to tornado

1. The path that the HIWE took.
2. The HIWE impacted areas and the proportional wind strength.
3. Estimate of the wind's greatest speed.
4. The start and end times of the HIWE.
5. Rainfall connected to HIWE.

Regard Cloud Burst

1. The HIWE's impacted areas and the relative intensity of the winds.
2. The time at which the HIWE starts and ends.
3. HIWE-related rainfall is item
4. Height of the highest water level.

The officer should also take into account the following factors, which apply to every HIWE in addition to the considerations indicated above:

1. Remarks made on the accuracy and timeliness of the warnings by those who received them.
2. Advice and ideas on how to make the warning system, observational network, etc. better.
3. Any observations that have been recorded by other agencies.
4. Pictures of HIWE that have been gathered by any office or person.

Keeping the aforementioned in mind, the touring officer should make an effort to collect and maintain information that will allow him to assess the aforementioned qualities connected with the HIWE as quantitatively and objectively as feasible. Instructions and guidelines for officers conducting surveys of HIWE-related damage.

DISCUSSION

SOP knowledge

In order to get acquainted with the job, the officers appointed for the survey should read the SOP for post-event surveys as well as reports of similar prior surveys. The offices should also maintain these reports from the touring officers bound as permanent records since they include important scientific information on incidents that was diligently gathered and that may be needed in the future. Field officers should attend an annual pre-season session on various events sponsored by NWFC. Refreshing the process would be aided by this. On the post-event questionnaires, a mechanism for RMC experience sharing might be added for learning purposes. In order to prepare them for their activities, for paperwork, etc., each RMC may designate the officials who will serve as the members of such a post-Event survey team, along with backups or replacements in case of unanticipated crises [2].

Equipment

An officer who participates in such survey visits should have with him a few essential pieces of equipment at the very least. As follows: A digital camera or smartphone with a charger so you can take photographs and movies. A measuring tape that is at least 20 metres long. Magnetic compasses are third. a GPS device. Tiny plastic bottles for collecting water samples from the coastal area to test for salty inundation in the event of a hurricane. A survey theodolite and pole (which may be purchased from the local PWD); (As the maps for each district in the scale 1" = 16 miles are available with the State Governments, it would be advantageous if the MOs/MCs/RMCs obtained the maps of all the coastal districts related to their centres and kept them ready so that the touring officers could take these maps with them when they proceed on tour.) A detailed map of the area affected in the scale 1" = 16 miles (to be obtained from the State Government or survey of India map available with IMD.)

Tour route schedule

Before planning the survey's route, the concerned head and the touring officer should speak with representatives of the State Government to learn more about the regions impacted. To thank the State Relief Commissioner (SRC)/DM authorities for the post-event survey, the concerned Head MC/RMC should send them a formal letter or email. It would make it easier for these organisations to become involved with and take part in the most crucial activity, the post-event survey. The concerned MC/RMC is also responsible for gathering the data and information gathered by these entities.

Detailed assessment of the damage

As seen here, the touring officer must evaluate the damage in as much detail as possible.

(a) **Directions of bent poles:** In the case of electric or telephone poles, the direction in which the pole was bent (using a magnetic compass), the height of the pole overall and the height at which it was bent, the diameter of the pole, and whether it was solid or hollow, old or new. If possible, he or she may get information from the local PWD, DoT, or other relevant agencies on the material the pole is made of, its weight, age, etc.

(b) **Direction of fallen tree:** In the case of trees, information such if just a few branches were broken, whether the whole tree was uprooted, and which direction the tree had fallen; an approximate estimate of the diameter, height, etc.; and the name of the tree.

(c) **Building:** In the event of damage to real property, such as buildings, the specifics pertaining to the kind of building, such as whether it is a hut with mud walls and other features or a pucca concrete structure, the type of ceiling (thatched/tin/asbestos/tiled/concrete), and the type and size of the wall, among other things.

(d) **Wind Direction:** By using the magnetic compass to establish the general direction in which the majority of the trees have fallen or the poles have bent in that region, it is possible to estimate the direction of the wind over the area where many trees have fallen or poles have bent.

(e) **Height of water level:** Using the tape, it was possible to measure the height of the highest water level above the ground at when the flash flood caused flooding. The height may be calculated using the water's traces on trees and building walls. Interviewing locals will also provide estimates, such as knee-deep water, water up to the neck or belly, etc [3].

(f) **Victims:** Through interviews with locals, the precise cause and the overall number of victims should be recorded. The location's characteristics, such as terrain, population density, and vegetation, should also be taken into account.

Storm surge height and reach (only in the event of a cyclone)

In places that experienced storm surge flooding, precise estimates of the height at which the sea had risen in various locales of a village or group of villages should be collected. The sea water's traces on trees and building walls may be used to measure height. Keep in mind that the goal of this survey is also to get a profile of the water level as the surge moved farther inland. It is important to determine the length of the coastal strip across which this event happened as well as the height at which the water entered the inland space for this purpose. These data will make it possible to determine the storm surge profile in detail. Storm Surge is equal to the sum of the astronomical tides, waves, and freshwater input. One must utilise information about the event's time, location, datum point of the sea and land, and astronomical tide at that moment. One must do a methodical calculation of the storm surge height based on all of them [4].

Photos and videos to support such surveys

To clearly capture the specific effect that is intended to be illustrated, each item of damage that is necessary for determining the track and intensity of the HIWE should be photographed or videotaped. Examples include bending telephone, telegraph, or electric poles, uprooting trees, the distribution of broken tiles throughout the neighbourhood, watermarks on trees and buildings, and more.

Extra camera or smartphone

In order to not miss this exceptional chance to gather crucial information, it is recommended that a backup camera or smartphone be carried whenever it is practical. To complement the tour officer's photos and films, local photographers or news organisations should be contacted for images and videos of damage and other information. Interviewing those who have firsthand experience with the extreme weather occurrence. It is important to interview a variety of individuals. The locals who have personally experienced the effects of the HIWE are the greatest assessors of the events and the gravity of the phenomena, thus any chance to speak with them should be taken. The touring officer should choose a cross-section of the population who will be able to provide accurate and meaningful information and are typically geared up to the usual activities in the area, for example. Teachers, Village Development Officers, Panchayat Officials, Port Officers, Fishermen, Govt. agents, etc. Questions should be phrased in a way that the responses will allow us to estimate the time at which a particular weather phenomenon, such as heavy rainfall, a tidal wave, gales or squalls, or a calm centre, began as well as the intensity of the phenomenon and any unique effects that the people involved may have noticed or felt (such as a change in humidity and wind, acoustics, colour of the sky, shape of the cloud, movement of the cloud, frequency of [5].

Event's Progress Chart

A thorough track of the storm is one of the most crucial things that must come from such a study of the impacted regions. As a result, we must determine where the storm's eye passed. For this reason, determining which way the trees on each side of the railroad will fall will be crucial, and photographic proof of this must be meticulously noted. People in the vicinity of where the storm's eye may have passed should be questioned about if they encountered any clear weather or reasonably quiet wind for a brief time before gales and severe weather. If so, the start and end times of the tranquil period may be determined.

The track should be prepared in case of severe thunderstorm, lightning, thunder squall, or cloudburst based on the evaluation of wind direction and interviews with a cross section of the population. Ring of the highest winds and their relative intensity in each quadrant (only in cyclone cases). The ring of maximum winds, which must be measured, must be at least 28 knots in diameter in the centre and at least 34 knots, 50 knots, or 64 knots in various quadrants. To determine the wind intensity across a large belt on each side of the storm's route using the Beaufort scale, it is crucial to take note of the extent of the damage [6].

Rainfall

The amount of rain that has fallen at the rain gauges located in the surveyed locations, if it is not accessible in real-time, is another crucial piece of data that the touring officer must gather. Reproductions of photographic records, etc. The tour guide should also get copies of any significant autographic records, such as barograms, anemograms, or hyetograms, that are available from the local observatory. To determine if the observations made and reported throughout the event period were accurate and consistent, he or she may also carefully review the observational data in light of the local damage seen [7].

Depiction Shows The Damage In Detail And The Derived Parameters

The following maps and drawings need to be created based on the survey that was conducted: A map or diagram showing the locations visited and the route taken by the touring officer. A map illustrating the optimal path taken by the cyclone, thunder storm, tornado, or cloud burst across the land based on the data gathered. When feasible, the direction of the wind and the time of occurrence should be included together with the highest wind speed reported at each location visited. A map depicting, in the event of a cyclone, the regions subject to storm surge and the height of the surge at various locations along the coastal strip. On the above sketches and maps, the N-S line has to be delineated clearly. The aforementioned maps might be created at the greatest resolution scale [8].

Communicating with Warnees: Operation of the warning system

Warnees receiving warnings

The warnees (Collectors and other government representatives in the affected region (BDO, Tehsildar, Police station), Officials of PWD, Railways, DoT, Ports, Fisheries, etc.), to whom warnings were given in connection with the storm, need to be called. The touring officer wanted to know whether they had gotten the warnings in a timely manner and if they had been helpful. He must also find out how they were put to use. He should check to see whether warnings that were serially numbered were indeed received that way. The comments of the relevant authorities about the receipt of Four Stage Warnings, severe rainfall via AIR broadcasts, short to medium range forecasts, and nowcasts in cases of thunderstorms must be gathered. For port officers and designated/registered warnees, the forms on which they must fill out the information on receipt and action taken on warnings may be gathered for taking appropriate action with the DoT authorities in instances of non-receipt or late receipt of warnings by the warnees.

Improvement Suggestions

Additionally, he or she should solicit ideas from the warnees for enhancing the warning system and include pertinent recommendations in his or her report. In a similar vein, any shortcomings in the observational organisation should be called up by him/her along with recommendations for corrective action. Meeting with representatives of AIR/Door Darshan and other media people. He or she should also go to the AIR station or Door Darshan station, if one exists, and inquire of the authorities whether the bulletins for broadcast were received by them on time, in accordance with the serial number sequence, and whether they were broadcast right away. He or she should also find out whether the AIR station or Door Darshan station extended the transmission hours to broadcast the bulletins received beyond the planned transmission hours and, if not, the reason for not doing so.

The touring group will, if at all feasible, get in touch with any local media workers who have covered the incident throughout their tour to inquire about the incident's gravity. The travelling group should also gather proof in the form of video and electronic media footage recordings. These have to be included in the tour officer or party's report [9].

Practical language proficiency

It is preferred that the touring officer has a solid grasp of the regional language of the HIWE afflicted area because he or she will be interviewing locals as well as governmental authorities for information. When an HIWE impacts several meteorological regions, one officer from each area must be assigned to the trip and must limit all research, surveys, and other activities to the region in which they are travelling. A final consolidated report will be created by the officer from the area most severely impacted by the HIWE based on the contributions of these officials [10].

CONCLUSION

The importance of incorporating communities, first responders, government agencies, and non-governmental organisations in the post-event survey process is discussed in the fourth section. A thorough knowledge of the effects of the occurrence and the measures made in response is ensured through inclusivity. The advantages of incorporating post-event survey results into catastrophe planning and response programmes are highlighted in the seventh section. Communities and authorities may increase their resilience and event response capabilities by reflecting on the past and adopting the lessons gained. The conclusion of the study emphasises the crucial significance that post-event surveys play in forming efficient disaster management procedures. Post-event surveys help to create communities that are more resilient and responsive to catastrophes by collecting input, evaluating effects, and finding areas for improvement.

REFERENCES:

[1] N. Mori *et al.*, "2018 Typhoon Jebi post-event survey of coastal damage in the Kansai region, Japan," *Coast. Eng. J.*, 2019, doi: 10.1080/21664250.2019.1619253.

[2] N. Mori *et al.*, "Nationwide post event survey and analysis of the 2011 Tohoku earthquake tsunami," *Coast. Eng. J.*, 2014, doi: 10.1142/S0578563412500015.

[3] D. Dominey-Howes, "Post-event field surveys," in *Geological Records of Tsunamis and Other Extreme Waves*, 2020. doi: 10.1016/B978-0-12-815686-5.00010-9.

[4] P. Javelle, J. Demargne, D. Defrance, J. Pansu, and P. Arnaud, "Evaluating flash-flood warnings at ungauged locations using post-event surveys: a case study with the AIGA warning system," *Hydrol. Sci. J.*, 2014, doi: 10.1080/02626667.2014.923970.

[5] W. Widiyanto, P. B. Santoso, S. C. Hsiao, and R. T. Imananta, "Post-event field survey of 28 September 2018 Sulawesi earthquake and tsunami," *Nat. Hazards Earth Syst. Sci.*, 2019, doi: 10.5194/nhess-19-2781-2019.

[6] D. Cox *et al.*, "Hurricanes Irma and Maria post-event survey in US Virgin Islands," *Coast. Eng. J.*, 2019, doi: 10.1080/21664250.2018.1558920.

[7] P. Javelle, J. Demargne, D. Defrance, J. Pansu, and P. Arnaud, "Evaluation des avertissements de crue éclair sur des bassins non-jaugés en utilisant des relevés post-événement: Application avec le système d'avertissement AIGA," *Hydrol. Sci. J.*, 2014, doi: 10.1080/02626667.2014.923970.

[8] R. Omira *et al.*, "The September 28th, 2018, Tsunami In Palu-Sulawesi, Indonesia: A Post-Event Field Survey," *Pure Appl. Geophys.*, 2019, doi: 10.1007/s00024-019-02145-z.

[9] R. Paulik *et al.*, "Tsunami Hazard and Built Environment Damage Observations from Palu City after the September 28 2018 Sulawesi Earthquake and Tsunami," *Pure Appl. Geophys.*, 2019, doi: 10.1007/s00024-019-02254-9.

[10] M. H. Hodges *et al.*, "High and equitable mass Vitamin A supplementation coverage in Sierra Leone: A post-event coverage survey," *Glob. Heal. Sci. Pract.*, 2013, doi: 10.9745/GHSP-D-12-00005.