1875 - 2001
125 YEARS
SERVICE TO THE NATION

INDIA METEOROLOGICAL DEPARTMENT


ALIPORE OBSERVATORY

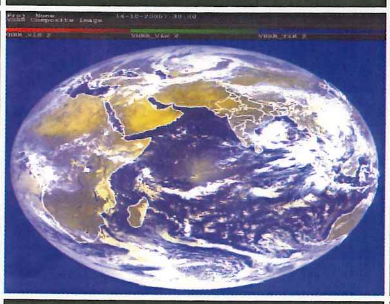

COLABA OBSERVATORY


PUNE OBSERVATORY


MADRAS TOWER


MAUSAM BHAVAN, NEW DELHI


ANTARCTICA


VHRR VISIBLE IMAGE

125 YEARS OF SERVICE TO THE NATION

A RETROSPECTIVE AND FUTURISTIC OVERVIEW

125

YEARS OF SERVICE TO THE NATION

A retrospective and futuristic overview

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FOREWORD

The beginning of Meteorology in India can be traced to ancient times. Early Philosophical writing of the 3000 BC era, such as the Upanishadas, contain serious discussion about the processes of cloud formation and rain and the seasonal cycles caused by the movement of earth round the sun. Kautilya's Arthashastra around 300 BC contains records of scientific measurements of rainfall and its applications to the country's revenue and relief work. Kalidasa in his epic, `Meghdoot', written around the 1st century AD, even mentions the date of onset of the monsoon over central India and traces the path of the monsoon clouds. Varahmihira's classical work, the Brihat Samhita, written in 6th century AD provided a clear evidence that a deep knowledge of atmospheric processes existed even in those times. It was understood that rains come from the sun (Adittyat Jayate Vrishti) and that good rainfall in the rainy season was the key to bountiful agriculture and food for the people.

Meteorology, as we perceive it now, may be said to have had its firm scientific foundation in the 17th century after the invention of thermometer, barometer and the discoveries of physical laws governing atmospheric gases. It was in 1636, that Halley, a British Scientist, published his treatise on the Indian Summer monsoon in which he attributed it to a seasonal reversal of winds due to the differential heating of the Asian land mass and the Indian Ocean.

In the first half of the 19th century, several observatories began functioning in India under provincial governments. In the year 1875, the Government of India established the India Meteorological Department with its headquarters at Calcutta. The headquarters of IMD were later shifted to Simla, then to Poona (now Pune) and finally to New Delhi.

From a modest beginning in 1875, IMD has progressively expanded its infrastructure for meteorological observations communications, forecasting and weather services and it has achieved substantial scientific growth. IMD has always used comtemporary technology. In the telegraph age, it made extensive use of weather telegrams for collecting observational data and send warnings. Later IMD became the first organisation in India to have a message switching computer for supporting its global data exchange. One of the first few Electronic computers introduced in the country was provided to IMD for Scientific applications in meteorology. India was the first developing country in the world to have its own geostationary satellite, INSAT, for continuous weather monitoring this part of the globe and particularly for cyclone warning.

IMD has continuously ventured into new areas of application and service and steadily built upon its infrastructure in its history of 125 years. It has simultaneously nurtured the growth of meteorology and atmospheric science in India. Today meteorology in India is poised at the threshold of an exciting future. The National Meteorological Services (NMS) is a fundamental component of the national infrastructure of all countries. The basic purpose of NMS is to meet government's responsibilities to contribute to the safety, security and general well-being of their citizens by providing timely and accurate weather forecasts and warnings and to ensure the ongoing collection and long-term custodianship of a reliable national climate record for use by future generations. The National Meteorological Service has also to fulfil the country's essential international obligations under the convention of World Meteorological Organization.

There is no doubt that the citizens of all nations expect to continue to enjoy the range and quality of meteorological services which modern science and technology have made possible in the closing years of the 20th century. With technological advancement, we can be comfortable under different environmental conditions. Unfortunately, in doing so we have been interfering with nature to such an extent that some climatologists apprehend global climate changes due to human activities. Even then, human health depends on climatic and weather conditions. The atmosphere is one of our potent natural resources. It cannot maintain its purity if man's activity is resulting in polluting the same. Human induced climate change, is a major issue which is closely associated with the concept of sustainable development. Food, water energy and natural resources have to be used optimally in the face of growing population. Studies on long term monitoring of earth's climate and environment will come centre stage calling for action by National Meteorological Services.

We live in `Information' age where information is strength. IMD is a scientific department responsible for weather, climate, positional astronomy and earthquake related services, all of which are assuming greater and greater importance everyday. We have to prove to the scientific community and the public at large that the department is really scientific. To achieve this we require technological updating, modernization and considerable expansion in our support services like telecommunication and instrumentation. While trying to improve the quality of our service and intensify our research efforts, coming years will see the department grow from strength to strength and a bright and prosperous future will unveil as we proceed as a dedicated team to deal with the challenges ahead.

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CHAPTER 1

ANCIENT BEGINNINGS OF METEOROLOGY IN INDIA

Meteorology is the science of the atmosphere. It includes phenomena such as wind and rain. All ancient civilizations bear ample testimony to man's realization of his intimate dependence on weather and climate. Meteorology was perhaps the essence of knowledge relating to the atmosphere, weather and environment in those times and these phenomena were considered as attributes of the gods.

इन्द्रो रथाय प्रवंतं कृणोतिं

यमध्यास्थन्मधवा वाजयन्तम ।

युथेव पश्वो व्युनोती गोपा

अरिष्टो याती प्रथमा: सिषासन्

(अत्रि मंडल 5 सु. 31. 1)

Rain causing God (Indra) Seated in a Chariot driven by electricity, Taking help of updraughts in achieving enrichment of precipitable (rain) water and when the speed of ascending (Chariot) increases the enrichment in precipitable rain water also considerably increases. The high luminocity causing many luminous effects also cause activation and energised elements glittering. At this time the (security) arrangement is such that some elements are receiving assistance in enrichment in moisture from some anti elements in motion.

The beginnings of Meteorology in India can be traced to ancient times. The earliest references to meteorological phenomena are found in the 'Rigveda' which was composed between 5000 to 2000 BC. One has to wade through the metamorphical language of the ancient literary works to sift scientific contributions from mythology and religion. Early philosophical writings of the 3000 BC era, such as the Upanishadas, contain serious discussion about the processes of cloud formation and rain and the seasonal cycles caused by the movement of Earth round the Sun. Rigveda contains descriptions of meteorology of Northwest India including classification of seasons, bursts of monsoon, rain producing weather systems, cloud formation and their classification. The text also describes prolonged periods of drought, epochs of good rainfall, at times leading

to floods, and vagaries of meteorological phenomena in general. Several deities were associated with weather events. The principal among them are Varuna-sky, Marut-wind, Parjanya-rain cloud, and Indra-lightning. The pleasure or displeasure of these deities was considered to be responsible for favourable or disastrous weather events. Prayers to these deities are found in the ancient texts invoking their blessings for good weather and for providing protection against weather hazards.

Besides these principal deities many minor meteorological deities such as Surya- the Sun-God, Agni- the God of fire and light and Vayu – the wind have also been mentioned in the Rigveda. The prayers were combined with several rituals. The "Fire God" was supposed to be the carrier through whom various deities received what man had offered by way of burning in sacred fires known as 'Home - Havan' and 'Yagnas' for inducing rain. This seems somewhat similar to the present day technique of cloud seeding from ground based generators. Divine control of weather is noticeable in literature of almost all ancient civilization.

Two great Hindu epics, the 'Ramayana' and the 'Mahabharata' give climatic and meteorological descriptions that prevailed in their respective periods. It is in later Sanskrit literature between 5th century B.C. and 7th century A.D. that we find objective attempts at understanding weather phenomena.

Kautilya, around 3rd century B.C. realised the importance of rainfall measurements and the need to understand its variability for proper assessment of agro-economic conditions of the state. Kautilya's Arthashastra contains records of scientific measurements of rainfall and its applications to the country's revenue and relief work. Manu, in his great compilation known as 'Manusmriti' recognised that the Sun is the ultimate source from which all weather systems derive their energy.

Slowly several attempts appear to have been made for rainfall prediction. 'Brihat Samhita' by Varahmihira (505 AD to 587 AD) and 'Meghamalatantra' consisting of a large number of Sanskrit verses, probably compiled by several scholars around 800 AD to 1200 AD, may deserve special mention in this context. It should be noted that these texts were only compilations of the then existing knowledge on weather and climate. These give us glimpses of the knowledge of astronomy and meteorology prevalent in ancient India.

It is worth mentioning here that Kalidasa, the celebrated Indian poet and dramatist of the 1st century AD, even mentions the date of onset of Monsoon over central India and traces the path of the monsoon clouds. He described the monsoon clouds in his famous epic 'Meghdoot' or the 'Cloud Messenger'. Addressing a monsoon cloud he says in a verse, 'Though your path is circuitous for travelling to the north, do not miss Ujjain'. Ujjain was the capital of the kingdom of Vikramaditya where Kalidasa was the court poet.

Thus, a keen sense of observation of cloud forms and their development leading to rainfall and of seasonal characteristics of rainfall were the basic tools for weather prediction even in those early times. The discoveries and the empirical rules to forecast weather events were applicable only to those regions for which they were developed. Animal, bird, and insect behaviour, at the time of occurrence or preceding a spell of rain, became an added tool for weather prediction. These observations culminated in rich weather related folklore and poetic imagination abounding in all Indian languages.

Varahmihira's classical work, the 'Brihat Samhita' written in the 6th century A.D. provides a clear evidence that a deep knowldege of atmospheric processes existed even in those times. It was understood that rains come from the Sun (Adityat Jayate Vrishthi) and that good rainfall in the rainy season was the key to bountiful agriculture and food for the people. Brihat Samhita exclusively devoted five chapters to meteorology one each dealing with clouds, air, rainfall, signs of immediate rainfall and atmospheric optics. In addition, at several other places weather phenomena were described in association with omens, planetary positions and astrological beliefs. These, together with observations on crop yield under varying climatic conditions, have led the ancient Hindus formulate generalisations aimed at making long range or seasonal weather prediction. The importance of seasonal forecasts for agricultural and economic planning, was recognized in ancient times as well.

Similar attempts to understand the vagaries of weather can be traced in all other ancient civilisations. Yuan Chwang, who travelled through India in the 7th century A.D., recorded his impression of the climate of some parts of India. Beginning from the 6th century B.C., the Greeks became prominent in science. They gathered and compiled the Egyptian and Phoenician knowledge into a number of treatises. Aristotle in 4th century BC knew that the water surrounding the earth was vaporised by Sun's rays, only to be lifted up as clouds which eventually came back to the earth as rain. He was also aware of the process of hail formation. He noted that hail storms were more frequent in summer. By the 1st and 2nd century BC there was a great decline in the science of Greeks and Romans. After the fall of Roman Empire , during the middle ages, the Greek science suffered a severe setback for several centuries. Then the centre of culture shifted to the East. Distinct civilizations emerged in the Arab land, Persia and India. They began taking keen interest in fostering the scientific ideas of the Greeks and the Romans, while at the same time independently developing their own scientific thoughts. The Arabs had to give them back the knowledge of their own scientific achievements including translations of Aristotle's meteorological treatise entitled "Meteorologica".

European travellers in the 16th and 17th centuries AD have recorded their impressions of the climate or events affected by severe weather. Till 17th century AD Aristotle's theories were the main tools of weather prediction. Stoffler, a 16th century publisher of an astrological calendar predicted a worldwide deluge to occur in 1524, due to configuration of Saturn, Jupiter and Mars in the house of Pisces. Of course, as it is usual with such predictions, it did not take place. It is not the failure that interests us but the human desire to predict natural events well in advance. The earliest human approach to weather prediction was to associate weather phenomena with non-meteorological events. The predictors of weather forecasting were essentially the same under different cultures in spite of their large separation both in time and space, at a time when intercommunications were nearly absent. This is an example of amazing similarity in human thinking.

Lack of precise observations of the atmospheric variable linked with weather and climate hindered the growth of scientific meteorology.

Though "Cause and Effect" methodology was attempted to explain the observed weather system with other non- meteorological parameters which failed due to obvious reasons.

The advent of modern science had to await the invention of instruments for making precise- and accurate measurements. These measurements brought meteorology in the domain of Science and removed many ancient and medieval myths. Thus, it was only during and after the Industrial Revolution and the French Revolution that science began to grow. The invention of the thermometer and barometer in the 17th century gave impetus to the instrumented observations of the atmosphere which served as a precursor to the development of modern meteorology.

CHAPTER 2

FOUNDATIONS OF MODERN METEOROLOGY IN INDIA

Meteorology, as we perceive it now, had its firm beginning with the scientific invention of the barometer in the 17th century, the mercury thermometer in 1709 and the formulation of laws governing the behaviour of atmospheric gases. Aristotle's 'Meteorologica' is a discourse on atmospheric phenomena. In his honour the science of the atmosphere has come to be known as Meteorology. It was in 1636 that, Halley, a British astronomer published his treatise on the Indian summer monsoon, which he attributed to seasonal reversal of winds due to the differential heating of the Asian land mass and the Indian Ocean. Meteorology in its widest sense encompasses every aspect and every phenomenon that takes place in the atmosphere.

In the 18th century European scientists were concerned with astronomical and magnetic observations to aid navigation in the high seas. Meteorological observatories were set up, at a comparatively later date, as an aid to those two main concerns. Gradually, the economic importance of meteorology began to emerge out as the maritime trade and commerce alongwith colonisation by European countries expanded.

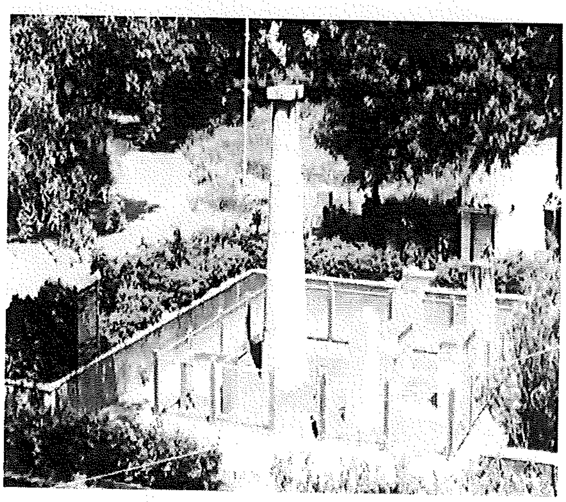


Fig. 1: Old Madras Tower

Climatic surveys, along with many other surveys went on in full swing, all over the occupied country, like India to assess the agricultural potential of a region as well as to search for health resorts for troops and settlers. The tide observations conjoined with weather observations were made on the coastal areas for proper harbour-making, port warning and safe entry of mercantile and naval ships.

Here, in India, the first scientific activity began through surveying by triangulation after the Mysore War. The great Trignometrical Survey of India commenced its work in 1802. The longitude of Madras was determined from astronomical observations taken as a substitute for the prime meridian of Greenwich observatory for which longitudes of other places across the Peninsula were reckoned. An astronomical observatory was also set up in Fort William, Calcutta, in 1774 near Treasury Gate for measuring the longitudes along the eastern coast from Calcutta to Madras.

Colonel T.D. Pearse of the Bengal Artillery undertook a series of astronomical observations from 1774 to 1782 and his Meteorological journal covers a period from 6 March 1785 to 28 February 1788. His Meteorological journal includes daily observations of the barometer, thermometer, hygrometer, direction and force of wind and rainfall taken generally at about 7 a.m. and 2.15 p.m.

India is fortunate to have some of the oldest meteorological observatories of the world. The earliest Meteorological observation at Madras (now known as Chennai) observatory is known to have been taken in September 1793 by J. Goldingham (Fig. 1). The second observatory in India started by the East India Company was at Colaba, Bombay (Now Mumbai) in 1823. The third observatory in India was established in 1836 at Trivandrum now known as Thiruvananthpuram. Simla recorded magnetic and Meteorological observations during the period 1841-1845. In Bengal, the first observatory was set up in Calcutta, at Surveyor General's Office at Park Street in the Year 1829. The first European Superintendent of this observatory was V.N. Rees who recorded meteorological observations from 1829 to 1852. He became the Chief Computer of the Survey of India in 1850-51. On his retirement in October 1852, Radhanath Sikdar took charge of the Calcutta observatory. Radhanath was the first Indian to enter the Trignometrical Survey in December 1831 and the first Indian Superintendent of the Government observatory. Radhanath's competence in geodetic surveying was universally acknowledged.

When Radhanath took charge of the Calcutta observatory there was no well-laid methodology for noting down weather observations and tabulating them systematically for future work by different users. So, right at the outset he prepared a table to be used for reducing barometric observations to 32^{0}F by devising his own formula. The formula used by him to compute a reduction table was very much similar to the formula used by Galbraith in 1834 and then by Boileau in 1849. Radhanath introduced accurate and systematic hourly observations in the Calcutta observatory right from December 1852. Meteorololgical abstracts containing daily means, monthly means and hourly means for a month of all principal weather parameters along with other derived hygrometric elements appeared regularly in the proceedings and Journal of the Asiatic Society of Bengal from 1853 to 1876. These abstracts show not only daily ranges but also extreme values, monthly ranges of all the principal weather elements besides rainfall, aspects of the sky with description and symbol of the clouds, wind direction. However, regular observations were started at above observatories in the middle of 19th century. The British East India Company established several such stations, by 1874, there were 77 Meteorological observatories in the country.

Meanwhile meteorology in India received substantial encouragement from the Asiatic Society of Bengal, formed in 1784 at Calcutta by Sir William Jones for the advancement of Sciences in Asia. Captain Harry Piddington, Calcutta published 40 papers during 1835 in the journal of the Asiatic Society dealing with tropical storms and coined the world cyclone, meaning the coil of snake. In 1842 he published his monumental work on the "Laws of the storms".

Prior to 1875, meteorological observations, forecasting and other related activities were conducted by provincial agencies under the charge of the respective meteorological reporters in a somewhat independent way. In 1875, the Government of India decided to set up the Meteorological department bringing all meteorological work in the country under a central authority. The objectives of the National Meteorological Services were to study systematically the climate and weather in India as a whole and the application of the knowledge thus acquired to the issue of storm and other warning and daily forecasts. The headquarters of the department was at Calcutta (Fig. 2). H.F. Blanford was appointed as the first Imperial Meteorological reporter to the Government of India.

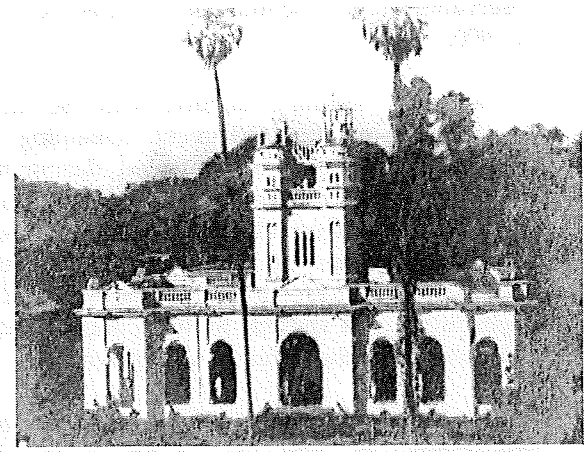


Fig. 2: Alipore Observatory

In 1875, Blanford opened a temporary branch office at Simla. Thereafter, four Provincial Meteorological Reporters to the Government of Bengal, Punjab, Madras and United Provinces (Now known as Uttar Pradesh) based at Calcutta, Lahore, Madras and Allahabad respectively were established and all the observatories except the central observatory at Alipore (Calcutta) started functioning under the direct control of the respective Provincial Meteorological reporters.

After India experienced a severe famine in 1877, the India Meteorological Department (IMD) was asked to prepare a seasonal forecast of the South West Monsoon rains. The first operational Long range forecast for south west monsoon rains was issued by the IMD on 4th June 1886. This was based on an observed inverse relationship between the seasonal monsoon rainfall in India and the preceding snow cover over the Himalayas. Thus, India became the first country to start systematic development in long range forecasting.

From 1875 to 1905 the headquarters of India Meteorological Department were located at Calcutta. In 1875, the network of observatories in India and its dependencies consisted of 198 rainfall stations and 87 observatories measuring temperature and other meteorological observations. Later the number increased to 200 by 1900.

The 20th century dawned with the main headqaurters of the department remaining in Calcutta with a branch in Simla but during the last decade of the 19th century most of the work of India Meteorological Department was attended to from Simla. In 1905 the headquarters of India Meteorological Department was shifted to Simla and Calcutta office was given the status of a branch office.

The India Daily Weather Report made its first appearance in 1878 from Simla during the monsoon season. The office at Simla not only took up the work of preparing and issuing India Daily Weather Reports but also carried out an increasing amount of ordinary and special work of Head Office, such as preparing data for Monthly Weather Review, Annual Summary, Seasonal Forecasts and Inland flood. Warning work was also carried out regularly from this office. Very early in the history of IMD, the importance of the publication of scientific results had been recognis-ed. Blanford introduced the publication of the "Memoirs of the IMD" and himself authored several of them. His work on the "Rainfall of India" is unsurpassable in clarity of thought and content. In view of the importance of foreshadowing monsoon season for agricultural economy of the country, Blanford initiated the system of Long Range Forecasting (LRF). The system of LRF of monsoon rains went through several revolutionary phases and eminent pioneers like Sir J. Eliot and Sir Gilbert Walker (Both Directors General of Observatories) and generation of Indian researchers have made their contribution to this scientific effort. The credit goes to Sir Gilbert Walker for linking the monsoon with global meteorological parameters and his discovery of the so called Southern Oscillation phenomenon. Later, the Southern Oscillation was linked by J. Bjerknes with the EL Nino in the Equatorial pacific ocean and Bjerknes also coined the term "Walker Circulation" for describing the East West vertical circulations in the equatorial planes in honour of Walker.

Fig. 3 : Meteorological Office, Pune in 1928

The outbreak of the World War I in 1914 had its adverse effects on the department as many of the officers were drafted for military service. During the war, special forecasts were prepared at Simla on many days for military operations in the Middle East. After World War I there was much dissatisfaction in India and Government decided that it should induct more Indians in the All India Services. Blanford had also recognised the need for inducing young Indians in IMD and the first Indians to be recruited for IMD were Lala Ruchi Ram Sahni (Father of late Professor Birbal Sahni) and Lala Hemraj who joined IMD in 1884 and 1886 respectively. The Indianisation of IMD was accelerated under Walker soon after World War I, and was further boosted by Sir CWB Normand (Director General during 1928 to 1944) Normand was succeeded by Dr. S.K. Banerji as the first Indian DGO in 1944. During these years many Indian Scientists joined IMD. IMD became one of the few government agencies having many senior posts occupied by Indians. They took IMD to great heights in the post independence era.

The Department had under consideration the removal of headquarters from Simla to the plains, to some place where officers of the department could undertake research of monsoon with better facilities. For this purpose Poona was suggested to the Government as a suitable place, by Walker in 1924, and was approved by the Government in early 1926. The new headquarters building of India Meteorological Department was located on a land of about 10 acres in Shivajinagar which was then known as Bhamburda. The building was completed in June 1928 and the opening ceremony of new H.Q. building was performed by the then Governor of Bombay on 20th July 1928. Pune continued to be the headquarters of the organisation till the out break of Second World War.

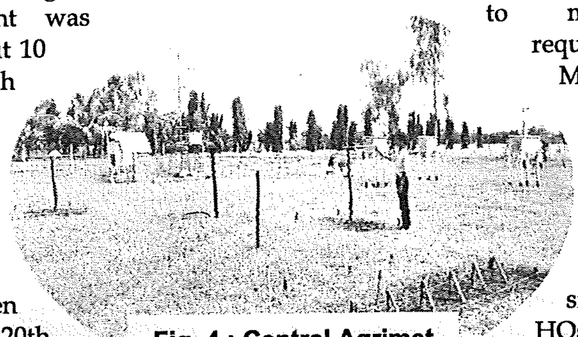


Fig. 4 : Central Agrimet Observatorv. Pune

An Agricultural Meteorology branch started functioning in Poona from 1931, under Dr. L.A. Ramdas, Meteorologist. It became a permanent division of India Meteorological Department from 1st April, 1940. Dr. Charles Normand, the Director General introduced partial decentralisation in 1931-32, by transferring the control of certain observatories to Karachi and Calcutta offices. The distribution of the control of observatories stood as headquarters Poona 182, Calcutta 69, Karachi 30, Rangoon 24. After reallocation it became Poona 130, Calcutta 101 and Karachi 74. Testing and supply of instruments was transferred from Calcutta to the Instruments section of the headquarters at Pune.

Fig. 5 : Mausam Bhavan, New Delhi

The Second World War started in September 1939. The war and the needs of the Airforce, accelerated development of the department. A number of pilot balloon stations, current weather and surface observatories and forecasting offices were set up within a short span of time.

During the Second World War Govt. of India felt that the Director General should be in close touch with Air HQ and other departments to meet the wartime requirements of the Meteorological services. Consequently, the administration of the Director General was transfered to New Delhi for the war period and has continued there since. At present a new HQs building 'Mausam Bhavan' which was construct-ed in 1975 and inaugurated by Honorable President of India the late Dr. Fakruddin Ali Ahmed on 25th November 1976 houses the HQs office of the National Met. Service.

From the beginning of 1942 rapid expansion of the Department took place mainly in the context of war requirements. The workshop at Pune and New Delhi could meet the increased demand for meteorological instruments needed for operational stations. A new hydrogen factory was started in Bangalore with equipment supplied by U.S. Airfoce, radiosonde observations using U.S. instruments were in operation at a number of Airforce stations.

A joint Meteorological Committee was formed by the Government in October 1942 to co-ordinate the Civil and Defence Meteorological requirements during the war. In the field of Meteorological tele-communications an All India Meteorological Broadcast Centre (AIMBC) was started by RAF (Signals) at Nagpur and a number of point to point W/T links were established to transmit coded meteorological data. The R.A.F. and V.S.A.F set up a network of land line and radio teleprinters for data transmission. These links became the foundation on which the subsequent telecomunication organisation of the Department was built up.

The post second world war era saw the country gaining independence from the colonial rule of 150 years. With this the national meteorological service was called upon to play a major role in the all round nation building activity of the country. The next few chapters would essentially deal with the post independence growth of IMD.

CHAPTER 3

A BRIEF HISTORY OF IMD

During the 125 years of its existence, the India Meteorological Department has grown significantly in terms of its man-power strength, the number and type of observatories in its network, and the range of weather and climate related services rendered by it to different users. Beginning with a few officers and handful of staff in 1875, the department has by now grown in strength with a work force of more than 8000. Even though the growth of the department has been gradual, substantial improvements in many technical faculties of the department have been achieved during the last two to three decades.

Present Departmental Organisation

The Director General of Meteorology (DGM) is the chief of the India Meteorological Department (IMD) with headquarters at New Delhi. There are 5 Additional Directors General (ADGs) and 20 Deputy Director Generals (DDGs) of which 4 ADGMs and 10 DDGs are located at New Delhi and one ADG and 5 DDGs are based at Pune. For the convenience of administrative and technical control, there are six Regional Meteorological Centres, each under a Deputy Director General at Mumbai, Chennai, Calcutta, New Delhi, Nagpur and Guwahati. Under the administrative control of Deputy Director General, there are different types of operational units such as, Meteorological Centres headed by Directors at state capitals (Srinagar, Chandigarh, Jaipur, Lucknow, Patna, Bhopal, Bhubaneswar, Ahmedabad, Bangalore, Hyderabad and Thiruvnanthapuram), Agrometeorological Advisory Service Centres, Flood Meteorological Offices, Area Cyclone Warning Centres and Cyclone Warning Centres. In addition there are separate Divisions to deal with specialised subjects viz. Satellite Meteorology, Hydrometeorology, Weather Forecasting, Positional Astronomy, Seismology, Civil Aviation, Climatology, Instrumentation, Meteorological Telecommunications, Training, etc. (Fig. 6).

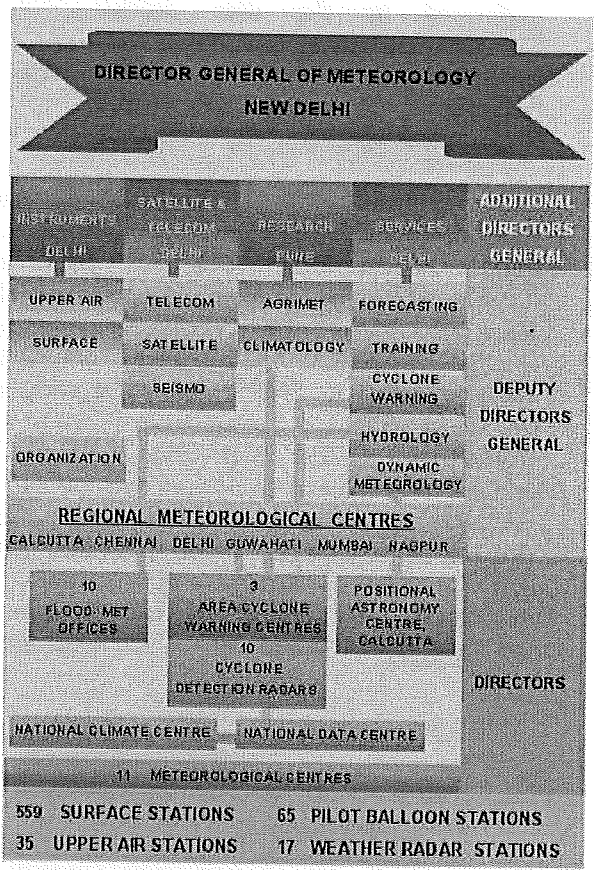


Fig. 6: Organisational Structure of India Meteorological Department

Observational Organisation

As of now, IMD maintains 559 surface observatories all over the country. Of these, 62 are more than 100 years old. Similarly, 35 radiosonde and 34 radiowind, 65 pilot balloon, 8 radiation and 4 ozone observatiories are monitoring the upper air structure of the atmosphere which are useful for studies of the upper atmosphere and as well for aviation and general forecasting. There are 7 ozone monitoring stations, 45 radiation measurement stations, 10 Background Air Pollution Monitoring Network Stations (BAPMoN) and 14 ozone measuring stations in the country. 653 hydrometeorological and about 8500 non-departmental raingauge stations are of great use for water management project and hydrological studies. For the agricultural purposes there are 17 agromet advisory service centres located at state capitals, 219 agrometeorological observatories, 222 evaporation stations 39 evapotranspiration stations, 49 soil moisture measurement stations, 80 dew gauge stations and 50 snow fall stations spread all over the country. There are 58 seismological observatories in the IMD network. There are 210 ships registered under the Indian Voluntary Observing Fleet taking observations over the high seas and the oceans around the country. For observational support to the aviation services, IMD maintains 71 current weather observatories. Similarly 19 aviation weather forecasting offices are functioning at different national and international airports in India. In addition there are three Area Cyclone Warning Centres (Mumbai, Chennai and Calcutta) and three Cyclone Warning Centres (Ahmedabad, Visakhapatnam and Bhubaneswar) which issue warnings for tropical storms and other severe weather systems affecting the Indian coasts and other maritime activities over the Indian seas. IMD has a network of 17 X-Band storm detection radars and 10 S-Band cyclone detection radars. With the launch of INSAT - 1B in 1983, round the clock satellite image reception became possible. 100 INSAT Data Collection Platforms (DCPs) are located at remote places. The INSAT imagery is transmitted to IMD's field offices via the INSAT Meteorological Data Dissemination System.

Growth of the Department Before the Second World War

Even before IMD was formally established in 1875 many observatories were already in existence and a system of telegraphically reporting the observations had been introduced. This system was however, modified by introducing a new telegraphic weather code in 1875. Coded observations from 50 stations were collected every day for the publication of Indian Daily Weather Report.

Besides the meteorological activities, IMD was also involved in seismological observations and geomagnetic and astrophysical work. Meteorological and geomagnetic observations were started at Colaba (Mumbai) in 1841. The geomagnetic observatory was shifted later to Alibag, a nearby small town located 18 miles south south east of Mumbai. Alibag observatory started recording regular observations from 1906. Likewise the first seismological observatory was set up in 1882 at Silchar. Seismological observatories were set up at Alipore (Calcutta) in 1897, and at Colaba (Mumbai) and Chennai in 1898-99. The instruments at Chennai were later transferred to Kodaikanal in 1899.

The first solar observation in India was taken at Dehra Dun at the beginning of 1878. However, continuous and regular observations were taken from December 1879 by Trigonometrical Survey Office at Dehra Dun. Although solar observations were being recorded at Dehra Dun, it was felt that it was desirable to build a full-fledged solar observatory preferably in South India. In August 1893, the Government of India sanctioned a solar physics observatory under IMD's budget, at Kodaikanal in the upper Palani hills.

The earliest upper air observations in India were made in January 1843 by Dr. Buist who was in charge of Colaba observatory, Mumbai when he sent a balloon from Byculla (Mumbai) to study the upper air movement. Realizing the importance of upper air measurements, work on upper air measurements was started in 1905. Routine pilot balloon observations were started in 1913. Later in 1943, radiosonde ascents, and in 1949, radiowind ascents were also started. During the second World War, radiosonde ascents were taken in the country using U.S. equipment. By 1943, the clock type (C-type) radiosonde was developed by L.S. Mathur and his associates and Fan type (F-type) radiosonde by S.P. Venkateshwaran and associates. These two types of Radiosonde were in use for well over two decades in the country.

With the advent of the jet age in aviation, the demand for very accurate meteorological data from high altitudes grew rapidly. The existing types of radiosonde in use were found to be inadequate. Development of Audio Frequency Modulated Radiosonde was started in Delhi in 1966 and the first station was started in December 1967. By March 1971, 18 radiosonde stations in the country were converted to this type. Later, transistorized radiosonde receivers and transmitters were designed and used for this purpose.

After 1920's, service to aviation became one of the major activities of the department. The first known aviation forecasts were issued in 1921, for the Royal Air Force operations in the then NW India. In December 1926, a forecasting office was opened at Karachi to provide weather service to aviation.

India being mainly an agricultural country, its economy is dependent on its agriculture. It was more so during the early decades of the 20th Century. Following the recommendation of the Royal Commission of Agriculture in 1926, the Agricultural Meteorology Division was established in 1932 at Pune under Dr. L.A. Ramdas. It was one of the earliest divisions of its kind anywhere in the world.

Growth of the Department after the Second World War

During the Second World War, Meteorological services in India like elsewhere, saw a phenomenal growth. Aviation and meteorology in the country grew together, till a decade or two after the war. This fast expansion lead to decentralization of the department. In 1945, seven Regional Meteorological Centres (New Delhi, Bombay (Mumbai), Madras (Chennai), Nagpur, Calcutta, Lahore and Karachi) were set up for technical and administrative control of field units in the areas of their responsibility.

In 1947, the Regional Meteorological Centres at Karachi and Lahore and all other observatories in their control were transferred to the Pakistan Meteorological Service. The other five Regional Meteorological Centres continued to be in IMD along with workshops at Pune and Delhi. This expansion further continued and in 1970, Meteorological Centres were established in the capitals of some of the states in the country, thus promoting more effective liaison with various user agencies. In April 1997, a sixth Regional Meteorological Centre was established at Guwahati for North East India.

After the independence, major progress was achieved under the Five year Plan programmes adopted by the Government of India. The first storm warning radar was installed at the Calcutta airport in 1954. A radio-tele-type link between New Delhi and Moscow was established on 1st January 1960 and with Tokyo in 1961 as a part of the World Meteorological Organisation (WMO) scheme for the establishment of New Delhi as one of the five Northern Hemispheric Exchange Centres (NHEC) of the world. In 1961, a directorate of seismology and a Northern Hemispheric Analysis Centre (NHAC) were established. An important landmark during this period was launching of the first Meteorological Satellite TIROS-1 on 1st April, 1960 by U.S.A. and Indian meteorologists had for the first time an access to satellite imageries. Two extended analysis and prognostication centres were started in 1964 at Bombay and Calcutta airports. A Directorate of Satellite Meteorology was created in 1971. In addition, Regional Area Forecast Centre (RAFC) started functioning at NHAC New Delhi during 1971 to cater to the needs for South Asia under the ICAO Scheme.

Growth of IMD's Services

The basic object of the formation of the department was the systematic study of the weather and climate of India as a whole and the application of the knowledge thus acquired to the issue of storm and other warnings and daily forecasts. The activities of the Department were not confined to Meteorological work only but also included seismology and allied subjects of varied nature. IMD provides a wide range of public services, including user-specific services for the agricultural and aviation sectors. It also undertakes and promotes research and development in meteorology and provides specialised training in this field. For achieving these objectives, India Meteorological Department maintains sophisticated observational and telecommunication network and data processing facilities.

IMD is one of the well-established scientific organisations of the Government of India and the National Agency for service in the field of Meteorology. With its extensive network of observatories, telecommunication systems and forecasting offices, it provides weather data for all nation building activities, issues forecasts and warnings for protection of life and property during adverse weather situations and helps in optimum planning for economic development of the nation.

IMD took significant steps for the induction of high technology, periodically and progressively through introduction of five year plan schemes of the Government of India to contribute to efficient planning and implementation of the development programmes of the country. This has resulted in refined observational techniques using satellite and radar data, development of computer based weather analysis systems, more accurate weather warnings and their timely dissemination via satellite. IMD's long range predictions of the monsoon have gained increasing credibility in recent years.

Agricultural Meteorology

Agriculture is perhaps one of the most weather sensitive activities in the world. India Meteorological Department was one of the pioneers in establishing Agricultural Meteorology Division at Pune in 1932. Since then, it has been maintaining a network of Agrometeorological observatories across the country with the cooperation of agricultural universities and research institutions. The Central Agrimet Observatory at Pune and the agrimet observatories at Bangalore, Anand and Rahuri have many specialised instruments and facilities for research.

The Agricultural Meteorology Division prepares crop weather calendars which depict state and stage of the crop under normal weather condition and the weather elements detrimental to the crops in various growth stages.

This division has also prepared an agroclimatic atlas of India and aridity anomaly maps. It also estimates the crop yields of principal crops with the help of regression models which parameterise the effect of various weather parameters during the different growth stages of the crops, to help agricultural planning in drought-prone and dry land farming areas of the country.

Agrometeorological advisories are prepared by IMD twice a week in consultation with agricultural experts of state agricultural departments. They are broadcast by AIR stations and also telecast by Doordarshan. These advisories are useful to farmers for scheduling of irrigation to conserve water and choosing the opitimum time for spraying of pesticides, application of fertilisers, etc. This service is functioning at 17 state capitals.

Farmers' weather bulletins are issued daily by IMD's forecasting offices for broadcast in different regional languages through the stations of All India Radio in their morning and evening programmes. These are also published in newspapers. They also provide districtwise forecast of weather during the next 48 hours, with an outlook for following two days, taking into account the effects of weather on crops grown in the respective regions.

Climatological Services

The observational data recorded at various types of surface and upper air observatories, are scrutinised and archived at the National Data Centre, Pune. The Centre has a powerful computer system with peripheral devices for transferring the data from manuscripts to magnetic and electronic media for electronic data processing and archival. The Pune archives have approximately 8 billion characters of data storage which includes ship data and rainfall data of state raingauges spanning over a century. The archives form the basis for computation of means, normals, frequencies and other derived parameters, for their analysis and interpretation, and for the preparation of district and state climate summaries and atlases. The statistics thus compiled are periodically revised and updated.

Different types of climatological data are supplied by the National Data Centre, Pune and other offices of IMD in response to a large number of enquiries and requests received from Central and State Governments, Universities, research institutes, public undertakings, private enterprises and individuals. The information supplied is used for a variety of applications such as laying of runways at airports, town planning, tourism, mountaineering, air-conditioning, location of industries, port installations, design of high towers, bridges and telecommunication structures, operation of multipurpose hydel projects, water and power management, location of projects for the exploitation of nonconventional energy sources.

The department has published many atlases such as the Climatological Atlas of India, Rainfall Atlas of India and Agroclimatic Atlas of India.

IMD brings out a monthly publication entitled "Climate Diagnostics Bulletin of India".

Weather Forecasting

Every aspect of human activity from agriculture to aviation, and sports to space flight depends on weather. Issue of early warning and forecasts is perhaps the most challenging activity of a meteorological service.

India Meteorological Department has been issuing various types of forecasts for more than a century. The centralised forecasting service was started in 1928 through Weather Central at Pune.

IMD provides a large number of services which cater to the needs of all different users interest, such as aviation, shipping, fisheries, ports, agriculture, irrigation, power projects, flood control, public works, railways, telecommunications, public health, mountaineering expeditions, defence services, industries, oil exploration and of course for the general public.

The current weather and weather forecasts are provided to aviation for conducting the safe and cost effective flights. For the benefit of ships on high seas, coastal and fishing rafts, weather bulletins are issued for broadcasting four times daily. When storms or depressions occur, weather bulletins are issued frequently by the Area Cyclone Warning Centres along the coast. In the event of cyclone development, warning messages are sent as frequently as necessary to the parts that are likely to be affected. Department is also been issuing heavy rainfall warnings to various authorities. Every year over 19,000 warnings are issued. In addition, there are over a 1000 registered users all over the country who are provided with specific type of weather warnings.

Cyclone Warnings

Cyclone warnings are disseminated through a variety of communication media, such as, radio, television, print media, telephones, fax, telex, telegrams, or the police wireless network. A specially designed Cyclone Warning Dissemination System which works via the INSAT satellite provides area-specific service even when there is a failure of conventional communication channels. Warnings are issued for general pubic, fishermen, farmers and different categories of users such as central and state government officials responsible for disaster mitigation and relief, industrial and other establishments located in the coastal areas, railways, aviation, communications and power authorities.

The cyclone warnings are issued in two stages. The first stage warning known as "Cyclone Alert" is issued 48 hours in advance of the expected commencement of adverse weather over the coastal areas. The second stage warning known as "Cyclone Warning" is issued 24 hours in advance. A "Pre-cyclone Watch" may be instituted prior to the cyclone alert and a post-landfall outlook is issued for areas in the interior which may be affected by the cyclone as it continues to move inland and dissipate. NHAC, New Delhi, has been designated as the Regional Specialised Meteorological Centre for Tropical Cyclones. It is one of the five such centres recognised by the WMO under a global system for monitoring tropical cyclones. As an international commitment, through the WMO/ESCAP Panel on Tropical Cyclones, tropical cyclone advisories are issued by RSMC, New Delhi to the panel member countries during the tropical cyclones in the Bay of Bengal and the Arabian Sea.

The advisory messages are issued four to eight times a day. The ESCAP Panel countries are Thailand, Myanmar, Bangladesh, Pakistan, Sri Lanka, Maldives and Oman.

Services for Civil Aviation

IMD provides a crucial service to the national and international civil aviation sector in fulfilment of the requirements prescribed by the International Civil Aviation Organisation and the Director-General of Civil Aviation of the Government of India.

Full-fledged Aeronautical Meteorological Offices in state- of-art meteorological equipment have been established in IMD at the four international airports at New Delhi, Mumbai, Chennai and Calcutta. These forecasting offices also serve as meteorological Watch catering to flights in their respective Flight Information Regions. IMD also has aeronautical meteorological offices at all major national and international airports in the country. These offices provide forecasts of winds and temperature required for flight planning, prognostic weather charts, forecasts for aerodrome weather for landings and take-offs, and significant weather information for aviation operations. The Regional Area Forecast Centre of IMD at New Delhi caters to the aviation needs of India and the neighbouring countries and keeps liaison with other such centres at London and Washington DC.

For observational support to the aviation services, IMD maintains 71 Current Weather Observatories within the country.

Satellite Meteorology

Till 1963, India Meteorological Department had to depend on United States Weather Bureau for satellite cloud pictures. The International Meteorological Centre (IMC) at Mumbai set up in connection with the International Indian Ocean Expedition received the necessary ground equipment from the US National Science Foundation. This Automatic Picture Transmission (APT) ground station has been functioning at Mumbai since December 1963 and has been providing excellent pictures of cloud cover. Realising the great usefulness of these satellite pictures for weather forecasting, the Department developed indigenous ground equipment. Four such new units were installed at New Delhi, Calcutta, Chennai and Pune during 1970 and a fifth one at Guwahati in 1975. A directorate of satellite meteorology was created at New Delhi in 1971 which is responsible for receiving and processing the imagery now available from Indian National Satellite INSAT.

Long Range Forecasting

India started issuing long range forecasts in the year 1886. In very recent years, long range forecast models developed inhouse through the efforts of our own scientists have enabled IMD to issue reasonably accurate monsoon forecasts for the country as a whole during the past 12 years in succession. IMD has also taken up a few pilot studies to develop LRF models for smaller regions, as well as, for part seasonal rainfall, as growing demands for such forecasts are being received from various users from the common farmer to government agencies. These studies have shown that statistical models and dynamical models can be developed for LRF of seasonal, part seasonal and monthly rainfall over state meteorological sub division scale. These forecasts are very much needed for detailed planning in several fields of national activities. Systematic research in meteorology on a continuous basis and exploitation of contemporary scientific techniques to improve the quality of its service is very essential as it has direct bearing on the weather forecasting services.

Hydrometeorology and Flood Forecasting

India receives 80 per cent of its annual rainfall during the southwest monsoon season of June to September. Rainfall over the country during this season shows a wide range of spatial variation due to orographic influence and preferential occurrence of rain-bearing systems in certain regions. India has a very extensive raingauge network and rainfall monitoring over the country is a stupendous task.

The real-time monitoring and statistical analysis of districtwise daily rainfall is one of the important functions of the Hydrometeorological Division of IMD at New Delhi. Based on the real time daily rainfall data, weekly districtwise, sub-divisionwise and statewise rainfall distribution summaries are prepared regularly by the Rainfall Monitoring Unit. Maps showing weekly and cumulative rainfall figures in 35 meteorological subdivisions of the country are prepared. This information is very important to many user agencies particularly for agricultural planning. Flood Meteorological Offices (FMOs) have been set up by IMD at ten locations viz., Agra, Ahmedabad, Asansol, Bhubaneshwar, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi and Patna. During the flood season, FMOs provide valuable meteorological support to the Central Water Commission for issuing flood warnings in respect of main rivers in the country.

Meteorological Telecommunication

The telecommunication division of IMD plans, executes, controls and coordinates the complete telecommunication needs of the meteorological service. Its responsibilities also include coordination with other offices and agencies including World Meteorological Organization (WMO) and International Civil Aviation Organization (ICAO) in regard to all telecommunication matters.

Timely receipt of observational data at forecasting centres is as much an operational necessity as the timely recording of the observation itself. IMD has all along used the latest and fastest means of communication available, for achieving this purpose. Weather telegrams were heavily used for transmission of weather messages in the early part of the century. In recent times, IMD was the first organisation in the country to acquire a Data Switching Computer for meteorological telecommunications. Currently, IMD offices are linked internally by T/P and telex circuits, satellite-based VSATs, satellite-based MDD (Meteorological Data Dissemination) services, HR/RT stations, etc. The

Regional Telecommunciations Hub at New Delhi is connected to centres of global data and products. IMD has now its own Internet web site at New Delhi and other regional offices.

Environmental Meteorology

The Environmental Meteorology Unit of IMD was set up at New Delhi under an agency scheme of the Ministry of Environment and Forests. It provides specific services to this Ministry and other Government agencies for the assessment of pollution impacts from various industries and thermal power plants. Atmospheric dispersion models are employed for prediction of air quality under different terrain and meteorological conditions. These studies facilitate decisions regarding siting of industries and adoption of control strategies.

This unit also operates a meteorological observatory in the vicinity of the Taj Mahal at Agra. The data is provided to Ministry of Environment and Forests along with appropriate interpretations so that abatement measures can be planned.

Background Air Pollution Monitoring Network (BAPMoN)

With a view to documenting the long term changes in composition of trace species of the atmosphere as a result of changing land use pattern, WMO had commissioned a global programme called Background Air Pollution Monitoring Network (BAPMoN) which is now a part of the Global Atmospheric Watch (GAW) Programme. India had set up 10 such BAPMoN stations.

At these stations, rain water samples are collected every month and these are sent to the Central Chemical Laboratory at Pune for complete chemical analysis. Acidity of rain and mineral deposition is determined from these.

Atmospheric turbidity which indicates the columnar aerosol load of the atmosphere is also measured at these stations using sunphotometers. These data are important for identifying the current levels of pollution as well as for study of the long term trends in the concentration of trace constituents of the atmosphere which may affect the environment and induce a climate change.

To study the impact of industrialisation, urbanisation and terrain modification on microclimatological features of urban areas, urban climatological studies are carried out in metropolitan cities.

Seismology

Seismic observations in India started as early as in 1890s, at Mumbai, Calcutta and Chennai. This seismological observatory network which consisted of only 15 stations in 1960 has since grown and at present 58 seismological observatories are manned and maintained by the department. Many of them are located near dam sites.

With seismology gaining importance, a separate Directorate of Seismology was created in 1961. A catalogue of earthquakes from historic times to date in India and adjoining areas has been prepared. These data were extensively used to study the origin and the cause of the important earthquakes which have occurred in and near India. Special studies have also been conducted in connection with the reservoir - associated seismic activity around Koyna, Pong, Sundernagar and Bhakra dams. At present ten seismological stations are of global standard forming the part of Global Standard Network (GSN).

Instrumentation

IMD has been manufacturing the upper air and surface instruments required for use in its network since 1940s. The office of the Deputy Director General of Meteorology (Upper Air Instrument), New Delhi, consisting of Hydrogen Factory at Agra and Laboratories and Workshop at New Delhi, is responsible for coordination of all technical aspects related to the field of upper air instruments and the office of the Deputy Director General of Meteorology (Surface Instruments), Pune, consisting of laboratories and Workshop are responsible for the surface instrumentation. Instruments manufacturing workshops located at New Delhi and Pune produce 80 types of Meteorological instruments and total number of 450 industrial workers are at present engaged in this work. These workshops and laboratories have developed several systems for Meteorological measurements. The Current Weather Instruments System (CWIS) is one such example. This system is used at all airports to monitor temperature, dew point, wind speed and direction with digital display summaries. These laboratories cater to the development, production and testing of various surface and upper air instruments including radiosondes, ozonesondes and radiometersondes.

Research Activities

Research and service have always gone hand in hand in IMD. Pineering work has been done by IMD scientists in many fields of meteorology which is referred to even in modern text-books and reviews. It has been the policy of IMD to encourage and support organised as well as individual research work. IMD scientists contribute their research papers to the journal MAUSAM, the publication of which is itself an activity of IMD. Besides, a large number of papers of IMD scientists have appeared in other Indian and Foreign journals and presented at national/ international symposia.

IMD scientists have been actively involved in international collaborative programs. Important results pertaining to monsoon interaction with short period oscillations and global forcing have been derived under the collaborative programs.

A number of departmental officers have registered for Ph.D programs. IMD has been recognised as a research centre for Ph.D programmes by many universities like Banaras Hindu University, Anna University, Andhra, Pune, Delhi, Nagpur and Bombay to mention a few. The National Data Centre, Pune ensures that service and research demands can be met within reasonable time. Recently, an efficient data base management system has been installed.

Training

An in-house training unit in IMD was established in 1942 to meet the growing need of forecasters and supporting staff having diverse educational standards. Subsequently, the training activities have grown enormously by incorporating courses in various disciplines: General Meteorology, Instrumentation, Agrometeorology, Telecommunication and computerized data processing. Simultaneously, the syllabi have been updated keeping pace with development in meteorology. In addition, a number of advanced refresher courses on specialised subjects, including a number of SAARC seminars, have also been conducted.

TABLE – I

Director Generals of India Meteorological Department (IMD)

Mr. H.F. Blanford	1875 –1889
Mr. John Eliot	1889 –1903
Mr. Gilbert Walker	1904 –1924
Mr. J.H. Field	1924 –1928
Mr. Charles Normand	1928 –1944
Dr. S.K. Banerjee	1944 –1950
Mr. V.V. Sohoni	1950 –1953
Dr. S.C. Roy	1953 –1954
Mr. S. Basu	1954 –1959
Mr. P.R. Krishna Rao	1959 –1965
Dr. C. Ramaswamy	1965 –1966
Dr. L.S. Mathur	1966 –1969
Dr. P. Koteswaram	1969 –1975
Shri Y.P. Rao	1975 –1978
Dr. P.K. Das	1979 –1983
Shri S.K. Das	1983 –1986
Dr. R.P. Sarker	1986 –1988
Dr. S.M. Kulsreshtha	1989 –1992
Dr. N. Sen Roy	1992 –1998
Dr. R.R. Kelkar	1998 – 2003
Dr. S.K. Srivastav	2004 - 2005

Since 1967, the training centre has been extending its expertise and facilities to foreign countries. The training facilities of the department have been recognised as a Regional Meteorological Training Centre (RMTC) of the WMO in 1986 which is among the centres chosen by the WMO to support its global effort in development of human resources in the field of meteorology. Several WMO sponsored training seminars have also been organised by IMD in the field of tropical meteorology, storm surge, agrometeorology and monsoons.

The training facilities of the department consist of well-equipped laboratories, class rooms with modern audio-visual equipment, well furnished residential hostels and training school building.

Since the inception of the training centres, the department has trained nearly 12,000 trainees in various disciplines including 264 foreign trainees mainly from developing countries in Asia and Africa.

Outlook

From a modest beginning in 1875, IMD has indeed a long way. IMD has continuously ventured into new areas of application and service, and steadily built upon its infra-structure in its history of 125 years. It has simultaneously nurtured the growth of meteorology and atmospheric science in India. Today, meteorology in India is poised at the threshold of an exciting future.

CHAPTER 4

OBSERVATIONAL NETWORKS AND INSTRUMENTATION

The instruments and equipments required for the huge network of surface and upper air observatories in the country are mostly met by inhouse production in IMD's own Workshops and laboratories at New Delhi and Pune. These laboratories also cater to the development, production and testing of various surface and upper air instruments including radiosondes, ozonesondes and radiometersondes. Uniformity in the use of meteorological instruments, is ensured by evolving standard specifications for all basic meteorological instruments. The Workshops located at New Delhi and Pune produce 80 different types of meteorological instruments and a total number of 450 industrial workers are at present engaged in this work. These Workshops and the laboratories have developed several systems for making meteorological measurements and observations which are widely used all over the country.

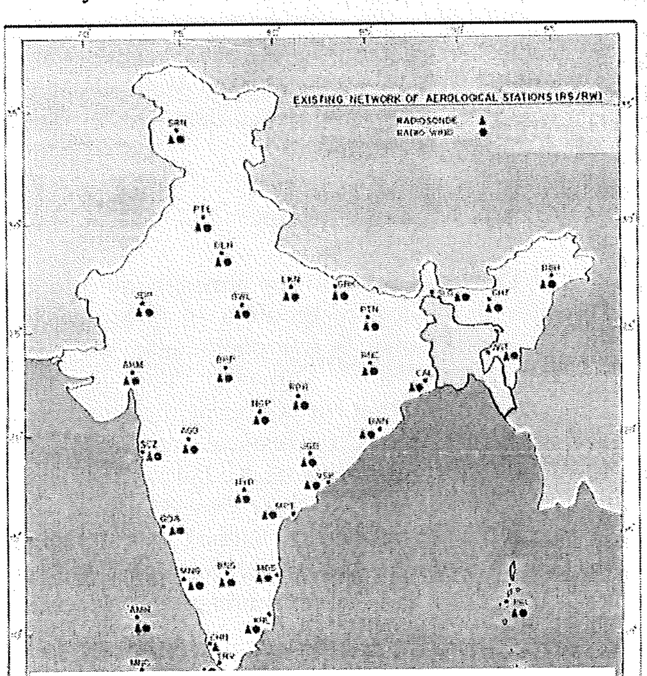
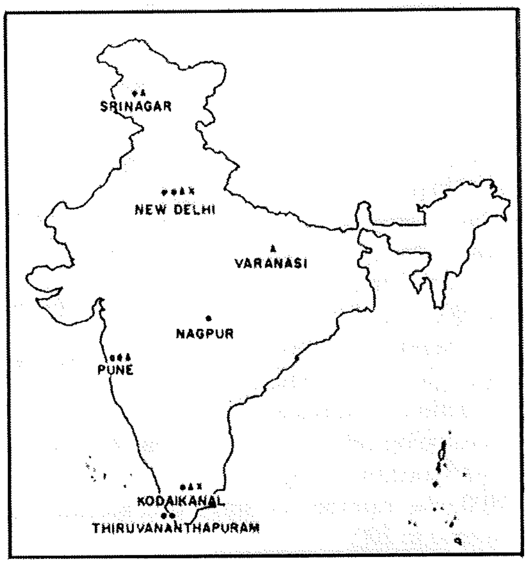


Fig. 7 : RS/RW Network of IMD



IMDS OZONE MONITORING NETWORK.

(LEGEND :
▲ : DOBSONS SPECTROPHOTOMETER
X : BREWER SPECTROPHOTOMETER
● : SURFACE OZONE
O : OZONE SONDE STATIONS)

Fig. 8 : IMD's Ozone Monitoring Network

India belongs to that select group of countries who manufacture their own upper air and surface instruments. The Office of the Deputy Director General of Meteorology (Upper Air Instruments), New Delhi, is responsible for co-ordination of all technical aspects related in the field of upper air instrumentation and the office of the Deputy Director General of Meteorology (Surface Instruments), Pune, is responsible for Surface Instruments. Measurements of Surface Ozone concentration are made at Delhi, Pune and Thiruvananthapuram. Pune is also designated by the WMO as the National Radiation Centre of RA II (Asia).

IMD's Observational Network

IMD maintains a dense network of surface and upper air observatories all over the country. In addition, it also maintains a network of storm detection radars, cyclone detection radars and observatories for measuring atmospheric ozone and atmospheric radiation.

Prior to 1875, the British East India Company had established 77 meteorological observatories in the country. From 1875 to 1905, the network expanded, mostly through the induction of surface meteorological observatories. By 1900, the number of surface observatories increased to 200.

As of now, IMD maintains 559 surface observatories of which 62 are more than 100 years old. In the surface network there are 45 radiation measurement stations, 10 Background Air Pollution Monitoring Network stations (BAPMoN). In addition there are 7 ozone monitoring stations, 653 hydrometeorological stations, 219 agrometeorological observatories, 222 evaporation stations, 39 evapotranspiration stations, 49 soil moisture measurement stations, 80 dew measuring stations and 50 snowfall measuring stations. For supporting the aviation activities there are 71 current weather observatories. Apart from this there are about 8500 non-departmental raingauge stations.

The upper air network consists of 35 Radiosonde (RS), 34 Radio-wind (RW), 62 Pilot Balloon (PB), 4 Ozonesonde and 8 Radiationsonde stations in the IMD's network. Two ascents are taken at the RS, RW stations daily while 2-4 observations are taken by the PB observatories.

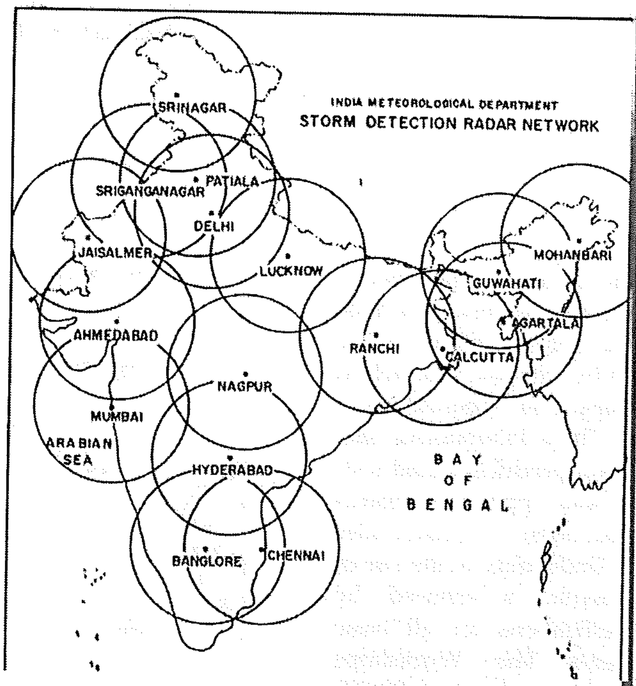


Fig. 9 : Storm Detection Radar Network

Weather Radars

IMD's first meteorological radar was commissioned at Calcutta airport in 1954. The first cyclone detection radar was operationalized at Visakhapatnam in 1970. The present network of meteorological radars in IMD consists of 26 X-band radars and 13 S-band radars. IMD is currently in the process of replacing the cyclone detection (S-band) radars by State-of-the-Art Doppler weather radars. The primary function of the S-band radars (10 cm wavelength) is to locate and track the tropical storm in the Bay of Bengal and Arabian Sea. The X-band radars (3 cm wavelength) are generally installed at airports for surveillance of weather around the airport. Most of the major airports like Ahmedabad, Bangalore, Guwahati, Calcutta, Chennai and Ranchi have now new digital X-band radars with the facility of computer controlled operation with colour monitors and printers. Useful meteorological products can be generated from these digital data with the help of appropriate software.

Ozone Measurements

The total ozone in the atmospheric column and its vertical distribution is measured by Dobson Ozone Spectrophotometer at New Delhi, Kodaikanal, Varanasi, Pune and Srinagar. In addition surface ozone measurements are made by electrochemical instruments at New Delhi, Nagpur, Pune, Kodaikanal, Srinagar and Thiruvananthapuram. Observation of vertical ozone profile by Balloon borne ozone sonde is made once every fortnight at New Delhi, Pune and Thiruvananthapuram.. Considering the importance of ozone as a major trace gas in the atmosphere, Brewer Ozone Spectrophotometers have been installed at New Delhi and Kodaikanal (Fig. 10). Recently, a similar instrument has also been installed at the Indian

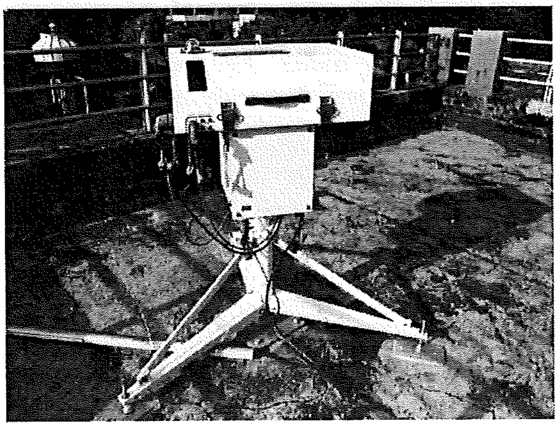


Fig. 10 : Brower Ozone Spectrophotometer

Antarctic station Maitri. This instrument is capable of monitoring NO_2, SO_2 and UV-B. IMD's National Ozone Centre at New Delhi maintains the ozone data base for the country.

Instrument Laboratories

The laboratories in the Instrument Division of IMD are located at Pune and New Delhi. These offices are headed by Deputy Directors General of Meteorology. The overall co-

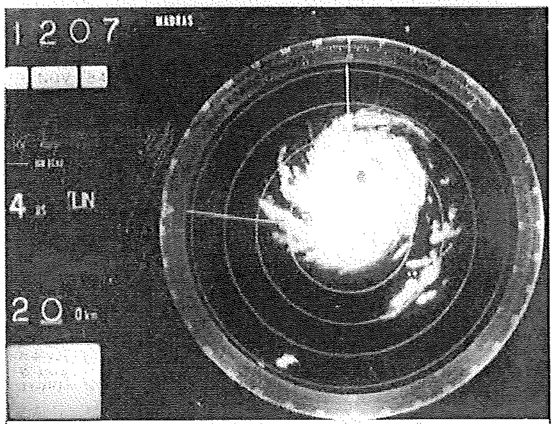


Fig. 11: Typical S-Band Radar Image

ordination is done by Additional Director General of Meteorology (Instruments). During the post independence era a radio-meteorological laboratory in New Delhi in the establishment of DDGM(UI) and a surface and electronics laboratory in establishment of DDGM(SI) were set up. The radiometeorological laboratory at New Delhi functioning under DDGM(UI) has the mandate of maintaining the radar and the upper air network, while the laboratory at Pune is mandated to fabricate and assemble aeronautical meteorological instruments, distant indicating wind instrument, current weather instrument systems etc. In addition, testing and calibration of conventional surface meteorological instruments is done in the laboratories at Pune. The facilities are used not only to test and calibrate the in-house production but also instruments manufactured by private manufacturers. IMD's certification is mandatory for all meteorological instruments before they can be put in use. The Pune laboratory also oversees the radiation measurement network in the country. The data gathered from 13 radiation stations are sent to World Radiation Data Centre (WRDC) at Petersburg, USSR.

Radiation laboratory is designated as the Regional Association (RA II) centre by WMO and hence a set of various regional standard instruments (viz., 4 absolute radiometers, 10 angstorms pyrheliometers, 7 pyranometers) are maintained by this laboratory. India has participated in the international pyrheliometer comparison since IPC II to the last IPC VIII regularly and thus the calibrations are traceable to the World Radiometric Reference (WRR)..

Workshops at New Delhi and Pune

The Workshop at New Delhi manufactures various types of Radiosondes, viz., 401 MHz Radiosondes, 1680 MHz Radiosondes, Ozone Radiosondes, for the measurement of upper air Pressure, Temperature and Humidity at 34 stations spread throughout India and one in Sri Lanka. The Radiosondes for Antarctica Expeditions, Ocean Expeditions, Indian Navy, Mountain Meteorology and other specialscientific projects are also supplied out of the production of the unit.

Workshop at Pune manufactures and maintains Surface instruments such as ordinary Raingauge, Cup Counter Anemometer, Mechanical Windvane, Selsyn/potentiometric windvanes, Mini Stevenson Screen, Mast and its accessories, Radar targets and Hand - held Anemometer. It also fabricates the main and slave panels of Current Weather Instrument System (CWIS) for airports. It is engaged in the manufacture and maintenance of all autographic instruments like Thermograph, Hair hygrograph, Barograph, Self recording raingauge, Dynes Pressure Tube Anemograph, etc.

The IMD production workshops and instrumentation laboratories are the backbone of the national meteorological service. More than that, the manufacture of instruments by IMD with its own facilities helps the country to save valuable foreign exchange.

Hydrogen Factory at Agra

A Hydrogen Factory for producing the hydrogen gas required for balloons used in the upper air observations was set up at Agra in 1925. The demand for hydrogen gas has expanded with the expansion of the upper air network. Hydrogen Factory at Agra produces about 30,000 cubic metres of gas costing about Rs. 1.2 crores annually. It also provides supply of Ferrosilicon, Caustic Soda etc. to outstations to augment the supply of hydrogen gas. Upper air network of Indian Air Force and Indian Navy are also provided with the supply of hydrogen gas from this factory.

CHAPTER 5

WEATHER FORECASTING

Weather plays an important role in various socio-economic activities like agriculture, irrigation, shipping, aviation, off-shore oil exploration, space flights, flood control, expeditions, public health etc. Accurate forecasts and timely warnings against severe and hazardous weather is one of the most challenging tasks of any national meteorological service.

Weather Forecasting Services in India

In 1877, a preliminary effort was made to prepare Weather charts by getting the meteorological data from field stations by post and analyse them. Since, there was a long time gap of ten to fifteen days before the data could be put together these reports were of limited practical use.

After the widespread drought of 1876-77, the Government desired to get early information of the progress of monsoon during 1878. To meet this requirement, the suggestions made by Eliot in May, 1878 for obtaining the weather reports from observatories by telegrams was approved. The first Daily Weather Report (DWR) of 15th June, 1878 (Fig. 12) was published under the new system two days later. This DWR service functioned satisfactorily from July onwards till the end of monsoon season and the quickness with which it was established in full working order in those early days was indeed very creditable.

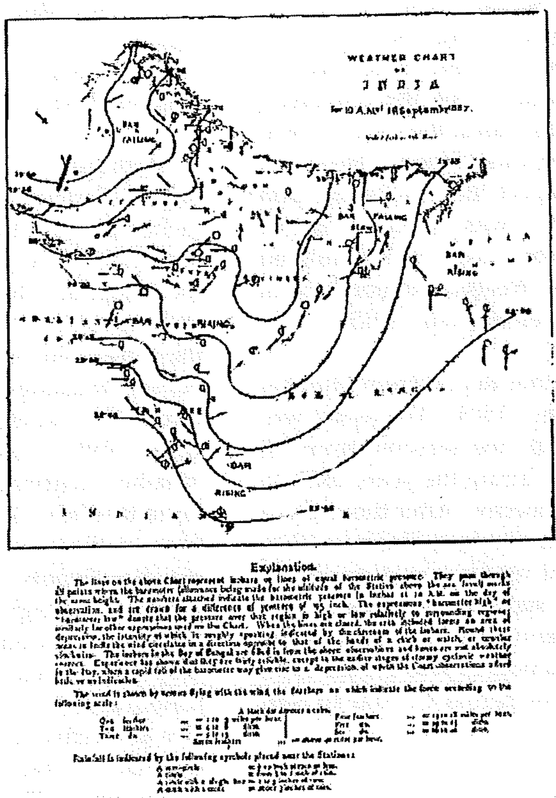


Fig. 12 : First chart published with India Daily Weather Report (1 Sept. 1887)

In addition to the DWR published from Calcutta, Simla also issued a DWR giving the observations at 10 AM for 51 stations and a short summary describing the chief features throughout the rainy season of 1878. A weekly summary of weather was also published in the Gazette of India. As this service proved to be very useful, it continued for the rest of the year as well, even though it was started for rainy season only.

From 1878 to 1880 the DWR was issued from Simla between 16th May & 15th October of each year and from Calcutta during the remaining period. The descriptive summary of each weather report was telegraphed to all the provincial governments and copies were furnished to the important daily newspapers at Calcutta, Allahabad and Bombay (Mumbai). Since 8th April, 1885, the daily weather reports issued under the authority of Department of Revenue and Agriculture were issued only at Simla, a permanent establishment being retained there for this purpose.

Publication of the Bengal Daily Weather Report commenced in 1883. This was the first provincial report and was issued only during the period April to November as it was primarily meant for noting the progress of rainfall. The first forecast regarding rainfall was given in the Bengal daily weather report only in 1884.

The Indian Daily Weather Report first included a weather chart on 1st September, 1887 describing the pressure distribution, direction of air movement at 10 AM of the day and the rainfall of the previous 24 hours. This was changed by Eliot to observations made at 8 AM so that daily weather reports could be printed on the same day.

Since 1883, two reports; namely the Bay of Bengal report and the Bengal Daily Weather Report used to be published during the rainy season from May to October. In 1896 these two reports were amalgamated. For the remaining period viz. November to April, the Bay of Bengal weather report alone was issued. From 1st April 1905 only one report "Bay of Bengal and Bengal Daily Report" was being issued throughout the year. The name was simplified as to "Calcutta Daily Weather Report" from 1st January, 1908 which remained till 1945.

The first Daily Weather Report from Mumbai was issued on 14th May, 1889. The report was not being published in the seasons from 1st November to 30th April during the years 1923 to 1928 as a measure of economy. After the shift of Headquarters office from Simla to Pune in 1928, the issue of the Mumbai report was stopped. In its place only a weather summary containing the principal features of weather over western India and the chief rainfall amounts was issued from Mumbai, daily during the period 1st May to 30th November each year.

The unsatisfactory seasons and partial failure of crops in the Madras (Chennai) Presidency during 1892 and 1893 arouse the interest of Chennai authorities and public in the issue of a daily weather report from Chennai Presidency. The first report was issued by the Chennai office on 1st October, 1893 containing the full information of weather in the whole of the Madras Presidency and for some additional stations chiefly in Burma (Myanmar), Bengal and Ceylon (Sri Lanka) coasts and also include a chart. From 1923, these reports were published for a part of the year and sometimes for the full year as a measure of economy but it was completely discontinued in 1931.

From 1928, the Indian Daily Weather Report (IDWR) covering the whole country was started which was issued from Weather Central, Pune. From 1936, ships' observations, upper winds measured by pilot balloons and temperature and humidity data from aircraft ascents were also included. During the Second World War period, these Reports were not issued due to security reasons. Initially the Weather Central, Pune was responsible for the issue of daily telegraphic summary of the general weather situation over the country with a forecast for the next 24 hours and for the publication of daily, weekly and monthly weather reports, storm warnings for the west coast (Arabian Sea) and inland warnings. The status of forecasting organisation was upgraded and post of Superintending Meteorologist - Forecasting (SMF) was created in November, 1943 and was located at Karachi.

With the formation of 7 Regional Meteorological Centres at Mumbai, Calcutta, Delhi, Karachi, Lahore, Chennai and Nagpur in 1945, the Regional Meteorological Centres started issuing the Regional Daily Weather Reports covering their areas of responsibility without charts but they included Farmers' Weather Bulletins containing warnings for weather affecting agriculture. The post of SMF was transferred to Pune in April, 1945 to enable him to supervise the Pune Weather Central which was responsible for all India forecast. Dr. S.N. Sen was the first incumbent to the post. In 1946, the post was redesignated as Deputy Director General of Observatories (Forecasting) and Shri. S. Basu was the first to occupy this post. In 1947, due to partition of the country, two regional centres i.e. Karachi and Lahore came under Pakistan Meteorological Service and remaining five Regional Meteorological Centres continued in the India Meteorological Department. This expansion further continued and in 1970 Meteorological Centres have been established in the capitals of most of the states in the country. These Meteorological Centres started issuing state daily weather reports. In 1978, the post of DDGO(F) was again redesignated as Deputy Director General of Meteorology (Weather Forecasting) (DDGM(WF)). In April, 1997 a sixth Regional Meteorological Centre was established at Guwahati for North East India.

Weather Central, Pune is the main forecasting centre of IMD. The Weather Central also provides technical guidance and co-ordination related to weather forecasting. It issues all India Weather Bulletins twice daily, covering all the 35 meteorological subdivisions and also for Bay of Bengal, Arabian Sea and the Indian Ocean. This unit also co-ordinates the activities of the Area Cyclone Warning Centres (ACWC) and Cyclone Warning Centres (CWCs) and issues advisory weather bulletins during the storm period.

Another activity of Weather Central is to provide current weather information and forecasts about the onset, day to day rainfall activity and the withdrawal of the monsoon, which is the most important weather phenomenon in the country. The Weather Central also prepares and publishes the Indian Daily Weather Reports (IDWR) and Weekly Weather Reports (WWR), monsoon summary and storm accounts.

The weather forecasting services provided by the IMD are used by various agencies. Today there are about 1000 Registered/Designated users who are on the mailing list of the Regional Meteorological Centre/Meteorological Centres receiving the forecasts for their specific requirements like heavy rainfall warnings etc.

Service to Aviation

Aviation Weather Service forms one of the major activities of the Department. All phases of aircraft operations are influenced by weather and the safety and economy of air transport depend to a large extent on the availability of reliable current weather information and forecast.

The first air flight over India was in 1911 from Allahabad to Naini, a distance of a few miles. The first known aviation forecasts were issued in 1921 from Simla for Royal Air Force (RAF) operations in Waziristan in the then NW India. To provide the upper wind data for aircraft in flights, upper air observatories were established at Agra and at Lahore in 1917 and 1918 respectively. Initially the aviation forecasts provided by India Meteorological Department were ad hoc in nature. In order to meet the exacting requirements of Royal Airforce Planes special aviation forecasts offices were opened at Peshawar, Quetta and Karachi during 1925-26.

In April 1929, the air mail service from England to India was inaugurated upto Karachi which was later extended upto Delhi in December 1929. A forecasting office was started at Delhi. The Karachi and Delhi Meteorological Offices were responsible for issuing weather warnings for these flights. During the same period the Calcutta Meteorological office was catering to the aviational forecasting needs of Eastern India and Burma (Myanmar).

During the World War II there was a phenomenal growth of aviation in India. Numerous air fields were opened all over India, especially in the border areas. The Delhi forecasting office was revived in 1939, and a special airforce meteorological office was opened at Lahore in 1941. A principal forecasting centre was started at Bangalore in 1942. By 1944, there were twenty seven forecasting offices specially catering to aviation. In October 1944, a few forecasting offices notably at Palam, Jodhpur and Chaklala were taken over by the Royal Airforce. Military aircraft operating at altitudes of 5-6 km a.s.l. over long distances led to the establishment of a number of radiosonde stations in India, for providing information about prevailing and forecast winds and temperatures at these heights.

The end of World War II saw a decrease of military aviation but civil aviation activities grew rapidly. India became a member of the International Civil Aviation Organization (ICAO) and World Meteorological Organization (WMO).

The 1950's saw the advent of the jet age in civil aviation. The first civil aircraft (BOAC Comet I) flew through Bombay (Mumbai) and Calcutta in 1952. The Meteorological offices at Bombay (Mumbai) and Calcutta were given the responsibilities of providing the new type of services for jet flights. As these aircrafts were flying at a very high altitudes the department expanded the network of radio wind finding stations, storm detection radar, commencing with the installation of a storm detecting radar at Dum Dum (Calcutta) Airport in 1954.

By the end of 1950's aircrafts were flying non-stop from Indian Aerodromes to distant places and the density of traffic also increased substantially. To meet this demand Extended Analysis and Prognosis Centres (EAPC) were opened at Calcutta and Mumbai covering practically the whole of Eurasia and North Africa. The Chart Form of Documentation (CFD) containing prognostic significant weather charts and prognostic upper air charts at standard isobaric levels was introduced progressively at major airports.

More sophisticated instruments such as Ceilometer (for the height of cloudbase), skopograph (for Runway Visual Range (RVR)) were installed at major airports to meet these developments. Quick exchange of aerodrome weather reports viz. Met. Aviation Reports (METAR) at half hourly intervals with alternate aerodrome were organised between airports. The airports were linked by separate teleprinter / telex channels for exchanging aeronautical meteorological information. Automatic Message Switching Systems (AMSS) were installed for speedy transmission and reception of meteorological data. Closed Circuit Television (CCTV) display of METAR and SPECI at different points in the Airport was started, which later paved way for a PC based display system in 1999. Modern equipments have been installed in the airports for satellite data reception, communication and for the preparation of aerodrome meteorological summaries.

The present meteorological organization for aviation in IMD consists of one Regional Area Forecast Centre (RAFC) at New Delhi, 4 Meteorological Watch Offices (MWO), functioning at New Delhi, Mumbai, Chennai and Calcutta, 19 Class I Meteorological offices and 52 Class III Meteorological offices. Starting with just two in 1925, the number of aviation meteorological offices rose to 22 in 1950, 50 in 1975 and 71 in 1999.

Weather forecasts are needed for various activities like trekking, expeditions, mountaineering, sports and recreation. Special weather bulletins are issued for mountaineering expeditions in the Himalayas and these are useful in planning the day to day operations. Special users like agriculture (farmers), fishermen and off-shore oil explorers need weather forecasts to optimize their day to day activities (Fig. 14). Special weather

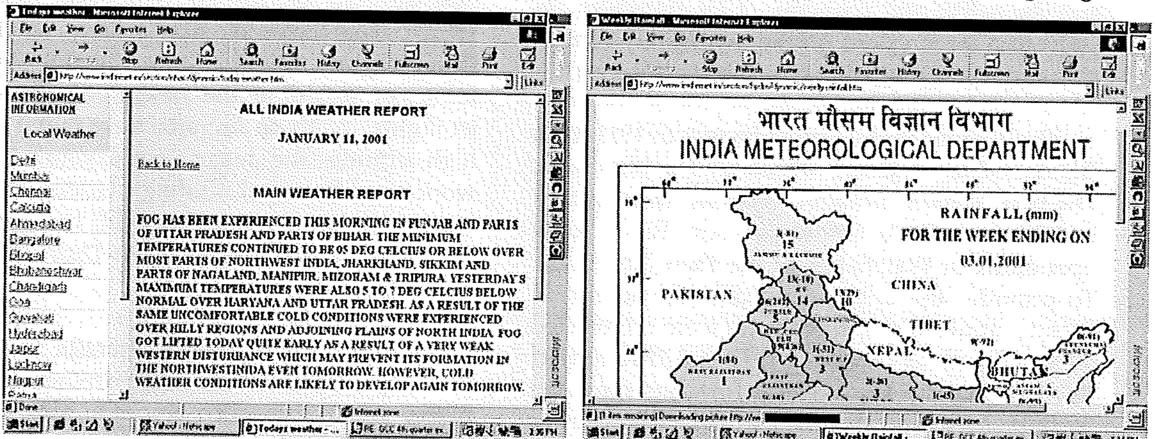


Fig. 14: Picture from IMD web site on weather report

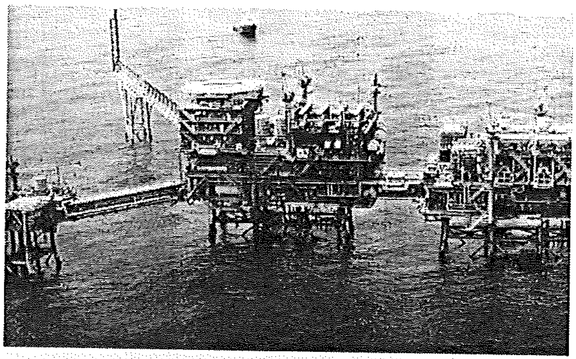


Fig. 13 : Offshore oil exploration by ONGC using weather forecast

forecasts for the farmers known as Farmers' Weather Bulletin are broadcast twice every day on the stations of All India Radio in regional languages from major AIR stations in the State Farmers' programme on T.V. project the role of weather to the farmers and hold useful discussions regarding the farming operations to be conducted keeping in view the weather situations. The forecasts of general weather condition, height and period of waves, occurrence of adverse weather in target areas are useful for the fishermen and the oil exploration activities e.g. ONGC activity in Arabian Sea.

Public Weather Services

The weather services to the public are tailored according to the need of the user, but most important are the forecasts and warnings against adverse weather. Every AIR station has a routine programme for broadcast of weather reports in the local language of each region. Special warnings against severe weather, like thunderstorms and duststorms based on radar observations are broadcast by the AIR stations. Weather information covering rainfall, temperature, pressure distribution and other special weather events alongwith the weather forecasts are telecast daily in Hindi and English on the National TV Programme. The latest cloud pictures from INSAT are generally telecast alongwith this information. Many newspapers publish regional weather forecasts and local forecasts, regularly. Weather reports, forecasts and telegraphic summaries are supplied to subscribers on request.

The latest weather information is also made available to the public through the special information service of the telephone system at important cities in the country. India Meteorological Department's web site, www.imd.ernet.in gives the latest update on national weather and daily forecast for internet users.

CHAPTER 6

IMD'S ROLE IN DISASTER MITIGATION

Weather plays an important role in various socio-economic activities like agriculture, irrigation, shipping, aviation, off-shore oil exploration, space flights, flood control, expeditions, public health etc. Accurate forecasts and timely warnings against severe and hazardous weather is one of the most challenging tasks of any national meteorological service.

India Meteorological Department was established in 1875 with a mandate to issue warnings about tropical storms and monsoon rains. Loss of human lives and property due to tropical storms and floods, damage to crops because of droughts, incidence of pests and diseases caused by unfavourable weather conditions are some examples of the adverse effects of weather. The India Meteorological Department which is one of the oldest scientific departments in India, has grown and expanded its activities in tune with these requirements.

Weather Service to Shipping and Storm Warning over the Indian Seas

A devastating cyclone struck Calcutta in October, 1864 which resulted in a loss of more than 80,000 lives. Within a few weeks another storm struck Machilipatnam and the storm wave killed about 40,000 persons. These tragedies caught the attention of the Government of Bengal. A Committee was appointed in 1865 to formulate a scheme for establishing meteorological observatories along the coast of the Bay of Bengal and at the Calcutta port for giving effective storm warnings to the port. The main functions of the scheme were to obtain meteorological observations for some stations around the north Bay by telegram and hoisting storm signals at the port.

The storm warning scheme for the west coast was adopted in 1880. In 1886, Blanford introduced a system of storm warning to all Indian ports including those in Burma (Myanmar) and storm warning operations began at these ports in 1888. Upto 1898 two different systems of storm signals were in use for the west and the east coast at Indian ports. This was a source of confusion. Later this was modified following the introduction of a uniform system of storm warning signals for use at all the ports. The uniform system consisted of an extended system of storm signals for large ports and a brief system for smaller ports. The extended system of storm signals is shown in Fig. 15.

Storm warnings by wireless

Wireless telegraphy in 1912, introduced a new mode of communication between the meteorological office and the ships at sea. Meteorological observations were passed to the coastal stations for transmission to ships requiring the information. Receipt of observations from ships through wireless messages helped the cyclone warning activity considerably. Side by side weather bulletins then began to be transmitted twice daily from the coastal radio stations

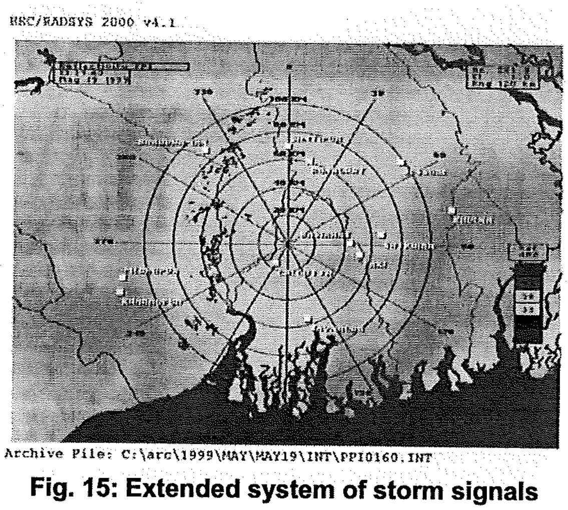


Fig. 15: Extended system of storm signals

at Mumbai, Karachi, Calcutta,Yangon (Rangoon), Chennai, Port Blair etc. for the ships on the high seas.

Evolution of Storm Warning Centres

The storm warning work for the Bay instituted at Calcutta was transferred to Simla for a brief period from 1922-27 to take advantage of the strength of full time officers there. However, delays in receipt of warning telegrams from Simla to Calcutta led to transfer of this work again to Calcutta in 1927 under the charge of a full time Meteorologist.

However, storm warning for the Arabian Sea was being issued from Simla from 1888 onwards after the post of Meteorological Reporter at Mumbai was made part time. With the shift of headquarters of the India Meteorological Department from Simla to Pune in 1928, the storm warning work was transferred to Pune.

With the formation of the Regional Meteorological Centres, responsibility of issuing storm warnings to the Bay ports south of Kalingapatnam in the Bay of Bengal was transferred to Madras (Chennai) in November, 1945. While Calcutta continued to issue storm warnings for the area north of Kalingapatnam in the Bay. The responsibility for the Arabian Sea ports was assigned to the Meteorological Office at the International Airport, Mumbai (Bombay) in 1947. A separate storm warning centre was set up at Colaba (Mumbai) in 1956 to separate it from the aviation activity at the airport.

For improving the accuracy of the cyclone warnings to ports and coastal areas, the department has set up three Area Cyclone Warning Centres (at Calcutta, Mumbai and Chennai), three Cyclone Warning Centres (at Bhubaneshwar, Ahmedabad and Vishakhapatnam) and 10 cyclone detection radar stations (Fig. 16). These radars can locate and track approaching cyclones within a range of 400 kms. The complete cyclone warning work is supervised and co-ordinated on real time basis by "Weather Central" in the office of Deputy Director General of Meteorology (Weather Forecasting), Pune and also by Directorate of Cyclone Warnings functioning in Northern Hemisphere Analysis Centre (NHAC), New Delhi.

A Cyclone Warning Division (CWD) at Headquarters was set up in 1990 to co-ordinate and supervise the totality of cyclone warning programme in the country. Doordarshan and AIR stations at New Delhi are provided Cyclone Warning Bulletins by this Division for inclusion in the National broadcast / telecast. Information on cyclone warnings are furnished on a real time basis to the Control Room set up in the Ministry of Agriculture, Government of India, besides other Ministries and Departments of the Government. Besides, the Cyclone Warning Division has the following functions at the International level :

a) To serve as Regional Specialised Meteorological Centre (RSMC) - Tropical Cyclones, New Delhi

b) To implement the Regional Cyclone Operational Plan of WMO/ESCAP Panel on Tropical Cyclones.

c) To prepare a comprehensive scientific report on the cyclones in the North Indian Ocean (the Bay of Bengal and the Arabian Sea) every year.

d) To issue daily Tropical Weather Outlook for the North Indian Ocean to the Panel Countries Thailand, Myanmar, Bangladesh, Pakistan, Sri Lanka, Maldives and Oman.

e) To provide Cyclone Advisories to the Panel countries four to five times a day.

Cloud pictures received from weather satellites are extensively used in locating the movement of cyclones over data sparse oceanic regions. At present, low resolution satellite pictures from the polar orbiting weather satellites are received at Bhubaneshwar, Mumbai, Calcutta, Guwahati, Chennai, Pune and Vishakhapatnam to help operational forecasting. Likewise an Advanced Very High Resolution Radiometer (AVHRR) facility is available at Delhi and Chennai for monitoring cloud imageries from the polar orbiting satellite which are specially helpful in storm warning operations. The processed cloud imageries are transmitted by INSAT Meteorological Data Processing Systems (IMDPS), at New Delhi to the 23 Secondary Data Utilisation Centres (SDUCs) of the Department. These inputs are now crucial for the cyclone warning activity of the department. Satellite picture of Orissa cyclone is given in Fig. 17.

Four High Wind Speed Recorders (HWSR), were installed and commissioned, one each at Paradeep in March, 1990, CDR Karaikal in March, 1993, CWC Vishakhapatnam in August, 1993 and at CDR Machilipatnam in March, 1995. The data from these are being utilised for the assessment of maximum wind and gust associated with cyclones.

The different types of bulletins and warnings issued by Cyclone Warning Centres for their areas of responsibility are:

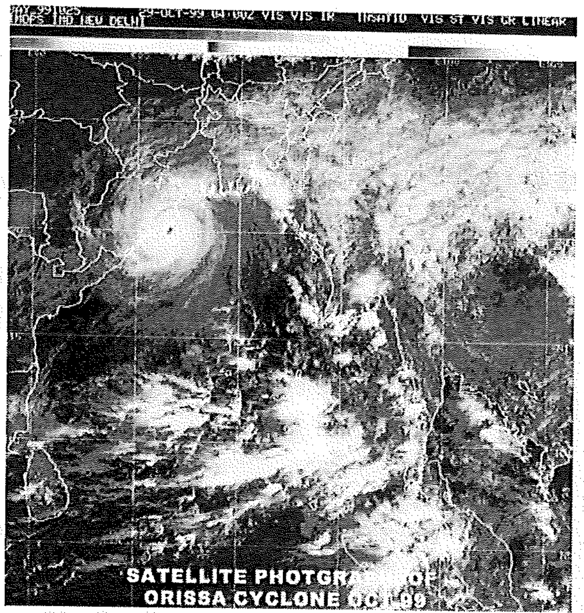


Fig. 17 : Satellite photograph of Orissa cyclone – October 1999

I. Sea Area Bulletins for ships plying in coastal waters.
II. Broadcast of forecast / warnings / bulletins through International Maritime Satellite (INMARSAT) Safety Met. Service under the Global Maritime Distress and Safety System (GMDSS) Programme of WMO for the ships in Indian Ocean (North of Equator) was started w.e.f. 1.6.96. This broadcast is made at 0900 UTC everyday through Indian Coast Earth Stations.
III. Bulletins for Indian Navy
IV. Port Warnings
V. Fisheries Warning
VI. Three stage warnings for State Govt. Officials
VII. Bulletins for broadcast through AIR and DD for general public
VIII. Warnings for registered recipients
IX. Bulletins for ships in the high seas through P&T's Coastal Radio Stations.
X. Bulletins for the Press
XI. Aviation Warnings (issued by concerned Aviation Meteorological Offices)

Cyclone warnings are communicated to Govt. officials and other parties by high priority Telegrams, T/P, Telex and Telephones. Police Wireless are also used as and when needed.The general public, the coastal residents and fishermen are warned through State Govt. officials and broadcast of warnings through AIR and telecast programme in national and regional hook up.

IMD follows a three stage warning system which is now discussed briefly. According to the "Three Stage Warning Scheme" the collectors of coastal and few immediate interior districts and the Chief Secretary of the concerned maritime state are warned in three stages whenever any coastal belt is expected to experience adverse weather (heavy rain / gales / tidal wave) in association with a cyclonic storm or a depression which is likely to intensify into a cyclonic storm.

The first stage warning known as "Pre Cyclone Watch" is issued 72 hours in advance by Northern Hemispheric Analysis Centre (NHAC), New Delhi when a depression forms in the Indian seas. The second stage warning called "Cyclone Alert" is issued 48 hours in advance of the expected commencement of adverse weather over the coastal areas. The third stage warning known as "Cyclone Warning" is issued 24 hours in advance. With introduction of new technology the cyclonic warning work has shown a steady improvement particularly in the last dec-

Fig. 18 : Damage to coconut trees during the Orissa Super Cyclone

ade. This has won high acclaim from the Government and the user agencies.

During disturbed weather over the Bay of Bengal and the Arabian Sea, the ports likely to be affected are warned through Storm Warning Signals. The department also issues "Fleet Forecast" for Indian Navy and coastal bulletins for Indian coastal areas covering upto 75 kms. from the coastline.

Cyclone Warning Dissemination System (CWDS)

In addition to the existing modes of dissemination of cyclone warnings to various user agencies through fax, telephone, high priority telegrams and telex by IMD a new scheme called the Cyclone Warning Dissemination System (CWDS) using INSAT has been implemented. This was started on an experimental basis for the coastal areas of South Andhra Pradesh and North Tamil Nadu in December, 1985 by establishing 100 CWDS Receivers. This scheme was made operational during 1986-87. State Government officials of Andhra Pradesh found this scheme very useful especially in Rural areas. This communication method is more reliable as they do not use terrestrial links which are disrupted during severe weather. The cyclone warning message is originated from ACWC Chennai whenever a storm is observed for reception by CWDS receivers located in areas likely to be affected.

After a successful demonstration of the scheme in areas of Tamil Nadu and South Andhra Pradesh, it has been extended to other cyclone prone coastal areas. About 230 CWDS receivers have been installed so far in cyclone prone areas of the east and west coasts.

CHAPTER 7

CLIMATE INFORMATION SERVICES AND NATIONAL DATA CENTRE

While a knowledge of weather and climate is very important for the proper utilization of natural resources, weather and climate are being increasingly looked upon as natural resources themselves. The climatology of a place or region is important for deciding the cropping patterns, planning land use, designing runways, air-conditioning, port installations, installation of high towers, bridges and other structures. Operation of multi-purpose hydro-electric projects, management of reservoirs, siting of wind and solar energy generators, defence operations, off shore drilling operations are some of the modern day activities which are crucially dependent on climatological data. Past climate data are also very important in climate modeling through which we can attempt to predict the nature of future climate change.

Even though the India Meteorological Department was established in the year 1875, it has preserved all earlier climatological records for the country. Such data were initially archived at Alipore (Calcutta) and later at Simla. The data archives were shifted to Pune in 1942 and are now a part of the National Data Centre in the office of Additional Director General of Meteorology (Research).

The Office of ADGM(R) has many Sections dealing with specific types of data and climatological services. Some of these functions are briefly described.

Data collected from surface meteorological network is archived by National Data Centre at Pune. Activities of the surface network including change of instruments, opening of new observatories, establishment and shifting of observatories are all co-ordinated at Pune.

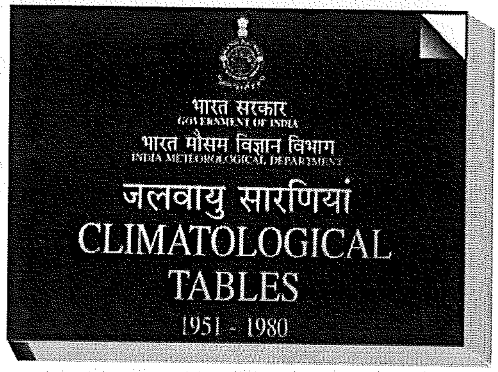


Fig. 19 : Cover page of Climatological Tables (1951-1980)

Preparation of bar reduction tables, wind rose diagrams, climograms, aeronautical met. summaries, monthly weather reports, handbook pages of surface observatories are some of the main functions of this unit.

Monthly Climate data for 44 Indian stations are globally disseminated by this Unit as per WMO's requirements.

A separate unit was set up at Pune in 1930 to collect, scrutinize and archive the meteorological data from the country's upper air network. Prior to this, upper air office at Agra was responsible for this activity. Various studies and preparation of upper air climatological tables and normals are also done by this unit.

At present, there are 35 radiosonde, 34 radiowind and 65 pilot balloon observatories covering the entire country. They take 2 or more flights a day. These data are scrutinised, processed and various quality control checks are carried out before archival. In addition to this data from special upper air soundings over the research vessel Sagar Kanya, Indian stations in Antarctica, and soundings made specially for programmes like Indian Middle Atmospheric Programme, Global Energy and Water cycle Experiment, Bay of Bengal Monsoon Experiment etc. are also processed and archived.

This unit computes Normals, Short Period Averages, Atlases of PB and RS/RW data. The normals are periodically updated and published.

Preparation and publication of climatological atlases, tables and other publications and their revision is one of the main functions of the office. These publications are in great demand and are periodically updated.

Climatological Division of IMD has brought out the "Climatological Tables of Observatories in India (1931-60)" in 1971. This publication has been revised using 1951-80 normals. The Climatological Atlases of India were published in 1971 and 1981. Separate volumes of the Climate of Various States and Union Territories of India have been also prepared and printed for the users.

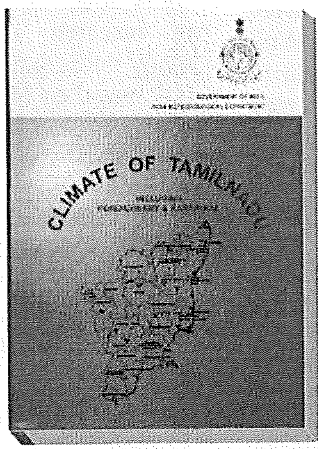


Fig. 20 : Cover Page of Climate of Tamil Nadu

Measurements of the solar radiation received on the earth is important in understanding the heat budget of the earth-atmosphere system as a whole. This in turn gives a better insight into the physical processes in the atmosphere, land and ocean. Keeping this in view a beginning was made by the India Meteorological Department (IMD) by setting up a network of 4 stations in the International Geophysical Year (IGY) 1957, to measure radiation parameters. The number of stations measuring radiation observations was augmented in stages during the International Indian Ocean Expedition (IIOE), International Quiet Sun Years (IQSY) periods and the network consisted of 13 principal radiation stations and 11 ordinary radiation stations. As the network was found to be inadequate for understanding of the radiation climatology of India, 14 more stations have been added in 1984. Apart from these, 8 other radiation stations were further added for monitoring the activity of desert locusts over northwest India.

Data on all radiation parameters like global, diffuse, direct radiation at normal incidence, global radiation on inclined plane, net radiation, net terrestrial radiation, reflected radiation, Angstrom's turbidity coefficient, etc are being recorded at various stations since 1957. The continuous recording of direct radiation data have been started for 10 stations since 1985. Also the measurements of Linke Turbidity factor "T" are being recorded at 24 stations since 1994.

The radiation data are collected, scrutinised and processed in the office of ADGM(R). In the context of the increasing importance of data relating to solar radiation, the processed data are utilised for detailed investigational studies on radiation climatology and also for a better understanding of the relationships between weather and solar radiation. Radiation data are supplied to departmental/non-departmental users for their research/project work. A Handbook on Solar Energy was prepared using the radiation data of IMD by Dr. A. Mani.

The daily/monthly mean values of Global and Diffuse radiation data of selected 13 stations are processed and sent to World Radiation Data Centre (WRDC), St Petersburg, Russia every year for publication.

National Climate Centre

Since 1996, the National Climate Centre (NCC) brings out monthly and seasonal 'Climate Diagnostics Bulletin of India' regularly on a near- real time basis. These bulletins are disseminated in the country and abroad.

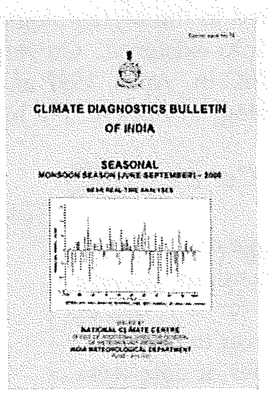


Fig. 21 : Cover Page of Climate Diagnostic Bulletin

The National Climate Centre, when fully evolved, will be responsible for the following functions :

- Monitoring variations of climate over the globe on a real time basis with particular emphasis on the Indian region
- Short period reviews of climatic behaviour
- Monitoring atmospheric composition on various parameters related to the climate systems e.g. green house gases, aerosols,

solar radiation, cloud cover, surface albedo, soil moisture etc.

- Conversion of basic and derived data for the last 30 years on a grid point basis
- Diagnostic studies of the climate of Indian region with a view towards better understanding and description of the mechanisms, underlying climatic fluctuations, ocean atmospheric interactions and teleconnections and large scale anomalies

Climatological Data

The India Meteorological Department has preserved the climatological records even for periods prior to 1875 when it came formally into existence. The meteorological observations at Chennai from 1793 and at Mumbai since 1841 are also available.

Prior to 1942, climatological records were preserved at Calcutta and Simla till 1906. With the shift of the headquarters from Simla to Pune in 1928 all the records were transferred to Pune in 1942. Upto 1930, the basic surface data of all observatories were collected at the headquarters office. After the partial decentralisation in 1932, Pune, Calcutta and Karachi offices collected the data of surface observatories falling under their jurisdiction. After the creation of Regional Centres in 1945, and after the partition of India the responsibility for collection of the surface observational records was vested with five Regional Meteorological Centres (New Delhi, Calcutta, Chennai, Mumbai and Nagpur). Later the work was entrusted to the Meteorological Centres which came into existence. Guwahati became the sixth RMC in April, 1997 and takes care of the climatological work for NE India.

National Data Centre (NDC)

With the passage of time there has been a tremendous increase in the set up of network of observatories all over the country. Thus huge volumes of data were generated. One of the prime functions of the National meteorological services is collection, processing and archiving of weather data and preparation of climatological summaries / statistics etc. Ever since the Office of the Deputy Director General of Observatories (Climatology and Geophysics) Pune was designated as National Data Centre (NDC) for weather data in India, there has been a continuous endeavour in IMD for introducing fast and modern computing facilities in NDC. Till 1945, the desk calculators were in use for the preparation of climatological statistics. In the beginning, the meteorological data were punched in the respective sections of this office. In sixties and early seventee's Tabulators, Collators, Sorters, Hand punches and Verifiers were the means of work for transferring the huge volumes of data that flowed into this office. The Central Data Punching (CDP) Unit was established in 1968.

The advent of high speed electronic computers revolutionised data processing techniques. Thus enormous amount of data could be processed and the results were achieved in a short time. To meet the ever growing needs of research and development activities in many fields such as climatology, agrometeorology, weather forecasting etc. (in addition to the main objectives of transfer of data from cards to electronic media), the department took a big leap forward by acquiring a modern third generation computer EC-1040 and the National Data Centre (NDC) was established in 1977. Salient features of this system were large storage capacity, fast transfer of data, facilities such as multi-programming, library utilities and built-in house keeping softwares such as sort / merge and update. This was the landmark towards achieving the goals of NDC ever since its inception.

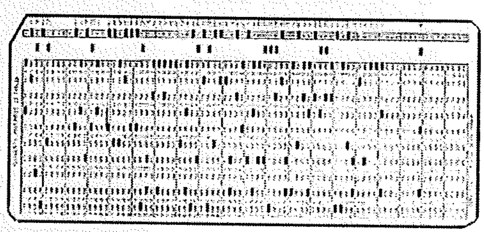


Fig. 22 : Punch Card

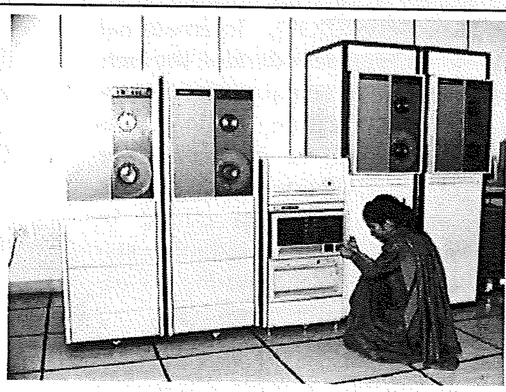


Fig. 23 : National Data Centre

In 1986, another computer system VAX-11/730 was added to strengthen the research, data processing activities and also data supply capabilities.

To handle the increasing voluminous data at the rate of about 2-3 million records per year, a new fourth generation mainframe computer system VAX-4000/300 was installed in 1993. This is a powerful system which includes a large number of peripherals connected on LAN, such as PCs', Dumb terminals, Workstations, CD ROMs, CTDs and Plotters with suitable software capabilities. The quality control checks on data to make them error free before permanent archival are being subjected at a faster rate and effectively by the in-house developed softwares. VAX-4000/300 has a large disk space and all the data have been transferred onto disk area for direct access and fast processing. With the availability of all data on the disks and Relational Data Base Management System (RDBMS) the response time for supplying of data decreased considerably.

A similar development took place in the data entry also. The era which began with the usage of old and conventional hand punch machines was changed into the practice of data entry with machines and key to tape convertor in the early 80's for an automatic and speedy punching work. To be at par with the latest technological developments 12 Personal Computers (data entry machines) were put into operation in the place of these (key to tape) machines.

NDC offers the following services :

Data Archival

NDC, Pune is the sole custodian of the meteorological data meticulously collected over the last 125 years. The climatological information is a national heritage and is being preserved at NDC very carefully.

The observations at each observatory are being entered in the standard meteorological formats. The transfer of data from manuscripts to punch cards was started way back in 1945 and from punch cards (about 25 million) to magnetic tapes in 1977 after the acquisition of EC-1040 Computer System and a compact data storage was built up. With the advent of speed and large storage spaced computer systems, the data are being subjected to various quality checks before archival at a faster rate. The current rate of addition of archival on an average per year is 25-30 lakhs. Presently, the total holdings of data are 80.9 million records. There are about 15 types of data being stored in the archival. These data include surface, upper air, autographic, marine, rainfall etc., besides data of special observations like Ozone, OLR, Rocketsonde, MONEX, Sagarkanya and Antarctica Expeditions.

Data Supply

Climatic data have innumerable applications in almost all human activities. Demands of climatological data come from Govt., public and private sectors, Universities and Research organisations and Industry. IMD uses this data for weather prediction, diagnostic studies, air pollution problems, simulation studies, drought and crop yield research and forecast and climate change studies.

On an average 10-12 lakh records of met. data are being supplied to users on floppies / Compact Disk every month. To promote and encourage research, only Computer charges are collected and data charges are not levied for the supply of meteorological data to Universities / research organisations and research scholars etc. As per the departmental policy the commercial users are charged for the cost of the data also. However, as per Resolution 40 (WMO Cg-XII), India Meteorological Department is providing a free and unrestricted basic essential data and products to the member countries which are necessary for the provision of services in support of the protection of life and property and the well being of all nations.

The VAX-4000/300 systems are being used by the various units of IMD and IITM at Pune for data processing, quality control of data, weather forecasting, long range forecast of rainfall, numerical modelling, drought research, crop yield forecast, climate change, air pollution studies and so on. Users are provided full software support for successful completion of their tasks. Help is also provided to users in making optimum use of all the software and hardware facilities available in NDC.

Projects and Special Activities

- In the National Data Centre an internet facility was installed recently to support and facilities research and operational activities.
- The climatological normals for the period 1951-80 for 391 observatory stations have been compiled and preparation of normals for 1961-90 is in progress.
- At Regional Meteorological Cetres/ Meteorological Centres the old data entry machines were replaced by 44 new pentiums for data entry and for their speedy processing and archival.
- 12 PC based digitisers were installed at Flood Meteorological Offices to speed up the work of digitisation of relevant data.
- An ambitious project for digitisation of analysed weather charts for the past 100 years on electronic media in digitised form for permanent archival for studying and re-analysis has been taken up.
- A project for the upgradation and expansion of the present computer system of the National Data Centre is in progress.

CHAPTER 8

AGRICULTURAL METEOROLOGY

Indian agriculture is heavily dependent on the southwest monsoon rainfall and India's agricultural production is modulated by its intra-seasonal and inter-annual variation. So much so that the Indian economy is often said to be a gamble on the monsoon. Nearly 68% of the net cultivated area of the country has only rain-fed agriculture. Heavy rains, floods, droughts, long dry and wet spells, delay in the arrival of the monsoon or its early withdrawal, all have adverse effects on crop production.

Way back in the 1920's, which were characterised by uncertain monsoons, it was realised that a sound scientific knowledge was needed on the relations between weather and crops. In 1926, Mr. J.H. Field, then Director General of Observatories, submitted a statement to the Royal Commission of Agriculture on this subject. The Commission recommended a collaboration between Agricultural Departments and IMD, and proposed the creation of a new branch of Agricultural Meteorology in IMD. The Imperial Council of Agricultural Research agreed to give the required grant.

Establishment of Agricultural Meteorology Division

The Agricultural Meteorology Division of IMD started functioning towards the end of 1932 at Pune under the leadership of Dr. L.A. Ramdaswho did pioneering work in this field. A Central Agricultural Meteorological Observatory was also established soon in the Agricultural College, Pune.

In the early years, the Agricultural Meteorology Division carried out studies relating to the climatic conditions near the ground, development of instrumental techniques for recording observations relevant to plant growth and soil-water phenomena and their influence on plant growth.

Any abnormalities in the weather during the season such as delay in the outbreak of rains, untimely or excessive rains, droughts, spells of too high or too low temperatures etc. very seriously affect the growth and final yield of the crops. Analysis of the existing data has indicated that climatic factors account for at least 50% of the variability of crop yields over a series of years. Manure, variety, cultural operations etc. all combined account for the remaining 50% of the variability.

In tune with the changing agricultural scenario in the country, the Division of Agricultural Meteorology has taken up more specific research problems like water requirement of crops, pests and diseases, rainfall probabilities in the dry farming tracts, modelling of crop weather relationship, application of remote sensing techniques in Agricultural Meteorology etc.

Network of Agromet Observatories

The Division of Agricultural Meteorology coordinates a wide network of Agrometeorological Observatories which are maintained by cooperating institutions and record different agrometeorological parameters. IMD provides technical assistance to these institutions for setting up the stations, maintenance of instruments, training of observers and validation of data.

1)	Agrometeorological Observatories	219
2)	Evaporation Stations	222
3)	Evapotranspiration Observatories	39
4)	Soil Moisture Observatories	49
5)	Dew-fall recording stations	80
6)	Desert Locust Activity Monitoring Stations	7

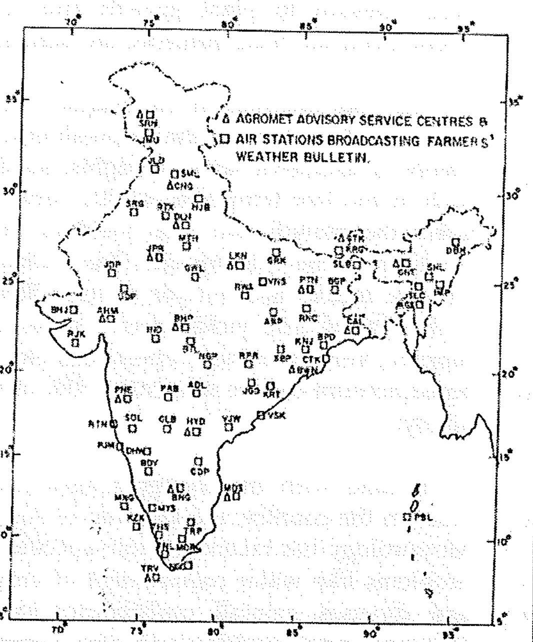


Fig. 24 : Map indicating–Agromet Advisory Service Centres (Δ) and Air Stations Broadcasting Farmers' Weather Bulletin (□)

In addition, the Division of Agricultural Meteorology has its own network of 39 evapotranspiration observatories to study water consumption of various crops in different agroclimatic zones of the country and 12 soil moisture observatories.

Data archival and supply

The data generated from the network of agrometeorological observatories are processed and sent to National Data Centre, Pune for archival. The data are supplied to various Agricultural Institutes/individuals engaged in research and development activities.

Services

Special Farmers' Weather Bulletins were introduced in 1945 from different AIR Stations in local languages. These are now broadcast twice daily from well over 70 AIR Stations. In order to further enhance the effectiveness of weather bulletins to farmers, a new service called "Agrometeorological Advisory Services (AAS)" was started in 1983. Agromet. Advisory Bulletins are issued weekly/bi-weekly through 17 AAS Units located at Regional Meteorological Centres and Meteorological Centres of IMD. These advisories are prepared in consultation with the experts from the respective State Agricultural Departments, taking into consideration the stage and state of the crop, agricultural operations in progress, prevalence of pest and diseases etc. and the immediate impact of the weather on the above. The bulletins are broadcast over All India Radio and telecast by Doordarshan in the regional language of the area.(Fig. 24)..

Based on a long series of weather and crop data, district-wise "Crop Weather Calendars" have been prepared for use by farmers and agricultural planners. The calendars show the effect of different weather elements on the growth of the crop during various phenological phases of the crop.

An important activity in agrometeorology is to collate and collect qualitative/quantitative information on crop pests and diseases from different collaborative Agricultural Universities/ Institutes and to develop forewarning models (Fig. 25). The weather based information generated from these studies for the incidence of pests and diseases is communicated to different end users for taking operational plant protection measures and also through the Agromet Advisory Bulletins.

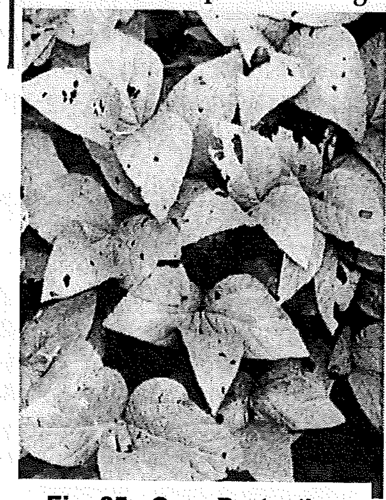


Fig. 25 : Crop Protection by Pest & Disease

The Division of Agricultural Meteorology plans to modernize the Central Agrimet Observatory (CAgMO) at Pune and 3 Agrometeorological Research Units located at Bangalore, Anand and Rahuri. It is also planning to carry out intensive studies on crop yield estimation, crop condition assessment including detection of water stress and soil moisture estimation using remote sensing data.

The following research activities are being pursued in the Division

- Forewarnings of the outbreak of pests and diseases of various crops in collaboration with different agricultural universities.
- Water consumption of different crops using the data generated by evapotranspiration (ET) stations.
- Preparation of ET-weather diagrams using the data for different crops

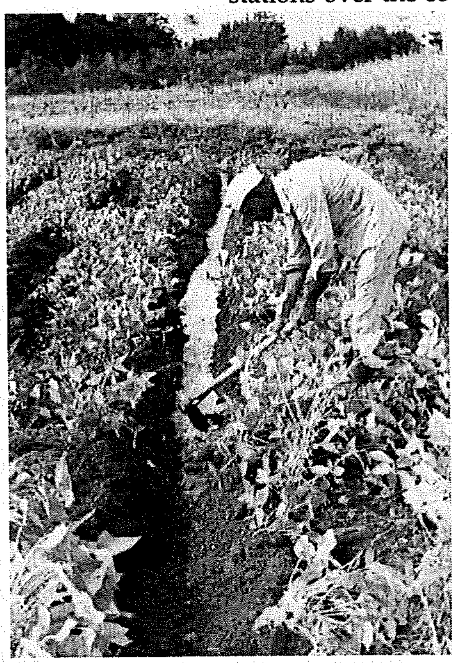


Fig. 26 : Water Use Management

Drought Monitoring and Research

After the widespread drought in the years 1965 and 1966, at the instance of Planning Commission, a Drought Research Unit was established in IMD at Pune in 1967, for agroclimatic and synoptic study of droughts.

Meteorological drought is defined as a large-scale deficiency of rainfall of more than 25 per cent. A rainfall deficiency exceeding 50 per cent is categorized as severe drought. Using these criteria, IMD has computed the frequency and severity of meteorological droughts over meteorological sub-divisions of the country and for the country as a whole, using rainfall data since 1875. Such studies help to identify the drought prone areas of the country and the probability of occurrence of drought. IMD monitors the rainfall scenario over the 35 sub-divisions of the country on a weekly basis and identifies areas which are likely to suffer from water shortage or crop stress (Fig. 26).

Dry Farming Research

The division of agrometeorology identified that a large part of the country receives rainfall of 40 cms or less annually. Such districts having annual rainfall less than 40 cms and without adequate irrigation facilities are known as dry farming areas. These are generally capable of supporting different types of crops provided the water resources are managed on a scientific basis. In order to meet this, studies have been carried out by analysing the rainfall records of nearly 2000 stations over the country, to compute the amount of "Assured Rainfall" for the various weekly periods in the growing season for the districts in the dry farming tract. The probability of assured rainfall has been determined through a statistical procedure in which Incomplete Gamma distribution model has been used.

Yet another approach is to compute the lengths of dry and wet spells and the Moisture Availability Index (MAI) for these areas. MAI is relevant to the crop growth since it gives the ratio of the assured rainfall (computed) to potential evapotranspiration for the same period. Assuredrainfall, MAI and the soil type have been used to get tangible agro-climatic classification. Such a classification is useful in deciding the most favourable growing seasons for the rainfed crops, evolving a suitable cropping pattern and in selecting drought tolerant crop varieties.

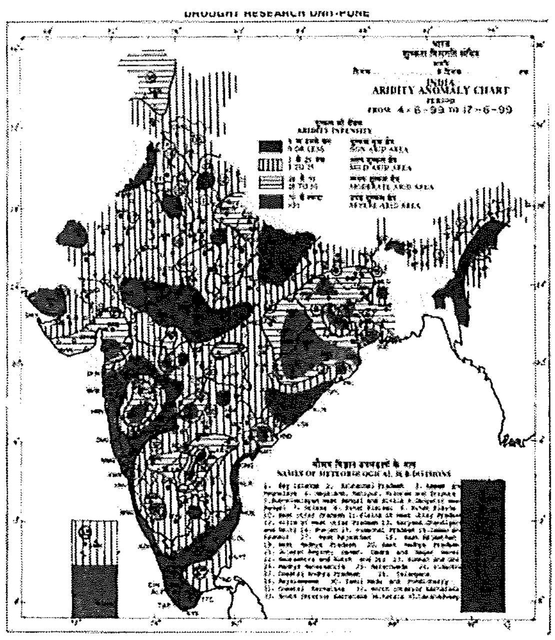


Fig. 27 : Aridity Anomaly Map

IMD monitors agricultural drought on a fortnightly basis, during the kharif and rabi seasons, for which aridity indices are calculated on the basis of potential and actual evapotranspiration, in addition to rainfall. The aridity index anomalies help to categorise areas of the country as non-arid, or mildly, moderately or severely arid. The real time monitoring of rainfall deficiencies and aridity anomalies provides early warning signals of approaching drought. The information is widely disseminated to central and state government agencies and other users.

Crop Yield Modelling

IMD has developed pre-harvest crop yield forecasting models which are used to issue crop yield forecasts for the country and for individual states for major crops like kharif rice and rabi wheat. The forecasts are supplied to the Ministry of Agriculture, Government of India for long-term contingency planning purposes. The first interim forecast for kharif rice is issued in August and is updated monthly until the final forecast is given in November/ December. For wheat, the first interim forecast is issued in January and the final forecast is issued in March/April.

The crop forecast models are based on statistical regression techniques which make use of the correlation between weather parameters like rainfall, temperature, relative humidity, cloud amount in critical stages of crop growth and the final yield. A long series of historical crop yield and meteorological data is used for developing the statistical relationships.

Future development plans and projects

- To develop mathematical simulation models of photosynthesis, plant growth, evapotranspiration and respiration process for management of agricultural systems.
- To study impact of land-use changes such as large scale irrigation and deforestation, on micro-climate.
- To study in collaboration with research institutions, boundary layer problems like various fluxes in crop canopy and on bare soils, to compute canopy resistance, stomatal resistance etc. from experimental data.
- To develop crop management systems in which weather and climate data are used to guide crop management.
- To make further use of remote sensing for crop identification, estimation of crop yield and development of early detection and warning system of crop hazards.

CHAPTER 9

HYDROMETEOROLOGY, GLACIOLOGY AND MOUNTAIN METEOROLOGY

India receives 80 % of its annual rainfall during the monsoon season (June-September). India's food production and water resources largely depend upon this rainfall. However, the monsoon rains are highly variable in both space and time and some parts of India may experience deficient rainfall while in the same year severe floods may occur elsewhere in the country. Monitoring of rainfall, particularly during the southwest monsoon season is therefore crucial. The science of hydrometeorology goes beyond rainfall analysis and deals with all aspects of water such as rain, snow, evaporation, evapotranspiration and soil moisture. Hydrometeorological inputs are important for hydro electric power generation, flood control, water resources management, drainage control, irrigation, river navigation and many public utility services. Rainfall, however, remains as the basic parameter for all kinds of Hydrometeorological studies.

Rainfall Resolution of 1890

About two centuries ago, the British East India Company set up observatories for recording rainfall at Madras (now Chennai) in 1793, in Simla and Colaba (Mumbai) in 1841, Dodabetta (near Uthagamandalam) in 1847 and Calcutta in 1853.

Towards the middle of the 19th century, many provincial Governments in India had begun recording rainfall at a number of stations supervised by their revenue officials. In those early years, there was no uniformity in the type of rainfall measuring equipment or in the manner of observations. Each province made its own separate arrangement for the collection of rainfall data, which were usually published in the Provincial Gazettes. The Government of India brought the subject of rainfall registration under the overall technical control of the India Meteorological Department by the resolution of August 1890, which is commonly known as the "Rainfall Resolution of India" and which is still in force.

Under this resolution, the following practices were made mandatory:

i) The adoption of a common type of raingauge (Symon's) for rainfall registration throughout India,
ii) Supply of instruments through the Central Meteorological Office, which would be responsible for the calibration and accuracy of raingauges,
iii) Regular inspection of raingauge stations and the submission of reports to the controlling offices,
iv) Scrutiny and examination of rainfall data by qualified officers and publication of annual data for the whole of India.

The India Meteorological Department was made responsible for,

i) Technical advice to State Governments on all matters connected with rainfall registration, such as selection of sites and installation of raingauges, methods of rainfall observation, inspection of raingauge stations and
ii) Compilation and issue of consolidated rainfall data for the whole of India in the publication entitled "The Daily Rainfall of India" and "The Monthly Rainfall of India" for each calendar year and their distribution among qualified recipients. The department was also required to initiate studies pertaining to rainfall.

Hydrometeorological Set-up

After the rainfall resolution of 1890, annual rainfall statistics were being compiled at the Headquarters of the Department for the whole country. After independence, the historical rainfall data available in IMD proved very useful in national planning of river valley projects and other development activities. A Hydrology Section was established at Pune in 1946 to co-ordinate all aspects of rainfall registration by State Governments and augmentation of the raingauge network in the country with the technical guidance of IMD.

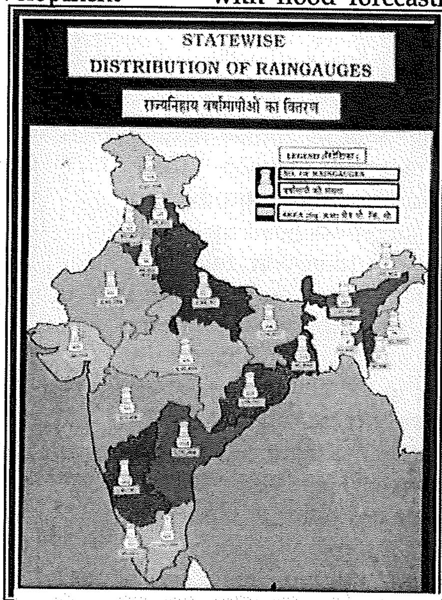


Fig. 28 : Statewise distribution of Raingauges

A special hydrometeorological unit was established in 1949 at Alipore to provide operational meteorological services for the Damodar Valley Project. The hydrometeorological studies and operational activities progressively increased, culminating in the establishment of a Directorate of Hydrometeorology at New Delhi in 1971.

Hydrometeorology Units were established subsequently at the six Regional Meteorological Centres (New Delhi, Calcutta, Nagpur, Mumbai, Chennai and Guwahati) for organisation and inspection of raingauge stations. The main activities of these units include continuous build-up of rainfall statistics, hydrometeorological analysis of different river catchments for the benefit of project authorities and meteorological support for flood warning and flood control operations by the field units of Central Water Commission.

Monitoring of daily rainfall data from a countrywide network of raingauge stations throughout the year on real time basis is one of the crucial functions of IMD. Based on the data, districtwise and sub-divisionwise weekly rainfall reports highlighting the temporal and spatial distribution of rainfall over 35 meteorological sub-divisions covering the whole country are being prepared at present. These reports are supplied to various Government departments and agencies for official use. These weekly statistics are used for drought and flood monitoring as well as for quick appraisal of the rainfall situation over the country.

Observational Network

The observatories recording mainly precipitation data, were set up in connection with flood forecasting, river basin studies (like the Damodar Valley, Ganga, Brahamaputra etc.), compilation of rainfall statistics for use in construction of dams, railways and road bridges, evaluation of snow melt in Himalayan rivers and water balance and glaciological studies. These observatories are manned by part-time staff. The number of observatories depends upon the needs of the specific projects.

In addition to the raingauges maintained by the Department, State Governments also maintain over 4500 raingauge stations whose data are made available to the India Meteorological Department in non-real time mode. Railways, Forests and Agriculture Departments and other organisations maintain more than 5000 non-reporting raingauge stations to meet their own specific needs. The department does not incur any expenditure on running these raingauge stations except on their periodical inspection.

Rainfall Analysis

Preparation of sub-divisionwise and districtwise weekly rainfall summaies was started during 1980-84. Later a Districtwise Rainfall Monitoring Scheme (DRMS) was introduced from June 1990 for preparation of districtwise and sub-divisionwise weekly rainfall summary on a real time basis using data from about 2,400 stations throughout the year. Preparation of sub-divisionwise updated monthly / seasonal rainfall summaries was also started under the scheme.

These weekly, monthly and seasonal rainfall maps are being widely disseminated for use by planners, policy makers, agricultural scientists, civil and irrigation engineers, research scholars and others in the field of hydrometeorology. The products are also available on IMD's web site for the general public.

Hydrology Project

The World Bank aided "Hydrology Project" was initiated in 1995 with the main objective of involving central government and state water resources agencies in the development of valid, comprehensive, interactive, easily accessible and user friendly data bases covering all hydrological and hydrometrorological aspects in Peninsular India. The project is being implemented by eight states (Andhra Pradesh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa and Tamil Nadu) and five central agencies (India Meteorological Department, Central Water Commission, Central Ground Water Board, Central Water and Power Research Station and National Institute of Hydrology). Ministry Of Water Resources (MOWR) is the central nodal agency for the project.

The Hydrology Project has been a major step in the process of development of hydrometeorology in the country. IMD has the following roles to play in the project:

- Designing raingauge and climatological observation network
- Training of over 3000 State Govt. personnel in observational and analysis work
- Technical assistance to State Governments for procurement, testing, calibration and installation of meteorological instruments
- Annual inspection / maintenance of about 2500 State Govt. raingauges
- Data monitoring, evaluation and archival of data at the centres in each participating state, National Data Centre (IMD), Pune and IMD HQRs' at New Delhi.

Contributions to International Hydrology

IMD has been actively rendering its support to international programmes such as the International Hydrology Programme (IHP) and the Hydrological Operational Multipurpose System (HOMS). IMD is one of the members of the Indian National Committee on Hydrology (INCOH) for implementation of IHP.

IMD has been actively participating in the Operational Hydrology Programme (OHP) of WMO. IMD has contributed extensively to the HOMS reference manual. HOMS is a technology transfer system of WMO for operational hydrology.

Storm Analysis for Designing Hydromet Structures

IMD works out hydrometeorological criteria for designing major structures like dams or reservoirs for irrigation on hydropower generation as well as for construction of railway and road bridges, drainage systems and designing spillways. Design estimates based on analysis of past rainstorms over catchment areas are supplied to the design engineers for major civil works. Detailed isohyetal analysis to find out estimates of Standard Project Storm (SPS) and Probable Maximum Precipitation (PMP). Maximum rainfall increments are used to get Depth Area Duration (DAD) curves.

Some of the important studies conducted so far include :

- Design estimates for more than 400 projects
- DAD/DD analysis of over 500 rainstorms in different parts of India
- Identification of historical rainstorms of various regions
- Regular updating of the catalogue of analysed rainstorm

IMD also provides hydrometeorological inputs for flood estimates for construction of major and minor structures like railway and road bridges, drainage systems and spillways. The hydrometeorological inputs include isopluvial maps of 25, 50 and 100 years return period, short duration ratio, time distribution curves and point to area rainfall curves. For this purpose, India has been divided into meteorologically homogeneous 7 zones and 26 sub-zones.

Rainfall Depth Duration (DD) frequency analysis is carried out which comprises

- Isopluvial maps
- Short duration ratios
- Time distribution curves
- Point to area rainfall ratios

21 Flood estimation reports have been brought out for 24 sub-zones in collaboration with CWC and Railways Research Design and Standard Organisation (RDSO).

Hydrometeorological Support For Flood Forecasting

Although flood forecasting comes under the mandate of the Central Water Commission, IMD supports this activity through the ten Flood Meteorological Offices (FMO) which it has set up in different flood prone areas of the country. These FMOs are located at Agra, Ahmedabad, Asansol, Bhubaneshwar, Delhi, Guwahati, Jalpaiguri, Hyderabad, Lucknow and Patna. During the flood season, FMOs provide the following vital information to CWC:

- Quantitative Precipitation Forecast (QPF) in different ranges of rainfall for the next 24 hours for the concerned catchments / sub-catchments
- Heavy rainfall warnings for the next 48 hours.
- Reporting of significant rainfall over the basin
- Preparation of synoptic analogues for forecasting daily QPF.
- Documentation of hydro-meteorological characteristics of river basins
- Digitisation of autographic rainfall charts for archival at the National Data Centre of IMD at Pune

Glaciological Studies

IMD conducts Glaciological studies relating to snow accumulation and snowmelt in the upper watersheds of the Himalayan rivers through ground observations as well as remote sensing techniques. Glaciological studies are carried out in collaboration with research institutions engaged in snow hydrology and glaciology, for effective management of water resources. Thirty Rainguage / Snowgauge stations were installed for glaciological aplications between 1977 and1999.

IMD scientists have participated in several multi-disciplinary glacier expeditions in the Himalayas, such as, Chotta Chigri glacier expedition 1987 and Dokriani Bamak glacier expedition 1994.

Mountain Meteorology Project

Observation and forecasting of weather in the mountains have their own difficulties. At the same time, they are very important for the populations residing in mountainous and hilly regions. Hostile weather, cloudbursts, landslides and snow avalanches take a heavy toll of life. A project for the development of Mountain Meteorology in Himalayas has recently been approved by the Government in order to enhance the observational system in the region and generate operational mesoscale weather forecasts which would also lead to improved avalanche predictions.

The Mountain Meteorology Project will be executed in three phases (Western, Eastern and Central Himalayas) jointly by the Army, Snow and Avalanche Study Establishment (SASE/DRDO) and Department of Science and Technology (India Meteorological Department and National Centre for Medium Range Weather Forecasting). IMD's role includes preparation of synoptic scale weather bulletins and advisories, supply of Global Telecommunication System (GTS) data and special satellite products, setting up 3 new upper air stations and upgrading 22 surface observatories. IMD personnel will work at the joint Mountain Meteorological Centre and a research and supporting unit will be created at New Delhi. IMD will also undertake training programmes in meteorology for army personnel.

CHAPTER 10

SATELLITE METEOROLOGY

Soon after the launch of the first U.S. Weather Satellite, TIROS-1 (Television and Infrared Observational Satellite) on April 1, 1960, and its successor satellites, IMD acquired in 1964, an Automatic Picture Transmission (APT) facility. This enabled reception of cloud imagery, albeit at low resolution (4 km.), from the polar orbiting satellite in real time with the help of inexpensive ground receiving equipment. IMD set up its first APT receiving station at Bombay (Mumbai) in 1965. Subsequently, seven more receiving stations were set up, at Delhi, Calcutta, stations were set up, at Delhi, Calcutta, Madras (Chennai), Bhubaneshwar, Pune, Visakhapatnam and Guwahati for receiving cloud pictures transmitted by TIROS and NOAA series of polar orbiting Meteorological Satellites of USA. One such station is now functioning at the Indian base station in Antarctica. In 1981, a ground station was established at IMD, New Delhi for reception of High Resolution Picture Transmission (HRPT) from NOAA series of US polar orbiting satellites with a picture resolution of 1 km. in Visible and Infrared channels. Availability of such pictures had enhanced IMD's operational weather monitoring and forecasting capability.

INSAT Programme

In the Eighties, Satellite Meteorology in India made a major breakthrough with the launch of India's own Geostationary Satellites. This first generation Indian National Satellite (INSAT) was a multipurpose operational satellite system. It met the needs of three different users viz. Television and Radio Broadcasting, Communication and Meteorology. India launched its first opera-

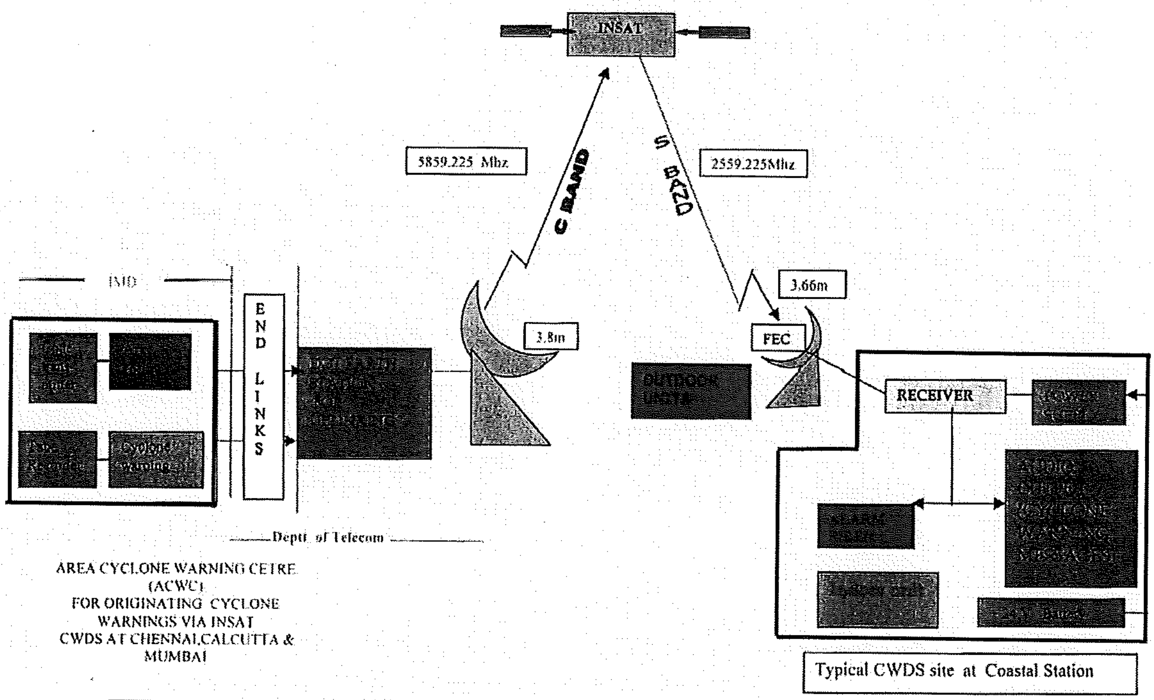


Fig. 29 BLOCK DIAGRAM FOR INSAT CYCLONE WARNING AND DISSEMINATION SYSTEM (CWDS)

Prepared by CWDS unit, Sat Met Div. .IMD .New Delhi Dated tional multipurpose geostationary satellite INSAT-1A on 10 April, 1982.

The second satellite of INSAT-1 series i.e.; INSAT-1B was launched on 30 August 1983 over the equator at 74^{0}E longitude which became operational on 15 October 1983. This was operational all through the 1980s and provided useful data and services. Under INSAT-1 programme, a Meteorological Data Utilization Centre (MDUC) was established in 1982 for processing INSAT-1 meteorological data and generation of various operational products. Processed data in analog form was also disseminated to the 20 Secondary Data Utilization Centres (SDUCs) located at important forecasting offices of I.M.D. through a dedicated communication link. After providing useful operational services for over ten years, it was deorbited in July 1993. The third Satellite of the series (INSAT-1C) was launched on 22 July, 1988 after which, it was operationalised. The last Satellite of INSAT-1 series (INSAT-1D) was launched on 12 June, 1990 and declared operational on 17 July, 1990. It was located at 83^{0}E and is still functional.

In early 1990s, India took a major forward step by inducting the second generation of indigenously built (INSAT-2) series of satellite designed and fabricated by Indian Space Research Organisation (ISRO) for operational use. The 2nd generation of INSAT Satellites (INSAT-2 series) were started from July 1992 with the launch of the first Satellite of the series (INSAT-2A) on 10 July 1992. The second satellite of this series (INSAT-2B) was launched successfully on 22 July 1993 and is located at 93.5^{0}E. Subsequently two satellites i.e. INSAT-2C and INSAT-2D did not carry a meteorological payload. The last satellite of this series viz. INSAT-2E was successfully launched on 2 April 1999 and is located at 83^{0}E.

Meteorological Services from INSAT

The resolutions of the two channels of the INSAT Very High Resolution Radiometer (VHRR) at sub-satellite point are 2.75 km. (Vis) and 11 km. (IR) for INSAT-1 and 2 km. (Vis) and 8 km. (IR) for INSAT-2 series of satellite respectively. Full earth images can be obtained in 23 minutes from INSAT-1 and in 33 minutes from INSAT-2. Limited areas of the earth can be covered with sector scans in 6 minutes from INSAT-1 and 7 minutes from INSAT-2 satellites.

The VHRR on board INSAT-2E satellite is similar to INSAT-2A/2B but has an additional water vapour band (5.7-7.1 μm) with 2 km. resolution in visible and 8 km. in IR and W V channel (Fig. 30). In addition, a camera using Charged Coupled Device (CCD) with three additional channels in visible (0.62-0.68 μm) near IR (0.77-0.86 μm) and shortwave IR (1.55-1.69 μm) each having spatial resolution of 1 km. provides high resolution imaging during daytime.

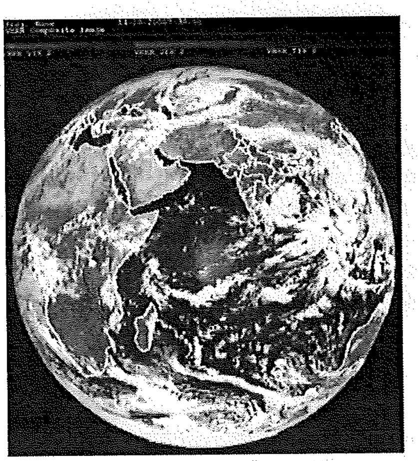


Fig. 30 : VHRR visible image of 14.10.2000

A Charged Coupled Device (CCD) payload on board this satellite provides for the first time an opportunity for continuous surveillance of cloud cover and surface features during day time at a very high spatial resolution. This capability combined with the unique combination of three channels in the visible, near IR and short wave IR bands makes CCD a very versatile instrument for a number of meteorological applications.

A CCD camera is mounted on the earth viewing face of INSAT-2E satellite. The ground resolution at the sub-satellite point is nominally 1 km x 1 km and in the normal mode of operation the instrument is designed to scan a 10^0 x 10^0 field of view which corresponds to a ground area of about 6300 x 6300 km.

The digitized data from all three bands are transmitted in extended C-band by the CCD transmitter on-board the satellite at a data rate of 1.288 Mb/sec.

A wide variety of applications are possible due to fine resolution and continuous temporal coverage provided by the CCD camera. Some of the important applications are given below :

- ***Tropical cyclone analysis***

Initiation of cyclone development over the ocean is generally indicated by the presence of curved cumulus lines and their interaction with deep layer convection. Such lines can be better resolved in higher resolution imagery. During the life cycle of a storm, cloud features appear to change in surges and variability in the cyclone cloud pattern is partly due to convective scale activity within the cyclone which is better observed in high resolution images. The fine structure of the eye wall region of the cyclone is also better resolved in high resolution images. There are convective cores embedded in the eye wall whose spatial extent is of the order of 1 km or less. Hence with the availability of 1 km resolution visible imagery, commencement of cyclogenesis can be detected at an early stage, and the fixation of centre and the intensity estimation of the cyclone can be done more accurately. The improved capabilities will provide better cyclone warning services for the coastal populations.

- ***Local severe storms***

One of the most important factors responsible for generation and maintenance of deep convection leading to local severe storm formations, is the cumulus scale interactions which can be observed only through high resolution imagery. Such interactions are sometimes seen as clouds forming at thunderstorms outflow boundaries. These clouds have a width of 1-2 km and they sometimes interact with another arc boundary or other cloud fields to initiate severe convection, which gives rise to adverse weather on very small spatial and temporal scales. Monitoring of such events is very important for issuance of intense precipitation advisories, aviation and flood forecasting applications.

- ***Heavy rainfall estimation***

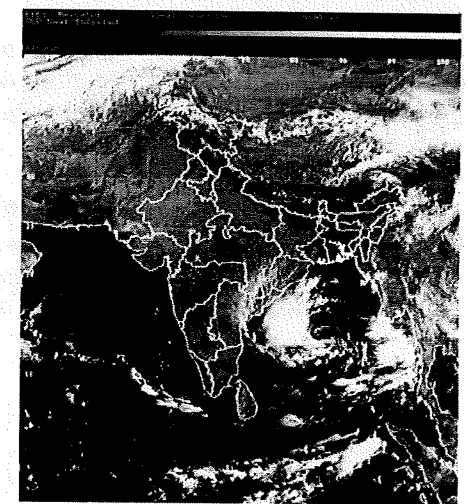


Fig. 31 : A Typical CCD near infrared image

For precise estimation of heavy rainfall from convective clouds high resolution visible channel imagery provides very important clues. In particular, the overshooting cloud tops which play a vital role in heavy rainfall leading to flash floods can be very well observed in high resolution imagery. Such observations are useful inputs to the heavy rainfall estimation models and are helpful in improving the accuracy of intense precipitation advisories being issued operationally by the department. This has useful applications in flash flood forecasting. Fig 31 shows a typical CCD near infrared image.

- ***Mountain waves observations***

These waves occur on the leeward side of high mountains under certain meteorological situations. There are certain areas of very severe turbulence associated with large amplitude mountain waves. Observations of such waves are, therefore, very important for aviation forecasting. Due to the very small spatial scales of clouds associated with these waves, they can be better observed in the high resolution imagery.

- ***Sea breeze front***

Sea breeze front is an important mesoscale circulation which is sometimes found to be responsible for development of severe convection, particularly during afternoons along the Western Ghats on the west coast of India. Since sea breeze is a small-scale phenomenon, it can be observed much better with high resolution cloud imagery. The interaction of sea breeze with the already existing field of cumulus cells over an area sometimes triggers severe convection. High resolution cloud imagery is the only tool available for observations of such phenomenon.

- ***Snow estimation***

Observations of aerial extent of snow cover are important for better management of water resources. These data are also one of the important inputs for long range monsoon forecast models. Snow estimation can be done with great accuracy with higher resolution visible imagery. Inclusion of the 1.55 - 1.7 μm band facilitates discrimination between snow and clouds because of the high sensitivity of this band to snow and water bodies on the earth's surface.

Current Meteorological Ground Segment of INSAT

Under INSAT-2 programme, a new ground segment was established in April 1992 for reception, processing and dissemination of meteorological data. At present the key facility of the INSAT meteorological ground segment is INSAT Meteorological Data Processing System (IMDPS) located in a multistoreyed building at Headquarters Office of IMD at Lodi Road, New Delhi.

The IMDPS system was commissioned in September 1992. The meteorological data are processed round the clock and various operational products are generated for dissemination to the users. Under normal weather conditions VHRR data is processed every three hours. However, more frequent data is processed in the event of a cyclonic storm in the Indian seas and also to monitor local severe weather phenomena during pre-monsoon season. The meteorological data transmitted by INSAT-1D is also being continued to be processed satisfactorily with this system.

The cloud pictures processed at IMDPS are analyzed on an interactive workstation to track different weather systems affecting India and adjoining areas. Based on the analysis of these pictures regular bulletins are issued to the various forecasting offices of the department for use in their day to day operational work. It is in the process of upgradation with advanced computers and high-tech equipments.

High Resolution Picture Transmission (HRPT) System

Advanced Very High Resolution Radiometer (AVHRR) ground equipments are provided at New Delhi and Chennai offices of IMD for reception of high resolution data (1.1 kms) transmitted by NOAA series of US Polar Orbiting Meteorological Satellites. Vertical profiles of temperature and humidity through an instrument called TIROS Operational Vertical Sounder (TOVS) is also recorded here. The ground equipment at New Delhi was established in early 1981 and that of Chennai in June, 1995. Both AVHRR and TOVS data and derived products are utilized by the weather forecasters. The Delhi system has recently been replaced by a more advanced system.

Satellite Data Applications/Products

Present operational forecasts are based upon observations and numerical weather prediction methods which are capable of resolving the larger, so called synoptic scale weather systems. For more detailed forecasting, it is necessary to be able to observe and model phenomena on the mesoscale. Most severe storms, heavy rainstorms and hazardous weather are caused by mesoscale phenomena. Even the weather system associated with large scale disturbances have significant mesoscale characteristics. Recent advances in remote sensing techniques such as radar and satellite have provided us with the means of observing atmospheric features continuously in time with high spatial resolution. This has helped to improve short range weather forecasting.

A major portion of the tropics is covered by oceans. Over these regions, the primary source of the meteorological observations have been occasional ships and a few island stations. These routine observations over the sea concentrated in major shipping lanes lack the necessary spatial resolution as well as temporal coverage and can have a large error due to poor calibration. One of the major synoptic event that occurs over these data sparse tropical oceans is the tropical cyclone.

With the heralding of geostationary satellite INSAT era, it has now become possible to view the depressions or tropical cyclones over the ocean from the same relative position at successive times, making it easier to follow the storm centre.

If we look at two- or three-hourly spaced satellite pictures of a tropical cyclone in its intense stage a striking similarity in appearance, mostly in features close to the centre, is observed. It is well known that the environmental flow field around tropical cyclones is an important factor in determining the cyclone motion. If there is a turning in the upper wind flow, then the front edge of the central cloud feature first reaches the turning point and the features start turning with the flow. Depending on the size of the cloud structure and the speed of its movement, the centre of cloud system reaches the turning point after a certain period and the whole system then starts turning with the wind flow. Thus INSAT is of great help in tracking tropical disturbances and cyclones.

Western disturbances which move from west to east over the northern parts of Indian subcontinent and intensify mostly under the influence of upper tropospheric westerly trough can be tracked easily with the help of systematic movement of the cloud band over northern parts of India.

Convective storms play an important role in meteorology. It is major weather feature hazardous to aviation. Prior to geo-stationary satellite, the interaction between convective storms and environment was not known much. With geostationary satellite data, one can visualize the mesoscale meteorological processes, the movement, orientation and development of convective storm etc., can be observed. Animation provides observations of convective behaviour at temporal and spatial resolutions compatible with scale of the mechanisms responsible for triggering deep and intense convective storms.

By careful observation fog and stratus can be distinguished from other clouds. Tops of fog and stratus are smooth and morning VIS imagery shows neither the shadows nor highlight common among other bright clouds. In geostationary images, fog/stratus is more easily identified as animated imageries showing slow movements and often in a different direction than other clouds. Their sharp boundaries also give a clue. The lack of day time development also is a clue in distinguishing fog and stratus from clouds. When inversion is strong, fog and stratus tops appear darker. Fog and stratus appear as smooth uniform gaudy shades whereas cloud-free surface appears textured.

It has been shown that enhanced IR imagery can be used to identify location of probable night time fog formation specially along coastal region. After sunset, clear moist areas often appear darker than surrounding clear, dry areas in successive imagery. When these clouds form under an inversion, the dark areas often become more pronounced and the boundaries become better defined.

INSAT OLR (Outgoing Longwave Radiation) values may also be used as a good indicator of onset/withdrawal of monsoon, it can also be used for precipitation estimates. INSAT imageries can also be used to identify mountain waves, jet stream, squall line development etc.

The following meteorological products are derived by IMDPS from INSAT and NOAA satellite data :

- Earth cloud imagery in visible and IR bands every three hours on black & white or colour recorders.
- Cloud Motion Vectors (CMVs) over Bay of Bengal, Arabian Sea and Indian Ocean at 00, 06 and 12 UTC.
- Sea Surface Temperatures (SSTs) at 00,06,12 and 18 UTC are being derived over Bay of Bengal, Arabian Sea and Indian ocean.
- Vertical temperature and humidity profiles of the atmosphere are being derived from NOAA satellite data.

Data archival and supply

The VHRR data from INSAT-1D, INSAT-2B and DCP data are processed at IMDPS New Delhi. The processing system is configured around eight Vax computers in a clustered network, with a number of other peripheral devices attached. The processed data include products such as Cloud Motion Vectors (CMVs), Outgoing Long Wave Radiation (OLR), Quantitative Precipitation Estimates (QPE) and Sea Surface Temperatures (SST).

Future developments, plans and products

METSAT

The first Indian geostationary meteorological satellite METSAT is planned to be launched by end 2001. This will not be a multi-purpose satellite but will be totally dedicated to meteorological applications. It will carry a 3-channel VHRR for observation in visible, infrared and water vapour channels.

Oceansat (IRS-P4)

Oceansat (IRS-P4) satellite was launched by ISRO during May, 1999. It is a polar orbiting satellite fabricated by ISAC, Bangalore under the IRS programme. It carries Ocean Colour Monitor (OCM) and Multi-frequency Scanning Microwave Radiometer (MSMR) sensors on board. IMD has plans to validate and use MSMR data in its Limited Area Model (LAM) analysis and forecast.

INSAT-3D

An advanced Geo-stationary Meteorological Satellite under INSAT-3 series, with capabilities of earth imaging in 6 channels and atmospheric sounding in 19 channels is being planned. The expected year of launch is 2004.

INDO-US Data Exchange Centre

A centre for exchange of satellite data has been established at IMD, New Delhi as part of Memorandum of Understanding (MoU) signed between India and US for bilateral exchange of data in the field of atmosphere and earth sciences. Suitable communication links have been established between India and USA for this purpose.

High Resolution data from Meteostat-5 is now being received in IMD New Delhi for operational use.

CHAPTER 11

LONG RANGE FORECASTING OF MONSOON RAINFALL

The Indian Summer Monsoon and its vagaries are very well-known. The Indian economy is largely dependent on the monsoon rains. Not only the agricultural output but hydro electric power generation, irrigation and domestic/industrial water needs are also crucially dependent on the quantum of the monsoon rains and its distribution during the season. It was once aptly said that "The Indian budget is a gamble on the monsoon".

India Meteorological Department started systematic operational forecasts more than 100 years ago. After a severe famine in 1877, IMD was entrusted the responsibility of preparing the Long Range Forecasts (LRF) on the performance of ensuing monsoon. H. F. Blanford, the then Meteorological Reporter to the Government of India, who established IMD, noted an association between excessive winter and spring snowfalls in the Himalayas and subsequent droughts over India. Blanford used this inverse relationship to issue tentative forecasts from 1882 to 1885. The first operational long range forecast was issued by IMD on 4th June 1886 based on the relationship with the Himalayan snow cover and mean Bombay pressure. Thus India became the first country to start a systematic attempt in long range forecasting.

Sir Gilbert T. Walker who became the Director General of Meteorology of IMD in 1904 started systematic studies for developing new objective LRF methods. In 1909, he introduced the concept of correlation in the field of LRF and developed a multiple regression model for forecasting the monsoon rainfall over India. His studies confirmed that variations in the monsoon rainfall were connected with widespread and long lasting changes in the pressure distribution over long stretch of the earth's surface. Walker's extensive studies on world weather, culminated in the discovery of the Southern Oscillation (SO), which provided sound physical basis for LRF. The regression technique, first introduced in India 90 years ago for long range forecasting has been widely used by different countries in some form or the other. Walker had issued forecasts for India as a whole upto 1916. Walker, after careful studies on the rainfall distribution of India, concluded that the entire country was too big to be taken as one homogeneous region. Consequently, in 1924, Walker had developed better multiple regression models by dividing the country into three homogeneous regions namely, NW India, Peninsula and NE India. Walker had calculated several hundreds of correlation coefficients for determining the relationship of the monsoon rainfall in different homogeneous regions of India with many meteorological parameters. Factors showing significant correlations were taken up for further analysis and finally 14 of them were utilized to form 5 regresssion formulae. Out of these, one formula each was used for forecasting seasonal monsoon (June-Sept.) rainfall over Peninsula, NW India and NE India. The remaining two formulae were used for forecasting the rainfall on the second half of monsoon season (August and Sept.) over Peninsula and NW India. These five forecast formulae developed by Walker in 1922 thus formed the basis of operational seasonal monsoon rainfall forecast in India.

Because of 'low' skill of the models, forecasts for NE India were discontinued in 1935. However long range forecasts for remaining two homogeneous regions of the country viz. NW India and Peninsula were continued till 1987. From 1988, till date the long range forecast are prepared for the country as a whole. In 1999, apart from the all India forecasts, forecasts for 3 homogeneous regions of India viz. Peninsula, NW India and NE India were again introduced.

Long Range Forecasts for NW India and Peninsula from 1924 to 1987

The forecast formulae developed by Sir Gilbert Walker, were modified from time to time, on the basis of the correlation of individual factors and also the multiple correlation coefficient of individual formula. A parameter that showed consistent changes in the sign or magnitude of its correlation was replaced by another after careful examination.

The first forecast formula developed by Sir Walker for Peninsula was revised on eight occasions (1931, 1934, 1935, 1941, 1954, 1961, 1970 and 1977) on the basis of correlation of individual factors. The latest model developed in 1977, used South American pressure, Indian March minimum temperature and 500 hPa mean April ridge position as the predictors. It had multiple Correlation Coefficient of 0.78. It has been noted that South American pressure was included as one of the predictors in all the model revisions.

Similarly, the first model developed for NW India was revised on six occasions (1930, 1941, 1946, 1955, 1972, and 1977). The formula developed in 1977 used 4 predictors, 500 hPa ridge position, equatorial Indian Ocean pressure, Argentina pressure and Ludhiana mean temperature in April. It had a multiple Correlation Coefficient of 0.73. South American pressure and Indian ocean equatorial pressure remained in all the six revisions.

In addition, separate regression formulae were used for issuing forecasts for the rainfall of second half of monsoon (August-September) over NW India and Peninsula. All these forecasts for the two homogeneous regions were continued till 1987.

Verification of long range forecasts issued during the period (1924-87) is shown in Table 1. Accuracy of all forecasts taken together is around 65 per cent, with a skill score of 0.35. For Peninsula, accuracy of forecasts for the second half of monsoon rainfall was better than the forecasts for the whole season, June-September. Therefore, the forecast technique used in India for predicting monsoon rainfall of different homogeneous regions of the country has provided more useful information than could be obtained from the climatology alone. The forecast failures were considerably high in the forties and fifties.

Table 1

Verification of long range forecasts : 1924-1987

Forecasts issued for the rainfall of	*Percentage of correct forecasts from*		*Skill Score*
	Formula	*Climatology*	
<u>June to Sept.</u>			
i) Peninsula	59.4	45.3	0.26
ii) NW India	60.9	37.5	0.37
<u>August-Sept.</u>			
i) Peninsula	62.5	35.9	0.41
ii) NW India	57.8	35.9	0.34
All forecasts taken together	*60.0*	*38.6*	*0.35*

Improvement in Model Forecast Scheme during the last two decades

Till 1980's the forecasts were issued based on multiple regression technique. During the 1980's, new techniques like Dynamic Stochastic Transfer (DST) and Parametric and Power Regression Models were developed and operationalized for LRF along with revised multiple regression models. In 1988, the operational forecast was issued for the monsoon rainfall over the country as a whole and the forecasts for homogeneous regions, NW India and Peninsula were discontinued.

Presently, the operational forecasts of monsoon rainfall over India as a whole is issued based on the Power Regression and Parametric models. These models use 16 global and regional land-ocean-atmosphere parameters as the predictors. In 2000, these models (models operationalized in 1988) were revised by replacing four predictors viz. 500 hPa ridge position in April, 10 hPa zonal wind at Balboa, North India Temperature and Darwin pressure (spring) with new four predictors. These four predictors were replaced as their statistical relationship with Indian monsoon rainfall showed a steady decline. The new 4 predictors introduced in the models are Arabian sea, Sea Surface Temperature (Nov, Dec and Jan), South

Indian ocean SST(Feb + March), Europe pressure gradient (January) and Darwin pressure tendency (April-January). The list of 16 parameters used in the revised power regression and parametric models is given in Table 2. Parametric model is used for qualitative forecasts while the power regression model is used for quantitative forecasts. A curvilinear fit was introduced through the power regression model which is considered better than the linear regression fit. These models are based on the assumption that the resultant signal from a group of predictors well distributed in space and time can improve the accuracy of forecast as it accounts not only for climatic association but for perturbed climatic association also. A mathematical form of the power regression equation is given below.

$$\frac{R+\alpha_0}{\beta_0} = C_0 + \sum_{i=1}^{i=16} C_i \left(\frac{X_i + \alpha_i}{\beta_i} \right)^{P_i}$$

where R is the monsoon rainfall C_i's, α_i's, β_i's and P_i's are the constants and X_is are parameters used in the regression equation.

Table 2
List of Parameters
(Revised power regression / parametric model 2000)

S.N.	Parameter
1.	El-Nino (S.Y.)
2.	El-Nino (P.Y)
3.	South Indian Ocean Sea Surface Temperature (Feb + March)
4.	East Coast India Temperature (March)
5.	Central India Temperature (May)
6.	Northern Hemispheric Temperature (Jan + Feb)
7.	Arabian Sea, Sea Surface Temperature (Nov, Dec, Jan)
8.	50 hPa Ridge East-West (Jan + Feb)
9.	Europe Pressure Gradient (Jan)
10.	N. H. Pressure (Jan – Apr)
11.	SOI (Spring)
12.	Darwin Pressure Tendency (April-Jan)
13.	Argentina Pressure (April)
14.	Indian Ocean Equatorial (IOE) Pressure (Jan –May)
15.	Himalayan Snow Cover (Jan – Mar)
16.	Eurasian Snow Cover (December)

All the past successive operational forecasts since 1988 based on the P. R. model were found to be reasonably accurate. Though, the qualitative forecast from the parametric model indicates good or deficient monsoon, none the less, it has a great demand from users. The inferences drawn from these successful forecasts were beneficial for the long term planning in various sectors like agriculture, water resources management, power etc.

Long range forecasting of date of onset of monsoon has received less attention as compared to the seasonal rainfall prediction, though the date of arrival of the southwest monsoon over India is also very crucial on many accounts. During the early fifties, an attempt was made for predicting the date of establishment of monsoon over west coast of India. In 1977, a refined and better multiple regression model was developed to forecast the onset of monsoon rainfall over Kerala using two predictors of upper air wind direction. After 1978, running mode MR models have been used for issuing the onset forecasts. Subsequently models with better skill were developed and the forecasts were continued since then.

As the winter precipitation over NW India (Comprising 11 sub-divisions viz., East U.P., Plains of West U. P., Hills of West U. P., Haryana, Punjab, Himachal Pradesh, Jammu & Kashmir, West Rajasthan, East Rajasthan, Gujarat Region, Saurashtra and Kutch) is very crucial for agricultural and water resources management purposes over NW India, the IMD also prepares a forecast for winter (January- March) precipitation for NW India, since 1918. Initially these forecasts were based on multiple regression models. At present IMD operates Multiple Regression, Power Regression and DST models for issuing this forecast. These forecasts have however limited skill as the inter-annual variability of NW India precipitation is very high.

Recent Developments

Diagnostic studies involving analysis of large climatic data to understand the mechanisms of monsoon variability are very important for developing reliable LRF models. Therefore, by analyzing various global climatic data sets simultaneously, efforts are made to identify new predictors which have good physically and statistically stable relationship with the monsoon rainfall. In the process, new insight into the inter-annual variability of Indian monsoon emerged and many new parameters/predictors were identified. These new parameters are being used as the predictors in new and experimental models. By keeping in line with the developments taking place out side India, in late 1990s, new techniques like Artificial Neural Network, Power Transfer, Principal Component Regression, Discriminant Analysis were also explored to develop better models. In 1998, some of the models based on these new techniques and new predictors were put in operational use. Some promising results were obtained from these models.

In 1999, the IMD reintroduced the long-range forecasts of summer monsoon rainfall (June-September) for 3 homogenous regions of India, viz., NW India, Peninsula and NE India. The homogenous regions are shown in Fig.32. NW India and NE India consist of 9 meteorological sub-divisions each and Peninsula consists of 17 meteorological sub-divisions. Sep-arate models have been developed for each of these homogeneous reg-ions based on techniques like Pow-er Regression, Multiple Regression, DST, Neural Network and Principal Component Regression.

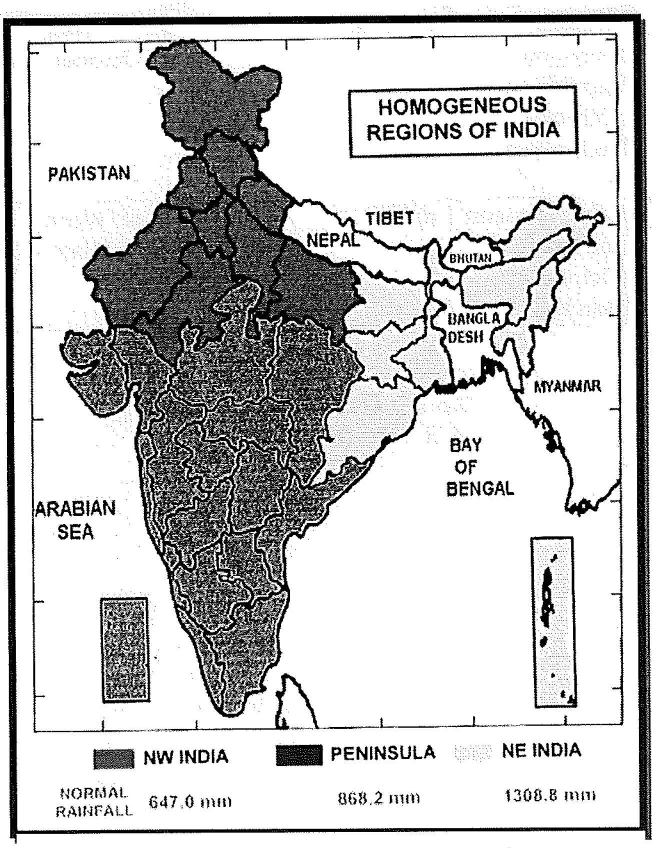


Fig. 32 : Three homogeneous regions

In view of the consistent demand from users, IMD in 1998, introduced for the first time, long range forecasts for northeast monsoon rainfall (October-December) over south Peninsula (Comprising 7 sub-divisions viz., Coastal Andhra Pradesh, Tamil Nadu, Rayalaseema, Coastal Karnataka, N. I. Karnataka, S. I. Karnataka and Kerala) and Rabi season rainfall (October-March) over Northwest India (11 meteorological sub-divisions). These forecasts are based on multiple regression, Power regression and DST models. At present these forecasts are given to senior Government officials only.

IMD also operates two experimental models, multiple regression and Canonical Correlation Analysis (CCA), for long range forecasts of monsoon (June-September) rainfall on sub-divisional scale. Multiple regression models are developed separately for each of 35 sub-divisions. The CCA model was developed for 27 meteorological sub-divisions excluding hilly regions. As these models have limited skill, the forecasts are prepared only on experimental basis and not supplied to the users.

The long range forecasts currently prepared by IMD are given in Table 3.

Future Plans

Long range forecast of monsoon has been quite useful to our country for well over 100 years. However, there is scope for improvement. Users need forecasts of better spatial and temporal resolutions. They also want forecasts for other meteorological parameters like temperature. To fulfill some of these requirements, a project with the following objectives has been taken up :

- To develop suitable statistical and advanced numerical models for long range forecasts of monthly and seasonal rainfall for smaller regions.
- To adopt, develop and operationalize dynamic forecast models (General Circulation Models) for LRF of different meteorological parameters for higher spatial and temporal resolutions.

Table 3
Long Range Forecasts currently prepared by IMD

	Forecasts	Technique / Model	Date of Issue	Region
1.	Monsoon Onset	MR	Last Week of May	Kerala
2.	Monsoon season (June-Sept) Rainfall	a) Parametric b) Power Regression c) DST d) M.R e) Principal Component Regression f) Neural Network g) Power Transfer	Last Week of May	India as a whole, Peninsula, NW India and NE India
3.	Second Half of Monsoon (Aug-Sept)		First week of August	
4.	Winter Precipitation (Jan-March)	a) M. R. b) DST c) Parametric	First Week of January	NW India
5.	Northeast Monsoon Rainfall (October-December)	a) M. R.	First week of October	South Peninsula
6.	Rabi Season Rainfall (October-March)	a) M.R.	First week of October	Northwest India.

D.S.T : Dynamic Stochastic Transfer
M. R : Multiple Regression.

CHAPTER 12

METEOROLOGY OF THE OCEANS

Ocean, land and atmosphere together play a decisive role in determining the state of the weather and climate on planet Earth. The land-sea temperature contrast, differences in thermal capacity and the movement of the earth around the sun are factors which lead to the seasonal reversal of winds. On a shorter time scale, the evaporation from the sea supplies the bulk of moisture for the hydrological cycle. The physical processes of evaporation, condensation and precipitation play a crucial role in the evolution of weather. Severe weather systems like tropical cyclones, with their associated storm surge, result from the interaction between the atmosphere and ocean.

History

Indian meteorologists were collecting meteorological observations from the sea even in 19th century. Meteorological observations recorded by mariners and ship captains are very valuable sources of meteorological data over the oceans. Observing weather on board a ship is not only beneficial for its own security but also for the safety of navigating ships in general through weather forecasts or storm warnings. Furthermore, because of the scarcity of data over the oceans, weather reports from ships are a very valuable source of information.

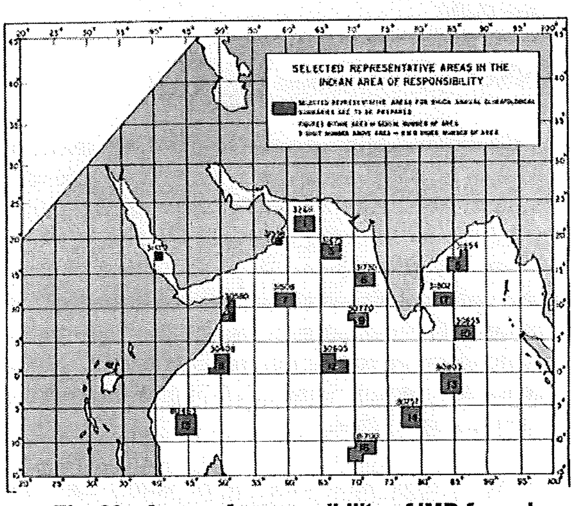


Fig. 33 : Areas of responsibility of IMD for collecting and processing of Voluntary Observing Ships data

The tradition of recording and reporting of observations at sea was later standardized under the Voluntary Observing Ship (VOS) scheme of the World Meteorological Organization (WMO). Under this scheme, which came into operation around 1947, maritime member countries of the WMO were entrusted with selection of merchant and other ships and providing them necessary standardized meteorological instruments. These ships record and report observations during voyages. Besides reporting the observations in coded form, ship's officers are also requested to ensure that the observational data are entered in the marine log form that are supplied to the ships. These log forms are then returned to port meteorological offices. The log form has been devised with a view to digitize the data entered on them for making climatological summaries. These observations form a useful tool in weather forecasting over the sea area. The fourth Congress of WMO in 1963 through the adoption of resolution 35 (Cg IV) had given the responsibility of collecting and processing the vast amount of meteorological observations acquired by these voluntary ships to eight responsible member countries. India is one of them. The area of responsibility assigned to India is the Indian ocean area north of 15°S and between 20°E and 100°E, as shown in (Fig.33). The Marine Climatology Section (MCS) was established in 1971 in the Office of the then Deputy Director General of Observatories (C&G) to compile and process the marine data to prepare annual, decadal climatological summaries and marine atlases under this WMO Marine Climatological Summary Scheme (MCSS).

Developments during the recent decades

The Marine Climatology Section (MCS) receives the marine data recorded in ships' weather logs from merchant ships and research vessels. These observations are initially scrutinized by the office of the DDGM(WF) who use such observations for operational forecasting. Then these are keyed in and checked for the minimum quality controls as prescribed by the WMO. The quality control includes time sequence checks and parameter checks. The quality controlled data are then formatted in the standard form and archived at National Data Centre, Pune, for climatological purposes.

Marine climatological information is used extensively for the operational planning of marine activities as well as for research purposes. Growing importance is being attached by users to climatological and other statistical meteorological data. It is essential to use standard data formats to facilitate International exchange of marine meteorological data for climatological purposes.

For this purpose, the layout of the International Maritime Meteorological Tape (IMMT) based on the new common code was adopted by then commission for Marine Meteorology (CMM)-VIII and approved by the 34th session of the Executive committee for international data exchange. Since 1995, these data are also being sent to the Global Collecting Centres (GCC) of WMO in UK and Germany for centralized processing and further distribution to other responsible countries. The data compiled by other responsible countries received through the Global Collection Centres at IMD are also archived for the climatological purposes. These data contain information on sea surface temperature, air temperature, humidity, clouds (amounts and type of low clouds), air pressure, wind speed and direction, visibility and wave height and Period etc. These data are useful for many marine activities like shipping, coastal zone management and oil exploration and also for the studies on climate change and global warming.

Under the WMO Marine Climatological Summary Scheme (MCSS), the designated country has to prepare the annual/decadal summaries for their area of responsibility. Marine Climatological Section had already published the annual summaries for the period 1961 to 1970 for the selected areas. The decadal marine climatological summary of the period 1971-80 in chart form also has been published recently. The work for the decadal summary, 1981-90 and Marine Climatological Atlas for the Indian Ocean for the period 1961-90 is in progress.

In addition, meteorological and oceanographic observations taken during the research cruises by *R. V. Sagar Kanya* and during the Antarctic expeditions are also quality controlled, digitized and archived separately for climatological purposes. Data from *Sagar Kanya* cruises are available from 1983 and that for Antarctica expedition from 1985.

Apart from archiving the data, scientists from IMD have been actively participating in making measurements of various atmospheric parameters during the *Sagar Kanya* cruise. Recent *Sagar Kanya* cruises as a part of Bay of Bengal Monsoon Experiment (BOBMEX) in 1999 received substantial support from the IMD scientists. These included supply of daily weather advisories to the cruise from a temporary project office set up in NHAC, New Delhi.

ENSO and Monsoon

Continents and oceans respond to seasonal changes in solar energy in a somewhat different manner. As a result of lower thermal conductivity of the land and greater penetration of solar energy in the ocean, there is larger warming/cooling of air over the land than that over the oceans. The monsoon is essentially the atmospheric response to this differential heating. There are several oceanic parameters which control the monsoon circulation.

On a longer time scale the El-Nino / La-Nina cycle and the Southern Oscillation have a close linkage with the Indian Summer Monsoon and

Northeast Monsoon rainfall. The Southern Oscillation Index (SOI) which is generally the pressure difference between Darwin (12° 24'S, 130° 52'E) and Tahiti (17° 33'S, 149° 37'W) was used by Sir Gilbert Walker in the Long Range Prediction of Indian Summer Monsoon. The term ENSO was first used by E.M. Rasmusson and T. Carpenter in 1982. They meant it to describe the interaction between the oceanic El-Nino with the negative phase of the atmospheric Southern Oscillation.

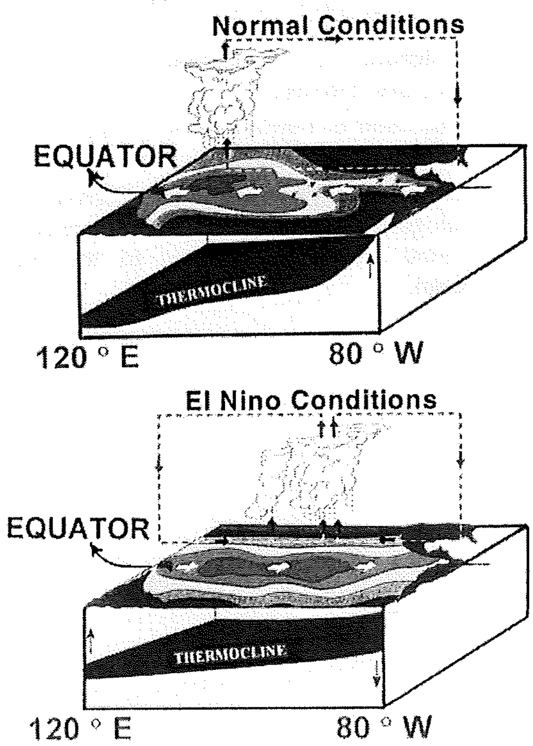


Fig. 34 : El-Nino - Monsoon Relation

The summer monsoon precipitation shows a good association with ENSO but this is not the only factor influencing the monsoon precipitation. It is found that during the warm phase with low SOI there is at least 50 mm decrease in the median precipitation which affects the western parts of the subcontinent. ENSO also affects the winter monsoon precipitation over Sri Lanka and southern India. Similarly during the high SOI epochs excess precipitation is reported. Usually excess precipitation is confined to the area south of 20°N. The studies have also identified that the impact of ENSO over the whole Indian subcontinent is not uniform.

Experiments carried out by GCM models show that SST anomalies which prevailed during late 1982 and 1983 have resulted in below normal monsoon activity during 1982 and 1983. This study also emphasized the role of latitudinal position and strength of Tropical Convective Maximum (TCM) over Indonesia and the West Pacific in the preceding spring, in modulating the ENSO-monsoon relationship. The importance of warm anomalies in the west Pacific was highlighted in a case study of 1994 monsoon. The year 1994 was an El-Nino year in which monsoon was unexpectedly active. In 1994, west Pacific was warmer.

Observational studies have revealed that during El-Nino years, the onset of monsoon over Kerala is delayed and its northward progression is also sluggish. During 1972, 1987 onset of monsoon was delayed over Kerala so also it was in 1997. Yet in 1997, which was a major El-Nino year, the All India Summer Monsoon Rainfall (AISMR) was normal while 1972 and 1987 were severe drought years for the country.

The variations of tropical cyclones in the north Indian Ocean have also been studied. It is seen that the maximum number of cyclonic disturbances occurred during decade 1941-50 when in general, the impact of El-Nino on AISMR was the least. Similarly, minimum number of cyclonic disturbances occurred during the decade 1911-20 when the frequent failure of monsoon occurred as a result of El-Nino. Similarly, during 1981-1990 and 1901-1910 there were smaller number of cyclonic disturbances over the Indian seas as a result of decreased frequency of depressions during summer monsoon season. These were also the decades when there were frequent failures of monsoon associated with El-Nino.

Remote sensing applications

Considering the general sparseness of surface observations over the oceanic regions, remote sensing of the oceans is an invaluable tool in our understanding of ocean processes. The INSAT series of satellites have provided a long series of data over the Indian Ocean since 1982. Recently (May 1999) OCEANSAT-1 (IRS-P4) has been launched by ISRO and this satellite provides information on oceanic parameters which is useful in meteorology and other geophysical sciences. The INSAT satellite not only helps in monitoring weather systems over the sea areas, but provides data from which other parameters can be derived over the Indian Ocean, such as Cloud Motion Vectors at various levels in the atmosphere, Outgoing Longwave Radiation and proxy large scale precipitation estimates.

Research Studies

The vast amount of meteorological data over the oceans compiled by IMD has wide applications in many fields. Some of the research areas in which IMD scientists are engaged are:

- Inter annual variation of Indian summer monsoon and NE monsoon in relation to the variations of SST over the Indian Ocean.
- Decadal variations of ocean-atmosphere climate system over the Indian Ocean.
- Climatology, decadal variation and long term trends of sea surface temperature and cloud amounts in the India Ocean.
- Comparison of the ground based cloud amounts with satellite derived cloud amounts in the Indian Ocean.

Future Plans

- Compilation and archival of historical marine data (data prior to 1961) pertaining to the area of responsibility from various sources in a uniform format.
- Publication of the Decadal Climatological Summary, 1981-90.
- Publication of Marine Atlas of Indian Ocean using the data of 1961-90.
- Further validations of satellite derived meteorological and oceanographic elements with ground based observations in the Indian Ocean.

CHAPTER 13

ANTARCTIC METEOROLOGY

Antarctica, with its unique biodiversity, geological, geophysical and meteorological characteristics, has always posed a challenge to scientists. India organized the first Antarctic Expedition in 1981 and India Meteorological Department was one of the participating organizations.

The first Indian Antarctic expedition was aimed at collecting and studying climatic and hydrometeorological features of Antarctica. This included in situ measurements over the Indian stations and measurements en route in the journey towards the continent. During the initial expeditions the measurements were carried out at a temporary station, Dakshin Gangotri, located close to the reference station. After the ninth expedition a permanent station, Maitri, was set up. The observations were carried out under most difficult environmental conditions. These have resulted in many interesting findings like the Ozone hole, vertical profile of ozone, surface and upper air atmospheric structure. The climate of Antarctica and its unique location control the southern hemi-spheric weather system which in a way modulates the airflow and ocean currents in the southern Indian Ocean. The permanent station now functioning in the Antarctic at Maitri maintains constant record of the meteorological conditions.

Observational programme

A. K. Sharma and K. M. Katyal were the two IMD scientists who formed the meteorological team in the first Antarctic Expedition in 1981. Since then IMD has participated in every Indian Antarctic Expeditions. The first two expeditions were exploratory in nature and surface meteorological observations were recorded at the base camp in Antarctica. Since Antarctica is located in the polar belt of southern hemisphere, measurements of solar radiation and related physical properties of the snow, formed an important part of the meteorological programme.

A meteorological station at Dakshin Gangotri was established in 1984 during the 3rd expedition. Since then, a manned meteorological observatory has been functioning there round the year.

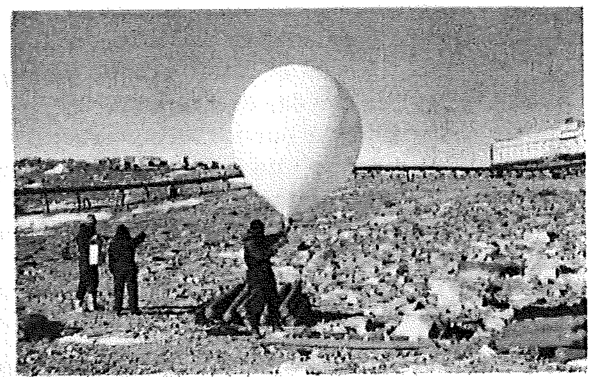


Fig. 35 : Ozonesonde ascent in progress

After the installation of the station Dakshin Gangotri, the meteorological data were monitored from that station. This is located on an ice shell. India established its 2nd permanent scientific research station Maitri (Lat. 70° 45′ 39″ S; Long 11° 44′ 48″ E, Altitude 117 m) in the Schirmacher ranges in 1988-89 during the 9th expedition. India Meteorological Department established a full-fledged meteorological observatory at Maitri in 1990 and discontinued meteorological observations from Dakshin Gangotri.

Radiosonde observations started over the Indian Antarctic Research Station in 1983. Observations of the vertical distribution of ozone and surface ozone concentrations are also made at the Indian stations.

The measurements of atmospheric turbidity using a double filter Voltz Sunphoto-meter (440 & 460 nm) are also carried out. Special observations of snow surface albedo were also conducted during these expeditions. New sub-programmes were added as the programme evolved. These include low level slow rising

Radiosonde ascents, Pilot Balloon ascents and installation of a Data Collection Platform (DCP) to transmit data to India via INSAT.

Daily synoptic meteorological observations recorded at the Indian station Maitri are exchanged with other Antarctic stations and with other countries through the WMO Global Telecommunication System, and they serve as inputs to global weather forecasting. The ongoing meteorological programme of measurement consists of the following :

i) Continuous recording of surface meteorological parameters including real time transmission of main synoptic messages four times a day over GTS.
ii) Recording of surface ozone measurement and vertical profile of ozone through weekly Ozonesonde ascents at Maitri.
iii) Measurements of turbidity through sunphotometer.
iv) Measurements of total and diffuse solar radiation at the surface and vertical profiles of net radiation with Radiometersonde ascents.
v) Daily reception of Satellite Cloud Imageries from polar orbiting satellite.
vi) Special hourly observation during blizzards.

Yet another interesting atmospheric phenomenon known as "Aurora" occurs during southern summer. The Antarctic team in their expeditions have reported occurrence of "Auroras". This beautiful atmospheric display consisting of green and yellow colour strips and sheet like illumination signifying the electrical activity in the polar region.

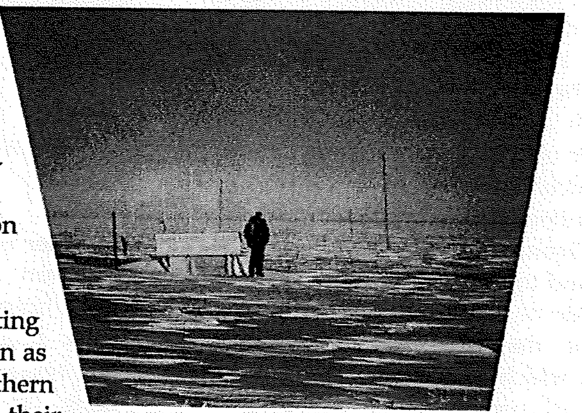


Fig. 36 : Dakshin Gangotri Station as in August, 1990

Results from Antarctic expeditions:

The meteorological data collected from the Antarctic expeditions provided various interesting results. Some of these are summarized below:

- The general climatology of the area at the Indian Antarctic Station is slowly emerging which clearly indicate typical seasonal and diurnal cycle in the meteorological parameters like pressure, temperature and wind.
- Blizzards are quite frequent in Antarctic area. In fact, the winds in the southern hemisphere particularly over Antarctic are much stronger than those observed in higher latitudes of northern hemisphere. Nearly 40 to 50 blizzards occur during the course of a year.
- It was also observed that the mean temperature of Maitri was higher by 8 to 10°C than that of Dakshin Gangotri during all the months. This difference is partly due to the fact that Maitri is situated over rocky area while Dakshin Gangotri is on ice-shell. Vertical profile of temperature in summer shows steep lapse rate in the lower levels and on the other hand in winter, ground inversions are often reported (fig.**)
- The winds over the station are mostly from east, eastsoutheast and southeasterly direction. Katabatic flow is experienced after 1800 hrs UTC almost throughout the year, this is because of the typical orography near Maitri.
- Ozonesonde ascents show maximum ozone concentration located at 15 km in winter and 35 km in summer. Ozone depletion starts by the end of August or early September and by the end of September, the total ozone concentration is reduced to less than a half. The ozone concentration starts rising again from November onwards (fig. **) Stratospheric ozone measurements which started in 1986, have shown that since that time the depletion of ozone over Antarctica, which is commonly referred to as the ozone hole phenomenon, has been intensifying in space and time.
- Surface ozone measurements show minima in summer and the maxima in winter.
- Most of the radiation received by the Antarctic is reflected back into the space by ice sheet. However, the thick clouds

over the surrounding oceanic region reflect back much of the radiation. Consequently, diffuse radiation dramatically compensates the loss of radiation due to reflection from the cloud top.

- The average Albedo value ranges between 60-70% in January and February.

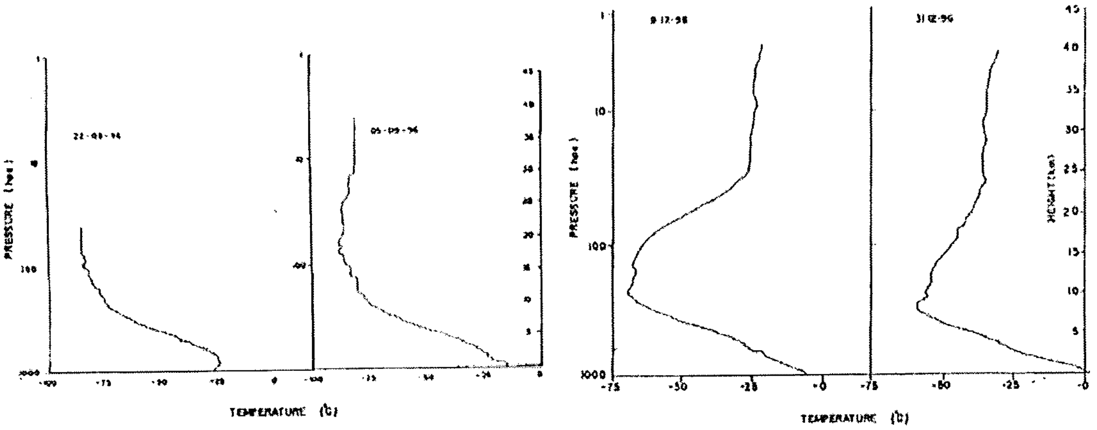


Fig. 37: Vertical Temperature Profile over Maitri

The data of Maitri station is now available nearly for 10 years. Longer series of Observations are needed to obtain a comprehensive climatological picture of the station. The objective of the Indian Antarctic Research Programme is to foster and promote scientific studies in the areas of geology, geophysics, meteorology, biology,

oceanography and geomagnetism. Since its very inception, India Meteorological Department has played a crucial role in measuring and archiving meteorological data which have proved very useful in the study of ozone depletion, radiation balance and atmospheric aerosols over the continent. Meteorology of Antarctic has a profound influence on the southern hemispheric circulation and radiation budget. India

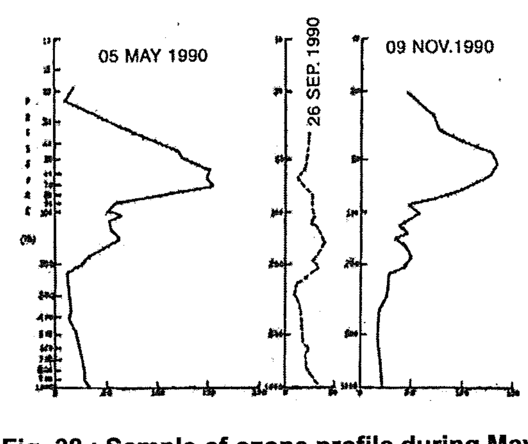


Fig. 38 : Sample of ozone profile during May, September and November, 1990

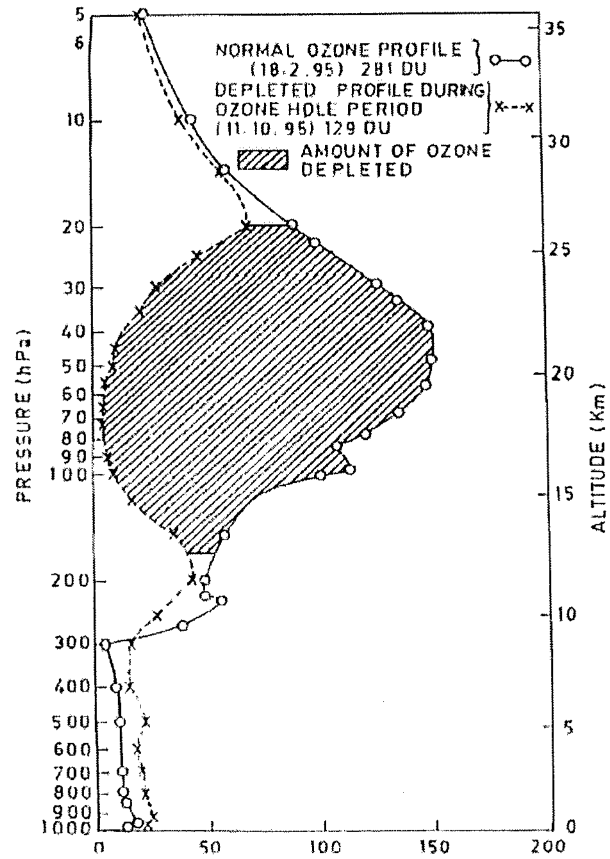


Fig. 39 : Depleted profile during ozone hole period

Meteorological Department's continued participation in these expeditions is essential for understanding the atmospheric physics and dynamics of the Antarctic. The meteorology of southern hemisphere has also several teleconnections with the Indian Summer Monsoon. Thus, a long term programme of observations and analysis of atmospheric data of the Antarctic and their interpretation will continue to be useful and relevant to the country's economy.

Annex I

IMD SCIENTISTS WHO PARTICIPATED IN INDIAN ANTARCTIC EXPEDITIONS

S. No.	*YEAR*	*NAME OF PARTICIPANTS*	*REMARKS*
1st Expedition	1981	1. A.K. SHARMA 2. K.N. KATYAL	
2nd Expedition	1982	1. DR. C.R. SREEDHARAN 2. A.K. SHARMA	
3rd Expedition	1983	1. DR. S.R. RIZVI 2. DR. L.S. RATHORE	1st WINTERING
4th Expedition	1984	1. BHUKAN LAL 2. DR. M. SATYA KUMAR	2nd WINTERING
5th Expedition	1985	1. T.V.P. BHASKAR RAO 2. N.Y. APTE	3rd WINTERING
6th Expedition	1986	1. DR. A.L. KOPPAR 2. S.C. NAGRATH 3. A.A. FARUQI	4th WINTERING
7th Expedition	1987	1. G. SUDHAKAR RAO 2. P.M. GULHANE 3. G. SHRINIWASAN	5th WINTERING
8th Expedition	1988	1. S.D. PRASAD 2. D.G. RUSSAL 3. P.K. NANDANKAR	6th WINTERING
9th Expedition	1989	1. SARABJIT SINGH 2. E. KULANDAIVELU 3. V. L. PRASADA RAO	7th WINTERING
10th Expedition	1990	1. P.M. GULHANE 2. S.S. KATARIA 3. R.K. SHARMA	8th WINTERING
11th Expedition	1991	1. DR. A.L. KOPPAR 2. S.P. SHARMA	9th WINTERING
12th Expedition	1992	1. S. VENKATESHWARLU 2. R.P. LAL	10th WINTERING
13th Expedition	1993	1. G. SUDHAKAR RAO 2. S.B. GAONKAR	11th WINTERING Shri Sudhakar Rao was leader for the expedition
14th Expedition	1994	1. K.S. HOASALICAR 2. P.N. MACHNURKAR	12th WINTERING
15th Expedition	1995	1. A.S. RASAL 2. D.R. MAHOR	13th WINTERING
16th Expedition	1996	1. DR. A.L. KOPPAR 2. S. VENKATESWARLU 3. U.P. SINGH (14th Wintering team) M.V. Polar Bird (LAVTX)	Dr. A.L. Koppar, Director was leader for the entire expedition
17th Expedition	1997	1. B.N. BISHNOI 2. MANMOHAN SINGH	
18th Expedition	1998	1. R.P. LAL 2. L. KRISHNAMURTHY	
19th Expedition	1999	1. E. KULANDIAVELU 2. S. VENKATESHVERA RAO	
20th Expedition	2000	1. MRS. S. STELLA 2. SURESH RAM 3. MANAS D. DEY	In this expedition one lady officer from IMD participated

CHAPTER 14

ENVIRONMENTAL METEOROLOGY AND AIR POLLUTION STUDIES

The precise knowledge of the chemical composition of the atmosphere is very important from the meteorological point of view, since many of the physical parameters of the atmosphere, including the climate of our planet, depend on this composition. The chemical composition of the atmosphere and the climate are duly related through the radiative processes of the Green House Gases (GHGs). An entirely new factor has been introduced into this relationship; the artificial pollution of the atmosphere due to human activities (industry, heating, transport, land use etc.). Thus due to these anthropogenic and inadvertent changes, new components have appeared in the atmosphere, and the concentration and distribution of others have changed quite noticeably. The background level of a pollutant is its concentration, without direct regard to sources, in the area being studied e.g. relative to large towns the background level of a pollutant is its atmospheric concentration measured under rural (regional) conditions. Thus, although pollution of the air in great cities (called urban or local pollution) may have important effects on the health and well being of the inhabitants as well as on the urban climate, it has relatively limited effects on the global scale. On the other hand, the so called background air pollution has a greater meteorological significance.

Atmospheric precipitation plays an important part in cleaning the atmosphere, since impurities in the air attach to precipitation elements, the sedimentation rate of which is much greater than that of the pollutants. Thus, the substances captured by the water droplets or snow crystals are carried to the earth's surface. Precipitation water contains materials deriving from gaseous and particulate pollutants. On the other hand, there are substances deriving only from the aerosol particles. e.g. the sulphur in rain water originate from trace gases (SO_2, H_2S) on the one hand, and from the sulphate particles on the other. Ammonium and Nitrate are derived from gaseous compounds of industrial and biological origin (NH_3, NO_2 etc.) as well as from aerosol particles formed from the above gases in the atmosphere.

The Background Air Pollution Monitoring Network (BAPMoN) Programme of the WMO was launched in 1970 with India becoming a contributing member in 1974. The objective of the WMO BAPMoN programme was to obtain, on a global and regional basis, background concentration levels of atmospheric constituents, their variability and possible long-term changes, from which the influence of human activities on the composition of the atmosphere can be judged. The measurements were useful in studies of :

a) Possible effects on climate;
b) Transport and deposition of potentially harmful substances;
c) The atmospheric part of biogeochemical cycles (including change rates).

In 1989, the BAPMoN programme was consolidated into the current Global Atmosphere Watch (GAW) of WMO. GAW is a co-ordinated network of observing stations and related facilities whose purpose and long term goal is to provide data, scientific assessments and other information on the changes in the chemical composition and related physical characteristics of the atmosphere, representative of all parts of the globe.

Network of Observatories

Ten BAPMoN (GAW) stations at Allahabad, Jodhpur, Kodaikanal, Minicoy, Mohanbari, Nagpur, Port Blair, Pune, Srinagar & Vishakhapatnam under GAW programme were established by India Meteorological Department. These stations are of Regional category as classified by WMO. These stations are locate sufficiently away from built-up areas to avoid fluctuations in pollution from local sources (Fig. 40)..

The fundamental requirement is a rural environment. Hence, these stations are established as far as possible in remote areas, with clean atmosphere.

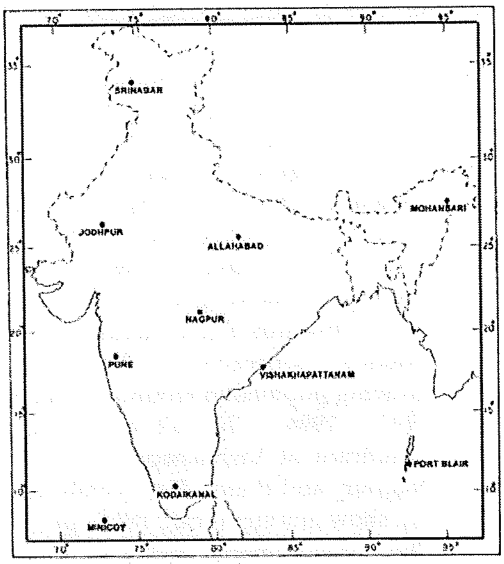


Fig. 40 : Background Air Pollution Monitoring (BAPMoN) stations in

These stations are equipped with following instruments –

1) Wooden Precipitation Collector (Manually operated)
2) pH Meter
3) Conductivity Meter
4) Volz's Sunphotometer

Research Activities

Chemical Analysis

Precipitation samples are collected by means of a specially designed collector. Precipitation collected on each rainy day is transferred into a polyethylene store bottle and kept in a dark and cool place. Well mixed monthly samples are received at Pune by Registered Post Parcel using wooden mailing boxes from all the BAPMoN (GAW) stations for chemical analysis. These monthly mixed precipitation samples are then analysed in Pune for various parameters.

Determination of metal ion contents, Cations like Sodium, Potassium, Calcium & Magnesium is done by using Atomic Absorption Spectrophotometer while Anions like Sulphate, Nitrate, Chloride are determined by using colorimetry & nephelometry and by measuring absorbance with the help of Double Beam UV-Visible Spectrophotometer.

pH and Conductivity Measurements

pH measurement is done on either analogue pH meter or digital pH meter having a pair of glass and reference electrode. The meter is calibrated by using 4.0, 7.0 & 9.2 standard buffer solutions. Conductivity measurement is done on digital conductivity meter. Conductivity measurement gives number of ions present in the sample. Meter is calibrated by using 100 Micromhos Potassium Chloride solution.

Atmospheric Turbidity Measurements (Aerosol Optical Depth)

The suspended aerosol particles in the atmosphere attenuate the Sun's radiation mainly by scattering. Turbidity may thus be defined as a reduction in the transparency of the atmosphere caused by solid or liquid aerosol particles other than cloud droplets and ice crystals. Human and natural activities are causing an increase in the amount of aerosol particles into the atmosphere, measurement of turbidity becomes important. Atmospheric Turbidity (or Aerosol optical depth) is a measure of the extinction of the solar radiation caused by the aerosol particles in the radius range of 0.1 to 10 micrometer. The extinction of solar radiation due to aerosols is measured for a wavelength of 500 nm.

In the absence of clouds, the intensity of direct solar radiation at the Earth's surface for a given solar wavelength depends on the variable amounts of dust, haze and water vapour in the atmosphere which cause absorption and scattering. The attenuation caused by these constituents is called atmospheric turbidity. The turbidity coefficient is the decadic extinction coefficient at a wavelength of 0.50 micron. The atmospheric turbidity affects the albedo of the Earth and the absorption within the atmosphere affects the Earth's energy budget. Further, turbidity measurement has the advantage of representing an integrated picture over large sections of the atmosphere thus is less affected by local pollution. All ten BAPMoN (GAW) stations in India have been equipped with Volz's Sunphotometers, which are relatively inexpensive instruments and easy to operate for measuring the atmospheric turbidity. Atmospheric Turbidity Data are also sent to WMO. Data are also archived at National Data Centre, Pune. Daily six observations are taken roughly at 2 hours interval under cloudless conditions. The data is sent to Central Laboratory at the Air Pollution Section, in the office of Additional Director General of Meteorology (Research), Pune for computation of Decadal turbidity coefficient (B), which is normally between 0.01 and 0.30, and wavelength exponent (α) gives an idea about the size distribution of the aerosols within the limited size spectrum of the particles having radius between 0.1 and 1.0 micron. Its average value is generally taken as 1.3 . Large values of α indicate comparatively higher ratio of small to large particles. B values thus give a measure of the quantity of scattering meterial and α provides the relative size distribution of these particles. The data are processed and stored and despatched to WMO(GAW).

Optional parameters measured by IMD's BAPMoN (GAW) network are: (a) Dustfall at 8 stations (i.e. excluding Kodaikanal and Srinagar) and (b) TSPM Studies (Total Suspended Particulate Matter) using High Volume Air Sampler at 3 stations viz. Pune, Sringar & Jodhpur.

Data archival and supply

The data are processed and subjected to quality control using criteria of ionic balance and ion mobilization. The BAPMoN (GAW) data for all 10 stations are sent in a prescribed format of WMO to the Data Centre in the USA.

Precipitation Chemistry Data for the period 1981 to 1993 and Atmospheric Turbidity Data for the period 1981 to 1993 have been archived at National Data Centre (NDC), Pune. The data are also available in published form.

Research Studies

The data collected from these ten BAPMoN (GAW) stations is being effectively used for identifying level of different types of pollutants in the atmosphere. Investigations have also been carried out for finding out the probability of acid rain in these stations by using this data pertaining mainly to Sulphur Dioxide and Nitrogen Dioxide. More than fifty research papers using the data collected by Air Pollution Section have been published in Indian and foreign journals.

Salient Results

The studies carried out in IMD by using the data set available indicate interesting results, some of them are summarized below :

- Upward trend in Turbidity Coefficient is observed at all ground level stations due to anthropogenic activity.
- pH of background rainfall in India is mildly alkaline (pH = 6.0 to 7.5). A few locations in far eastern parts of the country are mildly acidic due to aerosols having low cations exchange capacity (pH = 5.0 to 6.0)
- Trends towards acidic values to a marginal extent are noticeable at all stations having a growing population around, for an epoch of 1990 - 1994. The fall in pH have been significant at Vishakhapatnam, Allahabad, Nagpur and Pune. But overall trend does not show any significant fall in pH.
- The predominant radicals linked with acidification are Sulphate & Nitrate.
- Possible causes for acidification are increased emissions of NO_x & SO_2 from applications of fertilizers and vehicles, burning of fossil fuels in industries.
- Impact of change of Chemical Composition of atmosphere on other aspects of Earth system and on the Climate.
- Long-range transport of aerosols and toxic depositions.
- Natural global cycles and anthropogenic impacts.

Future Plans

A programme for monitoring Sulphur Dioxide (SO_2) & NO_x at two Indian GAW Regional Stations is being started soon. For this purpose, two Pulsed Fluorescent Sulphur Dioxide Gas Analysers & two Chemiluminiscent NO_x Gas Analysers have already been procured. All 10 Indian GAW stations will be equipped with Multichannel Sunphotometers (Filters at 368, 500, 675, 778, 1028 nm) replacing the single channel sunphotometer. Monitoring of PM-10, PM-2.5, PM-1 & TSP will be undertaken in near future at two Indian locations.

CHAPTER 15

RESEARCH AND DEVELOPMENT

Research activities in India Meteorological Department started at the very inception of the department. Many pioneering research contributions in various fields of meteorology have been made by several IMD scientists. Among the early scientists, H.F. Blanford discovered the linkage of the Indian summer monsoon rainfall with the Himalayan snow cover, Sir Gilbert Walker found many more such global teleconnections of the summer monsoon rainfall which enabled him to make systematic seasonal predictions, and Dr. S. K. Banerji is known for his theories of microseisms. Prof. K.R. Ramanathan will be remembered for his pioneering work on ozone and the structure of the upper atmosphere and Dr. P. Koteswaram for his discovery and explanation of tropical easterly jet and his explanation of the importance of the Tibetan plateau to the monsoon circulation. Studies of the role of air-sea interaction in the monsoon processes by Prof. P.R. Pisharoty, modeling of the storm surge associated with tropical cyclones in the Bay of Bengal by Dr. P.K. Das and studies of the effect of orography on rainfall by Dr. R.P. Sarker are some of the very fundamental contributions to the science of meteorology by IMD scientists.

Meteorology and Atmospheric Science grew almost simultaneously with the growth of the National Meteorological Service in India. In the 19^{th} century, there were a few universities which specialised in meteorological research. However, University Departments of Physics, Mathematics and Statistics in those days had shown interest in the analysis and study of meteorological problems including analysis of meteorological data. Many of them had close interaction with IMD on matters relating to studies in atmospheric physics and allied subjects.

In the initial days of IMD, Prof. P.C. Mahalanobis studied the rainfall data of Orissa and came out with the outstanding work on the hydrometeorology of the Mahanadi basin. Later, many scientists like Prof. S.K. Mitra, Prof. M.N. Saha, and also Prof. Sir C.V. Raman and their students took active interest in research problems related to atmospheric and seismological phenomenon.

Apart from research in mainstream meteorology, three major areas of research formed part of the early activities of the department. These were :

- Astrophysics
- Geomagnetism
- Seismology

The first two activities grew so much that in 1971 two separate autonomous institutions, the Indian Institute of Astrophysics and the Indian Institute of Geomagnetism were established. In the year 1963, the Institute of Tropical Meteorology (ITM) was established at Pune to focus on research relating to tropical weather and climate and this was given the status of an autonomous institution in 1971 with the name Indian Institute of Tropical Meteorology.

In the 19^{th} century Blanford, the first Head of the National Meteorological Service wrote the "Indian Meteorologists' Vade Mecum", which was the first text book of meteorology in India. He carried out many investigations including those on seasonal forecasting and published a number of papers and memoirs including the monumental work of 'The Rainfall of India' as a monograph. He also published a number of papers on the problem of monsoon rainfall forecast. Sir John Eliot wrote more than fifty original papers on various meteorological subjects which includes origin and progress of cyclones in the Bay of Bengal, cold weather storms of northern India and forecasting the winter rains. His report on the Visakhapatnam and Backerganj cyclones of October 1876 also drew attention outside India. He also brought out the first 'Climatological Atlas of India'.

Sir Gilbert Walker took recourse to statistical methods for giving quantitative instead of qualitative forecasts of the monsoon rainfall. He also considered that monsoon is not merely a regional feature but it is governed by several global meteorological parameters.

J.H. Field started systematic upper air observations in India. He devised several meteorological instruments and methods of observations, published meteorological memoirs relating to investigations on upper air. His study on the exposure of thermometers led to the replacement of thatched huts by standard Stevenson's Screens at the observatories after the 1920s.

G.C. Simpson is well known for his research on diurnal variation in pressure, thunderstorm electricity and atmospheric potential gradient. He later became the head of the British Meteorological Service.

C.W.B. Normand published a number of original papers concerning the physics of the atmosphere and introduced the concept of atmospheric instability and also of wet bulb potential temperature for adiabatic processes. There are certain fundamental theorems in thermodynamics which have been named as Normand's theorems.

During the last 125 years Indian meteorologists have contributed substantially to the research work on meteorology and allied subjects. These have been published as memoirs, scientific and technical notes, departmental publications including prepublished scientific reports, meteorological monographs and also as published papers in the national and International journals.

S.K. Banerji's research covers seismology, atmospheric electricity and meteorology. He gave a mathematical model for the origin of microseisms. He also studied the effects of orography on airflow over India through a hydrodynamical model.

K.R. Ramanathan received world wide recognition for his research contributions in varied fields such as atmospheric and solar radiation, structure of upper air over India, Indian monsoon, general circulation of the atmosphere over India and neighbourhood, atmospheric ozone, terrestrial magnetism, seismology and atmospheric electricity, in all these branches, he made outstanding contributions. As the President of International Ozone Commission for many years and as a pioneer in ozone research, he was directly responsible to a large extent for our present knowledge of atmospheric ozone and its role in atmospheric dynamics. He was the Chairman of the committee on international hydrological decade, in the sixties of the last century. The WMO awarded him the International Meteorological Organization Prize in 1961. The Govt. of India awarded him the 'Padmabhushan' in 1965.

S.N. Sen developed streamline analysis techniques. He detected a time sequence in occurrence of Norwesters. S.C. Roy made substantial research on earthquakes. He prepared a noteworthy seismometric account on the great Bihar earthquake of 1934. S.K. Pramanik worked on atmospheric tides and surface climatology. S. Basu worked on structure of depressions. N.K. Sur studied upper air changes during Norwesters.

V.D. Iyer was the first to trace the origin of monsoon depressions to Pacific Ocean typhoons. L.A. Ramdas pioneered the development of agricultural meteorology including micrometeorology. A.K. Roy's work on airmass structure is well known. S. Mull worked on tropical convection ranging from laboratory experiment to cumulus dynamics. P.R. Krishna Rao worked on the climatology of Tamil Nadu and pointed out the existence of easterly Jet Stream over southern India. B.N. Desai worked extensively on various aspects of synoptic meteorology including monsoon depressions, cyclones and western disturbances. S.L. Malurkar published a number of papers on forecasting and geomagnetism. C. Ramaswamy worked on monsoon circulation and the role of mid latitude perturbations in monsoon breaks. R. Ananthakrishnan and K.P. Ramakrishnan did extensive work on structure of upper air over India. G.C. Chatterjee, J.M. Sil, S.P. Venkiteshwaran and L.S. Mathur developed the Indian randiosondes which were brought in use during World War II.

K.N. Rao worked extensively on climatology and long range forecasting. P. Koteswaram discovered the existence of a tropical easterly jet stream over India and also postulated a reverse Hadley Meridional Cell for the SW monsoon circulation and the existence of cold top over hurricanes. P.R. Pisharoty worked on a variety of problems concerning monsoon and monsoon depressions. S.N. Sen worked on tropical cyclones and depressions. Y.P. Rao worked on monsoon in interhemispheric circulations and the cross-equatorial flow. He demonstrated the exchange of angular momentum between the two hemispheres. His treatise on the Southwest Monsoon remains as a standard source of reference on the subject. Miss A. Mani and her associates developed several instruments for the measurement of atmospheric radiation, ozone, turbidity and other parameters and their vertical profiles. B.B.D. Bhargava received Meritorious Inventions and Import Substitution Award for the multi frequency generators developed by him. In 1973, C.R. Sreedharan, got Import Substitution Award for indigenously developing an ozonesonde pump. A radio teletype (Modem) developed in IMD for direct radio teletype operations was given the World Telecommunication Award in 1974.

P.K. Das did pioneering work in the field of Numerical Weather Prediction, effects of mountain on large scale circulation, storm surges and zonal circulation during the southwest monsoon. K.R. Saha made extensive study on dynamical properties of the summer monsoon. P. Jagannathan published a large number of papers on climatology and long range forecasting. He also made studies on climatic trends and initiated such studies in early 50s with S.K. Pramanik.

As the problems of forecasting of weather in the tropics are often different from those of the temperate regions, the need for a Forecasting Manual for India was felt and a Forecasting Manual Unit started functioning in 1967 under the then Deputy Director General of Observatories (Forecasting). This unit did commendable work and published a series of volumes on various aspects of forecasting and typical synoptic weather situations.

Research divisions were created under the Deputy Directors General and small research units started functioning at various Regional Centres from 1962. In 1982, a post of Additional Director General of Meteorology (Research) was created in IMD for monitoring and guiding research. In most of the offices of the department a component of staff have been sanctioned specifically for research work. This has helped in taking up organized research projects by various groups of scientists in different meteorological offices.

With the availability of computers at New Delhi and Pune for more than last three decades, the department has undertaken research studies which used advanced methods involving large computing facilities.

R.P. Sarker, U.S. De and K.C. Sinha Ray made an exhaustive study of effects of mesoscale orography on airflow and rainfall with the help of analytical, quasi-numerical and completely numerical models. R.R. Kelkar studied net terrestrial radiative heat fluxes over India during monsoon, considering the effects of water vapour alone. He found minimum radiative heat loss near the surface over the Western Ghats while over NE and NW India, relatively high losses were observed. H.N. Srivastava and K.C. Sinha Ray studied predictability of monsoon system over India using theory of chaos. P.K. Das and H.S. Bedi made a detailed study on problem of large scale mountain barrier.

Monsoon Variability

Quasi-periodicities in northern hemispheric summer monsoon have been well known for several decades. R. Ananthakrishnan and R.N. Keshavamurty found a five day period in wind and pressure fields.

George Alexander and his co-workers have pointed out that the northward shift in the tropospheric circulation anomalies associated with active break cycles in the active summer monsoon season in India. A.B. Chowdhury, U.S. De, K.C. Sinha Ray and their coworkers made detailed study of low frequency mode (10-20 day and 30-60 day and their propagation in various meteorological parameters and their inter annual variability. Low frequency mode prevails upto 10°N which extends further northwards during good monsoon years.

U.S. De, Onkari Prasad and their co-workers have shown that Southern Hemispheric Equatorial Trough (SHET) and its activity during the northern summer appears inversely related to the rainfall activity over the Indian subcontinent in general and Central India in particular.

Decadal variations of meteorological parameters were studied by Srivastava (1992). The results indicate a decreasing trend of temperature in almost all the northern parts of the country (north of 23°N) and rising trend in southern parts (South of 23°N). While a small warming trend of the order of 0.35°C during the last 100 years was observed throughout the country, some rising and falling trends of temperature was observed in various pockets over India.

In recent years, several studies on monsoon teleconnections and the monsoon - ENSO relationship have been carried by the scientists in IMD.

Planetary Boundary Layer Studies

India initiated a major effort for organizing Monsoon Trough Bounday Layer Experiment (MONTBLEX) to understand land surface interactions over monsoon trough region through an integrated observing system along the trough axis. The enormous data of this experiment were processed and analysed for developing parameterisation schemes in the boundary layer and understanding the role of Planetary Boundary Layer (PBL) in maintenance of monsoon trough. IMD scientists actively participated in the research using these data and a number of papers were published

Studies on Air Pollution

Recently, the problem of air pollution has drawn considerable attention in the developed and developing countries. The department has started an Air Pollution Unit at Pune which takes up studies on problems like acidity, turbidity etc. with the help of data received from 10 BAPMoN (Background Air Pollution Monitoring Network Stations) as a part of WMO's GAW (Global Atmosphere Watch) programme. This BAPMoN programme commenced in 1974 and was fully commissioned in 1978. The objectives of the Regional BAPMoN stations include monitoring of changing composition of the atmosphere as a result of alterations in land use practices and other human activities

The precipitation samples are analysed for different parameters. These are (i) pH, Conductivity (ii) Sulphate, Nitrate, Chloride ..... (Anions) (iii) Sodium, Potassium, Calcium, Magnesium, Ammonium .. (Cations).

The data collected from ten BAPMoN stations are being effectively used for identifying level of different types of pollutants in the atmosphere. Investigations have also been carried out for finding out the probability of acid rain in these stations by using these data mainly pertaining to Sulphur dioxide and Nitrogen dioxide.

A publication was brought out viz. Atmospheric Turbidity and Precipitation Chemistry Data From Background Air Pollution Monitoring Network stations in India (1973-1980). In addition, several research papers are also published in departmental journals using precipitation chemistry and turbidity data of Indian network.

Investigations on problems of urban climatology also have been initiated. B. Mukhopadhyay and his co-workers found trends towards acidic nature in rainfall in several of these stations. They also found increase in turbidity.

Long Range Forecasting

Blanford (1884) used the relationship between excessive winter and spring snowfalls in the Himalayas and subsequent rainfall over India to issue the first tentative forecasts from 1882 to 1885. Operational long range forecasts covering whole of India and Burma was issued on the 4th of June 1886. Sir John Eliot who succeeded Blanford in May 1889 utilized weather conditions over whole of India and surrounding regions. Sir Gilbert T. Walker realized great complexities of the problem and started systematic studies for developing new objective LRF methods. His studies are referred all over the world in the field of Global Teleconnections. His studies led to the development of the multi regression model for predicting seasonal rainfall in India. Based on the correlation coefficients, he developed regression equations for i) one equation each for peninsula, NW India and NE India for monsoon (June to September) season and ii) rainfall of the second half of monsoon season (August and September) over peninsular and NW India. These five forecast equations developed by Walker in 1922 thus formed the basis of operational seasonal monsoon rainfall forecasts in India till 1987.

Thapliyal (1990) developed a Dynamic Stochastic Transfer Model (DST) considering 500 hPa April sub-tropical ridge over India (along 75° E longitude) as the input (X_t) and the monsoon rainfall during June to September over India as a whole as the output (R_t) of the atmosphere.

IMD scientists under the inspiring leadership of V. R. Gowariker have developed a parametric and a power regression model to predict monsoon rainfall by utilizing signals from parameters known to be related with the Indian summer monsoon rainfall. Some of the parameters are global and others are regional in nature. These parameters also have physical links with the Indian summer monsoon.

The parametric model is purely a qualitative decision making tool where equal weightage has been given to all the parameters. However, the relationship of monsoon rainfall with individual predictors exhibits a non-linear relationship. To take care of this non-linearity, a curvilinear relationship had been determined by them fitting the equation of different degrees. The best fit degree of relationship with all the parameters has been combined and a power regression model has been developed. H.N. Srivastava and S.S. Singh studied Empirical Orthogonal Function (EOF) associated with the parameters for the long range forecasting of Indian summer monsoon rainfall since the parametric and power regression models by V. R. Gowariker and his collaborators utilizes parameters, some of which are inter-related. M. Rajeevan and his co-workers developed a model for long range forecast of subdivisional monsoon rainfall over India based on Canonical Correlation Analysis (CCA).

P. Guhathakurta and his co-workers studied long range forecast of summer monsoon rainfall over India using Artificial Neural Network technique.

Numerical Weather Prediction

With the advent of electronic computers and their applications in the field of meteorology, numerical methods of weather prediction based on physical principles governing atmospheric motion were developed. These objective methods of weather analysis and prediction based on sound principles of physics and mathematics have shown continuous improvement in the forecast skill over the years.

Numerical Weather Prediction (NWP) is to predict the future state of the atmosphere from a given current state based on the fundamental laws of conservation of momentum, conservation of mass, conservation of energy, conservation of water vapour and conservation of other gaseous and aerosol material in the atmosphere.

The mathematical equations govern these principles for a coupled set of equations that must be simultaneously satisfied to form a numerical weather prediction model. Some components of these equations are direct function of parameters like wind, temperature, pressure, etc recorded during routine meteorological observations. The other components like frictional effects, diabatic heating and evaporation and condensation of water vapour are not measured directly and are parameterized suitably in terms of routine meteorological parameters. For prediction of large-scale atmospheric flow on short and medium scales, the effect of gaseous and aerosol material is unimportant.

One of the first few electronic computers which came to this country around 1964 was installed in IMD first at Mumbai and then at ITM Pune. This IBM-1620 computer was a small digital computer by current standards, but it provided very useful initial experience to Indian meteorologists in the use of computers. The first attempt towards a numerical simulation of the Indian monsoon was made by R.R. Kelkar along with R. V. Godbole and Takio Murakami in 1970 using the CDC-3600 computer at the Tata Institute of Fundamental Resaerch at Mumbai.

With the availability of IBM-360/44 computer at Delhi, developmental work in numerical weather prediction received further impetus in IMD. After experimenting with barotropic models and some diagnostic studies, the work on filtered multi-level model was started. Computer programmes for objective analysis of meteorological data and short-range prediction of flow patterns in the troposphere by a multi-level quasi-geostrophic model were developed and put in experimental operational use. With the installation of a data switching computer DS-714 at IMD New Delhi towards the end of 1975, the data reception and its direct storage on magnetic tapes became very fast. This cut down the time required for preparation and analysis of data by three to four hours using objective data analysis schemes. Important contributions in development of NWP were made by H.S. Bedi, Y. Ramanathan, R.K. Datta and M.C. Sinha.

An advanced numerical weather prediction system was operationalized to produce computerized analysis and forecast products. The system, known as Limited Area Analysis Forecast System (LAFS), consists of automated data decoding and quality control procedures, objective analysis based on three dimensional optimum interpolation and a multi-level primitive equation forecast model in sigma coordinates. The system produces analyses and forecasts of atmospheric flow variables and precipitation.

An important landmark in IMD's LAFS was development of a methodology to forecast tracks of cyclones originating in the Indian seas in IMD's limited area numerical weather prediction model. A scheme for generation of synthetic observations was developed with a view to correcting the initial objective analysis in the storm area. The system was operationalized and numerical guidance information based on the above system was introduced in operational mode for supply to the field offices of IMD in real time. Research and development of cyclone track prediction model was also pursued by K.Prasad and his group under another collaborative project with NCEP Washington using their high resolution quasi-Lagrangian model. J.C. Mandal studied in detail the numerical simulation of a tropical storm boundary layer.

Atmospheric Electricity

Sivaramakrishnan in 1957 made a detailed study of the point discharge current, the earth's electric field and rain charges during disturbed weather at Pune. A. Mani, G.P. Srivastava, C.R. Sreedharan B.B. Huddar developed an improved radiosonde for the measurement of electric potential gradient in the atmosphere and they also studied fair weather atmospheric electrical potential gradient in the free atmosphere over Pune.

Radar Meteorology

L.S. Mathur and S.M. Kulshrestha have done extensive work on classification and interpretation of weather radar echoes over India. S.M. Kulshrestha compiled the radar climatology of Delhi and neighbourhood and the occurrence of severe weather. He also studied normalized equivalent radar reflectivity factors for water and ice and their dependence on radar wavelength. S. Raghavan studied the tropical cyclones over the Indian seas with the help of radar echoes. R.N. Chatterjee and his co-workers studied the distribution of the areas and heights of the radar echoes from convective clouds around Delhi during monsoon season. A.K. Chowdhury and D.K. Rakshit made a radar study of premonsoon squall line over Gangetic West Bengal. D.V. Rao studied the ellipticity and gyration of the radar eye of a Bay storm.

Satellite Meteorology

Satellite meteorology became a major activity in IMD after the launch of the INSAT series of satellites in 1982. Extensive work was done leading to many research publications, on the interpretation of satellite imageries by S.R. Kalsi and his associates and on the quantitative derivation of products such as Cloud Motion Vectors, Sea Surface Temperature, OLR and large-scale precipitation by R.R. Kelkar, A.V.R.K. Rao and their co-workers.

Upper atmospheric studies

K.S. Raja Rao, and his co-workers studied the possible linkage between solar and geomagnetic activity and upper atmospheric phenomena. They also studied the Quasi- Biennial Oscillation (QBO) in the stratosphere using Rocketsonde data for the Indian region.

Studies by S.K. Srivastav, S.K. Peshin and V.S.Tiwari has brought out new insights into the variation of ozone in the tropics. Trends in surface ozone and the role of atmospheric pollutants have also been discussed in their studies.

Studies on thermodyanamic structure of the atmosphere and its role in weather forecasting has been the theme of studies from early forties. A.K. Mukherjee made several studies on severe convection using radiosonde data.

Research and Development of Seismology

Pioneering studies of historical earthquakes and their causes by S.K. Banerjee, S.C. Ray, Tandon and S.M. Mukherjee are a part of our research heritage. R.K. Dube and S.N. Chatterjee made an indepth study of crustal structure of Hindukush region. In recent years, the broadband data generated by the upgraded network of IMD, particularly that of the Jabalpur earthquake of May 21, 1997 was studied in great detail by IMD's seismologists. The source parameters of the Jabalpur earthquake and thefault plane solution were worked out by S.N. Bhattacharya and his co-workers .

Support to Research Work outside IMD

After independence, Departments of Meteorology, Oceanography and Geophysics were set up at some universities. Notable among them were the Departments of Geophysics at Banaras Hindu University (BHU) and Andhra University. Later, such departments were also established in Cochin University, IIT, New Delhi, IIT, Kharagpur and University of Pune. IMD continued to assist these newly formed Departments by way of sending experts for giving lectures and also by providing technical guidance to set up their laboratories and related infrastructure. Some of these universities like Andhra University and BHU have regular IMD observatories functioning in the university campus close to these departments.

The Centre for Atmospheric Science (CAS) at IIT Delhi, has been functioning under the joint collaboration of the Ministry of Human Resource Development (MHRD) and the IMD. The centre is engaged in the development of mathematical models relating to storm surge, monsoon circulation, atmospheric pollution etc. Research projects at the Universities of Pune, Calcutta and Jadavpur were also provided under IMD Grants in-Aid Programme.

CHAPTER 16

METEOROLOGICAL TELECOMMUNICATIONS

Weather forecasting is the primary concern of the India Meteorological Department like any other national meteorological service. Efficient weather forecasting activity depends on a sound observing system, a communication network and a centre for analysis and prognosis of these data. Operational meteorology is a globally locked enterprise in which meteorological data recorded in different parts of the world are exchanged through a telecommunication system known as Global Telecommunication System (GTS). Thus, the World Weather Watch (WWW) programme is one of the core programmes of the WMO. The programme combines observing systems, telecommunication facilities and data processing centres operated by members to make available meteorological and related geophysical information needed to provide the required services to all countries.

Under the WWW, New Delhi became a part of the Global system, in particular, of the GTS. The GTS provides telecommunication services for the rapid and reliable collection, exchange and distribution of observational data as well as processed products. The GTS is supported by World Meteorological Centres (WMCs), Regional Telecommunication Hubs (RTH), Regional Meteorological Centres (RMCs) and National Meteorological Centres (NMCs). Under the WWW, there are 3 WMCs i.e. Melbourne, Moscow and Washington and 14 RTH centres. New Delhi became a RTH in early 60's which was automated in 1976. The data exchanged through this RTH is used by the Indian Meteorological Service and other countries in the region as data inputs for their NWP models. The computer in the RTH, New Delhi was the first telecommunication computer not only in India but also in the whole of south Asia.

Telecommunications Structure in IMD

The RTH New Delhi, is the global component of the overall National Meteorological Telecommunication functions of IMD. The National Meteorological Telecommunication Centre (NMTC) is located at Mausam Bhavan. The global data exchange centre of NMTC is the RTH. At present a massive exchange of nearly 100 million characters of data and information is made every day through this network.

NMTC is the main source of collection of real time meteorological data in India and neighbouring seas and ocean. The voluminous exchange of daily data is done through 6 regional collection centres located at New Delhi, Mumbai,

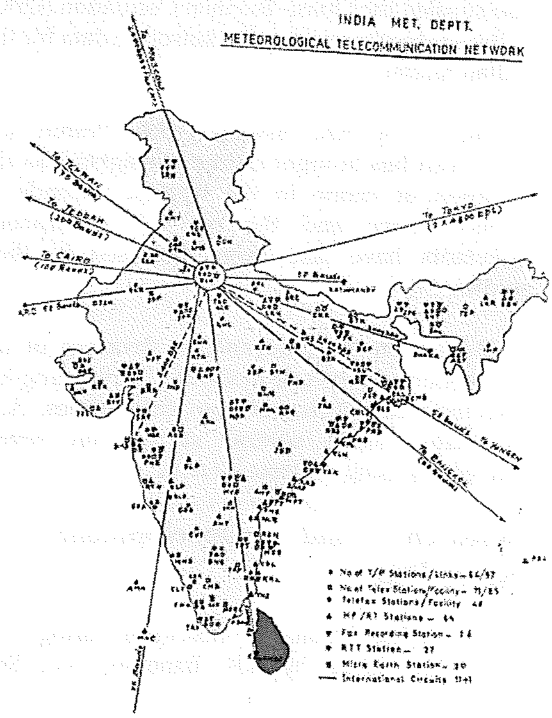


Fig. 41 : Meteorological Telecommunication Network

Calcutta, Chennai, Nagpur and Guwahati. These 6 centres are connected through high speed linkto the central computer system located at NMTC New Delhi.

Different communication media/equipments are used for collection of data from observatories. These are Telex, Teleprinter link, Radio Telephone, VSAT, Telephone and FAX. In some remote areas landline telegrams are still in use.

With the increasing volume of data, the computer system at the NMTC has been periodically upgraded. In 1976, only 7 million characters were exchanged in a day while in the year 2000 the number has risen to nearly 100 million. In 1988, a new computer system (VAX-11/750) was introduced. The existing VAX system was replaced in March 2000 by a State-of-Art computer while the national segment is fed by 6 regional collection centres. The RTH located at these centres is linked with 12 international centres. The RTH New Delhi operates circuits with operating speed ranging from 50 bauds to 9600 bits per second. All the six regional centres within the country are connected to the central Message Switching System (MSS).

Meteorological Services using INSAT based Communication Capabilities

The Indian National Satellite, INSAT, is a multi-service multi-purpose satellite with separate payloads. The communication payload of this satellite has been useful in collection and dissemination of meteorological data, forecast and warnings. The multi-service nature of the INSAT satellite system has been pragmatically used for various meteorological services. A Data Relay Transponder (DRT) enables automatic collection of meteorological data from remote and inaccessible areas through un-manned data collection platforms. In addition, the S-band television broadcast capability of INSAT is also being used for (i) Transmission of cyclone warnings to the coastal areas and (ii) Dissemination of meteorological information to the forecasting offices.

Cyclone Warning Dissemination System (CWDS)

This is a unique system in which the cyclone warning messages originating from IMD's Area Cyclone Warning Centres (ACWCs) are relayed back to the target district using the uplink and downlink capabilities of the INSAT transponder. This project was started on an experimental basis for the coastal areas of south Andhra Pradesh and north Tamil Nadu in December 1985. The warnings are received by CWDS receivers which are mostly located in the rural or semi-urban areas. Initially 100 CWDS receivers were installed in these two states. This communication method is more reliable as it does not use terrestrial communication links which are often disrupted during severe weather. After a successful demonstration the system is now extended to the entire cyclone prone coastal areas in east and west coast. About 250 such systems are in operation. Warnings for the affected districts which are sent through this mode have been greatly appreciated by the state-relief authorities and public. The CWDS system is now undergoing a process of modernisation after which it will become more user-friendly, compact and versatile.

Meteorological Data Dissemination (MDD)

From 1989, a new scheme for dissemination of processed cloud imageries to secondary users was implemented. In this scheme called MDD, processed INSAT cloud imageries are broadcast

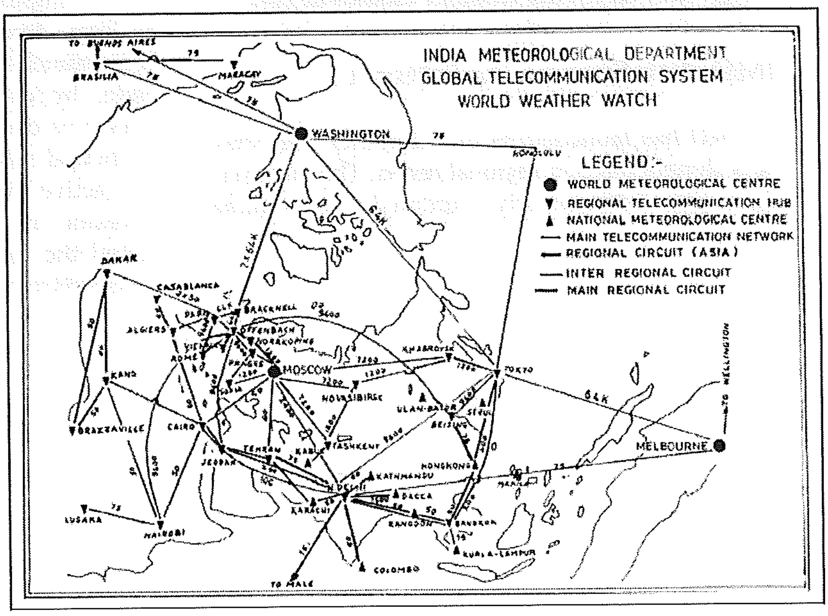


Fig. 42 : India Meteorological Department Global Telecommunication system World Weather Watch

through the INSAT S-band transponder in analog mode every three hours to the field stations. At present there are 31 MDD stations in India and one each in Maldives and Sri Lanka. Apart from IMD, there are many extra departmental users for MDD viz. Indian Air Force (IAF), Indian Navy, Snow and Avalanche Study Establishment (SASE), IITM. The system is also used for transmitting other operational meteorological inputs as well.

Data Collection Platforms (DCPs)

The Data Relay Transponder (DRT) on board INSAT is being used for collection of meteorological, hydrological and oceanographic data from remote inaccessible and unmarked location. IMD has 100 land based Data Collection Platforms. These record and transmit hourly observations of pressure, temperature (dry bulb and wet bulb), relative humidity, wind speed and directions, rainfall and hours of bright sunshine.

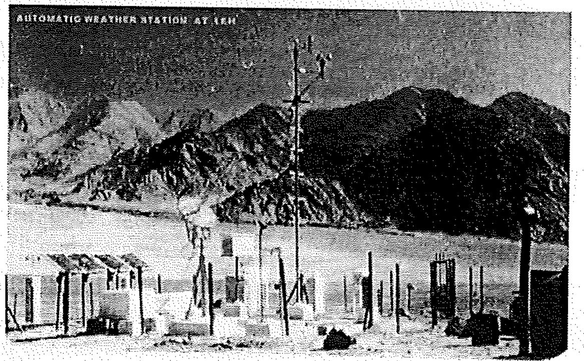


Fig. 43 : Automatic weather station at Leh

IMD Web Sites on the Internet

IMD has launched its own Internet web sites at both national and regional levels. The information gets dynamically updated at regular intervals for providing up to date information to the internet users. The national web site (http://www.IMD.ernet.in) has the latest INSAT imagery, in both full frame and sectors, which is updated every 3 hours, local weather information and forecasts for major Indian cities, all-India weather report, special severe weather warnings monsoon reports, earthquake reports, weather analyses and forecast charts, and sub-divisionwise weekly and seasonal rainfall maps. It contains a lot of information about IMD's activities and other useful reference material.

The regional web sites are operated by RMCs at Chennai, Mumbai and Calcutta and contain more detailed information of regional interest. The Positional Astronomy Centre, Calcutta also has a separate web site. The addresses of these web sites are :

RMC Mumbai	http://www.imdmumbai.gov.in
RMC Chennai	//education.vsnl.com.imdchennai
RMC Calcutta	//education.vsnl.com/calweather/calidex.htm
PAC Calcutta	//education.vsnl.com/pac_cal

Weather on Phone

Popularly known as `weather on phone' an Interactive Voice Response System (IVRS) has been launched by IMD in Delhi from July, 2000. Here, by dialling a special telephone number 1717, one can get quick weather information for Delhi and selected Indian cities through a simple interactive dialogue in English or Hindi without operator intervention. The service is available round the clock. There are plans to extend it to other metro cities.

CHAPTER 17

HUMAN RESOURCE DEVELOPMENT

Meteorology is not taught as a subject at the undergraduate level in this country, although many universities have introduced post-graduate degree courses in meteorology, geophysics and atmospheric sciences. The meteorological profession is also becoming more and more demanding and meteorologists are required to have a knowledge of many subjects which are not a part of their basic university education. Rigorous professional training for meteorologists has therefore always been necessary.

An organized training centre in meteorology started functioning at Pune in the year 1943. Initially, there were two types of courses, an Elementary Training Course of 3 months duration for Observers and Assistants and an Advanced Training Course of 6 months duration for weather forecasters and senior personnel. A Radio-Meteorological Training Section was established in 1962 at New Delhi. A Training Unit for Agricultural Meteorology was established at Pune in 1976. The Telecommunication Training Centre at New Delhi, was established in September, 1977, to provide specialized training in this growing field.

During the seventies and eighties the department decentralized the training by conducting Elementary (now called Basic) Course at 3 centres viz. New Delhi (1973), Calcutta (1975) and Madras (Chennai) (1984) and Intermediate course at New Delhi (1982) for meeting growing need of trained personnel.

The Training School started functioning at Pune under the control of the Deputy Director General of Observatories (Forecasting). Its status was raised to that of a Directorate in 1969, and came to be headed by DDGM (Training) in 1990.

Training in Instrumentation

Training in the operation, maintenance and servicing of meteorological instruments like Radiosonde/Radiowind instruments, Radio-theodolites, Radars, Satellite meteorological instrument is imparted in the Training Centre at New Delhi. This centre was established in 1962. The courses conducted include :

a. Intermediate Training Course (Instrumentation) ,
b. Advanced Training Course (Instrumentation)

The former is having a duration of four months while the later course has duration of six months. All candidates for the Advanced Course (Instrumentation) must pass the Intermediate Course (Instrumentation) before admission to this course. The maximum intake to this course is 8. This course is basically intended for direct recruit Professional Assistants. The duration of this course is 6 months. The course covers lectures on General / Advanced Electronics, Radar meteorology, Ozone etc.

Each trainee is also given "On the Job Training" (OJT) on the equipments. OJT includes theoretical/practical training on the following equipments.

a. 401 MHz/1680 MHz Radiotheodolite systems.
b. Weather Radars : Storm detection/ MultimetBEL-3 cm. Radar. EEC storm detection/EEC wind finding radars.
c. Cyclone detection radars S-band. BEL 10 cms, GRS 440/EEC WRS 74(S).

International Recognition

IMD's meteorological training facilities at Pune for General Meteorology and Agrometeorology and for Telecommunication and Radiometeorology at New Delhi were recognized by WMO as one of its Regional Meteorological Training Centres (RMTC) in 1986. In 1989 a trainees' hostel was built at Pune and the new building of the Central Training Institute (CTI) was ready in 1994.

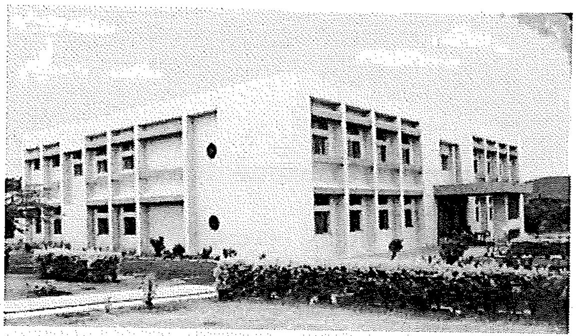


Fig. 44 : Training Centre Building at Pune

Training in General Meteorology is imparted at three levels i.e.at Basic (4 months), Intermediate (6 months) and Advanced (1 year) levels. The trainees include departmental persons as well as meteorological professionals and researchers from Indian organizations like Civil Aviation Department, Indian Navy, Army, Coast Guard, Indian Institute of Tropical Meteorology (IITM) etc. There is also a specifically designed one year training course for directly recruited Group-A Meteorologists of the department, which was introduced in 1980 in all major disciplines of the Department.

Under various technical co-operation programmes, candidates from several Asian and African countries have been trained in IMD. So far, a total of 264 foreign trainees have passed out of RMTC, India out of which 104 have been trained in General Meteorology at CTI, Pune. So far, about 12000 meteorological personnel have been trained out of which about 1200 were forecasters. (Fig. 45) indicates foreign nationals trained at RMTC, India upto December 1999.

Continuing Education

In addition to the regular courses, Advanced Refresher Courses of one or two weeks' duration are also conducted from time to time as part of continuing education. So far, 23 Advanced Refresher Courses have been conducted on the topics like Numerical Weather Prediction (NWP), Cyclone Warning, Agricultural Meteorology, Aviation Meteorology, Long Range Forecasting (LRF) and Climate Change etc. Different courses in hydrometeorology for central and state governmental agencies are also conducted, under World Bank-aided National Hydrology Project.

Specialised Training Courses

National Data Centre (NDC) conducts regular training courses on FORTRAN programming, PC-based software, operating system and climatological data processing for departmental personnel and foreign trainees sponsored under

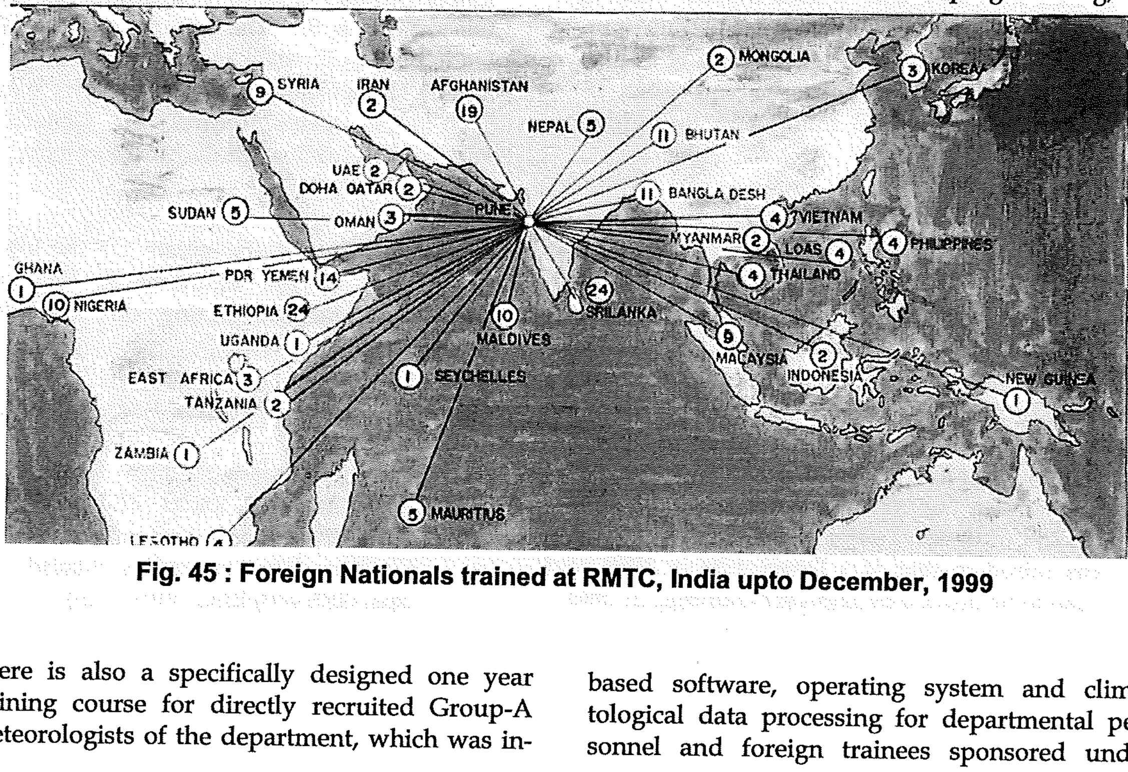


Fig. 45 : Foreign Nationals trained at RMTC, India upto December, 1999

WMO / UNDP, VCP and Colombo Plan etc. More than 500 persons have been trained by NDC so far.

The Agrometeorological Training Courses are being offered to various groups from India/abroad. So far over 1500 trainees (Indian and foreign) have been trained under various courses.

In order to operate and maintain large telecommunication network and keep pace with the technological development, continuous updation of knowledge is essential for the officers and technical personnel. So far, this centre has trained 524 departmental and 95 foreign trainees.

CHAPTER 18

SEISMOLOGY

It was as early as in 1877 that the Royal Society proposed the establishment of seismological observatories in India. This proposal was followed up by IMD and the Geological Survey of India and the first seismological observatory in India was established at Alipore (Calcutta) in December 1898. In the following year, two more seismological observatories were opened in Colaba (Mumbai) and Madras (Chennai). Madras Seismological Observatory was later shifted to Kodaikanal. All these three observatories used Milne's self-registering seismograph. An Omori-Ewing Seismograph was set up at Simla by Prof. Omori of Japan, soon after the destructive Kangra earthquake of 5th April 1905.

Table I
List of Major Indian Earthquakes

Date	Location	Magnitude
16.6.1819	Kutch, Gujarat	8.0
10.1.1869	Near Cachar, Assam	7.5
30.5.1885	Sopor, J&K	7.0
12.6.1897	Shillong Plateau	8.7
4.4.1905	Kangra, H.P	8.0
8.7.1918	Srimangal, Assam	7.6
2.7.1930	Dhubri, Assam	7.1
15.1.1934	Bihar-Nepal Border	8.3
26.6.1941	Andaman Islands	8.1
23.10.1943	Assam	7.2
15.8.1950	Arunachal Pradesh - China Border	8.5
21.7.1956	Anjar, Gujarat	7.0
10.12.1967	Koyana, Maharashtra	6.5
19.1.1975	Kinnaur, H.P.	6.2
6.8.1988	Manipur-Myanmar Border	6.6
21.8.1988	Bihar-Nepal Border	6.4
20.10.1991	Uttarkashi, U.P. Hills	6.6
30.9.1993	Latur-Osmanabad, Maharashtra	6.3
22.5.1997	Jabalpur, M.P.	6.0
29.3.1999	Chamoli, U.P.	6.8

The seismological monitoring organisation in India was gradually expanded and instruments system was upgraded. Milne-Shaw Seismographs with photographic recording instruments were installed in Colaba, Calcutta and Kodaikanal during the decade 1920-1930. The Seismological Observatory from Simla was shifted to Agra in 1928 when Pune became the headquarters of IMD.

After the disastrous Bihar earthquake of January 1934 and the Quetta earthquake of May 1935, new observatories were opened at Shillong, Patna, Allahabad and Waltair. Table 1 gives the list of major historical earthquakes in India. An observatory was set up in New Delhi in 1941. The number of observatories in the seismic network which was only 6 in 1940, rose to 8 in 1950 and to 15 in 1960.

Directorate of Seismology

Until 1952, the Seismological Division was located at Pune. In that year, it was transferred to Shillong thus fulfilling the recommendations made by the Seismological Committee which was constituted in 1936 for the modernization of the seismological organisation in the country. The Central Seismological Observatory at Shillong was made responsible for all seismological monitoring by IMD. The Seismological Division was shifted to New Delhi in 1958 for better liaison with the Central Government authorities, and given the status of a Directorate. Dr. A.N. Tandon, the first Director of Seismology, was a pioneer in seismological research in the country. A further upgradation in seismological instrumentation came in 1963 with the installation of standardised equipments at four stations (Shillong, New Delhi, Pune and Kodaikanal) provided under the US Government's scheme for a World-wide Network of Seismic Stations (WWNSS).

Modernization

By 1975, there were 16 Seismological Observatories in the national seismological network. In addition, under projects for special studies, 12 Seismological Observatories had been set up in the north-west Himalayas under river valley projects and 4 Seismological Observatories in and around Delhi. Prior to 1975, the seismographs recorded the seismic and earthquake signals on photographic paper. A Seismic Research Observatory (SRO), with broad band bore hold seismometer and digital recording system was installed at CSO Shillong in 1975. IMD started operating on digital seismo-graphs in 5 observatories during early 90s.

In addition to IMD, a large number of R&D institutions, universities and state governments are also operating seismological observatories /networks in different parts of the country. Total number of all such observatories in the country is 212. Out of these, IMD and other R&D institutions have 106 stations while River-Valley project authorities operate 79 stations and the universities operate 27 stations.

The observatories of IMD are used for operational determination of earthquake parameters. These are disseminated in operational mode. IMD's network has been upgraded from time to time. Some of these upgradations have resulted in introduction of State-of-the-Art systems.

Consequent to the occurrence of the Latur earthquake of 1993, a World Bank-aided project for

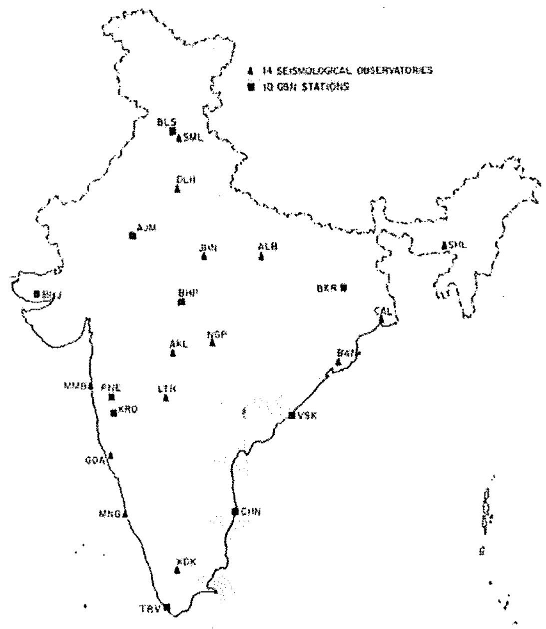


Fig. 46 : Global Standard Seismological Network

seismological instrumen-tation and its upgradation in the Peninsular Shield Region was launched. IMD was a major partner in this project under which 10 Seismo-logical Observatories in the Peninsula were upgraded with digital broad band seismographs and digital accelerographs to the standard of Global Seismographic Network (GSN). These stations were Bhopal, Pune, Karad, Bhuj, Bokaro, Bilaspur, Ajmer, Vizag, Chennai and Thiruvananthapuram. Under the same Project, 14 more observatories have been upgraded with similar instruments. These are Akola, Allahabad, Bhubaneshwar, Mumbai, Calcutta, Goa, Jhansi, Latur, Mangalore, Nagpur, Simla, Delhi, Shillong and Kodaikanal. Present 45 Seismological Observatories are run by the Department under the National Seismological Network, 12 observatories under special studies and a number of them being located near the dam sites. The upgraded stations (GSN type) have generated very useful digital broad band data sets for the major earthquakes that followed Latur, like the Jabalpur earthquake of 1997 and Chamoli earthquake of 1999.A Central Receiving Station (CRS) and National Seismological Data Base Centre (NSDC) have been established at IMD's headquarters at New Delhi with state-of-art computers and work stations. This centre does near real time data monitoring, data analysis, processing, archiving and dissemination to various user organisations. As a part of the human resources development, officers working in the Seismological Division of IMD were deputed abroad to get a first hand experience in the use of seismic analysis software, seismic instrumentation in organisations in USA, Norway and Mexico.

A 16-element digital telemetry system is being installed around a National Capital Territory of Delhi. The telemetry system utilizes a V-SAT based communication for near real time data downloading and processing.

Many IMD scientists have made outstanding contributions to the science of seismology. As early as in 1939, Dr. S.K. Banerjee gave a theoretical explanation, the first of its kind, for the origin of microseisms. He also wrote a book on 'Himalayan Earthquakes'. Two papers entitled, "Sedimentary Rayleigh waves across the Gangetic basin – A preliminary study" by H.M. Chaudhury (19..) and "The crustal structure of the Hindu Kush Region" by Dr. R.K. Dube and Dr. S.N. Bhattacharya (19..) were awarded the prestigious 'Mausam Award'.

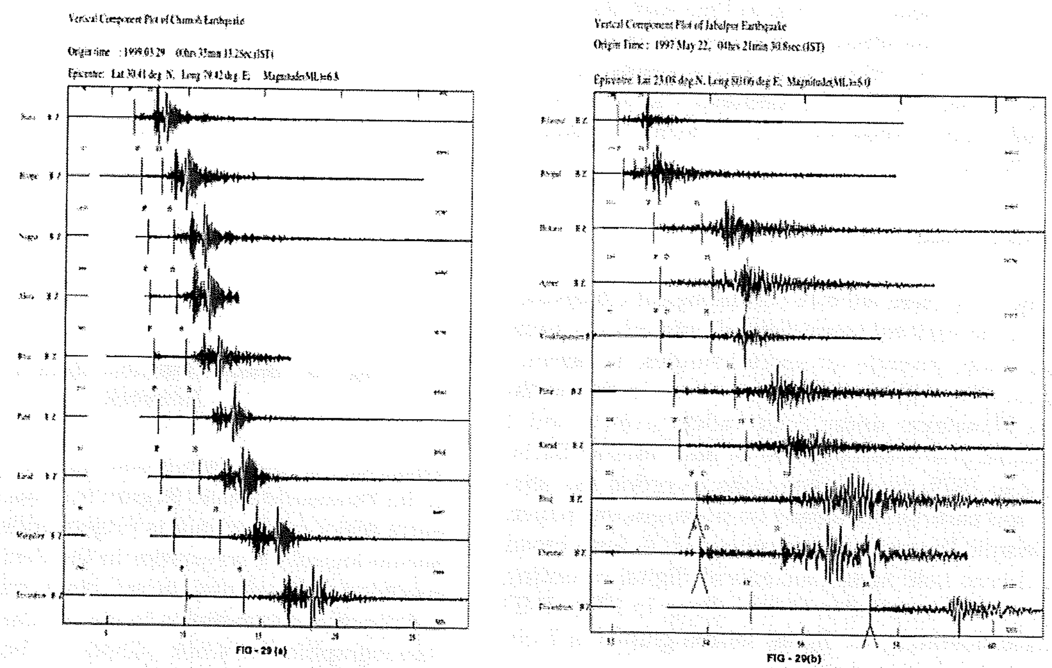


Fig. 47 : Seismic records of Jabalpur and Chamoli earthquakes

IMD has initiated action to integrate all the existing seismological observatories into a national network. This will ensure optimization of resources and determination of earthquakes of lower magnitudes also. Wherever required new observatories will be opened in the gap areas keeping in view the seismicity of the region. The expanded and upgraded seismological observatories in the national network are proposed to be connected through a V-SAT based communication system to IMD headquarters at New Delhi. Ground motions due to large earthquakes are responsible for substantial damage from earthquakes. Strong motion accelerographs are planned to be installed at a number of stations in the country in the coming years. The seismological organization of IMD is poised for a planned growth to serve the national requirements.

CHAPTER 19

POSITIONAL ASTRONOMY

Since ancient times, great Indian astronomers like Aryabhata and Bhaskara have made significant contributions to the science of astronomy. For seafarers, a knowledge of astronomy was crucial for safe navigation over the seas. Fishermen had to know about high and low tides. Much more than that, the positions of stars and planets governed the observance of religious events, festivals and rituals, making astronomy a part of daily life in India.

In today's world, almanacs and astronomical ephemeras facilitate the practical applications of astronomy. They help to foreshadow significant celestial events like eclipses of the sun and moon, unusual planetary configurations, phases of the moon, and so on. In India, such almanacs, known popularly as *Panchangs,* were being prepared from historic times but the method of calculations followed by them differed widely. The British rulers followed the Gregorian calendar for their official work, but different sections of the populations began using different calendar systems.

After independence, the late Pandit Jawaharlal Nehru, the first Prime Minister of our country, envisioned the need to adopt a unified calendar throughout India and to end the prevailing multiplicity of calendars each with different era and beginning time. A Calendar Reform Committee (CRC) was formed in 1952 under the Council of Scientific and Industrial Research (CSIR) of the Government of India with late Prof. M.N. Saha, FRS, as the Chairman. The Committee, after a thorough study of the existing practices in different parts of the world, recommended the compilation of an Indian Ephemeris and Nautical Almanac incorporating therein, along with usual astronomical data, the national calendar of India (the Saka Era) with the timings of *tithis, nakshatras, yogas,* etc. calculated with most modern astronomical formulae and also the festival dates. This work was entrusted to the India Meteorological Department on 1st December 1955.

The new unit known as the Nautical Almanac Unit was created and was attached to the Regional Meteorological Centre, Calcutta, as a part of that office. The late Shri N.C. Lahiri, the Member Secretary of the CRC headed the unit.

The first volume of the Indian Ephemeris and Nautical Almanac was published in March 1957

The Nautical Almanac Unit continued under the RMC Calcutta for several years. Later, as per the recommendations of the Ramanna Committee, the Unit was renamed as Positional Astronomy Centre (PAC) under the direct control of DGM, New Delhi with effect from 1st December 1979 and was formally inaugurated on 26th April 1980. The Positional Astronomy Centre is now housed in a rented building in the New Alipore area of Calcutta, but a new office building for the PAC is under construction in the Salt Lake City area.

Publications of the PAC

The PAC brings out the following important publications regularly:

- ***Indian Astronomical Ephemeris (IAE)***

From 1979, the title of the earlier publication 'The Indian Ephemeris and Nautical Almanacs' was changed to the 'Indian Astronomical Ephemeris'. The publication contains advance positions of the Sun, the Moon, Planets, Stars and details of eclipse and occultation with particular reference to India and neighbouring countries. It also contains a section of the Indian National Calendar giving all astronomical data required for the preparation of a *Panchang* and also the dates of different festivals observed in the country. The Government of India and other State Governments mainly depend on this publication.

- ***Rashtriya Panchangs***

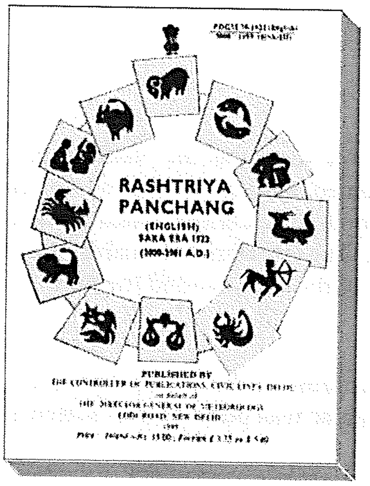


Fig. 48: Rashtriya Panchang

At the instance of the Ministry of Home Affairs, the 'Rashtriya Panchang' using the Saka Era is also being published by PAC. The main objective is to unify the divergent practices existing in different parts of the country and to promote a scientific basis for calendric computations. The first issue for the year 1879 SE (1957-58 AD) was published in June 1957. Initially it was issued in 9 languages but it is now being brought out in 14 languages viz., English, Hindi, Sanskrit, Urdu, Assamese, Bengali, Oriya, Telugu, Tamil, Malayalam, Kannada, Marathi, Gujarati and Punjabi.

- **Tables of Sunrise/Sunset, Moonrise/ Moonset**

This gives a part of IAE, published for various user agencies.

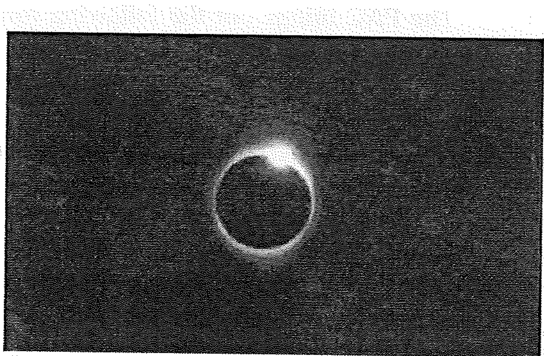


Fig. 49 : Diamond ring during total solar eclipse 24.10.1995

- **Monthly Star Charts**

These charts are published in many leading newspapers and show the relative positions of planets, moon and important stars.

- **Press Bulletins**

The occurrence of important astronomical events is widely publicized through the media.

The above publications and bulletins meet a very wide range of requirements of large number of user agencies like Survey of India, Defense, Railways, AIR, Judiciary, Police, Religious Organizations, Home Ministry (for declaration of official holidays) in addition to the scientific community, research scholars and common public.

A lot of information related to positional astronomy which is useful to the general public is available on the PAC Internet Web Site (PAC Calcutta : http://education.vsnl.com/pac_cal).

Field Observations

From time to time, PAC has conducted astronomical observation campaigns over different parts of the country as well as abroad.

NALGONDA in Andhra Pradesh	-	Observation of Total Solar Eclipse, 16th February 1980
FARAKKA in West Bengal	-	Observation of occultation of a star on 7th October 1980
SALUA in West Bengal (near Kharagpur)	-	Observations of Halley's Comet, November 1985 to May 1986
HAKIMPUR in West Bengal	-	Observation of Comet Wilson during May 1987
MAURITIUS	-	Observation of Supernovae 1987A, February-March 1988
MOUNT ABU in Rajasthan	-	Observation of Comet Austin, April-May 1990
NARENDRAPUR in West Bengal	-	Observation of Comet Austin during May-June 1990

Calcutta – Observations of transit of Mercury across suns' No. 1993 and of comet Shoemaker – Lavy – 9 in July 1994

ROBERTSGUNJ in Uttar Pradesh of Total Solar Eclipse, October 24, 1995

FALTA in West Bengal - Observation of Total Solar Eclipse, October 24, 1995.

KHARAGPUR in West Bengal (IIT Campus) - Observation of comet Halo-Bopp, February - June 1997.

GHATSHILA in Bihar - Observation of `Leonid Meteor Shower' November 1998.

SURENDRANAGAR in Gujarat - Observation of Total Solar Eclipse, August 1999.

In 1999, IMD signed a Memorandum of Understanding with the Indian Institute of Technology Kharagpur for the establishment of an Astronomical Observatory and for undertaking joint field studies.

CHAPTER 20

PUBLICATIONS AND LIBRARY SERVICES

IMD has a long tradition of preserving and documenting the valuable meteorological information that it possesses, in the form of various departmental publications:

- Memoirs of IMD
- Indian Weather Review
- Atlases and Compilations of Charts
- Weather Code Books
- Scientific and Technical Notes and Reports
- Observational Organization maual
- Climatological Tables of Observatories in India
- Instructions to observers at the surface observatories
- State Climatological Summaries
- Information on Disastrous Weather Events
- Forecasting Manuals
- Other miscellaneous publications.

Mausam

In 1950, IMD started publishing its own departmental research journal *"Indian Journal of Meteorology and Geophysics"* on a quarterly basis, so that all research communications were peer reviewed and could appear in a formal way. The scope of this journal was

widened in 1975 and its name was changed to the *"Indian Journal of Meteorology, Hydrology and Geophysics"* from Vol. 26 No. 1 onwards.

In 1979 (Vol. 30 No. 1) it was given the name *"Mausam"*, which was later amplified as *Mausam - Quarterly Research Journal of Meteorology, Hydrology, Geophysics.* Research papers in meteorology, hydrology, geophysics and allied disciplines authored by IMD scientists as well as other scientists from the country and abroad are accepted by the journal. Even though the journal has undergone substantial revision of format, its basic components have remained same. A special regular feature of this issue called "Weather Summary" is originated by the Forecasting Office at Pune. It describes the season's climatic features in the earlier year. In addition to this, every July issue contains a review of all cyclonic storms that originated during the entire earlier year over the Indian seas. The October issue also contains a consolidated bibliography of the annual volume.

Fig. 50 : IMD Library, Pune

Mausam has also devoted some of its issues for printing proceedings of symposia. These are as follows :

1. Proceedings of Symposium on "Earthquake prediction", held at Meteorological Office, Delhi, during 8-10 March 1978 - April and July 1979, Vol. 30, No. 2 & 3.
2. Proceedings of National Symposium on "Satellite Meteorology", held at Meteorological Office, Poona, during 13 April 1970 - July 1971, Vol. 22, No. 3.

3. Proceedings of International Symposium on – "Monsoon : Understanding and Prediction", held at Indian Institute of Tropical Meteorology, Pune, during 23-28 November 1988–April 1990,Vol. 41, No. 2.

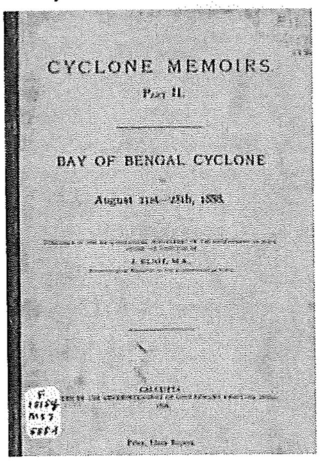
Of late, Mausam has started bringing out Special Issues on specific subject areas, which contain invited articles from leading researchers in the field. They are listed below :

1. Tropical Cyclones : Edited by Dr. P.K. Das – April 1997, Vol. 48.
2. Ocean Response to Tropical Cyclones : Edited by Dr. S.K. Dube – October 1997, Vol. 48, No. 4.
3. Climate Change : Edited by Dr. G. B. Pant - 2001, Vol. 51, No. 1.

Libraries

The two main libraries of IMD are located at Mausam Bhavan, New Delhi and Pune. Both the libraries are a treasure-house of scientific knowledge and information in the field of meteorology, and many specialised branches of atmospheric science, as well as other related subjects, accumulated over more than a hundred years. Besides IMD's own publications listed above, these libraries have a very large collection of national and international books and periodicals. The library services are available not only to the employees of the department but are also extended to a large number of outside users including those from the government, private agencies, universities, scientific and academic institutions, etc.

The Pune library procures WMO Publications directly from WMO, Geneva, and distributes them to IMD's own offices and libraries of the Indian Air Force. Apart from the two main libraries at New Delhi and Pune, fairly good library facilities exist at the six Regional Meteorological Centres at Calcutta, Mumbai, Chennai, New Delhi, Nagpur and Guwahati.



Some of the Meteorological Centres in the State capitals also have small libraries, storing mainly reference books and technical publications, useful for their day to day work.

As of now, the Pune library houses as many as 13,000 books, many of them are rare and of historical value. The collection is being constantly updated with new volumes of over 260 standard national and international journals. It is also a storehouse of data in the form of rare manuscripts as well as in printed form. The departmental library at New Delhi is also similarly well-equipped.

Printing Facilities

In 1954, the department set up its own printing unit at Pune, manned by its own staff with an imported Rotaprint machine. It has since been completely modernized and is now equipped with DTP workstation, laser printer, scanner, photo copiers, thermal binding, lamination machines and CD-ROM writers. This unit caters to all the basic printing requirements of all the offices at Pune as well as some of the printing requirements of other departmental offices. Publications like the Climate Diagnostics Bulletin of India, the State Climatological Summaries of all the states of India, Aridity Anomaly maps and reports,

Fig. 51 : DTP unit, Pune

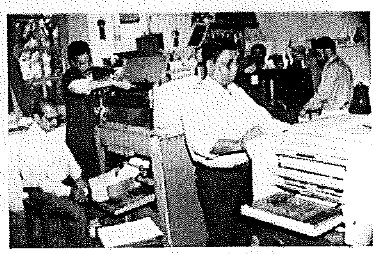
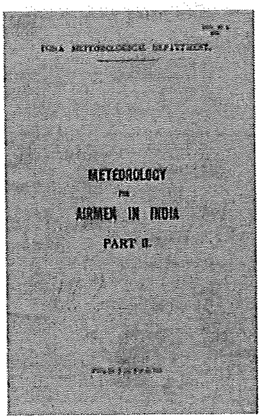


Fig. 52 : Printing unit, Pune



Meteorological Monographs, Pre-published Scientific Reports, Instruction Manuals, Observational Organization Manuals, Climatological Tables, Climatological Normals and Annual Reports on Disastrous Weather Events, Weather Code Books, etc. are printed in-house by IMD at Pune. Autographic charts required for use in the department and defence organizations are also printed by this unit.

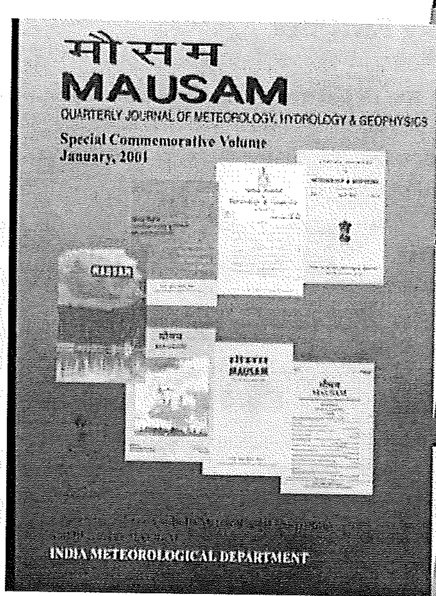


Fig. 53 : 50 years commemorative volume of 'MAUSAM"

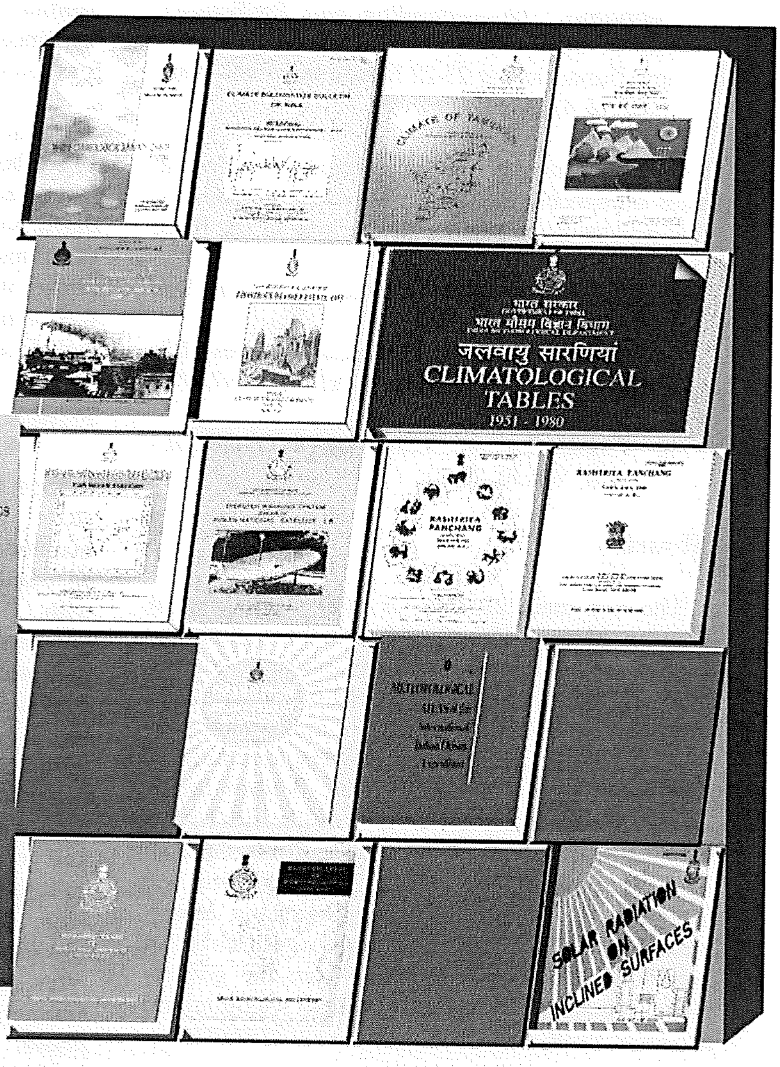


Fig. 54 : A few departmental publications

CHAPTER 21

INTERNATIONAL COOPERATION

It is often said that weather and climate processes do not recognise national boundaries. In fact, international co-operation has been the basis of the spectacular progress of the science of meteorology and the development of Meteorological Services all over the world in recent times.

World Meteorological Organization

The global meteorological community came together by forming the International Meteorological Organization (IMO) in 1873. India became a full member of the IMO in 1878. Later, after World War II, this organisation received the status of an inter-governmental body as a specialised agency of the United Nations with a new name, 'World Meteorological Organization' (WMO). The WMO came into existence on March 23, 1950 with India as one of its founder-members. Since its inception, India has always continued to be an active member of the WMO which now has 185 members.

IMD hosted the first meeting of the WMO Regional Association for Asia (RA-II) held in New Delhi in 1948 and at which Dr. S. K. Banerji was elected Chairman. Later, Shri V. V. Sohoni and Shri S. Basu were the Presidents of RA-II from 1951 to 1953 and 1953 to 1959 respectively.

During the last 50 years, India has almost always been elected to the prestigious seat in the WMO Executive Council, Dr. R. R. Kelkar being its present member.

Dr. P. Koteswaram was the first Indian to be elected as the Vice-President of WMO at the 6th World Meteorological Congress held in 1971. Again, in 1995, Dr. N. Sen Roy was elected as the Vice-President of the WMO.

Dr. S. N. Sen was closely associated with the activities of the Technical Commission for Synoptic Meteorology and he was its Vice-President from 1958 to 1961 and President from 1962 to 1968. Dr. L. S. Mathur was the President of the Commission on Instruments and Methods of Observation (CIMO) from 1962 to 1967. In 1998 again, Dr. S. K. Srivastava was elected as the President of CIMO.

Dr. P. R. Pisharoty and Dr. P. K. Das were members of the Joint Organising Committee for the Global Atmospheric Research Programme (GARP).

Prior to the establishment of the WMO, Mr. J. H. Field was elected a member of the International Meteorological Committee in 1926 while Dr. K. R. Ramanathan was a member of Radiation Commission of IMO in 1932 and Dr. S. K. Banerji was a member of the Commission for Aeronautical Meteorology in 1936.

International Expeditions and Experiments

Indian meteorologists have taken part in many international expeditions. Notable among them was the participation of Dr. G. C. Simpson in the South Polar Expedition in 1910. India participated in the International Geophysical Year (IGY) Co-operation Programme and in the International Quiet Sun Year Programme in 1964-65.

India played a leading role in the International Indian Ocean Expedition during the years 1962 to 1965. India operated the International Meteorological Centre at Bombay with Indo-US collaboration for collection and analysis of the meteorological data collected through the IIOE Expedition. Under the First GARP Global Experiment (FGGE), a Monsoon Experiment (MONEX) was organized during which extensive observations were made over the Indian Ocean, Arabian Sea and Bay of Bengal during 1979. This was preceded by a bi-lateral Indo-USSR Programme called Indo-Soviet Monsoon Experiment (ISMEX) during May-July 1973.

Following the success of MONEX, the World Climate Research Programme was jointly established as an inter-disciplinary programmeof three nodal agencies, WMO, IOC and ICSU. It formulated an international programme called the Global Energy and Water Cycle Experiment (GEWEX). This was established in 1990. Later on, a sub-programme of GEWEX known as GEWEX Asian Monsoon Experiment (GAME) was visualised. High-quality data sets under GAME were generated by India under the Intensive Observation Programme (IOP) from 15 May to 31 July 1998. The data generated by India during this programme is now available at the GAME Data Management Centre in Japan.

Current WMO-Related Activities

Of the many WMO activities in which India has been taking an active part is the WMO/ESCAP Panel on Tropical Cyclones established in 1972. The technical support unit of the Panel, when first established in 1976, was located in New Delhi. Regular meetings of this Panel are held to co-ordinate planning and implementation of cyclone disaster mitigation measures in the maritime countries of the area viz., Oman, Pakistan, Maldives, Sri Lanka, India, Bangladesh,

Fig 55 : WMO/FAO/IMD Roving Seminar on Crop Yield Weather Modelling, Pune, India, 19-30. Julv. 1999

Myanmar and Thailand. WMO has also designated New Delhi as the Regional Specialised Meteorological Centre since July 1988. India joined the WMO's effort in providing Global Maritime Distress and Safety System (GMDSS) in June 1996. Sea Area Bulletins for North Indian Ocean are issued for the marine community in the region. IMD is also the area meteorological co-ordinator for WMO's Marine Pollution Emergency Response Support System (MPERSS). A large volume of meteorological data from the oceans all over the world is collected by the ships plying over the high seas. These observations are archived by various countries. The data thus collected is processed by the designated country. The areas of responsibility for different zones were adopted by WMO in 1963 through Resolution 35 Cg IV. They also provide technical support and instruments through the sea going vessels. This is known as the Voluntary Observing Fleet (VOF). The data collected from these ships are archived and processed by India for the entire north Indian Ocean. These high quality data are exchanged with the Global Collecting Centre (GCC) of WMO in UK and Germany.

The IMD Central Training Institute at Pune is recognised by the WMO as a Regional Meteorological Training Centre and it has been functioning effectively since 1986 as a centre for human resource development and capacity building in meteorological services in developing countries in Asia and Africa.

The Asian Monsoon Activity Centre (MAC) was set up in New Delhi in 1984 following the decisions of the WMO/CAS project relating to Long Term Ocean Monsoon Studies (TMP Project M2) along with two more centres functioning at Kuala Lumpur (Malaysia) and Nairobi (Kenya) to implement the Winter Monsoon and African components respectively.

WMO and ICAO work in close co-operation for exchange of warnings and meteorological information for aeronautical purposes. In 1982, under the World Area Forecast System (WAFS), New Delhi was designated as the Regional Area Forecast Centre (RAFC) for the area covering Bangladesh, Myanmar, India, Maldives, Nepal, Pakistan and Sri Lanka. A Satellite Distribution System (SADIS) has recently been installed in IMD to provide such services under the WAFS scheme.

Cooperation in SAARC Region

India is one of the prominent members of the South Asian Association for Regional Co-operation (SAARC) established in 1980, for strengthening regional co-operation among seven countries of South Asia viz., Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka. The programme functions with IMD providing useful inputs in the field of meteorology. Meteorology, telecommunication, agriculture and health are some of the major areas of co-operation for SAARC. SAARC encourages young scientists in the region by giving SAARC award in Meteorology. Several refresher courses in the area of meteorology, data management, instrumentation, inter-comparison etc. were conducted in India under the aegis of SAARC. India has recently provided Meteorological Data Dissemination System (MDDS) to Maldives and Sri Lanka as a gesture of bilateral co-operation.

Under the Voluntary Co-operation Programme of the WMO, under the technical co-operation programme, India is both a recipient and a donor. India provides fellowships and training facilities under this scheme to several of the RA-II member countries. On the other hand, under voluntary exchange programme, telecommunication equipment and training facilities by several of our officers were availed of.

Bilateral Collaboration Programmes

Indo-US Co-operation

A Memorandum of Understanding (MoU) between DOS and DST from India and NASA and NOAA, USA defining the terms and conditions of scientific and technical collaboration in the area of earth and atmospheric sciences and exchange of satellite data was signed on 16th December, 1997 in Washington DC. Prior to this a Statement of Intent identifying eight theme areas in atmospheric sciences and statement of collaboration and data exchange possibilities was signed on 26th May, 1995 by both the sides. Under the terms of MoU the US party shall make available Earth and Atmospheric data produced by research and operational systems including GOES system of USA. The Indian party shall make available Earth and Atmospheric Science data produced by INSAT system to US party.

Following the MoU the first joint Indo-US Workshop was organised in New Delhi (February 10-12, 1998) to finalise the details of communication links and project proposals. During the meeting, 27 scientific projects were identified for joint research programmes.

For satellite data exchange, two dedicated communication links of 128 Kbps and 64 Kbps between NOAA, USA and IMD, India was established by USA on their server provider (World Com. USA) in May 1998. A National Satellite Data Centre has been established with facilities for INSAT-GOES satellite data exchange and receipt of archived satellite data from USA began with the 128 Kbps link in March 1999 and the 64 Kbps link in September 1999.

A Joint Indo-US Science Group meeting was held in New Delhi from 15 to17 November, 1999 for consolidating the documents for the seven projects and their implementation with effect from 1st December, 1999.

Mr. Gregory W. Withee, Deputy Administrator for Satellite Information Services of NOAA inaugurated the Indo-US Data Centre on 17 November 1999. The Centre has state-of-the-art facilities for exchange of GOES-INSAT data, its archival and analysis.

This significant event will further cement the long-standing scientific co-operation between USA and India dating back to 1960. It is hoped that availability of GOES and INSAT data to scientists of USA and India under the Indo-US MoU would lead to development of sophisticated weather analysis and forecasting tools in near future.

Indo-Russian Cooperation

During the first meeting of the Indo-Russian Working Group on Science and Technology held in New Delhi in November, 1993, it was decided to establish a Sub-working Group on Meteorology with IMD and ROSHYDROMET as the nodal agencies on either side. A Memorandum of Understanding (MoU) on Science and Technology Cooperation in Meteorology between the India Meteorological Department and the Russian Federal Service for Hydrometeorology and Environmental Monitoring (ROSHYDROMET), was signed on 30th June 1994 during the visit of Hon'ble Prime Minister of India to Russia.

Following the adoption of the MoU, the first meeting of Indo-Russian Sub-Working Group on Meteorology was held in Moscow from 10 to 16 August, 1994 and identified three themes viz., Study of Monsoon, Study of Climate Change and Study on Ozone for joint collaboration. The Hydrometeorological Centre of Russia (HMC), the State Hydrometeorological Institute (SHI) and the Central Aerological Observatory (CAO) of ROSHYDROMET are the participating agencies from the Russian side and the India Meteorological Department (IMD) and Indian Institute of Tropical Meteorology (IITM) from the Indian side. Prior to this, there was an Indo-USSR collaborative programme in Meteorology and Environmental protection in existence. Twelve IMD scientist visited USSR and equal number of USSR scientists visited IMD during 1984-87.

During the 2nd meeting of the Sub-Working Group held in New Delhi (15-19 April 1996), an additional theme, Computation of atmospheric pressure for the height data of tracking radar was included. Later, another theme, Study in the field of weather modification was included during the 3rd meeting of the Sub-working Group held in Moscow and Nalchik from 9 to17 September 1997.

In 1998 and 1999 one scientist each from both the countries made exchange visits for joint research on ozone studies. Analysis of TOMS/Nimbus-7, 1978-1993, TOMS/Earth Probe data 1996-99 and ground based Russian network station data was carried out to investigate both long and short term variations on global scale. It is observed that variations of total ozone with time scale of one month has stationary waves and it is possible to divide the global ozonosphere into three regions viz., tropical, sub-tropical/middle and polar latitudes.

The 4th meeting of the Sub-working Group was held in New Delhi from 1-7 December, 1999. Two more area of cooperation were added in this meeting viz., Study of Stratosphere-Mesosphere processes including rocket measurements and interpretation of real time 3-D weather radar data in terms of meteorological events.

To continue the above research programme further, two Russian scientists from ROSHYDROMET, Moscow visited IMD, New Delhi from 1-14 December, 2000 for studies on ozone and monsoon.

Studies on the influence of tropical cyclone on the ozone layer over India, and the connection of negative ion concentration with aerosols at 10-30 km height were carried out. Indian heavy precipitation data for 1999 was analysed for the development of the improved method for the forecast of heavy precipitation and its amount during monsoon period on the basis of interpretation of Hydrodynamical forecast of regional model. The initial results of the probability forecast of heavy precipitation during July-September 2000 over Indian region based on the Russian hydrodynamical prognosis model, are promising.

Indo-Australian Co-operation

A Memorandum of Understanding (MoU) between the India Meteorological Department (IMD) and the Australian Bureau of Meteorology (BOM) on cooperation in the field of Meteorological Science and Technology was signed in New Delhi in 1989.

Under this MoU, the following areas for cooperation in meteorology were included viz., Numerical Models, Tropical Meteorology, Satellite Meteorology, Agriculture, Instrumentation and Communication links.

During the period (1989-1998) 3 scientists from India visited BOM, Australia and 8 scientists from Australia visited IMD for conducting research on the various topics related. During the period (1989-1998) BoM provided software on CD-ROM of the Australian Tropical Cyclone Workstation (ATCW) to IMD in August, 1999.

Cooperative investigations in Numerical Modelling, Satellite Meteorology, and Tropical Meteorology are expected to continue over the next decade 1999-2008.

Indo-China Cooperation

A Memorandum of Understanding (MoU) in the field of Meteorological Science and Technology was signed between India Meteorological Department (IMD) and China Meteorological Administration (CMA) on 7th March 1997 in Beijing, China.

Prior to this a dialogue was held in New Delhi from 26 to 28 August 1996 between scientists of CMA and IMD, on the various issues involved in the proposed Indo-China Cooperation in conducting the Tibetan Plateau Experiment (TIPEX)..

Following the MoU, the first six-member Chinese delegation headed by Mr. Wen Kegang, Administrator, CMA, China visited IMD, New Delhi from 21 to 25 October, 1997 and held in-depth discussions on the possible scientific programmes of mutual interest aimed at improving the understanding of the Asian Monsoon system. Four areas of collaborative activities were approved and grouped into following broad themes: Monsoon studies including TIPEX, Typhoons and Tropical Cyclones, Radar Meteorology and Telecommunications between New Delhi and Beijing.

The collaboration involves collection and study of observational data relevant to scientific programmes of mutual interest and the exchange visits of scientists for familiarization and identification of further collaboration work. Both sides agreed to exchange observational data collected during special programmes like GAME and TIPEX. These include surface and upper air data over India (GAME-IOP) and Tibet (TIPEX) for the monsoon season of 1998.

IMD considered the proposal for establishment of a high speed (9600 bps) telecommunication circuit between Beijing and New Delhi within the framework of WMO/CTS for exchange of data as a bilateral arrangement.

Three Chinese scientists visited IMD, New Delhi from 24-28 November, 1999 for studies on Monsoon, Typhoons and Tropical Cyclones and establishment of meteorological Telecommunication circuit between New Delhi and Beijing.

Indo-Japan Cooperation

A bilateral Indo-Japanese agreement on Science and Technology Co-operation was signed in November, 1985. This agreement provided for establishment of a Joint Committee on S&T Cooperation with a responsibility of deciding the policy issues, reviewing the progress of implementation and suggesting specific measures to enhance the cooperation under the agreement.

During the third Joint Committee meeting held in New Delhi in April 1991, about 65 topics of collaboration in general in various fields were considered for implementation by respective Indian institutions and concerned agencies involved. Under Meteorology, the following two projects were identified for further study: (1) Utilization of GMS and INSAT data for research in Asian Monsoon - for implementation of this project, 2 Indian scientists visited Japan in 1991, 1992 and one Japanese scientist visited India in 1994. (2) Development of Limited Area Model.

Research programmes were conducted to find out the regions of origin of disturbances leading to development of tropical cyclones and also to study the synoptic settings responsible for initial genesis in the Bay of Bengal. Time-Longitude sections of Equivalent Black Body Temperature (TBBs) of cloud tops as seen by Geostationary Meteorological Satellite (GMS) of Japan were prepared for every 2^0 Zone strip from 1^0N to 20^0N. Analysis of these data revealed eastward migration of large scale cloud systems called super clusters in the lower latitude up to 5^0N and westward migration of easterly wave kind of disturbances. A few of these synoptic scale disturbances are seen in turn to evolve into tropical cyclones.

Summary

International co-operation is becoming increasingly important in the context of global climate change and international research relating to issues concerning various developments. Global warming, climate change and sea level rise are the issues which need sustained co-operation between the member countries of WMO. Warnings of severe weather, seasonal prediction and warnings against dispersal of disastrous material in the atmosphere depend crucially on exchange of global data and mutual co-operation at the bilateral, regional and global level. IMD's role as the nodal agency in matters relating to atmospheric and geophysical sciences has been unique and pioneering. In the years to come, the trend will continue to grow in a more pro-active and positive sense.

CHAPTER 22

INTO THE NEXT MILLENNIUM

The India Meteorological Department was established in 1875. The science of Meteorology was in its infancy at that time, not only in India but also in other parts of the world. Meteorology developed initially as a result of its operational mandate which consists of making accurate weather forecasts over different time and space scales. In order to achieve this mandate, the India Meteorological Department and for that matter, any National Meteorological Service in the world have constantly striven to improve the infrastrucuture needed for (i) observing the weather (ii) communicating the information speedily and (iii) analysing the data and information and finally (iv) archiving the data for use in future. During the early 19th century, weather observations recorded were of little use in weather forecasting as the mode of communication was very slow. The invention of telegraphy, and later wireless communication, was responsible for a major breakthrough in this direction. With this system of communication, meteorological data from distant locations could be received at a central office for preparing weather maps and using them for forecasting weather. The same mode of communication was extremely useful in transmitting weather warnings and forecasts to the affected areas within a short time.

Till the early part of the 20th century, the meteorological observations were confined to the land surface and the sea surface through the ocean going vessels. As upper atmospheric observations became possible with sounding balloons, weather radars and meteorological rockets, the three-dimensional structure of the atmosphere was revealed and many interesting facts became known such as the jet streams which encircle the globe. Till about 1950, subjective and manual methods were adopted in weather forecasting. Although it was known from theoretical studies that the atmospheric problem can be represented through mathematical and physical equations, their solutions defied human endurance. Use of electronic computers in solving these mathematical equations was a major breakthrough which gave rise to the science of Numerical Weather Prediction.

Meteorology, being a global science, depends on the exchange of data from different parts of the globe. Weather systems developing over regions far away, travel slowly into the area of interest; thus it is necessary for us to have wider coverage of data. Meteorological satellites, satellite communication, computer data exchange and data analysis became areas of development of the second half of the 20th century. During the last two decades, the growth in meteorology has been stupendous. The interest of the National Meteorological Services is no longer confined to the day to day weather forecasting alone. Crucial areas of seasonal forecasting, climate prediction and multi-season forecasts are now being demanded by the users. There is also a demand for high resolution forecasts over very small areas such as river catchments or mega-cities. Therefore, one needs global scale models as well as high resolution meso-scale models to address these wide range of requirements.

In the past, the long series of data collected from the observational networks was archived to compute the normals and the climate of a place, country or a region was considered to be static. This is no longer so. The atmospheric engine which produces weather and climate has its forcings from various sources. Changes in the atmospheric trace gases, known as the green house gases, changes in the vegetation cover and even such other extra terrestrial factors tend to influence the variation of climatic scale. The next millennium has to grapple with the problems of climate change and global warming as a result of human induced increase in the green house gases. Meteorology is, therefore, linked with human activity which, in turn, is linked with the development of the country. The idea of a sustainable development gives rise to the need for monitoring earth and environment. Any degradation in the quality of air, water and the land surface around us is likely to affect the climate and make these developments unsustainable. The tasks before National Meteorological Services will change, though some of its core activities will continue to remain as the main focus of the theme of activity.

Weather services all over the world, except a few countries, are fully funded by the Government which, in turn, is answerable to the public for the type of services rendered by it. Private entrepreneurship in many areas of trade, commerce and socio-economic development is replacing the government initiative. In the field of meteorology, private service providers will compete with the government-run National Meteorological Services to provide service needed by the users. In many countries, the role of the government agencies is getting restricted to issuing forecasts or warnings alone, while specialised services for tourism, sports and recreation, health and hygiene, are provided by private consultants or private agencies; but the practice is not uniform the world over. There has been growing concern among the National Meteorological Services (NMSs) of the developing countries as well as some of the developed countries regarding the impact of commercialisation of their activities. The World Meteorological Organization (WMO) through its recent Congresses has addressed this issue keeping a balanced view. At the beginning of the new millennium, some of the key areas which IMD would have to address are :

1. To reduce the effect of natural disasters through improved forewarning of tropical cyclones, floods, droughts and other phenomena.
2. To improve observations and analysis of hydrometeorological data for monitoring water resources which is a prerequisite for sustainable development.
3. To conduct studies on the impact of weather and climate on crop growth and food production, so that the growing population of the country has adequate food security.
4. To study and monitor the constituents of the atmosphere like ozone and other trace gases. These observations have a direct bearing on the global warming.
5. To develop infrastructure and equipment to observe weather in inaccessible areas as well as ocean surface. These will be used as inputs in the weather prediction models.
6. To generate seasonal and multi-seasonal forecasts for advance resource management and planning.
7. To make detailed studies of the urban environment with special emphasis on air quality, human health and the impact of city climate and its vulnerability against adverse weather.

These are not the only areas, but they are indicative of the growing role of meteorological services to support the unique global operational system for collection, exchange and analysis of weather and other environmental information and use it for the welfare of humankind.

For IMD's services to remain relevant to national and international needs, a continuing upgradation in their scope and content is called for. This entails a strong component of research and development under each thrust area, both in-house and through cooperative efforts supported by IMD.

Our past encourages us, and the future beckons us to move forward with renewed dedication, confidence and hope.

125 YEARS OF SERVICE TO THE NATION

A RETROSPECTIVE AND FUTURISTIC OVERVIEW

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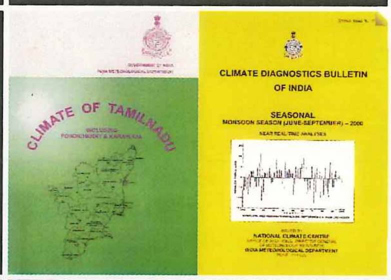

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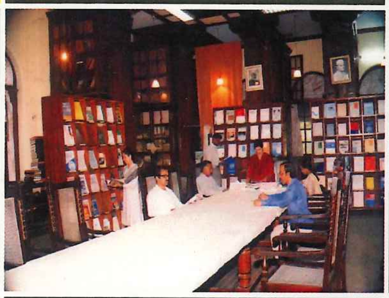

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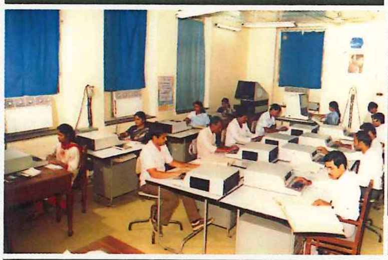

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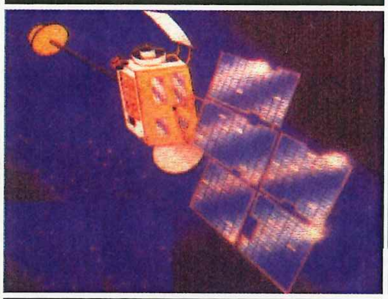

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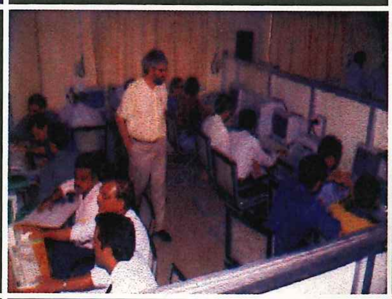

WMO/SAO ROVING SEMINAR
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