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Evolution of aviation meteorological services in India

AIR VICE MARSHAL (DR) AJIT TYAGI, R. SURESH*, R. K JENAMANI**, GAJENDRA KUMAR** and ANOOP KUMAR MISHRA**

174, Sector 28, Yamuna Enclave, Noida, (U.P.) 201303

**2/6, Alagirisamy Street, Vijaylakshmipuram, Ambattur, Chennai, Tamil Nadu 60053*

***India Meteorological Department, Ministry of Earth Sciences, New Delhi*

e mail : ngautam13@gmail.com

सार – विमान संचालन की सुरक्षा और परिचालन दक्षता में मौसम महत्वपूर्ण भूमिका निभाता है। 1913 की शुरुआत में भारत मौसम विज्ञान विभाग (IMD) ने विमानन का समर्थन करने के लिए उपरितन वायु का प्रेक्षण करना शुरू कर दिया था और पहला विमानन पूर्वानुमान 1921 में रॉयल एयर फोर्स (RAF) के लिए जारी किया गया था। जबकि शुरुआती वर्षों में विमानन मौसम विज्ञान सेवाओं का विकास मुख्य रूप से सैन्य विमानन द्वारा संचालित था, द्वितीय विश्व युद्ध के बाद वाणिज्यिक विमानन के तेजी से विकास ने भारत में विमानन मौसम विज्ञान सेवाओं को बढ़ावा दिया। आईएमडी ने अपने प्रेक्षण प्रणालियों, संचार और पूर्वानुमान को आधुनिक बनाकर विमानन क्षेत्र की बढ़ती मांगों के साथ तालमेल बनाए रखा। ऑन लाइन ब्रीफिंग सिस्टम (OLBS) कम लागत वाले वाहकों के लिए वरदान रहा है। आईएमडी के प्रतिनिधि कुशल अंतरराष्ट्रीय विमानन सेवाओं के लिए आईसीएओ कार्यवाही में सक्रिय रूप से योगदान दे रहे हैं। भविष्य की आवश्यकताओं को पूरा करने के लिए, आईएमडी प्रचंड विमानन खतरों के खिलाफ विश्वसनीय चेतावनी देने के लिए निर्णय समर्थन प्रणाली विकसित करने और मौसम संबंधी सूचना प्रबंधन (एमईटी)/वायु यातायात प्रबंधन (एटीएम) को लागू करने की प्रक्रिया में है। इससे सुरक्षा में योगदान मिलेगा और एयरलाइनों और हवाई अड्डों की परिचालन दक्षता बढ़ेगी। जलवायु परिवर्तन को देखते हुए, विमानन समुदाय और नीति निर्माताओं को हवाई अड्डे के प्रबंधन और विमान संचालन पर जलवायु परिवर्तन के प्रभाव को भी ध्यान में रखना चाहिए।

ABSTRACT. Weather plays a critical role in the safety and operational efficiency of aircraft operation. As early as 1913 India Meteorological Department (IMD) started taking upper air observation to support aviation and first aviation forecast was issued in 1921 for the Royal Air Force (RAF). While evolution of Aviation Meteorological services in early years was primarily driven by military aviation, it was post second World war rapid growth of commercial aviation gave boost to Aviation Meteorological services in India. IMD kept pace with growing demands of aviation sector by modernising its observing systems, communication and forecasting. The On Line Briefing System (OLBS) has been a boon to low cost carriers. IMD delegates have been actively contributing to ICAO proceedings for the efficient international aviation services. IMD is also working closely with Met Services of the Indian Air Force and Indian Navy to provide coordinated services at Joint User Airfields under UDAN scheme. To meet future requirements, IMD is in the process of developing Decision Support System and implementing Meteorological Information Management (MET)/Air Traffic Management (ATM) to give reliable warning against severe aviation hazards. This will contribute to safety and enhance operational efficiency of airlines and airports. In view of climate change, Aviation community and policy makers also need to take in to account the impact on climate change on airport management and aircraft operations.

Key words – Aviation weather hazards, Online briefing system (OLBS), Nowcasting, Runway visual range, UDAN, Air traffic management (ATM), Global air navigation plan (GNAP).

1. Introduction

The growth of meteorology in general and aviation meteorology in particular has been closely linked with growing demands of ever-expanding aviation sector. Meteorology and aviation have shown dependence right from early days of gliders to jet and supersonic aircraft of present age. Wright brothers made first successful flight on

17 December 1913. On the very first day after few initial flights a strong gust overturned the aircraft causing damage to it. This incident at the dawn of aviation demonstrated the importance of meteorological support for safe aircraft operations. While early developments of aviation were in response to demands of military aviation and airmail services, its growth in post 2nd World War period has been predominantly driven by phenomenal growth of commercial aviation. 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.

In spite of sophisticated on board and ground-based navigation and landing aids, basic requirement of meteorological information and weather forecast has not changed. Contrary to popular belief, modern aircraft require accurate weather observation and reliable forecast for safe air operations. For example, under Visual Flight Conditions (VFC) an error in the observation or forecast of few hundred meters of visibility will not make much of difference in landing decision. Whereas under Instrument Flight Conditions (IFC) at airfield equipped with Instrument Landing System (ILS Cat III) aircraft is permitted to land in visibility as low as 200 meters. On such an occasion observational error of a few meters can prove to be critical. From humble beginning in early twentieth century, Aviation Met Services provided by India Meteorological Services have evolved keeping in pace with growth in advancements in aviation sector (IMD 1976, De and Mazumdar 1997, Tyagi 2010, Suresh 2011).

2. Evolution of aviation meteorological services: early years

Ever since the first flight in India from Allahabad to Naini in 1911 was made successful, the need for current weather information and forecast was felt very much by the aviators. As weather has been proven to have a major influence on every phase of aircraft operations, the demand for reliable forecast started arising since then. To meet this requirement, *upper air wind observations* were commenced from Agra in 1913 and from Lahore in 1918. Based on these upper air observations, the first known aviation forecast was issued from Shimla in the year 1921 for the Royal Air Force (RAF) operations in Waziristan which was part of the then northwest India. Initially the aviation forecasts provided by India Meteorological Department were ad hoc in nature. Daily summary of upper wind was sent telegraphically during 1921-22 to the RAF HQ for deciding the aircraft operations and then to the regional military operations at Waziristan and Dardoni during 1923-24. The services rendered by India Meteorological Department (IMD) was well appreciated by the War Department, Washington, United States. Fig. 1 shows Amy Johnson (an English pilot) with Jason aircraft in Calcutta in 1930.

Fig. 1: Amy Johnson (an English Pilot) with Jason aircraft in Calcutta, 12 May 1930 (Picture source: Daily Mail, https://www.thisdayinaviation. com/tag/jason/)

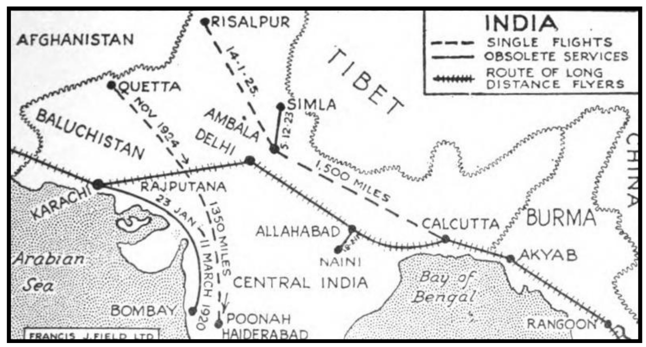


Fig. 2: Air Route of British India in 1925

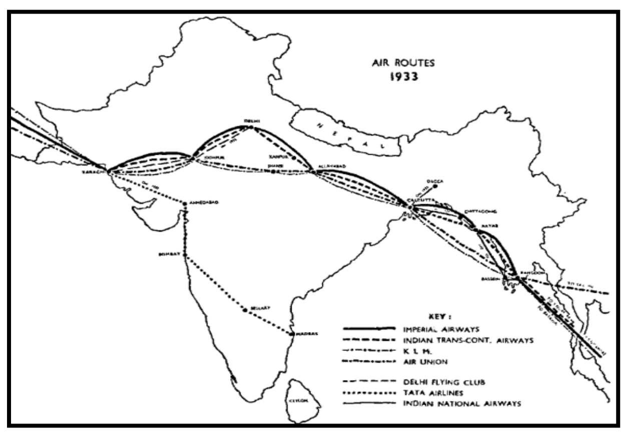


Fig. 3: Air Route in 1933 (picture source: The story of Indian Air transport by JRD Tata)

2.1. *Opening of specialized aviation forecast offices*

Forecasting offices at Peshawar and Quetta were opened during 1925 and at Karachi during December 1926. The responsibility of issuing weather forecast for a portion of Imperial route from England to India, *viz*., Basrah – Karachi was given to Karachi forecasting office. The first air mail service to India commenced during 1929 and Delhi and Karachi meteorological forecasting offices were empowered with the responsibility of issuing adverse weather warnings for the air mail service flights. Kolkata forecasting office catered to the aviation meteorological needs of Eastern India and Burma sectors. Flying boat service for the route Singapore – Kolkata commenced during 1929.

In April 1929, the air mail services from England to India was inaugurated up to Karachi which was later extended up to 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 aviation forecasting needs of Eastern India and Burma (Myanmar). During early 1930, the Tata and Sons' flights Karachi – Chennai and air taxi service between Chennai and Kolkata were catered to by Pune weather office. Wireless communication system for the quick dissemination of current weather information and forecast was set up during early 1930s.

2.2. *Aviation forecast offices during world war II*

During the World War II there was a phenomenal growth of military 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 air force 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. 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 forecasts winds and temperature at these heights. By the end of Second World War twenty-one IMD officers were serving RIAF. Among these were NM Philip, KR Saha, UR Acharya, KK Ramamurthy, TR Rao and Das Sarma. With the cessation of World War and withdrawal of Royal Air Force, the majority of IMD personnel reverted back to their parent department on demobilization

3. Post independence: rise of civil aviation era and subsequent progresses in aviation meteorological services

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. With the introduction of jet flights passing over India during 1952, a network of *radio-wind observatories* and *(thunder)storm detecting radar stations* were established by IMD to cater to the requirements of high-altitude flying jet aircrafts.

The first civil aviation 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 types of services for jet flights. As these aircrafts were flying at a very high altitudes the department expanded the network of radio wind h 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 India 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. Non-stop flights from India to destinations like Hongkong, Cairo *etc* were commenced thanks to the establishment of *extended chart analysis and prognostication centres* established at Mumbai and Kolkata by IMD which issued *chart form of documentation (CFD)* from 1st January 1964. As per ICAO recommendations, *Area Forecast Centre*s were opened at New Delhi, Tokyo, Cairo, Melbourne and Moscow during late 1960s to prepare and transmit the actual and prognostic charts.

In the 1970s, IMD as well as all domestic and international airports in India functioned directly under the Union Ministry of Tourism and Civil Aviation. This common administrative control had certain advantages for IMD in the sense that its presence at airports was taken for granted and resources and infrastructure were easily shared. In the 1990s, this situation slowly changed with the establishment of an autonomous Airports Authority of India and the transfer of IMD's administrative control to the Department of Science and Technology. Later on, IMD began raising bills for the expenditure incurred by it for providing services to AAI. The scenario altered further as the Indian aviation sector was opened to private airlines, some of the AAI airports were privatised, and IMD was transferred to the newly-formed Ministry of Earth Sciences.

Just as IMD as the national meteorological service has to follow certain global standards laid down by the World Meteorological Organization (WMO), all aeronautical entities in India, public and private, are also required to adhere to standards and recommended practices prescribed by the International Civil Aviation Organization (ICAO) from time to time. In India, the Director General of Civil Aviation (DGCA) acts as a watchdog to ensure that India's obligations to ICAO are fulfilled. IMD as the designated aeronautical meteorological service provider for international and domestic civil aviation in India, is required to function and fulfil its obligations in accordance with the regulations and procedures laid down by ICAO and the DGCA. Central Aviation Meteorological Division (CAMD) in DGM's Office, New Delhi was started in 2012. It has an overall responsibility in all matters pertaining to aviation meteorological services at civil airports in India. It oversees all the aviation related meteorological services provided by IMD to the users, ensures technical and quality control and provides guidance. It also maintains liaison with all concerned national and international entities in the aviation sector in India IMD also provides the support for Joint-Use Airports owned by the Department of Defence, at which both military and civilian aircraft make shared use of the airfield. The domestic aviation sector in India is now poised for a further leap forward, through what has been called the Regional Connectivity Scheme (RCS) or Ude Deshka Aam Nagrik (UDAN), which has been launched in April 2017.

The responsibility of IMD's offices situated at airports include the supply of current weather observations of their own station as also other stations as required, providing documentation for flights originating from their station, supply of forecasts and aerodrome warnings of different categories.

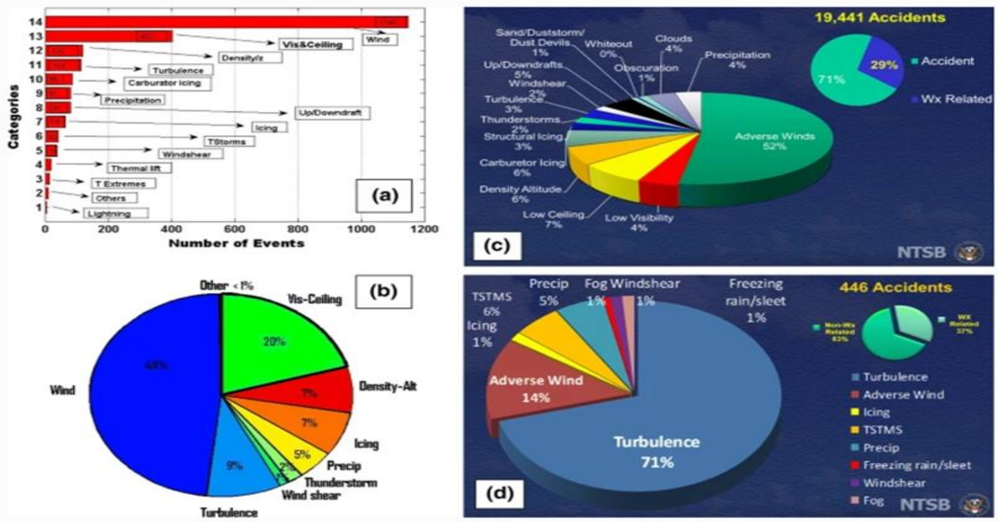
IMD has started providing the documentation through an On Line Briefing System (OLBS) which is a web-based facility for registered users like scheduled airline operators. It is also accessible to IMD's own airport offices.

3.1. *Establishment of state of art aviation equipment and Aerodrome stations/offices*

In order to meet the demands of growing aviation sectors, upgradation in aviation meteorological services in the form of advanced weather observing system was initiated by IMD *as early as 1960s.Transmissometer* to assess the runway visual range (RVR) was installed at Dum Dum airport in 1966. *Remote sensing instruments* were installed at runways during late 1960s and *Ceilometer* to estimate the height of the base of the low clouds during 1974 at Mumbai. *Dedicated teleprinter links* between Mumbai, Kolkata, Delhi and Chennai were established for quick exchange of aeronautical meteorological information and SIGMET warnings. As many as 19 aerodrome meteorological offices (AMO) to issue route and terminal forecasts for their own aerodromes as well as to the 57 attached aerodrome meteorological stations (AMS) were functioning during mid-1970s. As the current weather information and adverse weather warnings need to be disseminated through fastest mode of telecommunication system, *the teleprinter, telex and facsimile form of communication* were considered inadequate and hence *automatic message switching system (AMSS)* have been installed at Delhi, Mumbai, Kolkata and Chennai during mid-1980s. These systems have been used for meteorological data exchange, ROBEX [Regional OPMET (operational meteorological) Bulletin Exchange], SIGMET warning dissemination within and neighbouring FIRs. More sophisticated instrument such as Ceilometer (for the height of cloud base), 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 System (AMSS) were installed for speedy transmission and reception of meteorological data. Close Circuit Television (CCTV) display of METAR and SPECI at different points in the Airport was stated, which later paved way for a PC based display system in 1999. Modern equipments were installed in the airports for satellite data reception, communication and for the preparation of aerodrome meteorological summaries.

4. Post liberalisation era in aviation sector

With the Government's liberalisation and Globalisation policies, a sudden spurt in aviation activities were noticed during early 1990s with a number of private operators catering to the aviation services across the lengths and breadths of the country. Basically, these operators – some of them are known as low-cost carriers, made it possible for the common man to avail air traveloffering cheap air fare by cutting operational costs. These operators did not employ Flight DespatchersHaving recognised and understood the need for providing meteorological briefing services to the aircrews of low-cost civil air carriers, online aviation meteorological briefing system (OLBS) has been introduced w.e.f. 1st June 2007 after successful trial run from 22nd March 2006 from AMO, Chennai for flights originating from Chennai FIR. The OLBS has been extended to other FIRs subsequently during 2007 itself. Online meteorological briefing services for the short haul low level flights (up to 500 n.m and below FL100) have been introduced from AMO Chennai w.e.f. 15th March 2010 on trial basis with an ultimate view of extending this facility on operational basis throughout India.



a, **b** Statistics for aircraft related accidents related to meteorological parameters from 1994 to 2000: **a** actual numbers of accidents and **b** probabilistic distributions in pie chart (data from NTSB 2010; 1996). **c**, **d** Part 91-Weather as cause/factor during all accidents for the period of 2000–2011. The NTSB (National Transportation Safety Board) based statistics which resulted in 19,441 accidents and 29% of these accidents were related to weather conditions (**c**) (Eick 2014) and Part 121-air carrier weather related cause/factors for 2000–2011 (**d**)

Fig. 4 (a-d). Statistics of aircraft accident related to weather hazards from 1944 to 2000 (Gultepe *et al* (2019), Pure and Applied Geophysics)

4.1. *Integration of observations (airborne, insitu, and space borne) and advanced analytical tools for improved observations/forecasts of aviation weather hazards:*

Past studies have reported that weather severely impacts both civilian and defence aviation operations (*e.g.*, Cook *et al*. (2009), Rudra *et al*. (2015); Gultepe *et al*. 2014a, b, (2017a). The impact of atmospheric processes on aviation has been recognized since the 1900s. For example, Dines (1917) stated that "thus it appears that the demand of the airman on the meteorologist is that he shall be able to forecast wind and fog, and to less extent clouds, on the route, the airman is proposing to follow.".

Weather conditions that cause or contribute to the aviation accidents include wind, visibility/ceiling, high density altitude, turbulence, carburettor icing, updrafts/downdrafts, precipitation, icing, thunderstorms, wind shear, thermal lift, temperature (T) extremes, and lightning (NTSB 2010). Fig. 4a shows a bar plot of the statistics of weather-related conditions from 1994 to 2003 that affect near-surface aviation operations; they are mostly wind and visibility (NTSB 2010). In Fig. 4a, Vis, ceiling height (h_c), and precipitation related conditions occurred 485 times, wind and turbulence 1381 times, and icing and engine icing 150 times. This work suggested that from 2003 through 2007, there were 8657 aviation related accidents and weather was a factor in 1740 of these accidents. Fig. 4b shows these parameters in percentiles also for 1994-2003 period; wind and visibility are still the most critical parameters. For small, non-commercial aircraft (Part 91 class) the primary cause of weather-related accidents from 2000 to 2011 was adverse winds, followed by low ceilings (h_c) (Fig. 4c). At cruising levels of commercial jet aircraft (Part 121 class), this picture is different, with over 70% of weather-related accidents from 2000 to 2011 being related to turbulence (Fig. 4d) (e.g., Sharman and Lane 2016).

Jenamani and Ashok (2012) examined the impact of weather on Aircraft accidents over India. This study also made an extensive comparison of the aircraft accidents over India with global cases by reviewing past studies and statistics from National Transportation Safety Board (NTSB) and The Directorate General of Civil Aviation (DGCA). Study shows that out of total aircraft accident, weather related accidents are 21% in India compared to 22% in USA and 26-32% over the globe. This study also categorised the weather related aircraft accidents in India into multiple categories. 16% weather related aircraft accidents are attributed to winds from gust, updraft and downdraft whereas16% due to low visibility and ceiling while 12% due to Cumulonimbus (CB) and Thunderstorms. It was also reported that 40% weather related aircraft accidents were not related to any specific weather type. In USA, 48% weather related aircraft accidents are attributed to wind conditions followed by 20.5% due to low visibility and ceiling. Private Aircrafts including helicopters are more accident prone compared to bigger aircrafts during bad weather. Study shows that 56% weather related aircraft accidents happened to private aircrafts followed by 24 % in trainer aircrafts.

The way forward to improve overall safety against weather related accidents includes following:

(*i*) Observation techniques such as remote sensing instrumentation (Radar, Doppler weather radar, Wind profilers, satellite sounders and imagers, Lidars, lightning detectors *etc*):

(*ii*) Analysis capabilities such as numerical weather prediction models (NWP) through super computers

(*iii*) Method of in situ surface and upper air observations such as sophisticated electronic sensors for temperature, humidity measurements, laser ceilometers, transmissometers and

(*iv*) Air-borne weather detection and warning systems.

Major thrust in real time Fog forecast and warning system in India for civil aviation use started in 1998, when Met Office Palam started issuing fog outlook once a day at 1500 UTC daily in simple bulletin form for all users for time coordinated action. In 2003, the fog forecasting was increased to four times a day with 6 hourly updates and 12 hours outlook period. Such forecasts were made by traditional synoptic method till Dec 2006. IMD presently issuing airport wise fog warning at each 6-hourly intervals in winter period and these forecast are uploaded in IMD web page. It is presently operational at 12 airports which IGI Airport Delhi, Lucknow, Jaipur, Amritsar, Varanasi, Patna, Agartala, Bhubaneswar, Gaya, Bengaluru, Kolkata and Guwahati and regularly updated at each 6-houduring fog season covering months of Nov, Dec, covers Jan and Feb. New Techniques of Fog Detection, Monitoring and Nowcasting using RVR, current Weather, Synop, Upper air, Satellite (Kalpana, MODIS at IGIA New Delhi in 2012 (Jenamani and Tyagi, 2012). With current weather of all major airports and their fog forecast have been regularly updated and made available on-line, users take advantage of these fog information for proper flight planning to minimized impact aviation operation.

There has also been constant efforts to improve Thunderstorm, Heavy rainfall, Squall and Dust storm monitoring and Warning Systems at Airports over India. Present Monitoring System which are in use for their timely detection and further monitoring are:

(*i*) A meso-network of four number of AWOS and sixteen number of RVR at four Runways at IGIA New Delhi. It has winds at each second, RVR at 10-15 second data.

(*ii*) AWS and Synop network

(*iii*) DWRs in the region to help in the distance monitoring of TS/DS

(*iv*) Satellite based monitoring by INSAT 3-D at 30-minute gap for all 24X7 day and night cloud micro-physics tools in RGB and analysis by RAPID using five imaging channel TIR1, 2, MIR, WV and Visible at 1 km to 4 km resolution

The above developments made it possible for the Pilots to avert the hazardous icing, turbulence and wind shear areas, dangerous thunderstorm areas, cyclonic storms, volcanic ash cloud regions *etc*. and for the operations people to do proper flight planning, make diversion strategies, device optimal payload calculations *etc*. The economic benefits of meteorological information and forecasting services have been well recognized and documented the worldwide. It has been estimated and documented by the U. S weather bureau that advanced information and warning about the hazardous weather and accurate enroute forecast result in billions of US $ saving every year.

National Council of Applied Economic Research (NCAER) carried out a comprehensive study in 2013-14 to understand the perspectives of the main stakeholders on Aviation Meteorological Services. The major finding from the informed stakeholder’s field survey on qualitative aspects of provision of meteorological aviation services are that the weather forecast information provided by the IMD is quite useful to take quick and correct decision for flight planning as well as for flight safe landing and take-off. Also the weather forecast provided by IMD in severe weather condition are adequate.

5. Aviation meteorology: research and development

IMD Scientists have been carrying out scientific studies to improve prediction of weather elements affecting aviation. These include climatological, synoptic, thermodynamic, NWP and field studies of aviation hazards. Major research thrust have been on two prominent aviation hazards *i.e*. Thunderstorm and Poor visibility (Fog). Important The statistical knowledge of their time of occurrence is helpful to issue forecast and warnings. There have been many studies on climatological aspects of thunderstorms & squalls activity over different parts of India using synoptic and current weather data from airports and major Synoptic stations of India. Important among these are by Bhalotra (1954). Rao and Raman, 1961, Raman and Raghvan (1961), Mukherjee and Sen (1983), Tyagi (2009) Study to Duststorm over Northwest India was carried out by Joseph *et al*. in 1980 and of thunderstorm over Eastern India by Bandyopadhyay and Mohapatra (2022), over Delhi by Jenamani *et al*., 2009, Recently Satellite and RADAR data also have been extensively used to study their frequencies and characteristics like vertical extent associated hazards. *viz* low level wind shear (Suresh, 2009 and 2010). A coordinated field experiment SAARC SORM on severe thunderstorm observations and regional modeling over the South Asian Region" was conducted during 2009-2016 (Das *et al*., 2014).

New observation resources and forecasting techniques that have become available for operational thunderstorm forecasting in recent decades has led to significant improvement of the monitoring and prediction of thunderstorms. Currently, satellite data for Indian region is available from INSAT 3D and INSAT 3DR in real time for aviation forecasters at 15 minute interval. Additionally, a web based application RAPID (Real Time Analysis of Products and Information Dissemination) permits quick interactive visualisation and 4 Dimensional analysis by aviation forecaster. In view of the short lifetime and mesoscale nature of thunderstorms, real time observations from, ground based lightning detection networks of IITM and Indian Air Force, Doppler Weather Radars and Automatic Weather Stations have improved detection and Nowcasting of thunderstorms. Operational nowcasting of thunderstorms in IMD was started in 2103-2014 (Ray *et al*., 2015) Soma Sen Roy *et al*. (2019) have reviewed Nowcasting of convective weather over Indian region. Simpler nowcasting systems are based on radar echo tracking and extrapolation (Thunderstorm Identification, Tracking, Analysis and Nowcasting (TITAN), Storm Cell Identification and Tracking (SCIT)) to produce 0-2 hour usable nowcasts. WDSS-II (Warning Decision Support System- Integrated Information) suit of algorithms was used operationally for the Indian region (Sen Roy *et al*., 2014). SWIRL (Short-range Warning of Intense Rainstorms in Localised system) software (Li and Lai, 2004) is currently operational for the Indian region. With the increased availability of computing resources that permits finer resolution model runs and faster data assimilation such as Rapid Update Cycle (RUC), WRF and ARPS models have demonstrated significant improvement in the short range to nowcast scale of forecasting of thunderstorms (Srivastava *et al*., 2010).

Contrary to the general belief that wind shear iqs quite transient and short lived, cases of wind shear acting for more than 10 hours over Chennai airport were highlighted (Suresh, 2014). Wind shear for relatively longer duration over western ghat airports such as Thiruvanthapuram, Cochin, Calicut, Mangalore during active southwest monsoon conditions and also during winter were reported by Suresh

The occurrence of a very thick blanket of large-scale fog creates a typical weather situation that often severely impacts air traffic in. the Indo Gangetic Plains (IGP) region. The distinctive geographical structure, extensive irrigation system, extremely fertile agricultural land, land surface processes, urban expansion, and significant anthropogenic emissions in the IGP all contribute to an abundance of pollution supply as well as moisture feeding, which favours the long-term maintenance of hazy and foggy conditions over the IGP. Increasing trend in the frequency of fog occurrence over IGIA was reported by Jenamani, (2007, 2012a, 2012b, 2017) and Jenamani and Tyagi (2011 and 2012). It called for a field experiment to understand dynamical and physical processes involved in the formation, persistence and dissipation of the fog. A major thrust was given to the fog monitoring and forecasting systems by launching a field experiment (WiFEX) during winter of 2015-2016 by IITM-IMD-NCMRWF and funded by the MoES (Ghude *et al*., 2017), where additional multiple special equipment were deployed (Fig. 5) at Indira Gandhi International Airport (IGAI) New Delhi Since 2015-2016 was successfully conducted in every winter till 2022-2023. The objectives of the Winter Fog Experiment (WiFEX) over the Indo-Gangetic Plains of India have been to develop better now-casting and forecasting of winter fog on various time- and spatial scales. The physical and chemical characteristics of fog, meteorological factors responsible for its genesis, sustenance, intensity and dissipation are poorly understood. Improved understanding on the above aspects is required to develop reliable forecasting models and observational techniques for accurate prediction of the fog events. WiFEX completed 8 season of fog (2015-2023) and yielded fog data of about 425 days and 4300 hours of fog and 130 days with 550 hours of dense fog. WiFEX is now one of the largest special fog campaign data set where multiple monitoring systems were deployed to collect fog micro-physics data at temporal resolution ranging from few seconds to few hours. More details and related research are described by Pithani *et al*, 2018 and Ghude *et al*. (2023).

Experts from IMD also regularly participate in international Science Steering Committee (SSC) for ICAO-WMO's Aviation Research Demonstration Project (AvRDP) on MET-ATM Integration which was conducted under the Joint ICAO CAS/CAeM-WMOby HKO during

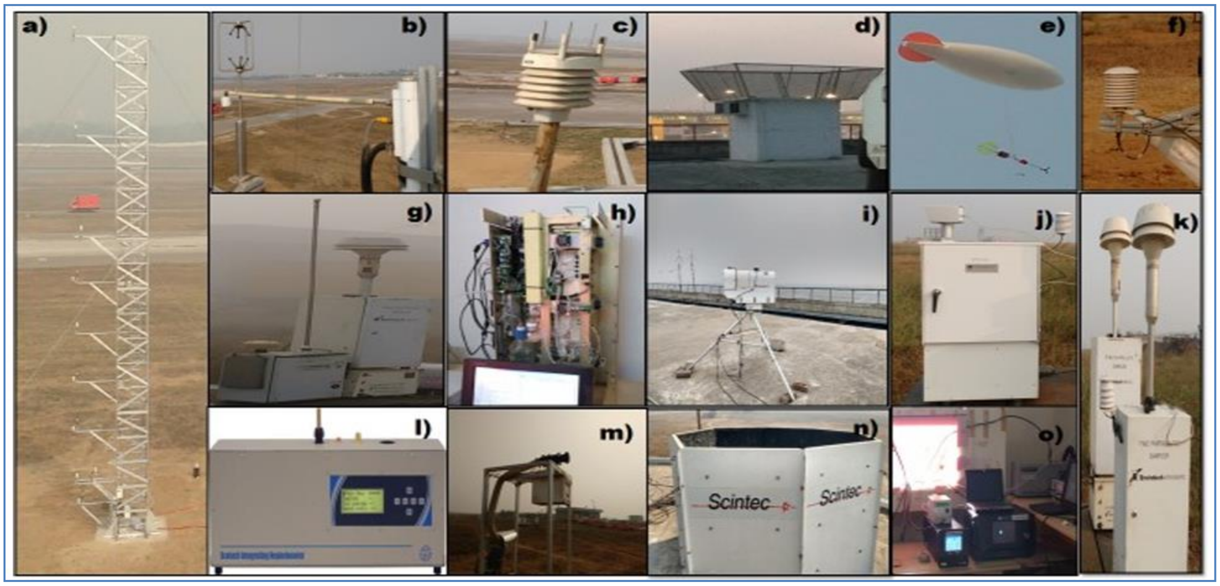


Fig. 5. Instruments deployed during winter fog field campaign at Indira Gandhi International Airport (IGIA), New Delhi: a, 20 m eddy covariance flux tower; b, Eddy covariance system; c, All-in-one weather sensor; d, Wind profiler; e, Tethered sonde balloon; f, Gill wind sensors; g, GRIMM; h, CCN counter; i, Microwave radiometer profiler; j, Fog collector; k, PM10 and PM2.5 samplers; l, Nephelometer; m, CDP with aspirator; n, SODAR; o, Aethelometer, NH4 analyser and MCPC.

2015-2019. IGI Airport was chosen among major airport in the world for inclusion in this project for demonstration of MET-ATM integration at real time in view of Delhi has been one of the most busiest airport in the Asia, with C-ATFM was also made operation since 2016 and it also regularly affected by severe weather like prolonged dense fog in winter and both severe thunderstorm and dust storms in Summer severely affecting flights operations. It was conducted and demonstrated for both dense fog days and severe thunderstorms using cases of 2018-2019 using all in-house NWP model products and state of the art observations which were operational by IMD at IGI Airport Delhi. Winds and RVR data from 18 RVR and 8 AWS and DWR products and WDSS-II nowcast at 10 min to 3-h gap and NWP products from WRF-GFS-NCUM-ECMWF based forecast for thunderstorms/dust storms and heavy rains in the period have been used for local storms under this project to demonstrate the MET capability. Similarly, a wide verities of fog products were used under this project *e.g.* time to time microphysics observations and both vertical moister, temperature and wind data from Radiometer and wind profiler *etc* were shared various fog nowcast/forecasts for dense fog dates as were with dynamical fog forecast system made operational and available under WiFEX at IGI Airport for successful MET-ATM demonstration (Jenamani and Ray, 2019). India also actively participated in the 1st Annual Aeronautical Meteorology Scientific Congress (ASMC-2017) organized by ICAO-WMO(for more- http://www.meteo.fr/cic/meetings/2017/aerometsci/docs/extended_abstracts/2017-11-10-0920.pdf)

6. Aeronautical climatological summaries of airports

The aviation industry in India has emerged as one of the fastest growing industries in the country during the last three years. India is currently considered the third largest domestic civil aviation market in the world. Same time meteorological information plays an essential role for all sectors of the Aviation industry - airlines, airports, air traffic control and management for taking correct and timely decisions that makes navigation safe, efficient and cost effective. Aircrafts fly in the atmosphere where most of the weather systems develop and decay. Information of important meteorological parameters related to the safety of aircraft such as atmospheric Pressure, Temperature, Wind direction and speed, Visibility, Runway Visual Range (RVR) and Cloud Height are needed for smooth operations of an aircraft from take-off to the landing phase. It is therefore very essential that climatology of an airport is available as a ready reckoner to understand mean number of occurrences (frequencies) of various weather elements in different temporal scales which affect aircraft operations round the clock. Aeronautical Climatological Summary (ACS) of an airport provides this vital information. ACSs for various National and International Airports are being prepared and updated at regular interval. ACSs are being prepared on the pattern of WMO Models and in accordance with the procedures laid down in Technical Regulations as per International Civil Aviation Organization (ICAO) standards. Till now, ACSs of 51 airports have been prepared for various aeronautical applications.

MONTH : DECEMBER **MODEL** : A

TABLE : Mean number of occurrences of Runway Visual Range or Visibility and/or the height of the base of lowest cloud layer covering more than 4/8 th of the sky (HS), below specified values and time.

Time (UTC)	Runway Visual Range OR Visibility / HS (metres)								TOTAL
	VIS <100	<200	<400	<800	<1500	<1500	<3000	<8000	
	HS		<30	<60	<90	<150	<300	<600	
00					1.6	1.2	21	5.2	29
01					3.4	0.6	22.6	2.4	29
02		0.2			4	1.4	21.8	1.8	29.2
03					2.4	0.6	22.8	3.4	29.2
04					0.6	0.2	21.2	7.2	29.2
05					0.2	0.2	16.2	12.6	29.2
06					0.2	0.2	12.8	16	29.2
07					0.4		10.4	18.4	29.2
08				0.2	0.2		10.6	18.2	29.2
09							9.2	20	29.2
10					0.2		9.4	19.6	29.2
11					0.2		10.2	18.8	29.2
12					0.2		13.2	15.8	29.2
13					0.2	0.2	16.8	12	29.2
14					0.4	0.2	19.2	9.4	29.2
15					0.4	0.6	20.2	8	29.2
16					1.4		22	5.8	29.2
17					1.4	0.2	22.4	5.2	29.2
18					2	0.8	22.2	4.2	29.2
19					2.6	0.4	22	4.2	29.2
20					2.2	0.6	22.4	4	29.2
21					2	0.4	22.8	4	29.2
22					1.6	1.4	20.6	5.6	29.2
23					1.4	0.8	21.8	5	29
TOTAL		0.2		0.2	29.2	10	433.8	226.8	700.2

Fig. 6: Example of climatological summary of RVR (December) of Mumbai airport

7. International cooperation

The International Civil Aviation Organization (ICAO) is a specialized agency of the United Nations that coordinates the principles and techniques of international air navigation, and fosters the planning and development of international air transport to ensure safe and orderly growth.

In dealing with international civil aviation on a world-wide scale, there are many subjects which ICAO has to consider on a regional basis. The Organization has set up seven geographical regions, both to facilitate detailed planning and to cater to different types of flying operations. The seven regions are (*i*) Bangkok: Asia and Pacific (APAC) Office (*ii*) Cairo: Middle East (MID) Office (*iii*) Dakar: Western and Central African (WACAF) Office (*iv*) Lima: South American (SAM) Office (*v*) Mexico: North American, Central American and Caribbean (NACC) Office (*vi*) Nairobi: Eastern and Southern African (ESAF) Office (*vii*) Paris: European and North Atlantic (EUR/NAT) Office. India is located in Asia and Pacific (APAC) region and takes part in the Regional Air Navigation meetings

India has been contributing significantly in ICAO meetings for the safe and cost-effective aviation services to be provided by Member States in Asia pacific (APAC) and taken up cases pertaining to maintenance of service at appropriate level and get the loose ends fixed. India has presented working papers, status papers and Information papers under multiple agenda items of various meetings and contributed significantly for the effective and efficient international aviation services. India contributes significantly in revising the various handbook, annexures and reports of various MET subgroups, ad hoc and steering sub groups of ICAO, APAC and Asia Pacific Air Navigation, Planning and Implementation Regional Group (APANPIRG).

The Online Aviation Meteorological Briefing System (OLBS) introduced by IMD from 1 June 2007 with more than 2200 users throughout the world was presented in the 1th meeting of CNS/MET held at Jakarta, Indonesia during 19-22 July 2010. Based on recommendations of IMD in the meeting, WAFS has introduced wind/temperature prognostic charts at additional levels. IMD also took up the case of non-availability of required crucial operational meteorological (OPMET) data which paved way for the update of Regional OPMET Bulletin Exchange (ROBEX) guide. Recognizing the work done in India on low level wind shear (LLWS), Dr Suresh was invited by IACO Asia Pacific (APAC), Bangkok in December 2010 as a trainer to cover topics on low level LLWS.

One ICAO designated Tropical Cyclone Advisory Centre (TCAC) is also functioning at New Delhi. It is this center's responsibility to monitor the development of tropical cyclones in its area of responsibility, using geostationary and polar-orbiting satellite data, radar data and other meteorological information and provide advisory information on tropical cyclones to the Meteorological Watch Offices in India and neighbouring countries. IMD presented an important paper on Development of reconstructed Radar reflectivity for convective storm monitoring over India in the 27th meeting of the ASIA/PACIFIC Meteorology Sub-group (MET SG/27) during September 04-08, 2023.

8. Support to military aviation meteorological services

Military aviation has played important role in the evolution of Meteorological services in India. The first known aviation forecasts were issued in 1921 from Shimla 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 observations were established at Agra and at Lahore in 1917 and 1918 The India Meteorological Department opened forecasting offices at Peshawar and Quetta in 1925 to support RAF operations. Interaction between the British scientists like Tizard and Watson Watt, UK's Meteorological (Met) Office staff and Fighter squadrons of RAF and Royal Indian Air Force (RIAF) located in North West Frontier Province that brought the Science of Met into the focus of aviation services in India. During the Second World War (1939-45), military air operations witnessed phenomenal growth. The Delhi forecasting office was revived in and a special air force meteorological office was opened at Lahore in 1941. A principal forecasting centre started functioning at Bangalore in 1942 attached to the RAF Group Headquarters. By 1944. 27 forecasting centres were operating. These were manned by IMD staff working for the RAF and RIAF. During the Second World War, IMD was asked to provide specialized meteorological services to the Royal Air Force and so in 1944, the headquarters of IMD were shifted to New Delhi into its building on Lodi Road named as 'Aerological Office'. With the cessation of the World War II and withdrawal of the RAF, the majority of IMD personnel reverted back to their parent department

After independence, number of Air Force airfields and Air Force operations increased manifold. During fifties and sixties IMD assisted Air Force Met by providing manpower, training, equipment and data, Scheme of Short Service Commission (SSC) was revived once again to man Air Force Met Sections. In this process, 13 officers in 2 batches were inducted and commissioned after as hort course of General Service Trainingduring1952-53 and. 1958-59. Of these, Air Commodore P. A. Menon, Air Vice Marshal S. Lakshminarayanan and Air Vice Marshal R. K. Mathur rose to head the IAF Met Branch. After 1962 Indo-Chinese War, 22 IMD officers were inducted under Air Defence Reserve scheme. All of them came back to IMD after completing their tenure.

Though the formal Indian Air Force Met branch came in to being in the year 1957, the Air Force was still dependent on the IMD for meteorological training of the Officers till 1967. Over a period of time working closely with the IMD, Air Force Met has modernized it observation and forecasting capabilities. IAF witnessed quantum jump in the hierarchy of Met equipment with the induction of systems like Microwave Radiometer (MWR), Network of Lightning Detection System (LDS), GPS based Upper Air Sounding System (UASS), Doppler Weather Radars and High Resolution Picture Transmission (HRPT). Air Force Met upgraded its forecasting capability by establishing Air force Centre for Numerical Weather Prediction (AFCNWP).

The Met component of the Navy came into being with the induction of the Air Arm in 1951. The meteorological services in Indian Navy formally commenced in 1953 with the commissioning of the first Naval Air Station – INS Garuda at Kochi. With the passage of time, a separate Meteorological Training Section (MTS) was established within INS Garuda to meet the meteorological training needs of the Indian Navy. It was upgraded and rechristened as the 'School of Naval Oceanology and Meteorology (SNOM) in 1985.

IN's charter to safeguard oceans of this country doesn't only limit to its afloat assets, but also to its airborne assets. Indian Navy (IN) aviation has been catering to varied operations and IN Meteorological services has been Hand in Gloves to it. For every aviation sortie, weather plays a dominant and crucial role and this requirement of weather monitoring from varied locations across IN coastline, catered to the formation of many Naval Air stations. INS Hansa and INS Dega are premiere Naval Air stations on the Western and Eastern seaboard respectively, as they are home to varied air operations. Stretching from Porbandar in North-West to Campbell Bay in Andaman and Nicobar Islands, IN Meteorological set up comprising of surface observatories and modern equipment; and sensors have been keeping vigil over the respective areas round the clock and sharing observations with the IMD.

Under the UDAN scheme of the Government of India, many airfields and Advance Landing Grounds (ALGs) have been transformed into Joint User Airfields (JUAs) for inclusion of regular civil flight operations, thereby posing greater challenges of the Meteorological requirements with multiple platform operating from the same aerodrome. To cater to the requirements of JUAs, AFCNWP provides uninterrupted weather information such as METAR and TAFOR of all existing JUAs with IMD through Data Diode on a dedicated 100 mbps channel for real-time weather information to civil aviators.

Proliferation of Doppler Weather Radar (DWR) coverage primarily by IMD, complemented by IAF's own DWRs and Lightning Detection System significantly enhanced the sensor based weather monitoring network across the country. Integration of these inputs with satellite imageries and 24X7 observations from more than 50 IAF airfields and nine Indian Navy airfields have augmented National Aviation Meteorological Observation Network benefiting both civil and military aviation in the country.

9. User interaction

IMD interacts with its users on various levels. The most common way is through the aviation met offices for the immediate redressal of issues related to met information. Quarterly Regional Operators Committee (ROC) meetings are held regularly by all the stake holders of aviation industry, of which IMD is also a member. Issues related to meteorological services are also discussed at these meetings for the timely and effective disposal, especially when the involvement of many agencies are necessary. Users' Interactive workshop on Fog monitoring, Forecasting and Dissemination System" was organised at Airport Met Office Palam on 4th December 2009. Fifty participants from DIAL, Airlines, IAF, India Railways participated in the workshop. Another example of the interaction of IMD with its users is the workshop on 'Meteorological Support for Helicopter Operations' which was organised on 12th September 2014 at ONGC helibase, Juhu Airport, Mumbai. This workshop was based on the request from the helicopter operators and was aimed at keeping the operators updated about IMD's meteorological products and tools in support of helicopter operations, and can be considered as a last mile connectivity for the users of IMD's services. The response from the helicopter operators was overwhelming and more such workshops were organized in subsequent years.

National Council of Applied Economic Research (NCAER) carried out a comprehensive study in 2013-14 to understand the perspectives of the main stakeholders on Aviation Meteorological Services, Sea Water Desalination, Ornamental Fish Culture and Lobster and Crab Fattening: Economic Benefits, Project Impact Analyses and Technology Policy. The major finding from the informed stakeholder's field survey on qualitative aspects of provision of meteorological aviation services are that the weather forecast information provided by the IMD is quite useful to take quick and correct decision for flight planning as well as for flight safe landing and take-off. Also the weather forecast provided by IMD in severe weather condition are adequate.

Union Minister of Finance and Corporate Affairs Shri Arun Jaitley felicitated the DGM of IMD Dr. L. S. Rathore (Fig. 7) in 2016 for providing needful Meteorological Infrastructure and for efficient Aviation Meteorological Services at IGI airport.

9.1. *International participation & capacity building*

In October 1947, International Civil Aviation Organization (ICAO) became the specialized agency of the United Nations (UN). It has its Head Quarters at Montreal, Canada. Non- governmental organizations which also participate in ICAO's work include the International Air Transport Association (IATA), the Airports Council International, the International Federation of Air Line Pilot's Associations, and the International Council of Aircraft Owner and Pilot Associations. Representatives of IMD participated in various meetings, workshops organized by ICAO on the matter of aviation meteorology during 1950 to 2010.

A special training course was conducted at Pune for seven personnel from Bhutan Aviation Met. Services of the Civil Aviation Department of Bhutan during the period from 15th October 2012 to 11th January, 2013. Experts from IMD delivered talks related to various aspect of aviation meteorology and OJT was conducted for the participants.

Fig. 7. Union Minister of Finance and Corporate Affairs Shri Arun Jaitley felicitating the DGM of IMD Dr. L. S. Rathore

Shri M. K. Bhatnagar, Scientist "E" & Director Aviation Services from IMD attended the 14th session of WMO Commission for Aeronautical Meteorology (CAeM) held in Hong Kong, China during 03-07, February 2010 During this period he visited and interacted with the officers from the Hong Kong Observatory and Hong Kong airport Meteorological office

Mr. Abdul Qadeer Qadir, President of Afghanistan Meteorological Authority & PR of Afghanistan with WMO and Mr. Luc A. ChangKo, Senior Meteorology Expert, ICAO TC Project, UNDP Office, Kabul visited IMD, New Delhi for two days during 14-15, July 2009 for familiarization with Aviation meteorology and facilities at I.G.I Airport New Delhi and to discuss bilateral cooperation program.

Dr. S. N. Roy, DDGM, RMC Kolkata and Dr. R. K. Jenamani, Scientist 'E' visited Sri Lanka and participated in two days SAARC Seminar in Colombo, organized by SMRC, Bangladesh, Dhaka and Department of Meteorology, Government of Sri Lanka on "Application of Meteorology in Mitigating Aviation hazards" during 14-15 June 2010.

The annual WMO/UK Met Office Aviation Seminar was hosted by the India Meteorological Department (IMD) in New Delhi, India, from November 13-17 2017. The aim of the seminar was to provide training, guidance and practical examples of several key aspects of meteorology and forecasting for Aviation, to support forecasters in this specialized area. Topics including impact of thunderstorms on aviation, observing and forecasting thunderstorms, supercells and MCSs, Competency assessments, fog, dust, sand storms, Volcanic Ash, SIGMET Exercise, Tropical Cyclones, Icing, SIGMET Templates *etc* were covered in the seminar. 30 participants attended the seminar.

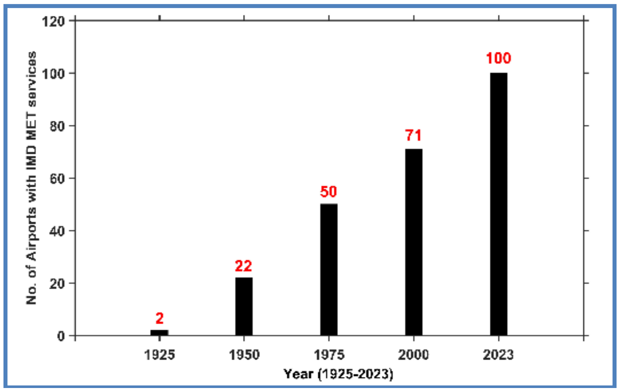


Fig. 8. Growth of IMD Aviation MET Services

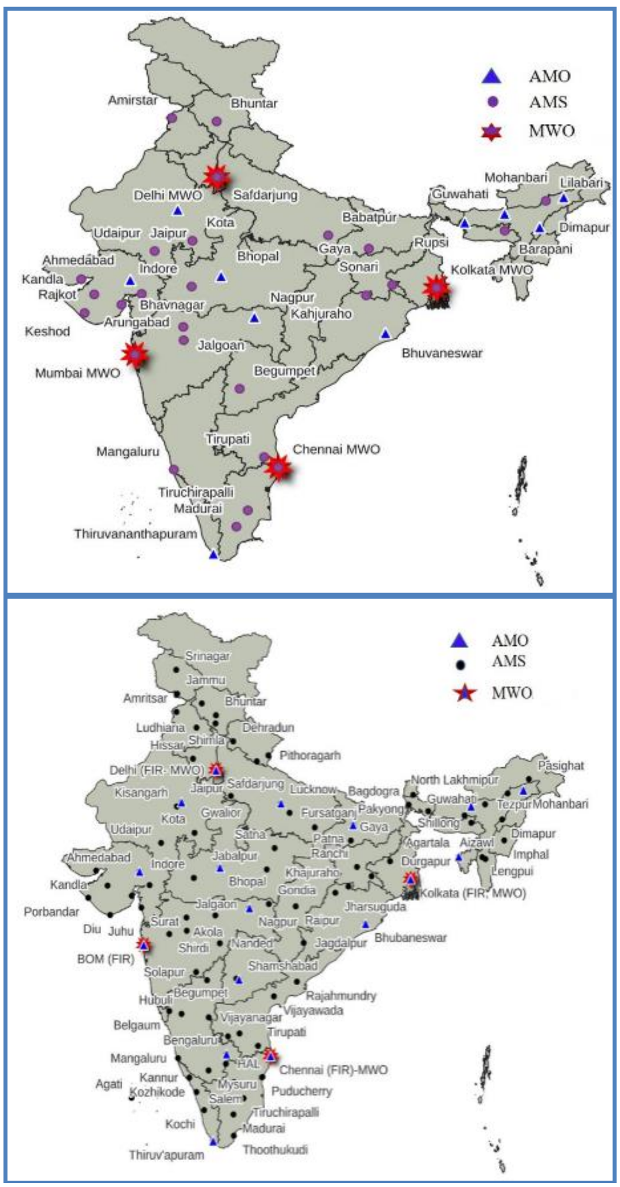


Fig. 9. Number of stations where IMD is providing met services before 1975 and as on date in 2023

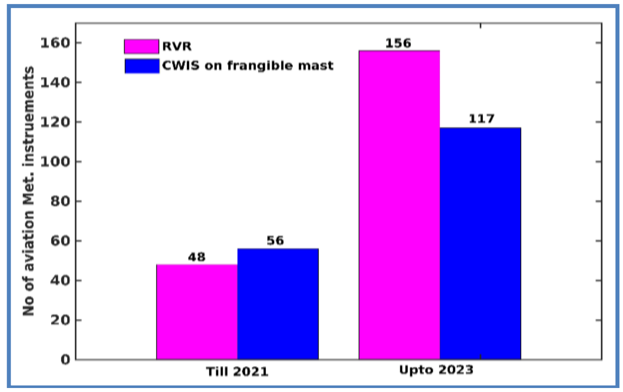


Fig. 10. Progress in the installation of aviation met instruments in recent years.

10. Recent developments and future scenario

At present, IMD is providing aviation MET services at 100 airports through 4 Meteorological Watch Offices (MWO), functioning at New Delhi, Mumbai, Chennai and Kolkata, 18 Aerodrome Meteorological offices (AMO) and about 82 Aeronautical Meteorological Stations (AMS). Starting with just two in 1925, the number of airports increased to 22 in 1950, 50 in 1975, 71 in 1999 and 100 in 2023 (Figs. 8 & 9).

In recent years, the aviation sector in India has emerged as one of the fastest growing industries in the country and has witnessed rapid growth both in terms of density of air traffic and number of airports. As per report of the International Air Transport Association (IATA) (2018 REPORT, Importance of air transport to India) air transport market in India is forecast under the “current trends” scenario to grow by 262% in the next 20 years. This would result in an additional 370.3 million passenger journeys by 2037. If met, this increased demand would support approximately US $126.7 billion of GDP and almost 9.1 million jobs. In 2017, more than 158 million passengers flew on routes to, from and within India. This represents an increase of almost 15% over 2016 and is the third consecutive year of growth in the order of 15-20% per year.

Indeed, utilising data from the World Bank and ICAO, which measures the number of passengers carried by airlines based in the particular country, we can see the growth of the Indian market in a longer-term perspective. From flying just 16 million passengers 20 years ago, Indian airlines have seen their passenger volumes increase more than 8-fold in the period since. Along the way, India has overtaken a host of countries, including Germany and Japan, in the process.

Recently, aviation services in India have been significantly upgraded with the installation of 108 forward.

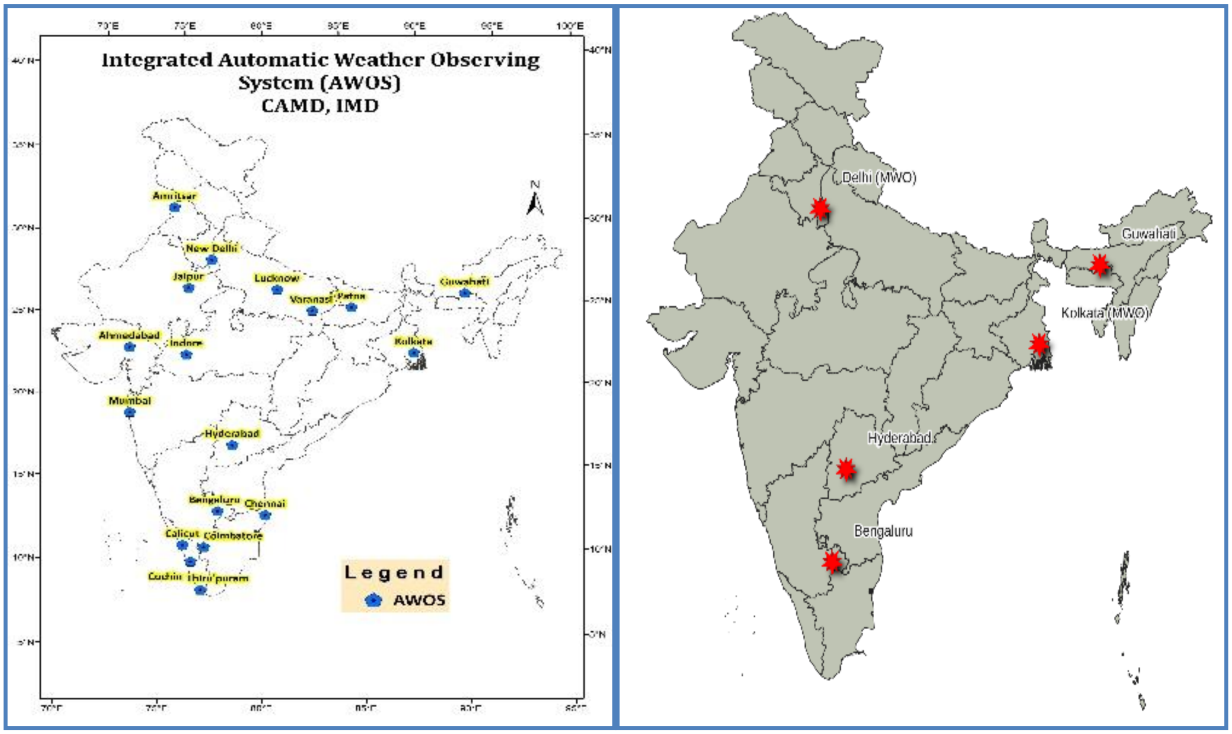


Fig.11. Proposed location of airports where installation of AWOS (18 airports) Ground based Microwave Radiometer (5 sites)

scatterometer type RVR systems during 2021 to 2023. This has revolutionized the aviation meteorological services especially over fog prone airports in India. Network of RVR systems increased from 48 to 156IMD has upgraded airport meteorological instruments through installation of Digital Current Weather Instrument Systems (DCWIS) on frangible masts for real time monitoring of temperature, atmospheric pressure, wind speed and direction using various sensors. Installation of DCWIS on frangible masts completed at 117 airports in India. Installation of a few more systems on frangible masts are planned in near future (Fig. 10)

Based on recommendation of Expert Committee constituted by MoES under chairmanship of Dr. Ajit Tyagi Former DGM, IMD has commenced the process of installation of integrated Automatic Weather Observing System (AWOS) at 18 airports where the weekly flights are over 500. The integrated AWOS will consists of multiple components including Aviation Meteorological Sensors (AMS), Central Data Processing and Integration System (CDPI), Data Acquisition System (DAS), Data and Product Archival System (DAPS), Communication Systems (CS). Multiple workstations and display systems aids in generation and dissemination of meteorological observations and reports. Distribution of AWOS over India is shown in Fig. 11. IMD has started the process of the procurement and installation of 7 wind profilers/Doppler LIDARS and 5 microwave radiometers. The integrated observations from proposed wind profilers, microwave radiometers and existing radiosonde data will be very crucial for the identification and forecast of the turbulence. This will further enhance the aviation weather monitoring capability and provide a boost to aviation sector in India.

IMD adopted radar technology for meteorological applications in the early 1950s.

Fig. 12. Inauguration of Weather Radar by Shri Jawahar Lal Nehru, First Prime Minister of India

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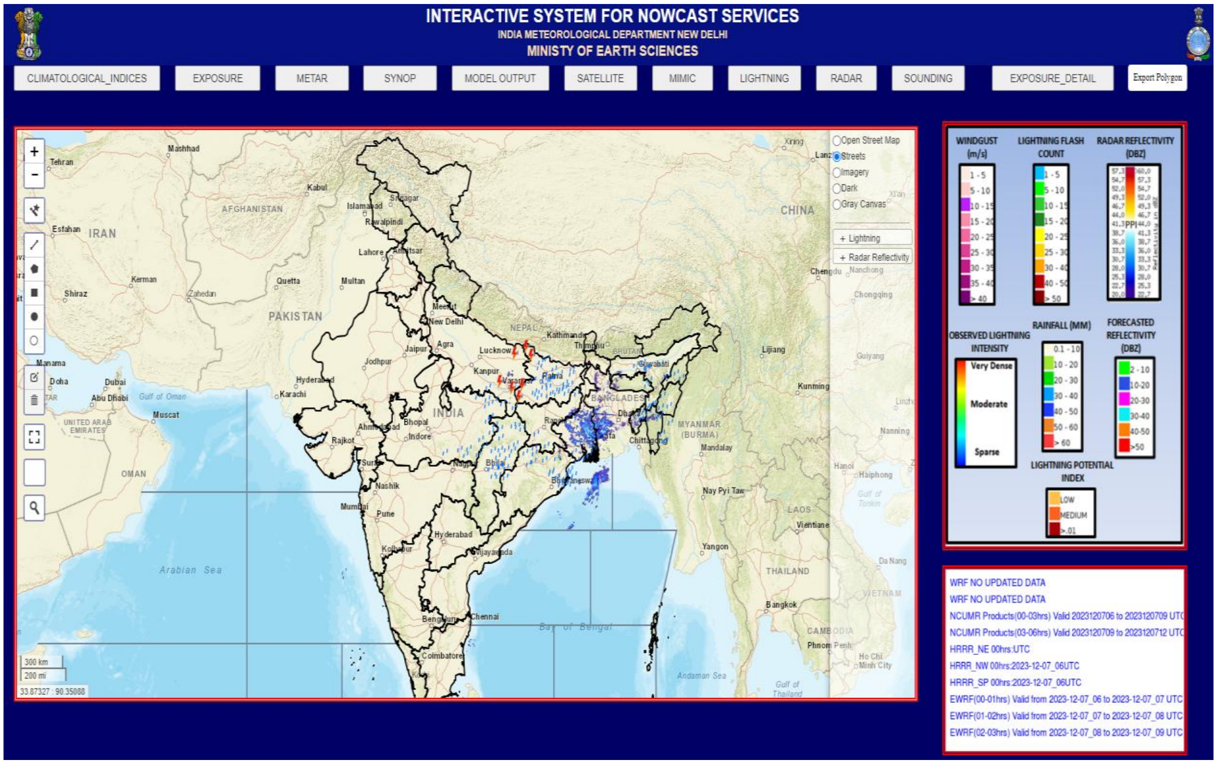

Fig. 13: Aviation Decision Support System at India Meteorological Department

Weather Radar at Safdarjung airport, New Delhi was inaugurated in 1958 by Shri Jawahar Lal Nehru, First Prime Minister of India (Fig 12). The first S-band radar was installed at Visakhapatnam in 1970, followed by at Kolkata, Chennai and Paradip in 1973, Mumbai in 1975, Goa in 1979, Karaikal in 1980,Machilipatnam in 1982, Bhuj in 1987 and Kochi in 2007. The first indigenously designed and developed X-band storm detection radar was installed in 1970 in Delhi and first indigenous S-band Cyclone Detection radar was commissioned in Mumbai in 1975. One indigenous DWR developed by ISRO was installed at Sriharikota in 2004.

Advent of Doppler Weather Radars (DWR) have revolutionized the weather forecasting and now casting. Observations from DWRs aid to improved aviation observations/forecasts/nowcast of aviation hazards. At present IMD has 39 DWRs (working in X, C and S band) installed across India. By 2025, IMD has planned to operate 70 DWRs across India.

Online Briefing System (OLBS), a web based pre-flight information briefing systems, has been implemented for flights originating from FIRs in India. OLBS is being maintained by the AMOs functioning at Chennai and New Delhi. Through this system an authorized stake holder can avail meteorological briefing and download all required documents for flight planning

10.1. *Decision support system and recent advancement for improved forecasts*

Combining the observed meteorological data of crucial meteorological parameters from runway, products from Doppler weather radars, data obtained through satellite imagers and sounders with the NWP model outputs and developing a decision support system and synergizing all the information for improved forecasts and to give a reliable warning against severe aviation hazards have been planned and is being introduced at Delhi. A screenshot of the decision support system is illustrated in Fig. 13.

It is proposed to introduce a chart form of documentation (CFD) for low level flights through OLBS. NWP model based forecast charts having validity 6, 12, 18 and 24 hours from the observation timings for the flight levels (FL) 010, 020, 030, 040 and 060 are being tested. These charts are similar to the wind /temperature forecast charts provided for international air navigation by the World Area Forecast Centres (WAFC) located at London and Washington for flight levels, FL050, 100,140, 185, 230, 300, 340, 390, FL450 and FL530. It is hoped that the low-level flight operators will have the CFD before the end of 2010.

The icing information provided in the domestic significant weather charts issued by IMD has been appreciated and well acknowledged by the Pilots, especially the foreign Pilots flying in Indian FIRs. The introduction of OLBS and the contemplated introduction of OLBS for low level flights (below FL070 specifically) have been acknowledged not only by the Pilots but also by the Operational group as these save time and give much more additional information than that could have been obtained through personal / oral briefing in the limited time period when they visit the local meteorological office. Traditionally IMD has always been understanding the needs of the aviators and meet their requirements and at times provide vital information much more than the user expected to have.

The feedback from the user community, especially from the flight crews, is very much needed to improve our services specifically in the areas of low-level wind shear (LLWS) and turbulence observation and reporting. It may not be out of place to mention here that as per provisions of ICAO Annex 3 (Chapter 5, paras 5.5 and 5.6,; Appendix 4, paras 2.6 and 4.1), the information on LLWS observation and reporting and clear air turbulence (CAT) based on aircraft measured eddy dissipation rate (EDR) and conversion into turbulence index (TI) shall be reported by the Pilots [Quote: "*icing, turbulence, and to a large extent wind shear are elements which for the time being cannot be satisfactorily observed from the ground and for which in most cases aircraft observations represent the only available evidence"*].This information will be vital for validating the algorithms used for warning the air crews against LLWS and /or for devising new warning strategies on LLWS / CAT or to validate the NWP products. These points have been discussed in-depth at various forums such as Regional Operations Committee (ROC) meetings *etc* in Chennai with a request to pass on in-flight / post flight reports so that a good data base can be generated to devise a suitable wind shear alert / warning strategy exploiting the data likely to be obtained from Doppler weather radars being introduced by IMD in major cities.

It is hoped that user interactions on de-briefing about the weather forecast provided to the air crews and timely dissemination of aircraft observations and in-flight reports to the Meteorological office through ATC or as de-briefing report, as per procedures laid out by ICAO, will enhance the services being provided by IMD and ultimately beneficial to the airlines for the safe, economic, effective and efficient conduct of flights.

11. Way forward: integration of met with c-atfm (central air traffic flow management), ganp upgradation and impact of climate change on aviation operations

Globally, major airports have been using real time information on aviation weather hazards and their early warning for air traffic management (ATM) in terms of their occurrences over the airports or along the routes. In state of art aviation met services, NWP based aviation weather products combined with DWR and Satellite products play key role in MET-C-ATFM *i.e*. integration of Met data and forecasts with central air traffic flow management, a new need for delivering customized impact based aviation forecast and warnings both for airports and air routes and to declare airport capacity in a given weather scenario. At IGIA New Delhi fog information is being provided as part of the C-ATFM operational at IGI Airport since 2019. However, a real time information about all aviation hazards needs to be provided by all MWOs. For this MWOs to be equipped with computer and communication facilities and NWP model expertise to generate aviation weather products at the regional and local scale and need automation and DSS using all products at one domain.

The Global Air Navigation Plan (GANP) is a mean to help achieve a global interoperable air navigation system for all users for all phases of flight, which meets agreed safety levels, provides optimum economic operations, is environmentally sustainable and meets national security requirements. Its objective is to increase capacity and improve efficiency of the global civil aviation system whilst improving or at least maintaining safety. Long-term vision of GANP is to ensure continuity and harmonization with ICAO, States and industry modernization programs.

The other major focus is to find the role of long term Climate Change on aviation operations especially routine air-routes of various upper flight levels covering major national and international flight routes both for short and long haul non-stop flights and also airport localized extreme weather including flash floods" those raised from due to global warnings and numerous studies have already been conducted by various major centres across globe for various regions. In the 1st Aeronautical meteorological Science conference - AMSC-2017 organized by World Meteorological Organization in coordination with ICAO http://www.meteo.fr/cic/ meetings/2017/aerometsci / held at France where a total 270 scientists/engineers/pilots and head of airlines like Cathay Pacific, SIA, *etc* have participated. There were presentations from aviation technical engineers and aircraft manufactures *e.g.* Boeing and Airbus and issues *e.g* how bigger flights with large body aircraft accommodate more passengers in coming era, means more sensitive to weather and higher winds-turbulence likely and issues for future plans. All such teams working in coordination with other world's renowned center like NCAR, UCAR, NOAA, NCEP, UKMO, WAFC to study and find role of climate change on trans-Atlantic or Trans-Pacific jet winds and severe convection activities projections as expected rom more warmer summer and winter which are likely to have great impact on net flight duration. Studies shows upto 30 minutes gain/loss say from London to New York. Flight Trajectory based on wind and severe weather guidance to flights with new planned routes also demonstrated how airlines saves millions of dollar else would be losses amounting to high fuel consumption if would have followed normal routes. Also, due to increasing extremely heavy rainfall events with shorter period very intense rain spells over India from warming environment due to global warming, Airports are reporting more frequent flash floods with some cases are cases, severely impacting aircraft landing/take off at RWY due to flooding resulting airport closures, also affecting aircraft parking and also passengers safe movement at airport terminals and roads (*e.g*. Delhi airport approach roads and terminal severe flood 2011, 2013, 2021, Chennai airport and RWY severe flooding 2015, Kolkata airport flooding 2021, Ahmedabad airport flooding 2023, *etc*, reference available in google search). Besides such increasing incidents of heavy rainfall frequency/flash flooding raised from issue of climate change there are also studies showing sea level rise, increasing trend of severe convective activities/turbulence events at some areas of globe and also changes was noted in the upper level wind pattern/speed at some levels as discussed at some pockets/region say for trans-Atlantic and Pacific which have been due to global warming and climate change scenario. It is also to be noted that emissions from aviation are a significant contributor to climate change. Aeroplanes burn fossil fuel releases CO2 but also has strong warming non-CO2 effects due to nitrogen oxides, vapour trails and cloud formation triggered by the altitude at which aircraft operate. So Indian aviation fraternity must consider these issues and collaborate with IMD and other various knowledge partners to carry out research in this regard and for future Indian aviation safety both at airports and across various air traffic route to keep this high growing industry economically viable in the days to come say for next 50-years.

12. Summary

India Meteorological Department has kept pace with the growing requirements of aviation sector. IMD has moved from manual analogue observations at the airports to the state of art Automatic Weather Observing System (AWOS). The AWOS consists of integrated digital sensors for temperature, humidity, wind, pressure measurements and RVR assessment, ceiling height estimation (i.e., height of the base of low clouds) at runway. The introduction of On Line Briefing System (OLBS) has been a boon to low-cost carriers. IMD works closely with Meteorological Directorates of Indian Air Force and Indian Navy for safe air operations at military and common user airports under UDAN scheme. IMD delegates actively participate in ICAO meetings and contribute significantly for the effective and efficient international aviation services. One ICAO designated Tropical Cyclone Advisory Centre (TCAC) is functioning at New Delhi

IMD is in the process of developing Decision Support System by combining the observed meteorological data of crucial meteorological parameters from runway, products from Doppler weather radars, data obtained through satellite imagers and sounders with the NWP model and synergizing all the information for improved forecasts and to give a reliable warning against severe aviation hazards. This will help in the implementation of MET-ATM, GNAP, and contribute to the safety and enhance operational efficiency at the airports. In view of climate change, Aviation community and policy makers also need to take in to account the impact on climate change on airport management and aircraft operations.

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Amy Johnson (an English Pilot) with Jason aircraft in Calcutta, 12 May 1930 (Picture source: Daily Mail, https://www.thisdayinaviation.com/tag/jason/)

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