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An innovative approach of meteorological observation integration to develop a state-of-the-art web-based visualization tool

ARPITA RASTOGI, K. C. SAI KRISHNAN, ANSHUL CHAUHAN, RANJU MADAN and M. I. ANSARI

India Meteorological Department, MoES, New Delhi – 110 003, India

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e mail: arpita.rastogi@imd.gov.in

सार– वर्तमान वायुमंडलीय स्थितियों के आकलन में तात्कालिक अनुमान एक महत्वपूर्ण भूमिका निभाता है। उच्च प्रभाव वाली ऋतुनिष्ठ घटनाओं के अल्पकालिक अनुमान (तात्कालिक अनुमान) से चेतावनियों में महत्वपूर्ण सुधार हो सकता है। इसलिए, भारत मौसम विज्ञान विभाग की क्षमताओं को उन्नत करने में वस्तुनिष्ठ पद्धतियों के माध्यम से कुछ उपकरणों का विकास अत्यधिक महत्व रखता है। वर्तमान में पारंपरिक पद्धतियाँ प्रचलन मेंहैं जो अधिक सटीक नहीं हैं। एक ही प्लेटफ़ॉर्म पर विभिन्न डेटासेट की अनुपलब्धता सबसे बड़ा कारण है, जो तात्कालिक अनुमान को निरर्थक और अक्षम बना देता है। इस प्रकार, एक प्रबल वेब-आधारित टूल की आवश्यकता है जिसमें वास्तविक समय में सभी उपलब्ध डेटासेट को एक ही स्थान पर एकीकृत करने की क्षमता हो। यह वेब-आधारित उपकरण वर्तमान स्थिति में वातावरण की सर्वोत्तम और सटीक स्थिति बताने में पूर्वानुमानकर्ता के लिए बहुत मददगार होगा। इस उपकरण के विकास के लिए, विभिन्न डेटासेट जैसे रेडार, उपग्रह, उपरितन वायु परिज्ञापी डेटा और तड़ित डेटा आदि का उपयोग किया गया है। इस उपकरण को एक एकीकृत डिस्प्ले के रूप में उपयोग करके, पूर्वानुमानकर्ता एक शहर जैसे छोटे क्षेत्र में मौजूद छोटे पैमाने की विशेषताओं का विश्लेषण करने और अगले कुछ घंटों के लिए सटीक पूर्वानुमान लगाने में सक्षम होंगे। यह उपकरण उष्णकटिबंधीय चक्रवात, गर्ज के साथ तूफान, बिजली गिरने और विनाशकारी पवनों सहित संकटपूर्ण, उच्च प्रभाव वाली ऋतुनिष्ठ घटनाओं के लिए जनता को चेतावनी देने में सक्षम है। इसशोधपत्रका उद्देश्य तात्कालिक अनुमान के लिए विभिन्न वास्तविक समय मौसम प्रेक्षण डेटासेट के एकीकरण द्वारा एक वेब-आधारित विज़ुअलाइज़ेशन टूल विकसित करना है।

ABSTRACT. Nowcasting plays a crucial role in the assessment of current atmospheric conditions. Short-term prediction (nowcasting) of high-impact weather events can lead to significant improvement in warnings. Therefore, development of some tools through objective methods has immense importance in upgrading the capabilities of the India Meteorological Department. At present, conventional subjective methods are running which are not very accurate. The biggest limitation is the non-availability of various datasets on a same platform, which makes nowcasting redundant and inefficient. Thus, a robust web-based tool is required which has the ability to integrate all available datasets at the same place in real time. This web-based tool will be of great help to forecaster or delivering the best and accurate state of the atmosphere in current condition. For development of this tool, various datasets like radar, satellite, upper air sounding data and lightning data *etc* has been utilized. By using this tool as an integrated display, forecaster shall be able to analyze small-scale features present in a small area such as a city and make an accurate forecast for the next few hours. This tool is capable of providing warning to the public for hazardous, high-impact weather phenomenon including tropical cyclones, thunderstorms, lightning strikes and destructive winds as well. This paper is an attempt to develop of a web-based visualization tool by integration of various near-real time weather observation datasets for nowcasting purpose.

Keywords – Doppler weather radar data, Upper air sounding data, Nowcasting, Web based visualization tool.

1. Introduction

Weather, especially severe weather, is responsible for many natural disasters that cause damage and huge loss of life. Weather forecasting is an essential part of early warning systems and consecutive actions within crisis management and risk prevention. As the World Meteorological Organization defines it, the Nowcasting comprises the detailed description of the current weather along with forecasts obtained by extrapolation for a period of 0 to 6 hours ahead. In general, trained forecasters are involved in nowcast preparation. Nowcasting requires rapidly updated observation data on an integrated display. Ideally, this display system contains observations from the various instruments and sensors. The observation data basically includes doppler weather radar data, satellite data, radiosonde data and lightning network data. During severe weather events, the forecaster continuously monitors these data for assessing the atmospheric conditions.

Nowcasting is particularly concerned with accurate warning. The available observations and nowcasting techniques are significantly responsible for providing the same. By providing such accurate early warnings spares lead time to devise strategies and take actions accordingly. Doppler weather radar (DWR) is the primary observation system for issuing warnings with confidence during severe weather events. DWR has a distinct advantage over other observation data when precipitation occurs as it directly observes precipitation particles in three dimensions over a large area with an update rate of a few minutes. Radar can estimate the amount of precipitation, observe 3D structure of a storm and its movement. In addition to DWRs, upper air sounding data provides with the information pertaining to vertical structure of the atmosphere, which clearly depicts the stability condition of the atmosphere.

The frequent and comprehensive data collected by satellite can also aid weather forecasters to recognize and monitor severe weather phenomenon such as thunderstorms, thus, making an important contribution to nowcasting. The greatest advantage of satellite data is the added capability of nearly continuous monitoring of the instability fields with improved temporal as well as spatial resolution compared to upper air sounding observations which has limitations of two upper air sounding observations (at 0000 UTC & 1200 UTC) at only a few numbers of sounding stations. Satellite based estimation of precipitation is the only alternative in the absence of radar and rain gauge data. The presence of lightning can complement the satellite information in case of deep mixed phase convection.

Real time lightning detection demonstrates an early indication of developing convection. By identifying the electrically active storms in space and time, can increase lead time for generating warnings and watches. The strength and lightning information near real time provides added value to radar and satellite data. The “lightning-Radar-Satellite” trio becomes the instrumental data for superior nowcasting system for high impact convective weather.

As the World Meteorological Organization defines Nowcasting comprises the detailed description of the current weather along with forecasts obtained by extrapolation for a period of 0 to 6 hours ahead. The India Meteorological Department has a sounding network of forty-three upper air sounding stations, INSAT 3D satellite, lightning data from Indian Air Force and a robust radar network which consists of twenty-three S-band, three C-band and eleven X-band Doppler Weather Radars stationed at different locations in the Indian region.

All these meteorological datasets at the same basemap in realtime makes this product more reliable and efficient for nowcasting users. As per earlier practices, different datasets used to be received on different platforms at different times, which makes nowcasting very time-consuming and complex while analyzing weather features. There is usually a mismatch seen in terms of time and location due to different methods of reception and translation of datasets for users.

Integration of various datasets simultaneously using GIS overlaid maps on common platform makes this product unique and highly accessible. Due to its uniformity and dynamic features, users can gain access to greater details of regions, points and areas which earlier products were not capable of providing instantaneously.

2. Datasets used

2.1. *Lightning data*

Lightning is one of the deadliest natural phenomena known to man, contributing to more than 24,000 fires each year leading to about $407 million of damages, these electrical discharges can heat the air they pass through to temperatures as high as 50,000 degrees Fahrenheit. According to the National Weather Service that is about five times hotter than the surface of the sun. Knowing where and when lightning is occurring and is able to track the movement of severe storms with intense lightning, especially over the oceans and other remote areas, is vital for protecting lives and property. A web-based GIS enabled tool has been developed for visualization of real time lightning flashes overlaid along with several other weather observations such as radar images, radar winds, sounding data, satellite images *etc*.

The lightning data being obtained and processed by Lightning Detection Network (Earth Networks) of the Indian Air Force. The lightning detectors are passive sensors that detect electromagnetic pulse radiation that is emitted by lightning strikes. The lightning data received from the Indian Air Force is cloud to ground lightning flashes data. Real time lightning data is received at Radar Lab, IMD every 15 minutes, which is then processed on a server to be converted to a suitable format. The Lightning Detection Network (Earth Networks) technical details are as follows:

TABLE 1

Lightning Detection (Earth Networks) Technical Details

Types of Lightning Detected	Cloud-to-Ground (CG) and In-Cloud (IC) strokes
Location Accuracy	<250 meters (ENLS density dependent)
Detection Efficiency	CG: > 95%; IC: > 85% (ENLS density dependent)
Sensor Baseline	20 km to 400 km
Sensor Sitting Criteria	Roof or tower mounted on existing structures with power and internet connectivity
Sensor Radio Frequency Bandwidth	1 Hz to 12 MHz (industry leading); 20x more
Sensor Timing Accuracy	<15 nanoseconds
Sensor Re-Arm Time	None
Waveform Digitization	Standard; ENLS is a fully digital system. Full waveforms delivered from sensor
Points in Waveform	Standard; 1000 points per second. Full waveform analysis is available
Digitizing Resolution	HF: 12 bit; LF: 24 bit
Digitizing Speed	HF: 24 MHz; LF: 625 KHz

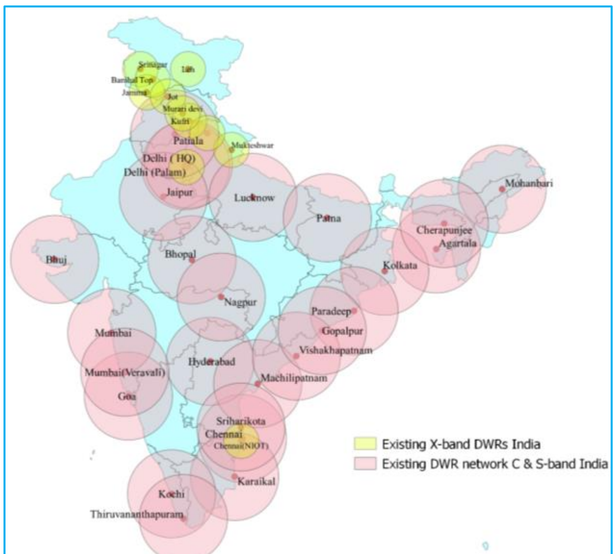


Fig. 1. India Meteorological Department Doppler weather Radar Network

2.2. *Radar Data*

Doppler weather Radar is an observation instrument used to locate precipitation area, its motion, and provide an estimate about the hydrometeor shape's and size even. Radar Data in real time is received every ten minutes at the central server of IMD Radar Lab. Radar data is further converted to geolocated data which is then further sent to another server for overlaying on the web-GIS platform.

TABLE 2

India Meteorological Department
Doppler weather Radar (DWR) Stations

S. No.	DWR Station	State	Type of DWR
1.	Agartala	Tripura	S – Band
2.	Bhopal	Madhya Pradesh	S – Band
3.	Bhuj	Gujarat	S – Band
4.	Chennai	Tamil Nadu	S – Band
5.	Cherrapunjee	Meghalaya	S – Band
6.	Delhi (Palam)	Delhi	S – Band
7.	Goa	Goa	S – Band
8.	Gopalpur	Odisha	S – Band
9.	Hyderabad	Telangana	S – Band
10.	Jaipur	Rajasthan	C – Band
11.	Kolkata	West Bengal	S – Band
12.	Kochi	Kerala	S – Band
13.	Karaikal	Tamil Nadu	S – Band
14.	Lucknow	Uttar Pradesh	S – Band
15.	Machilipatnam	Andhra Pradesh	S – Band
16.	Mohanbari	Assam	S – Band
17.	Mumbai	Maharashtra	S – Band
18.	Nagpur	Maharashtra	S – Band
19.	New Delhi (Mausam Bhawan)	Delhi	C – Band
20.	Paradeep	Odisha	S – Band
21.	Patiala	Punjab	S – Band
22.	Patna	Bihar	S – Band
23.	Srinagar	Jammu And Kashmir	X – Band
24.	Thiruvananthapuram	Kerala	C – Band
25.	Visakhapatnam	Andhra Pradesh	S – Band
26.	Sriharikota		S – Band
27.	Veravali	Maharashtra	C – Band
28.	Pallikarnai	Tamil Nadu	X - Band
29.	Jammu	Jammu And Kashmir	X - Band
30.	Leh	Ladakh	X - Band
31.	Banihal	Jammu And Kashmir	X - Band
32.	Jot	Himachal Pradesh	X - Band
33.	Murari Devi	Himachal Pradesh	X - Band
34.	Surkandaji	Uttarakhand	X - Band
35.	Kufri	Himachal Pradesh	X - Band
36.	Mukteshwar	Uttarakhand	X - Band
37.	Ayanagar (Delhi)	Uttarakhand	X - Band

Radar radial winds are also overlaid on the Web-GIS platform. IMD has a wide network of Doppler Weather Radars (Fig. 1). The location and type of these Radars are given in (Table 2).

TABLE 3

Technical description of INSAT-3D

Satellites	INSAT-3D (positioned at ~82° E)
Orbit Type	Geostationary
Instrument	IMAGER
Resolution	1.0 km for 0.65, 1.62 μm bands, 4.0 km for 3.9,10.8, 12.0 μm bands & 8.0 km for 6.8 μm band

TABLE 4

INSAT-3D IMAGER specification

Band	Central Wavelength (μm)	Primary Uses
1	0.65	Visible cloud and surface features
2	1.62	Near-Infrared surface, cloud phase, snow
3	3.9	Infrared low-level cloud/fog, fire detection
4	6.8	Infrared mid-level water vapor
5	10.8	Infrared surface/cloud-top temperature
6	12	Infrared surface/cloud temperature, low-level water vapor

2.3. *Satellite data*

India Meteorological Department has INSAT 3D Meteorological Satellite has an instrument "IMAGER". The INSAT-3D technical Description is given in Table 3 and its Instrument IMAGER specification is given in Table4.

Infrared Channel Satellite data is received every 25 minutes from Satellite Division, IMD in the processing server. The data received is in HDF5 (Hierarchical Data Format) which is further processed using Python for conversion into an appropriate format for overlaying.

2.4. *Upper Air Sounding data*

A radiosonde is an instrument which measures various atmospheric parameters such as Pressure, Temperature, Relative Humidity, Dew point Temperature, Wind speed and wind Direction *etc*. It gives the vertical profile of the atmosphere which draws the stability condition of the atmosphere at the observation site. Sounding data plays an instrumental role in weather forecasting. IMD has a very dense Sounding network across the Indian Region. At each station, two sounding ascents are taken regularly at 0000 UTC and 1200 UTC. After successful completion of soundings, each station transmits the Sounding data to the IMD server within tenminutes of completion of Sounding. The detailed description of the sounding network list and location is given in Fig. 2.

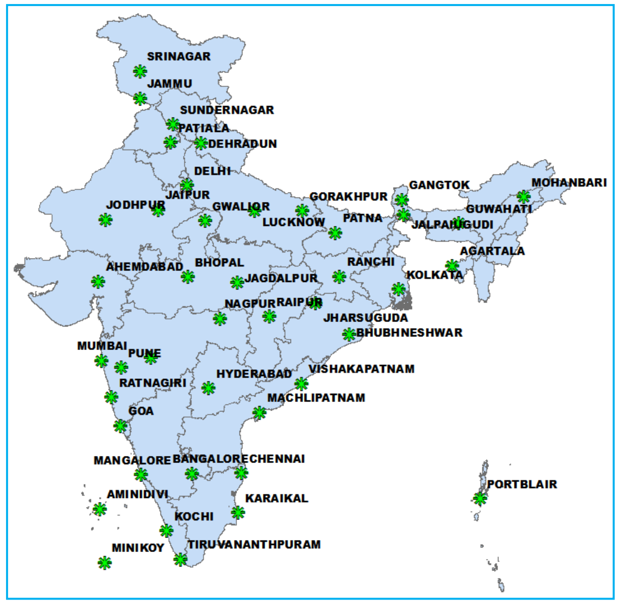


Fig. 2. India Meteorological Department Sounding Network

After successful completion of Soundings, each station transmits the Sounding data to IMD server within ten minutes of completion of Sounding. As the data is received by the server, it is further processed to generate skew *T* plot with detailed parameter values to be overlaid on GIS Map.

3. Development methodology

The technology platform used for developing the webpage is HTML programming and for web-based GIS applications is *leaflet*. The visualization webpage has been developed to overlay all weather observational parameters such as real-time Radar images, real time Lightning Flashes, Upper Air Sounding Data, Radar winds and Satellite images *etc*. The utilities and data translation details used are as follows:

3.1. *HTML*

HTML coding has been utilized for creating webpages by logically structuring the content of the page. There are several versions of HTML. The HTML5 version has been used on the said webpage.

3.2. *Base Map for GIS*

The Open-source utility *Leaflet* has been utilized for basemaps on the web-GIS platform. Leaflet is an open-source JavaScript library used to build web mapping applications. It supports most mobile and desktop platforms, supporting HTML5 and CSS3.

3.3. *Data translation Details*

3.3.1. *Radar data translation*

Radar data has three basic variables: Radar Reflectivity (Z), Radial Velocity (V) and Spectrum width (W). Various Radar products are derived from these three basic variables by following approved algorithms. In this tool Reflectivity data is taken for generation of the Maximum Reflectivity product. The Maximum reflectivity product provides an easy-to-interpret presentation of the echo height and intensity in a single display. It is especially useful for depicting areas of severe weather. The product is based on a volume scan TASK and is calculated by first constructing a series of CAPPI's to span the selectable layer, and then determining the maximum value of Z for the horizontal and two vertical projections - East-West and North-South. In this tool, for Generation of Maximum Reflectivity Product, Py-ART - The Python ARM Radar Toolkit has been used.

3.3.2. *Lightning data translation*

The Geolocation of lightning discharges is significantly important in a wide variety of applications. These include lightning warning and safety applications, thunderstorm nowcasting and forecasting. In this tool, lightning data is overlaid on a leaflet map with a given latitude and longitude. These latitude and longitude data have been converted into location with detailed address by using the independent Nominatim server with the Reverse Geocoding technique which has been further converted into warning messages of lightning events by using festival tool at the respective defined India Meteorological Stations.

3.3.3. *Radiosonde data translation*

Understanding and accurately prediction of changes in the atmosphere requires upper air observation data. Radiosonde provides a primary source of upper air data. It consists of sensors for the measurement of pressure, temperature and relative humidity. Changes in these three primary variables defines the state of the atmosphere. This tool has Sounding data as a layer in which radiosonde data at 0000 & 1200 UTC has been translated into a Skew *T* Diagram with detailed weather parameter. The derived Skew *T* diagram and parameters gives an overall idea about the stability condition of the atmosphere at the observation site without using any numerical models.

3.3.4. *Satellite data translation*

The monitoring and prediction of the Mesoscale convective systems is attempted worldwide on a nowcast basis. The RADAR based nowcasting application software, Warning Decision Support System Integrated Information (WDSS-II) developed by National Severe Storms Laboratory (USA) in collaboration with Oklahoma University (WDSS-II; Lakshmanan *et al*., 2007) is used in IMD for real time. Due to limited stations, another mesoscale model, Advance Regional Prediction System (ARPS) has also been attempted by IMD (Srivastava *et al*., 2010). These mesoscale convective systems are not forecasted well because of the absence of a mesoscale observational network over the Indian region and a suitable expert system to cover the entire country to compensate for this limitation, Satellites play the dominant role for nowcasting of these thunderstorms. INSAT 3D IMAGER has six channels from which various geophysical parameters have been derived as given in Table 5.

TABLE 5

Geophysical parameters from IMAGER

S.No.	Parameter	Input Channels/Data
1.	Cloud Mask	MIR, TIR-1, TIR-2
2.	Outgoing Longwave Radiation	WV, TIR-1, TIR-2
3.	Quantitative Precipitation Estimation	TIR-1, TIR-2
4.	Sea Surface Temperature	SWIR, MIR, TIR-1, TIR-2
5.	Snow cover	VIS, SWIR, TIR-1, TIR-2
6.	Fire	MIR, TIR-1
7.	Smoke	VIS, MIR, TIR-1, TIR-2
8.	Aerosol	VIS, TIR-1, TIR-2
9.	Cloud Motion Wind Vector	VIS, TIR-1, TIR-2
10.	Water Vapour Wind Vector	WV, TIR-1, TIR-2
11.	Upper Tropospheric Humidity	WV, TIR-1, TIR-2
12.	Fog	SWIR, MIR, TIR-1, TIR-2

Thermal Infrared 1(TIR-1) channel data covers almost all the derived geophysical parameters which are required during nowcasting. This tool selects the thermal infrared channel (TIR-1) for the Satellite data layer. This data has been converted as per a given lookup table for weather features and been overlaid as an image over a GIS map. The complete flow Diagram for this tool development is in Fig. 3.

4. Developed application tool

The web page developed using Leaflet looks like in Fig. 4.

The webpage shown in Fig. 4 named as Integrated Display of Weather and Thunderstorm Warnings (IDWTW) displays user selectable layers such as Lightning layer, Radiosonde data, Radar Reflectivity

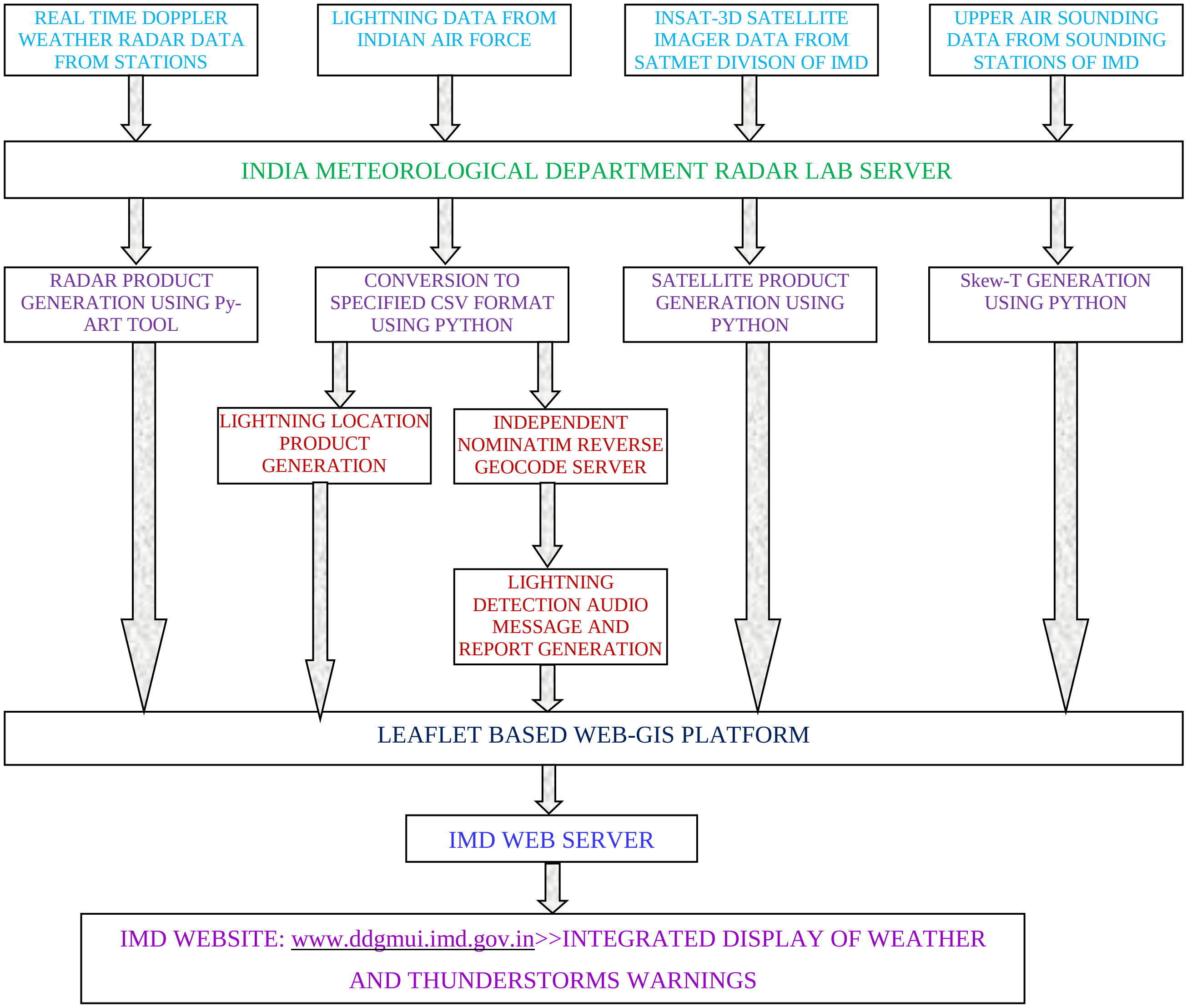


Fig. 3. Flow diagram of the development of a web-based Tool

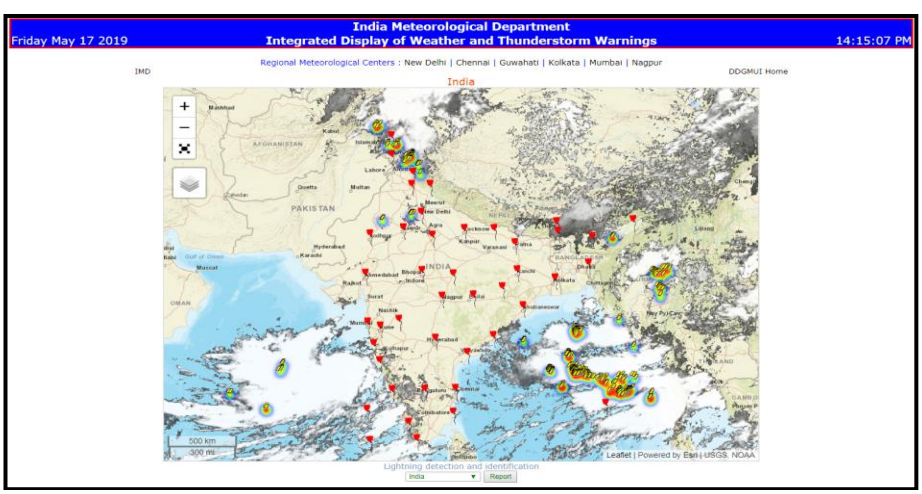


Fig. 4. Current extreme weather observations by overlaying Radar data, Satellite data, Radiosonde data, lightning data during Vayu cyclone on the Web-GIS platform

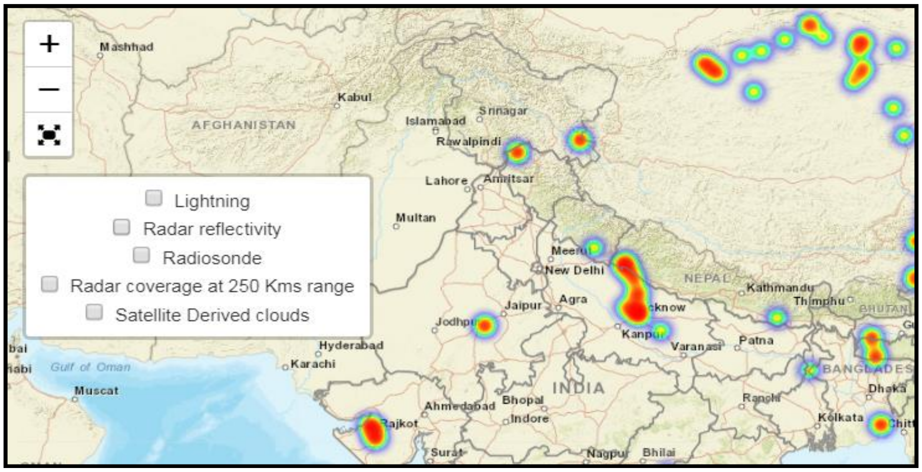


Fig. 5. Displaying user selectable layers for several weather observations

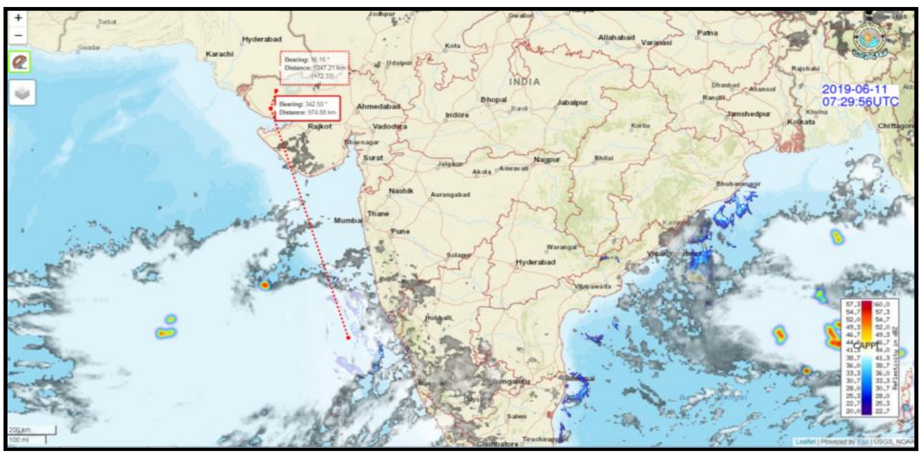


Fig. 6. Bearing and distance measured of forecasted Cyclone "Vayu" landfall point on the application webpage

layer, Satellite data, Radar coverage at 250 kms range overlaid on web-GIS platform as shown in (Fig. 5). In this display, more than one layer can be selected simultaneously as per the users' requirements.

Among various applications, users can also find out azimuth bearing as well as the distance between two points on the map (as shown in Fig. 6).

Latitude and longitude as well as time of occurrence of cloud to ground lightning flashes can be seen on the webpage by clicking on the lightning icon on the map (as shown in Fig. 7).

A detailed report for all lightning events over the Indian region can be achieved by clicking on the report at the bottom of the page as shown in [Fig. 8(a)]. The report can be viewed state wise also.

For assessing atmospheric stability conditions, radiosonde layer has been made available to the user. By clicking on the balloon icon, the Skew *T* diagram of the station with respective essential parameters can be viewed as shown in (Fig. 9).

During Cyclone "Vayu" on 12 June, 2019, the web-based tool shows dataset layers as shown in (Fig. 10). By utilizing the location click feature, cyclone's eye can be exactly located and its distance from any point on the coast can be measured. By continuous monitoring of radar and satellite data, cyclone movement can be tracked and its forecasted track can be updated accordingly.

5. Conclusion

Integration of real-time IMD weather radars and INSAT - 3D satellite with lightning and radiosondes data

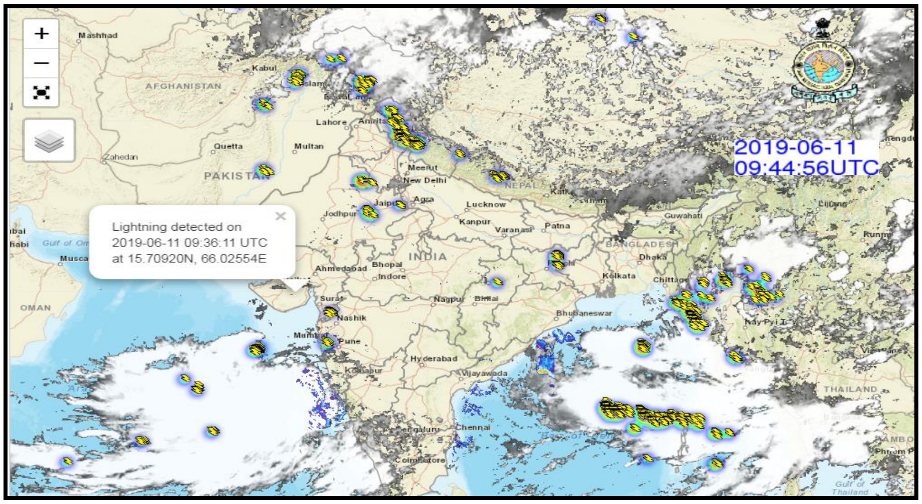
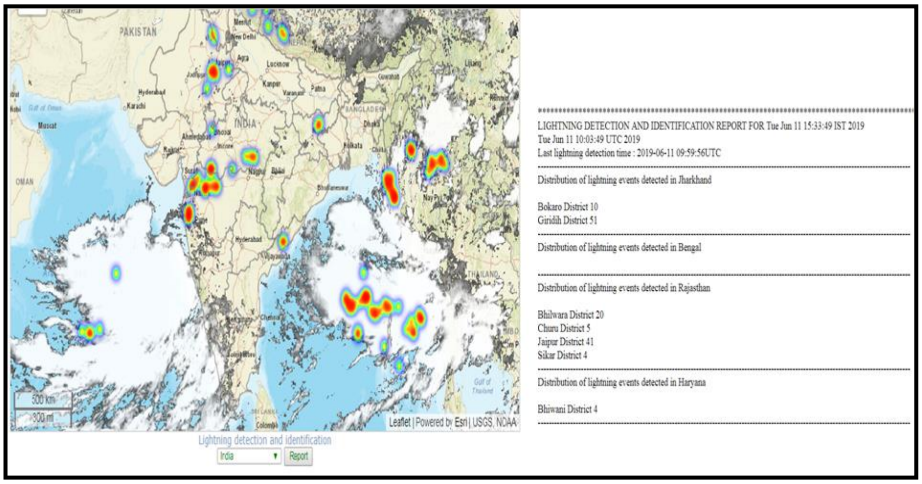
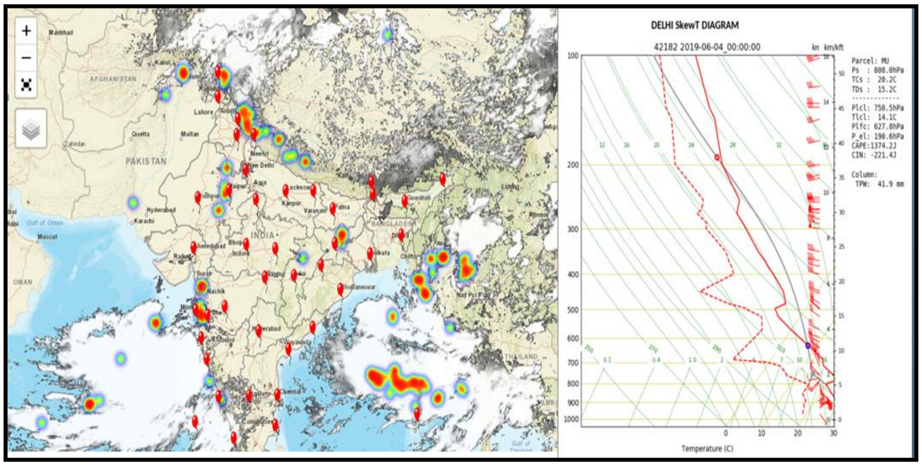


Fig. 7. Latitude and longitude of location of the occurrence of a single lightning flash



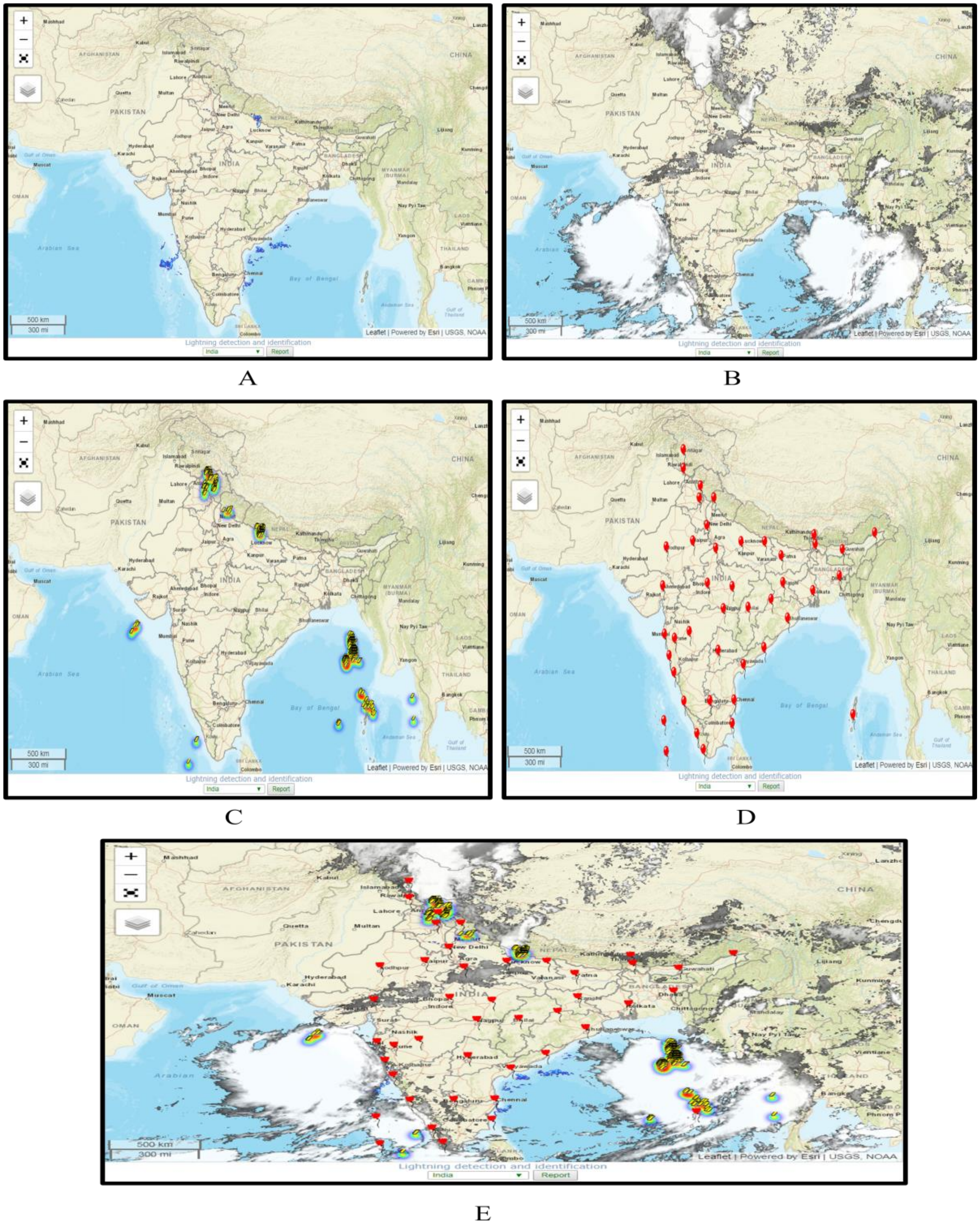
(A) (B)

Figs. 8(a&b). (A) Web page displayed as lightning layer selection and (B) A full lightning report for the Indian region on 11 June 2019 at 09:59:56 UTC



(A) (B)

Figs. 9(a&b). Web display of tool after Radiosonde layer selection (A) Location of sounding station and (B) Delhi Skew T diagram by clicking on the Delhi balloon icon



Figs. 10(a-e). Web display of tool on 12 June 2019 during Cyclone "Vayu" at 04:45 UTC (A) Radar data (B) Satellite data (C) Lightning data (D) Radiosonde data and (E) Combined data by overlaying all datasets

makes this tool more efficient and precise in comparison to conventional methods of analysis for a weather event. This tool has point analysis capability of meteorological datasets.

During cyclonic activity, keep an eye on the movement of a cyclone and updating forecasted cyclonic track accordingly will be very easy and fast because of real-time availability of Radar and Satellite data on the same platform. When Lightning flashes, it is very necessary to know the exact location of the strikes to warn nearby people. This tool generates a complete audio and text message which can further be communicated to specific locations. This lightning message communication will have great impact on weather warning services.

As there are many weather features which require more than one meteorological dataset for analysis. In those cases, sometimes one meteorological dataset is more dominant due to limitations in dataset measurement of others. To make such decision-making for selection of datasets, this tool will be of great help for making the final call in Nowcasting. Hence, this tool allows users to select the most suitable data for analysis of such events. Being a user-friendly interface, this tool, which is also available at national level as well as at regional levels, can provide nowcast assistance to forecasters with improved confidence. If there is inclusion of forecasted outputs of models and other meteorological observations, it will improve the analyzing capability of forecasting. Upgradation and verification of this web-based tool could be taken up in the future scope of work.

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