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Convective weather event monitoring with multispectral image analysis of INSAT-3D/3DRover Indian domain

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सार — **मॉनसून पूर्व ऋतु (मार्च से मई) बहुत चुनौतीपूर्ण होता है क्योंकि संवहनीय गतिविधियाँ लगभग पूरे देश में रहती हैं। अधिकांश रबी फसलों की कटाई प्रभावित होती है और कभी-कभी अचानक वर्षा या तेज़ हवाओं के कारण बहुत नुकसान होता है। इन्सैट-3डी/3डीआर उपग्रह चित्रों और व्युत्पन्न उत्पाद ऐसी घटनाओं की निगरानी में पूर्वानुमानकर्ताओं और अंतिम उपयोगकर्ताओं को निरंतर सहायता प्रदान करते हैं और उसके बाद पूर्वानुमान देने में महत्वपूर्ण रूप से सुधार होता है। यह जानकारी वहाँ बहुत उपयोगी पाई गई जहां वास्तविक रूप से सतह का या उपरितनवायु प्रेक्षण सीमित हैं या विशेष रूप सेविरल या दुर्गम भूभाग वाले क्षेत्र के कम डेटा हैं।**

इस कार्य में, हमने विभिन्न भौगोलिक स्थानों पर तीन मौसम की परिघटनाओं की जांच की है (*i*) **बिहार में** 24-26 **जून**-2020 **को हुई वर्षा** (*ii*) 17-06-2022 **को दिल्ली और एनसीआर क्षेत्र** (*iii*) **पूर्वोत्तर क्षेत्र मेंजून के दूसरे सप्ताह में** 16-18 **जून** 2022 **तक की गतिविधि।**

उत्पादों और सूचना प्रसार का वास्तविक समय विश्लेषण (रैपिड) वेब आधारित उपकरण का उपयोग द्युति तापमान और बहिर्गामी दीर्घ तरंग विकिरण, ऊपरी क्षोभमंडलीय आर्द्रता, सूर्यातप आदि तथा दिन और रात के समय माइक्रोफ़िज़िक्स दैनिक परिचालन उत्पाद संबंधी आरजीबी चित्र जैसे समग्र व्युत्पन्न उत्पादों के आधार पर संवहनी मौसम की परिघटनाओं की निगरानी और निदान करने में किया गया था। राष्ट्रीय राजधानी क्षेत्र दिल्ली में वर्षा और पूर्वोत्तर क्षेत्र के वर्षा उत्पादों के लिए पवन की समय श्रृंखला भी व्युत्पन्न उत्पादों RAPID **के माध्यम से प्राप्त की गई है। सिनॉप्टिक मॉडल विश्लेषण इन मेसोस्केल संवहनी मौसमी परिघटनाओं के लिए महत्वपूर्ण इनपुट प्रदान करता है। यूरोपियन सेंटर फॉर मीडियम रेंज वेदर फोरकास्टिंग (ईसीएमडब्ल्यूएफ) का दक्षिणी हवा का प्रवाह** (925 **एचपीए पर**) **और वेग अभिसरण** (500 **एचपीए पर**) **विश्लेषण** 16-18 **जून**, 2022 **को हुई पूर्वोत्तर की परिघटना की गंभीरता का समर्थन करता है।**

इसलिए, उचित सिनॉप्टिक मॉडल विश्लेषण के साथ-साथ वास्तविक समय पर INSAT-3D/3DR **उत्पादों का उपयोग पूर्वानुमानकर्ताओं को ऐसी मेसोस्केल संवहनी परिघटनाओं के बारे में बेहतर ढंग से समझने में मदद कर सकता है और पर्याप्त लीड समय के साथ सटीक पूर्वानुमान जान माल को बचा सकता है।**

ABSTRACT. Pre-monsoon season (March to May) is very challenging as convective activities prevails almost throughout the country. Most of the Rabi crops harvesting affected and sometimes suffer great losses due to sudden rain or high winds. INSAT-3D/3DR satellite images and derived products provides continuous support to the forecasters and end users in monitoring such events and thereafter significant value addition improves the prediction. This information was found to be very useful where actual ground based or upper air observations are limited or especially over data sparse or difficult terrain regions.

In this work, we have examined three weather events at different Geographical locations (*i*) Rainfall over Bihar-24-26 June, 2020 (*ii*) Delhi & NCR region on 17 June, 2022 (*iii*) NE region activity in 16-18 June, 2022.

The Real Time Analysis of Products and Information Dissemination (RAPID) web based tool was utilized in monitoring and diagnosing the convective weather events based on the brightness temperature & derived products like Outgoing longwave radiation, upper tropospheric humidity, insolation etc & RGB imagery composite in terms of day &

night time microphysics daily operational products. The time series of the wind derived products for Delhi NCR rainfall and NE rainfall products also generated through RAPID. The synoptic model analysis provides valuable inputs for these mesoscale convective weather events. The southerly wind flow (at 925 hPa) and velocity convergence (at 500 hPa) analysis of European Centre for Medium Range Weather Forecasting (ECMWF) supports the severity of NE event occurred on 16-18 June, 2022.

Therefore, utilization of near real time INSAT-3D/3DR products along with appropriate synoptic model analysis can help the forecasters to understand better about such mesoscale convective events & accurate forecast with sufficient lead time can save the life and property.

Key words – INSAT-3D/3DR, Insolation, Time series and European Centre for Medium Range Weather Forecasting (ECMWF).

1. Introduction

Satellite and its derived produces play an important role in understanding the dynamics of weather system. A new version of gateway to Indian Satellite data known as Real Time Analysis of Products and Information Dissemination (RAPID) which is hosted in India Meteorological Department (IMD) website have many new advanced capabilities. It is easily operated on mobiles and capable of analyzing weather events occurred throughout the year over Indian domain. Weather events starting from western disturbances in winter, snowfall, fog, cold wave, thunderstorms, pre-monsoon season thunderstorms, cyclones duststorms, monsoon intense rainfall & post monsoon season's events like rainfall, tropical cyclones etc. easily monitored and analyzed with the NSAT-3D/3DR data sets with RAPID. It further help and support the forecasters, end users, academia and researchers to understand the role of satellite derived products and images over Indian region. The role of atmospheric wind vectors and its derived products like, convergence, divergence, vorticity, wind shear, shear tendency etc. play an important role in monitoring / forecasting of the movements especially for mesoscale and synoptic scale systems (Giri *et al*., 2011; Kishtawal *et al*., 2009; Panda *et al*., 2015 & Sankhala *et al*., 2021). Recently installed Multi-mission Data Receiving and Processing System (MMDRPS) system at IMD satellite division have the capability to generate real-time INSAT-3D/3DR sounder/imager products. These products are very useful in diagnosing the moisture and atmospheric stability, cloud information and red-green-blue (RGB) images (Lensky & Rosenfeld, 2008), composite imageries are useful for monitoring and for user preparedness in advance. Rosenfeld and Lensky, 1998 studied about the convective development both in continental and maritime environment and found that satellite imagery and product response is quite different in both the cases.

Satellite derived information have their own limitation and uncertainties in respect of design and resolutions. The winds derived products have coarser resolution and other products are generated either at pixel level or better resolution. Therefore, climatological inference, model derived analysis and forecasters own experience play an important role to deal with in totality for such different resolution products.

In section 2, the data and methodology used in the present study have been discussed and section 3 describes the results and discussions based on the thunder event of Delhi NCR as well as intense rainfall activity over NE region during 3rd week of June 2022 (13-17 June, 2022) in section 4 includes a summary and conclusions of the study.

2. Data and methodology

Satellite data of Indian region INSAT-3D/3DR satellites currently operational at 82.5° E and 74.0° E respectively has been taken from India Meteorological Department (IMD), Lodi Road, New Delhi. The 6 spectral channels of INSAT -3D/3DR are operated in staggering mode and we get images every 15 minute interval over a coverage area [30° E to 130° E, 50° S to 50° N]. Each satellite have the same configuration of IMAGER operated on (*i*) Visible (VIS) for [0.55–0.75 µm], (*ii*) Shortwave infrared (SWIR) for [1.55–1.70 µm], (*iii*) Mid-wave infrared (MIR) for [3.8–4.0 µm], (*iv*) WV for [6.5–7.1 µm] and two split-window thermal infrared (TIR) channels, (*v*) TIR1 for [10.2–11.2 µm] and (*vi*) TIR2 for [11.5-12.5 µm] ranges of spectrum at 1.0, 1.0, 4.0, 4.0, 8.0, 4.0 & 4.0 km spatial resolution respectively. Each satellite retrieval process is done for each acquisition at every 30 minute interval. This data have been analysed with RAPID web-interface to study the rainfall events over Delhi and NE region during the months of June-2022.

INSAT-3D/3DR based RGB, Nigh and day time Microphysiccs (Lensky & Rosenfeld, 2008)

2.1. *INSAT-3D RGB Composite Images*

RGB composite images are produced composing satellite images coloured in red, green and blue (RGB). In the multi-spectral imager era RGB composites are an excellent addition to the tools available at the forecaster's bench. In an operational environment it is important of course, to judiciously select the RGB composites and limit their number to a strict minimum in accordance with the problems at hand.

Two application specific RGB products Day Microphysics RGB, Night Microphysics RGB are generated in IMD by using data from INSAT-3D Imager.

2.2. *Day Microphysics RGB Imagery*

2.2.1. *Channel combination "recipes" of the Day Microphysics RGB*

In the Red beam - The visible reflectance at 0.64µm approximates the cloud optical depth (thickness) and amount of cloud water and ice. Typically, water cloud is more reflective than ice cloud and thus will have a stronger red beam component.

In the Green beam - The 1.67µm SWIR (shortwave infrared) solar reflectance gives a qualitative measure for cloud particle size and phase. Typically smaller water droplets or small ice particles have a higher reflectivity, resulting in a stronger green beam component.

In the Blue beam - The 10.8µm TIR1 brightness temperature is a function of surface and cloud top B. Temperatures. The scaling for this beam results in a strong blue beam component for warm surfaces, whereas cold cloud tops will not have any contributing in this beam.

Day microphysics RGB scheme

Beam	Channel	Range	Gamma
Red	VIS(0.55-0.75 µm)	0….+100%	1.0
Green	SWIR(1.67 µm)	0….+60%	1.0
Blue	IR(10.8 µm)	+203….+323°K	1.0

This product is used during the daytime because a solar reflectance component is adopted.

Night Microphysics RGB Imagery

The Night Microphysics RGB product is designed and tuned for monitoring the evolution of night time fog and stratus clouds.

The distinction between low clouds and fog is often a challenge. While the difference in the TIR1 10.8µm and MIR 3.9µm channels is applied to meet this challenge, the Night - time Microphysics RGB adds TIR2 12.0µm channel difference to indicate cloud thickness and enhances areas of warm clouds where fog is more likely.

2.2.2. *Channel combination "recipes" of the Night Microphysics RGB*

In the Red beam - The channel differencing gives an indication of optical depth, it uses. There is a strong signal in this beam for thick clouds. For thin meteorological cloud there is greater absorption 12µm channel. In addition, the 12µm radiation is absorbed more strongly in ice phase cloud compared to water phase clouds.

In the Green beam - This channel differencing is used in fog/low cloud detection method. It uses TIR1 - MIR. The 3.9µm radiation has lower emissivity compared to the 10.8µm radiation for small water droplet clouds. Therefore, there is a large contribution to the green beam in this RGB product for water clouds with small droplets.

In the Blue beam - The 10.8µm infrared brightness temperature is a function of surface and cloud top temperatures. The scaling for this beam results in a strong blue beam component for warm surfaces.

Night microphysics RGB scheme

Beam	Channel	Range	Gamma
Red	IR12.0 µm – IR10.8 µm (TIR2 – TIR1)	-4….+2°K	1.0
Green	IR10.8 µm - IR3.9 µm (TIR1- MIR)	-4….+60°K	1.0
Blue	IR10.8 µm (TIR1)	+243….+293°K	1.0

3. Results and discussions

It is evident that space based monitoring provides a continuous coverage and observations for all type of weather systems. These observations act as supplement for data sparse regions and backbone of theoretical weather modeling and data assimilation. The satellite derived information is used almost in every sphere of the society like ocean ecosystem, coastline dynamics, marine, traffic, aviation, power, mapping of agriculture activities, fisheries, environment pollution monitoring, chemical composition etc. The geophysical parameters derived from INSAT data have their own limitations or challenges related to the accurate instrument calibration, design of instruments etc. Further it is constrained to define appropriately a priori knowledge and ancillary observation for theoretical understanding and modeling.

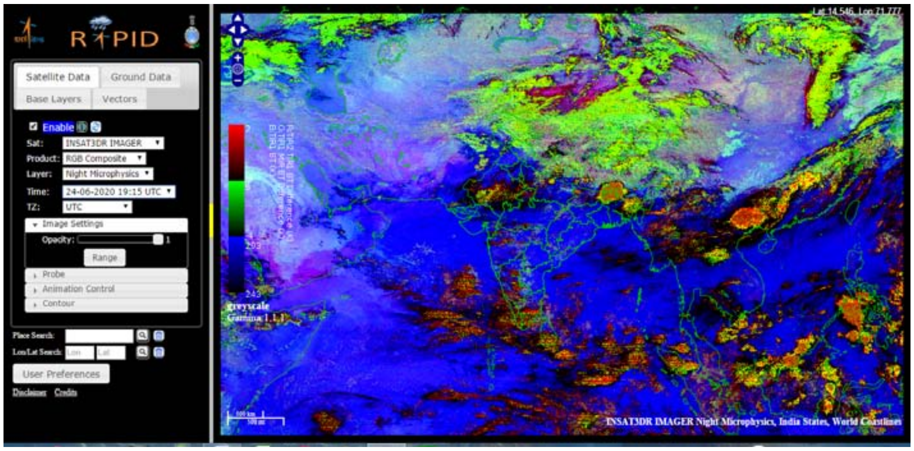

Fig. 1 (a). Night time RGB -24-June-2020 at 1915 UTC from INSAT-3DR Image data

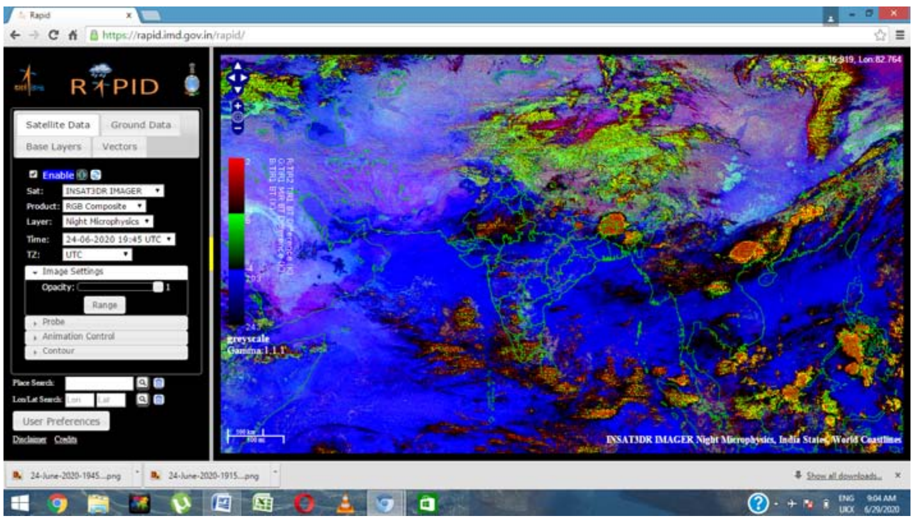

Fig. 1(b). Night time RGB -24-June-2020 at 1945 UTC from INSAT-3DR Image data

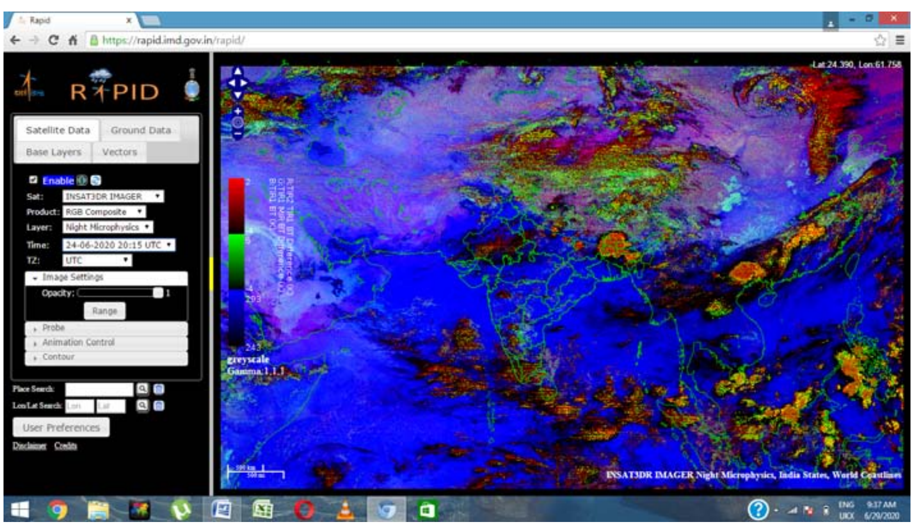

Fig. 1(c). Night time RGB -24-June-2020 at 2015 UTC from INSAT-3DR Image data

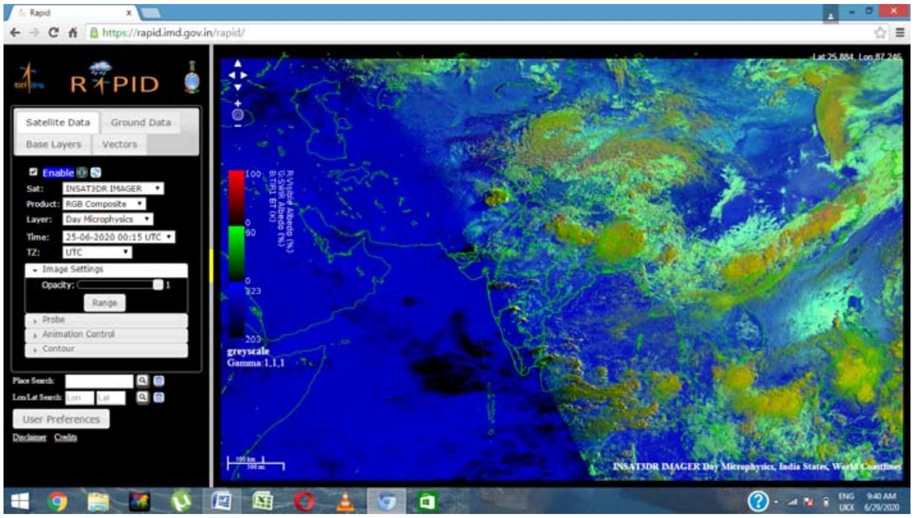

Fig. 1 (d). Day time RGB -25-June-2020 at 0015 UTC from INSAT-3DR Image data

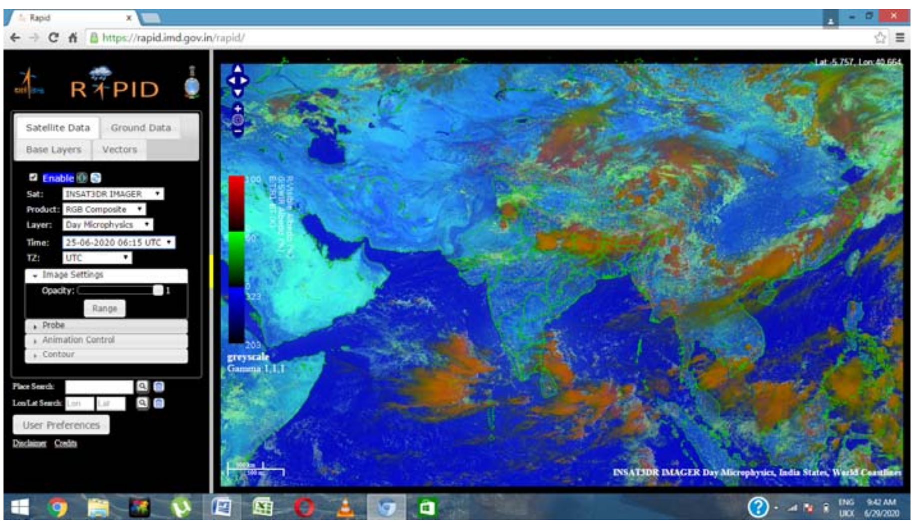

Fig. 1 (e). Day time RGB -25-June-2020 at 0600 UTC from INSAT-3DR Image data

During analysis of weather systems in normal practice we see the prominent features of the season along with daily/past day observations. Then model based output provides a clue about the persistency and movement of the systems. The current observations have their own limitations like availability and continuity. Information from remote sensing fills this gap, although it has own limitations or uncertainties. Therefore, we first examine the severity of the weather events and movement with the help of OLR, UTH, RGB, Winds and wind derived products. Other products like insolation and water vapor, infrared brightness temperature further decides the possible development and horizontal extent of the event. This information is very important and critical for the forecasters for further decision making of the government. Some of the events monitored and analyzed with satellite data and products are given below.

Case-1 : 24-26 June-2020 (Bihar rainfall)

During 24-26 June -2020 Bihar region was engulfed due to heavy rainfall with intense thunderstorm and lightning. RGB images generated from INSAT-3D/3DR satellite, Figs. 1 (a-e) shows intense convection over the area marked with different grey shades in the figures. The end result of the rainfall is reflected in the annual report prepared by IMD, Fig. 6 (d). Multispectral satellite RGB images used in day time and night time physics products name plays an important role in monitoring the coverage and severity of the weather, Figs. 1 (a-e).

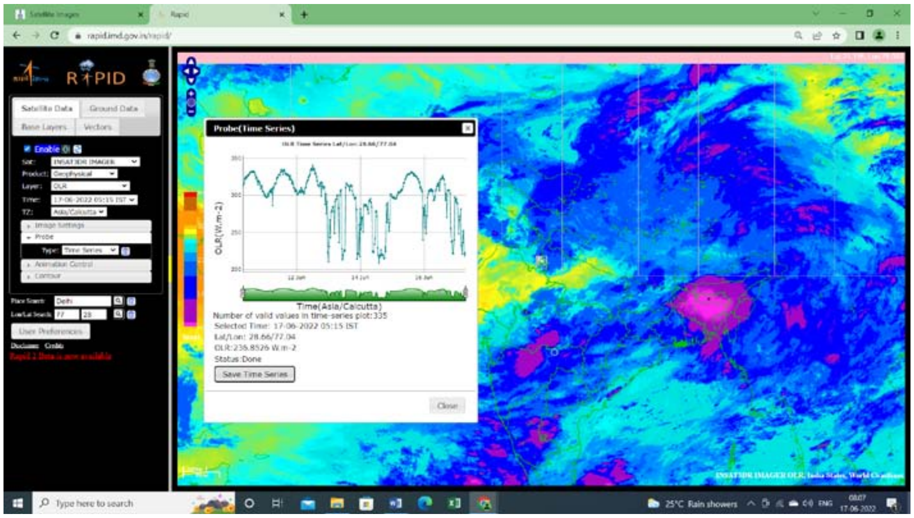

Fig. 2 (a). OLR (<220 watt/m^2) 0415 IST-17-06-2022

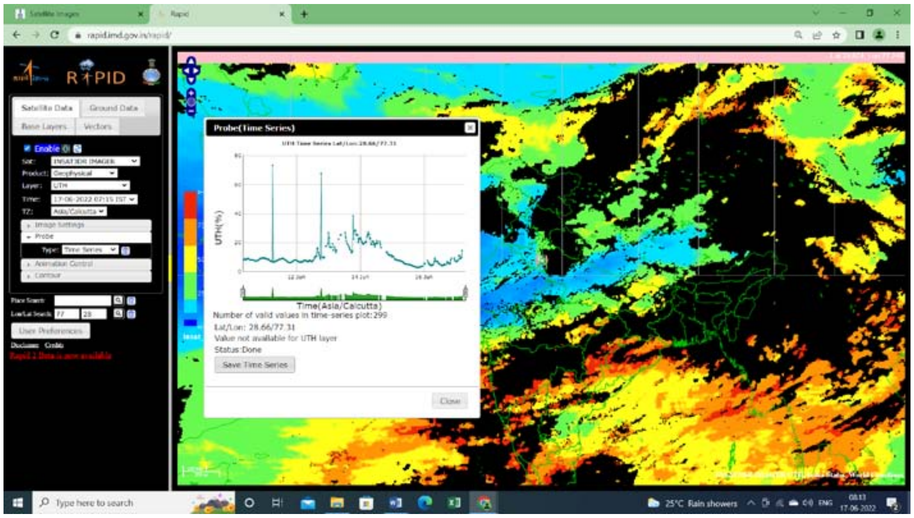

Fig. 2 (b). UTH (15-18 %) 0415 IST-17-06-2022-Delhi-NCR

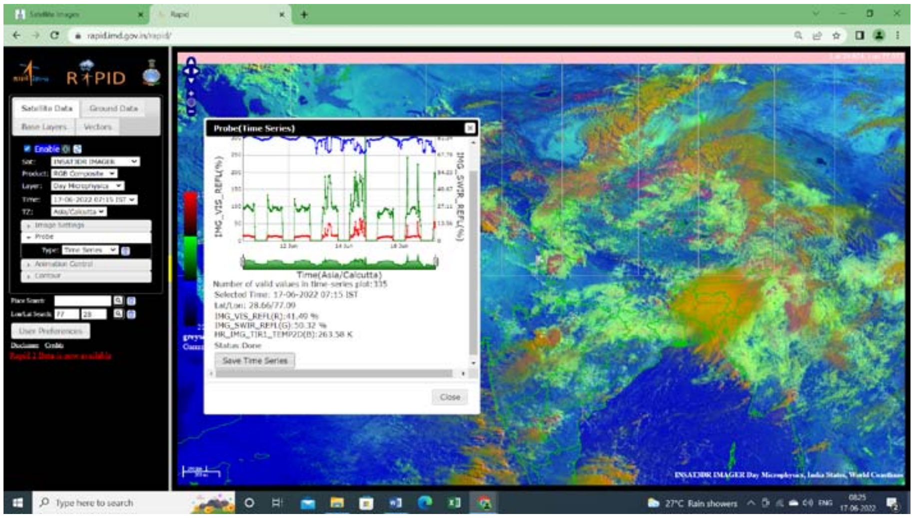

Fig. 2 (c). RGB-DMP 0715 IST-17-06-2022-Delhi-NCR

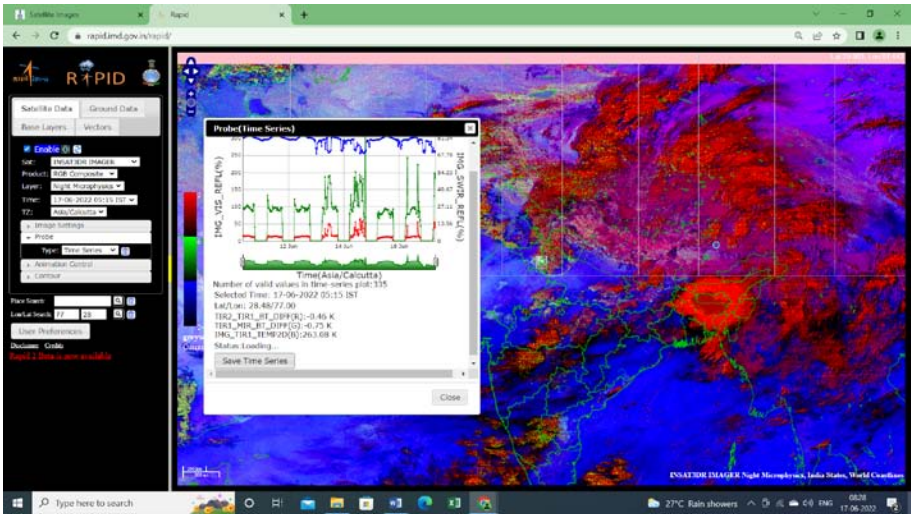

Fig. 2 (d). RGB-NMP 0515 IST-17-06-2022-NCR Delhi

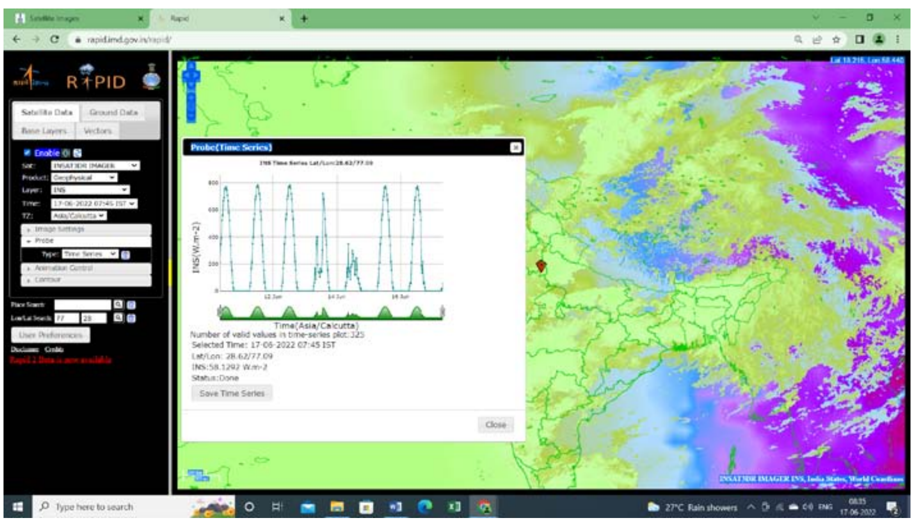

Fig. 2 (e). INSOLATION (0.0 watt/m^2 :1845-0515 IST) 17-06-2022-NCR Delhi due to light rainfall cloudy sky

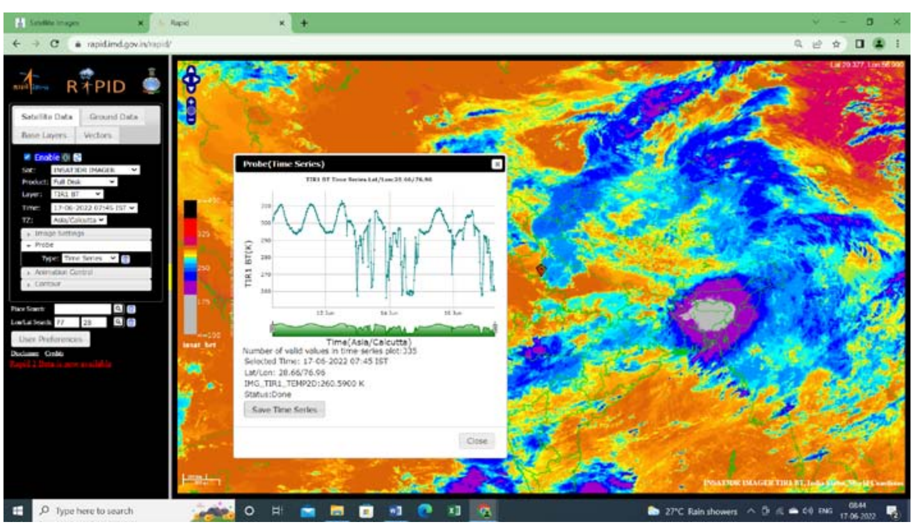

Fig. 2 (f). TIR-1 BT time series over 0715 IST-17-06-2022-NCR Delhi

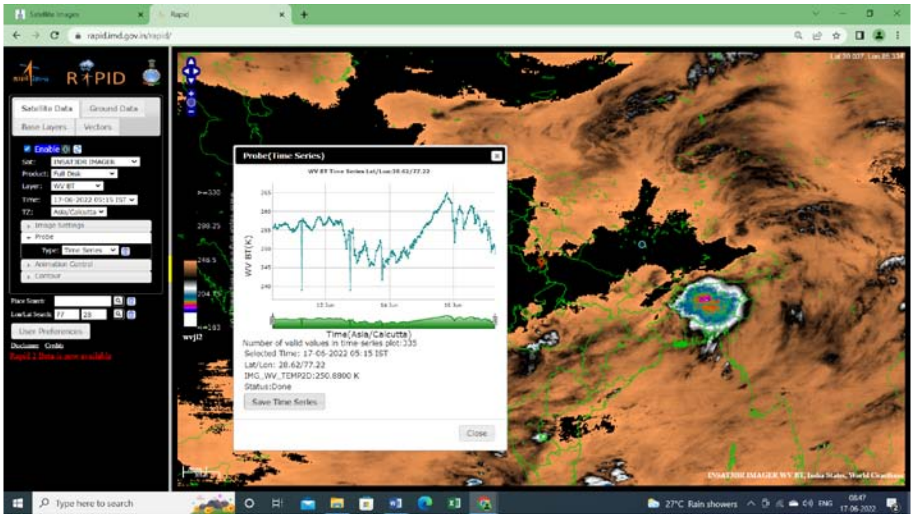

Fig. 2 (g). WV BT time series over 0515 IST-17-06-2022-NCR Delhi

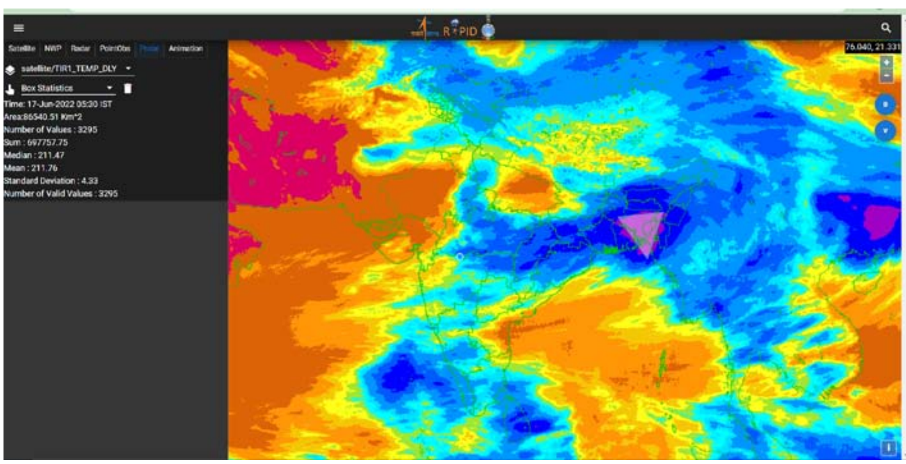

Fig. 3 (a). Daily TIR-1 brightness temperature over NE region (average TIR-1 temperature 211 °K)-17 Jun-2022

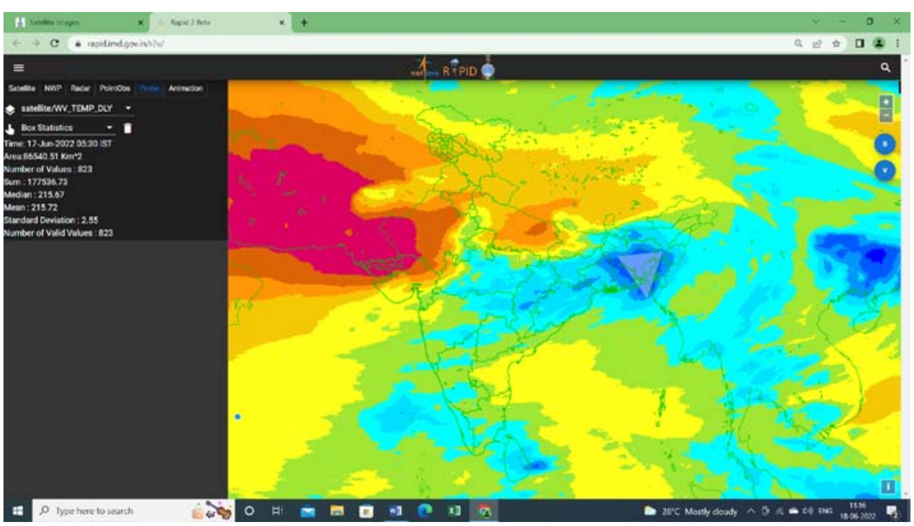

Fig. 3 (b). Daily WV brightness temperature over NE region (average TIR-1 temperature 215.67 Deg K)-17 Jun-2022

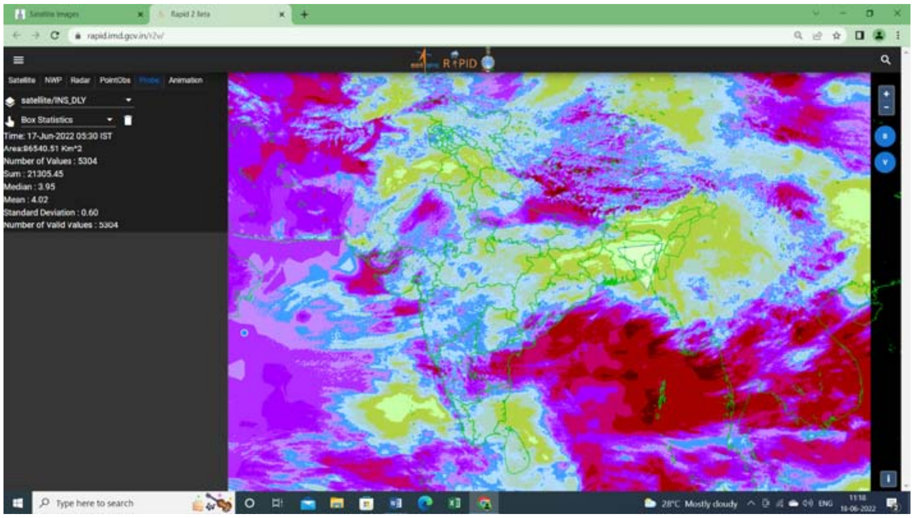

Fig. 3 (c). Daily INSOLATION over NE region (average value 4.02 watt/m^2)-17 Jun-2022

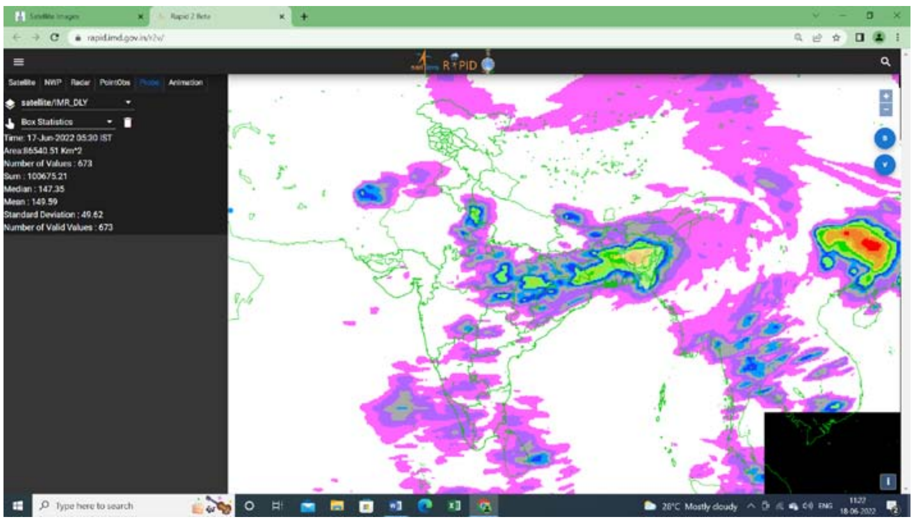

Fig. 3 (d). Daily IMR rainfall in mm over NE region (average value 149.59 mm)-17 Jun-2022

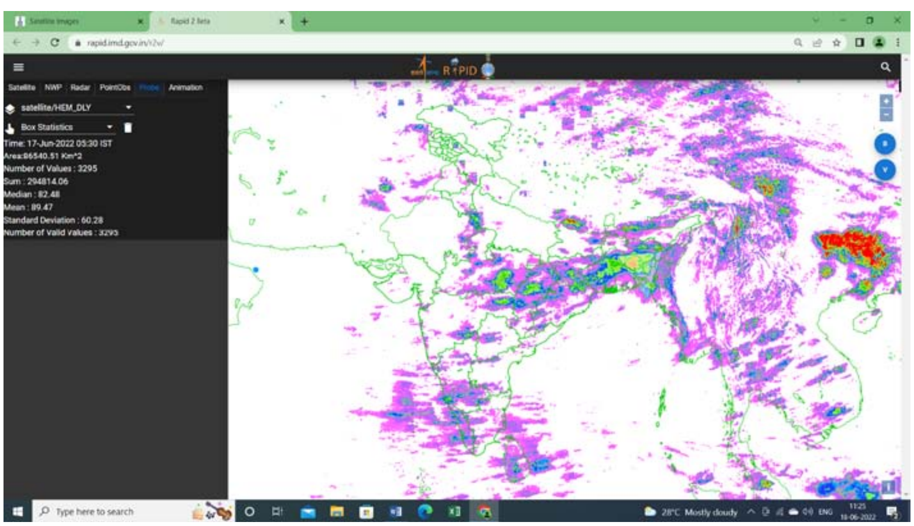

Fig. 3 (e). Daily HEM rainfall in mm over NE region (average value 89.48 mm)-17 Jun-2022

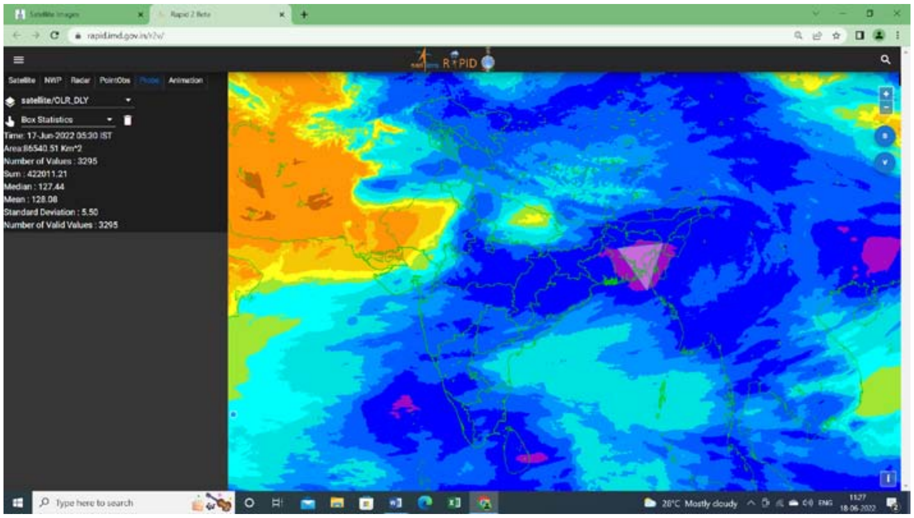

Fig. 3 (f). Daily OLR in watt/m^2 over NE region (average value 128.08 watt/m^2)-17 Jun-2022

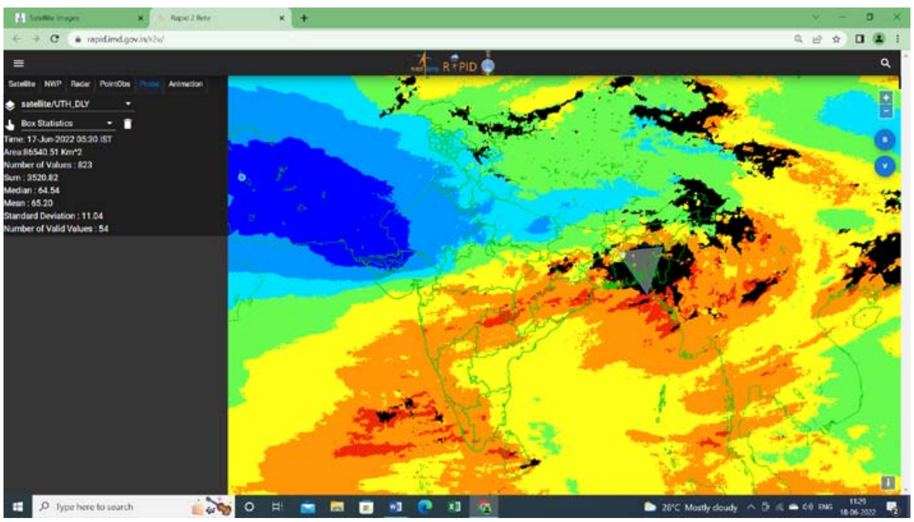

Fig. 3 (g). Daily UTH in % over NE region (average value 65.20 watt/m^2)-17 Jun-2022

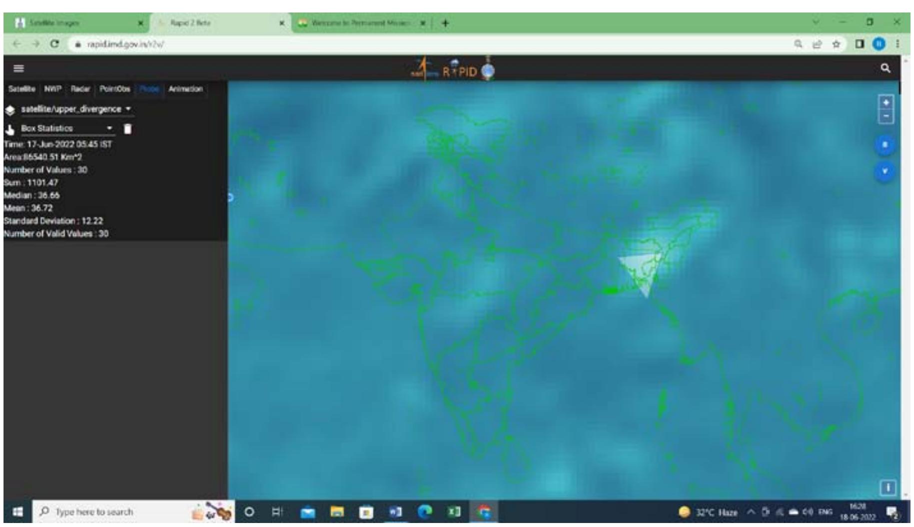

Fig. 3 (h). Mean divergence (36.72) of selected area NE region (marked as triangle) in the figure 17 June, 2022

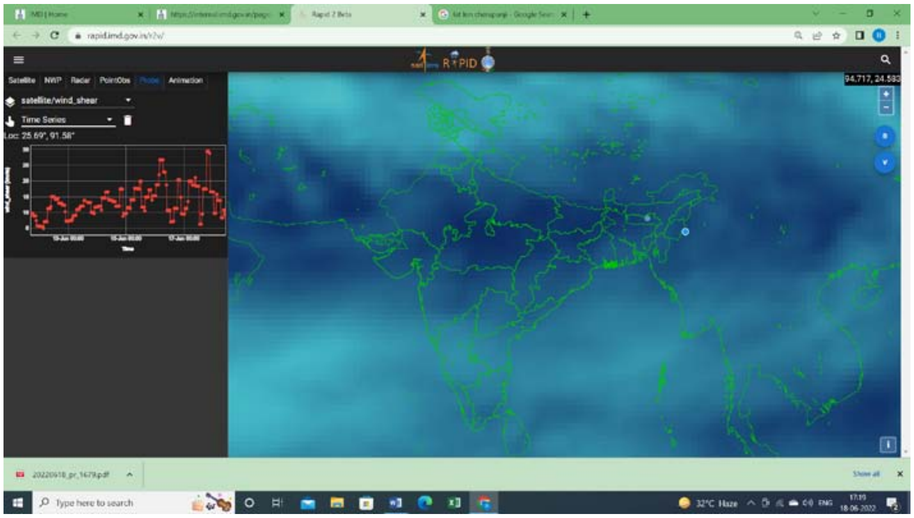

Fig. 4 (a). Wind shear time series 13-17 June, 2022 (Cherrapunji-Assam)

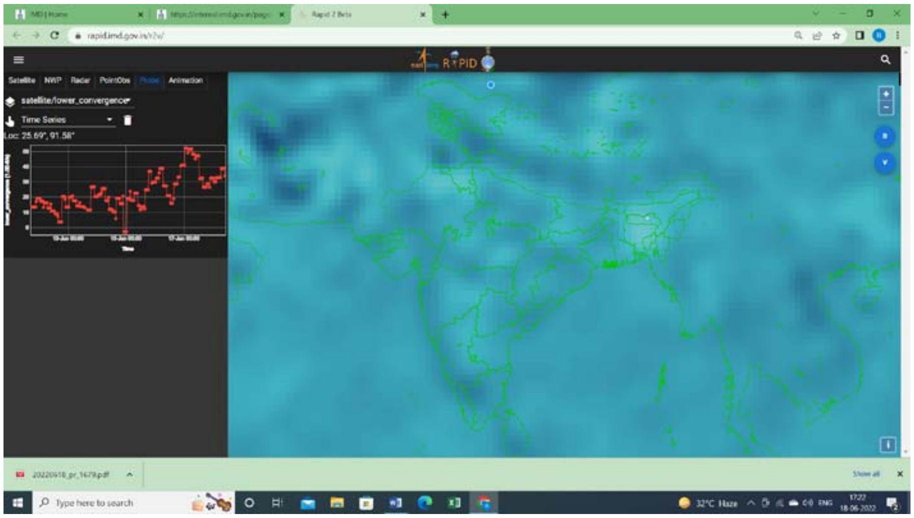

Fig. 4 (b). Lower Convergence time series 13-17 June, 2022 (Cherrapunji-Assam)

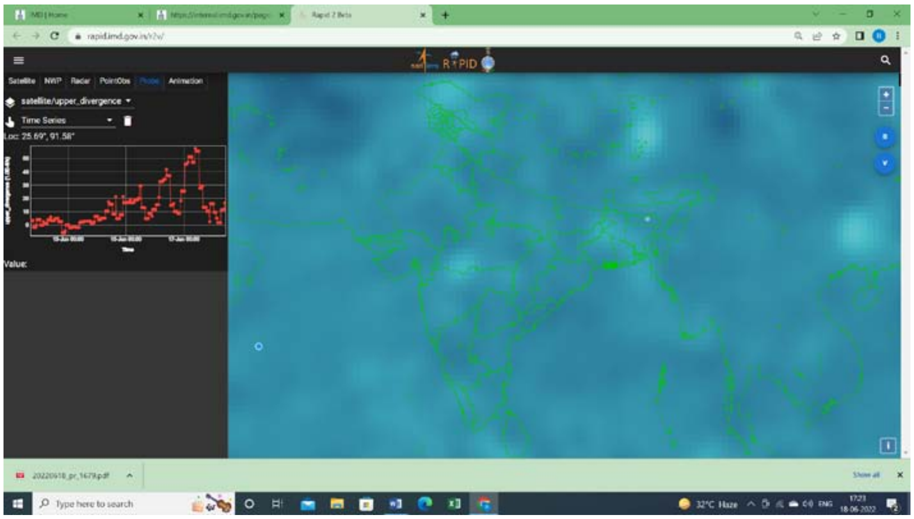

Fig. 4 (c). Upper Convergence time series 13-17 June, 2022 (Cherrapunji-Assam)

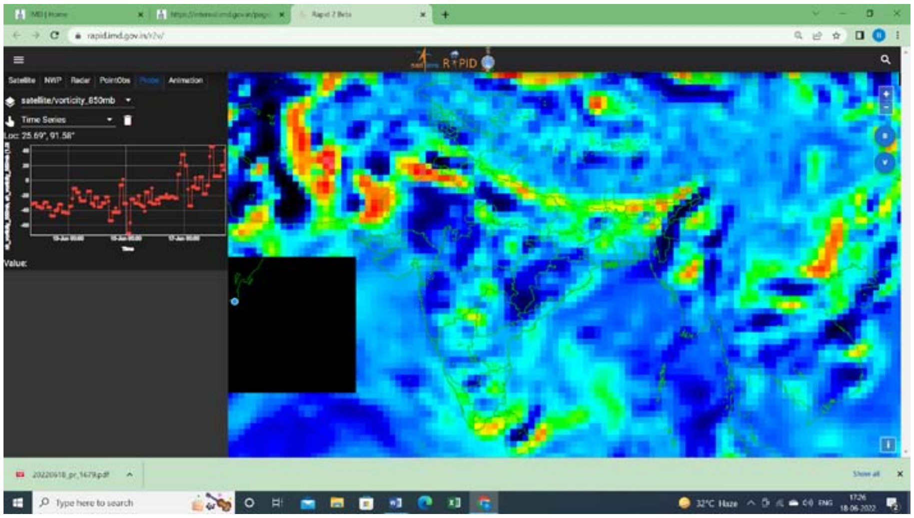

Fig. 4 (d). Vorticity 850 hPa time series 13-17 June, 2022 (Cherrapunji-Assam)

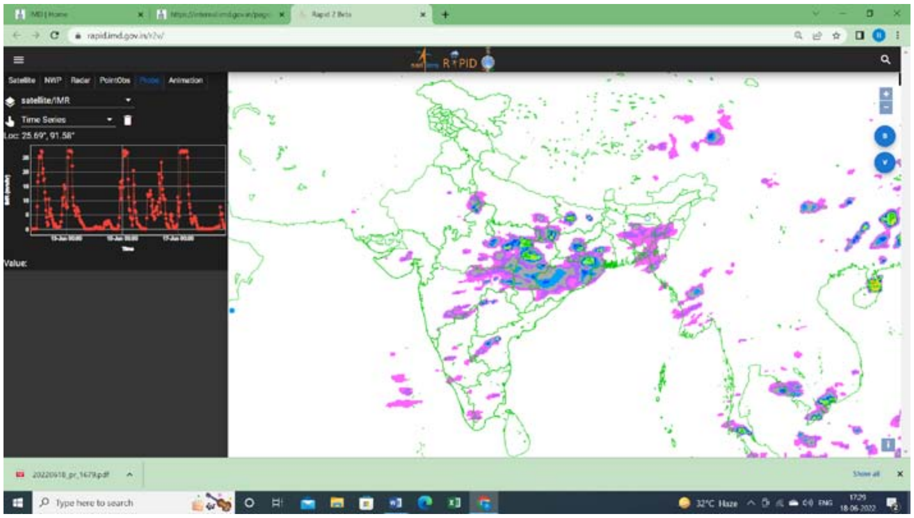

Fig. 4 (e). IMR rainfall in mm time series 13-17 June, 2022 (Cherrapunji-Assam)

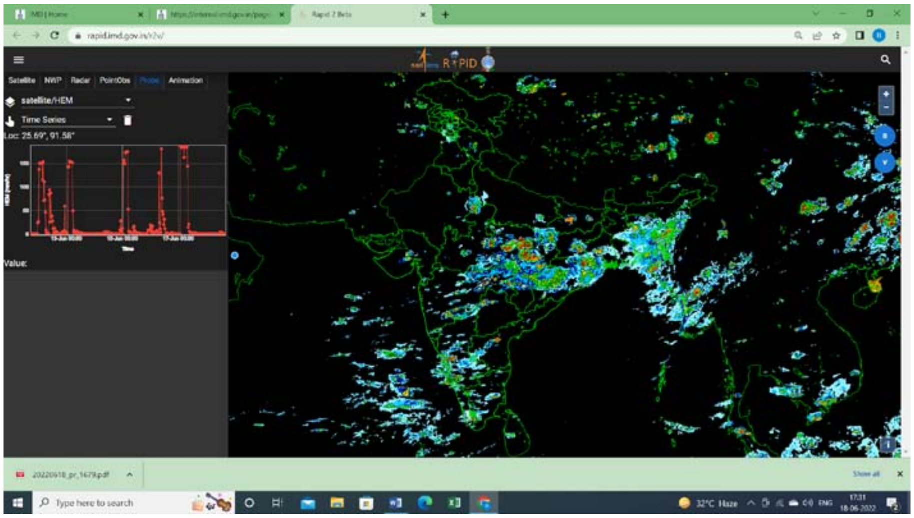

Fig. 4 (f). HEM rainfall in mm time series 13-17 June, 2022 (Cherrapunji-Assam)

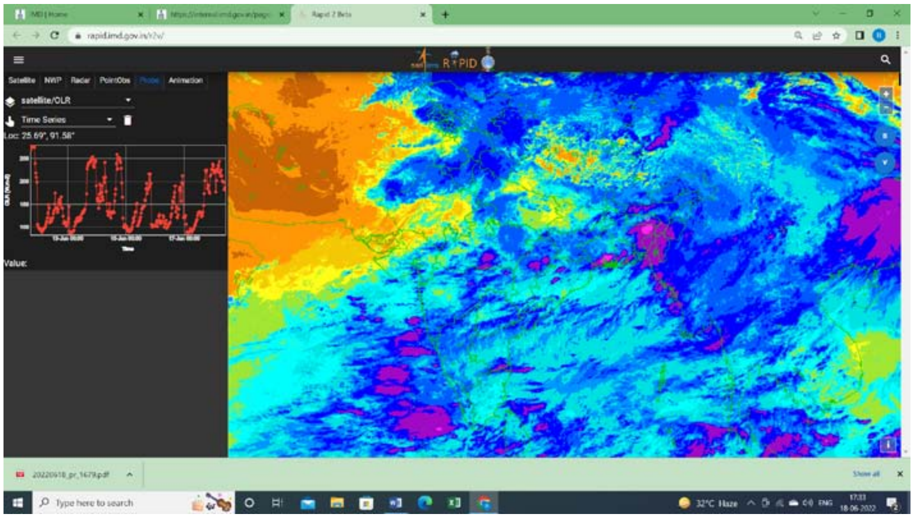

Fig. 4 (g). HEM rainfall in mm time series 13-17 June, 2022 (Cherrapunji-Assam)

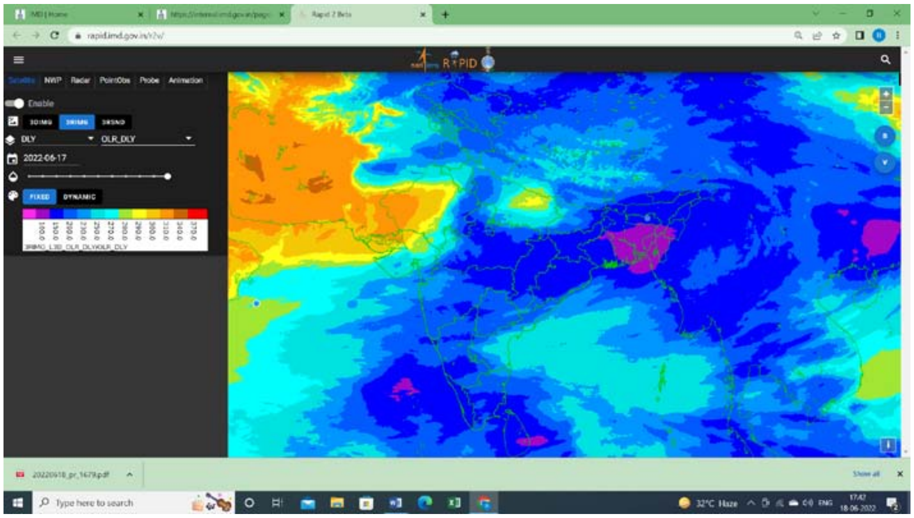

Fig. 4 (h). OLR daily 17 June, 22 NE convergence area

Case 2:Delhi-NCR region convective rainfall on 17-06-2022 at 0515 IST

This case was analyzed with the help of INSAT-3D/3DR satellite derived products, like outgoing long wave radiation (OLR) which was < 220 watt/m^2 indicated the moderate to severe convection over the area, Fig. 2 (a). The upper tropospheric humidity (UTH) was ranges from 15-18 % indicates the localized moisture and gradually lift up to generate the clouds due to solar heating, Fig. 2 (b). Similar convection building up is seen in the Figs. 2 (c-d) which builds up suddenly and affected the National Capital region (NCR) region of Delhi. Insolation values were nearly 0.0 watt me due to fully cloudy sky, Fig. 2 (e). The brightness temperature of thermal infrared 1 and water vapor regions indicates quite low values which supports the localized sudden convection over the area. The satellite data and its processing through RAPID tool will provide the forecasters the aerial view of convective building up and with the support of other satellite derived products it develops the confidence to the forecasters and decision makers.

Case 3 : NE region activity in second week of June, 16-18 June, 2022

NE region of India affected badly with heavy rainfall in many states of Assam, Meghalaya, Manipur, Mizoram and Tripura during 16-22 week. The rainfall during the week was represented excess rainfall, Fig. 6 (c). The ECMWF chart analysis on 16th June at 925 and 500 hPa shows the southerly flow and velocity convergence over the area.

Time series of Delhi convective activity rainfall (17 June, 2022)

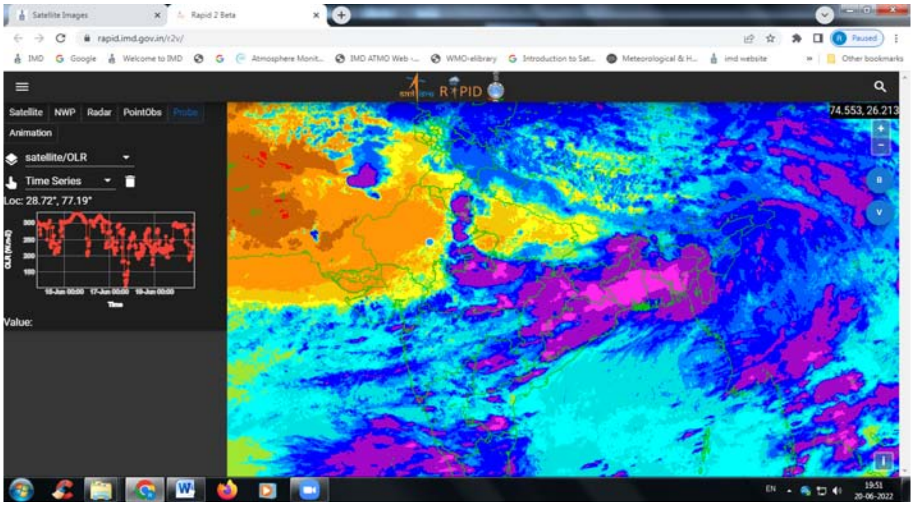

Fig. 5 (a). OLR time series at NCR on 17 June, 22

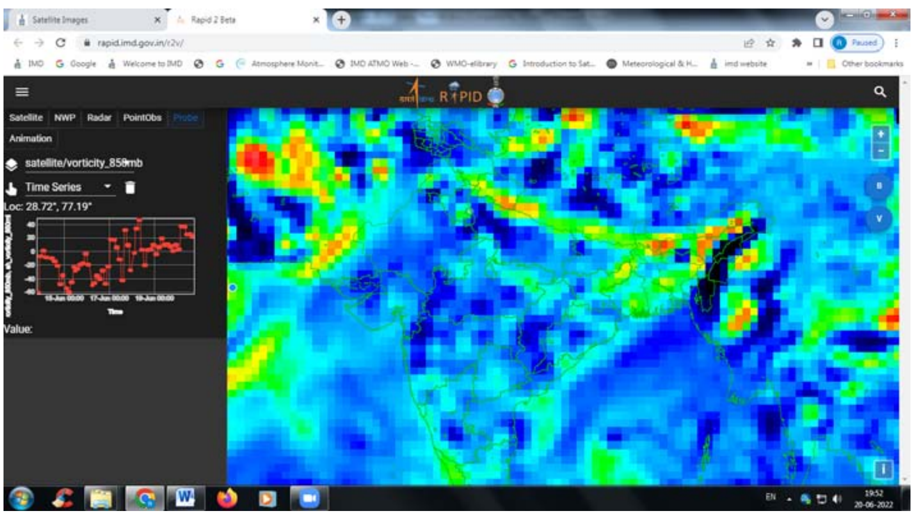

Fig. 5 (b). Voritcity at 850 hPa time series of Delhi NCR event on 17 June, 22

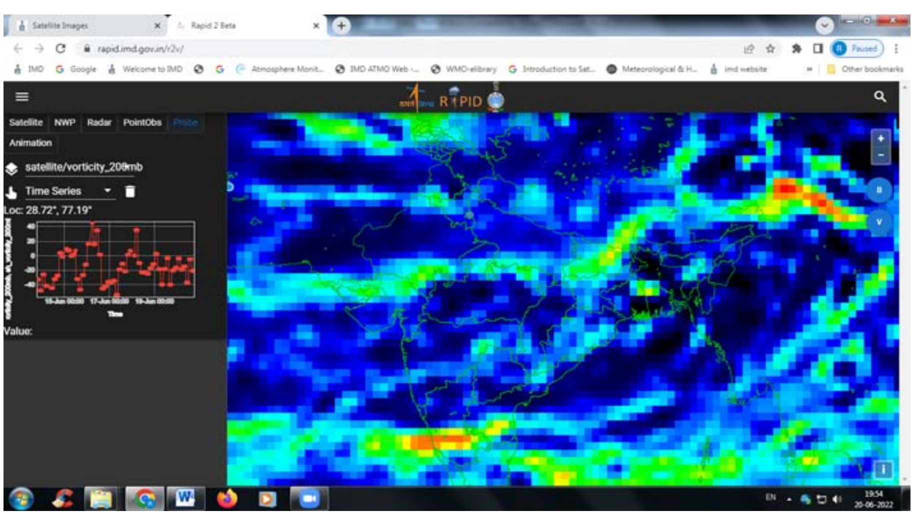

Fig. 5 (c). Voritcity at 200 hPa time series of Delhi NCR event on 17 June, 22

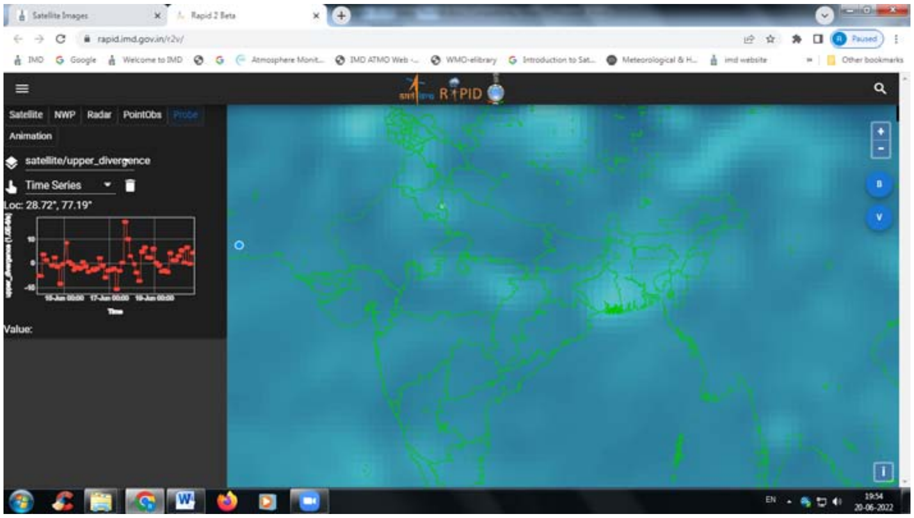

Fig. 5 (d). Upper divergence time series of Delhi NCR event on 17 June, 22

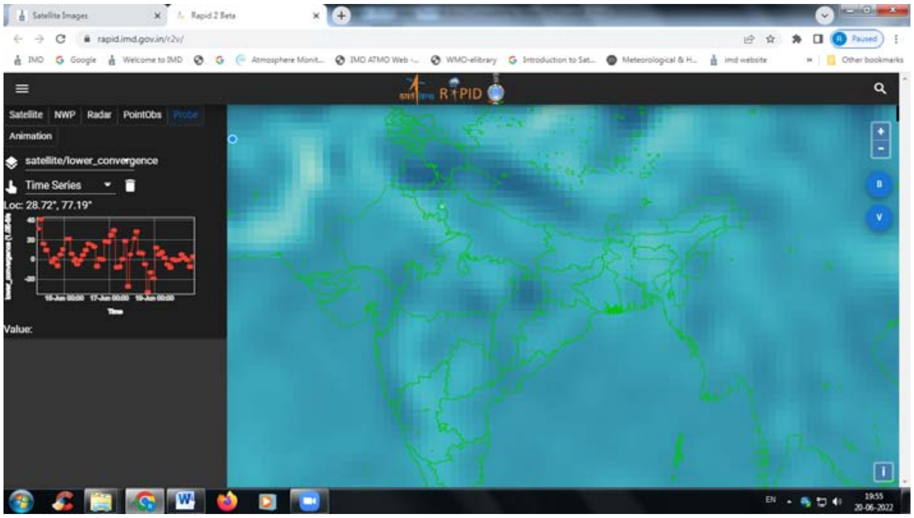

Fig. 5 (e). Lower divergence time series of Delhi NCR event on 17 June, 22

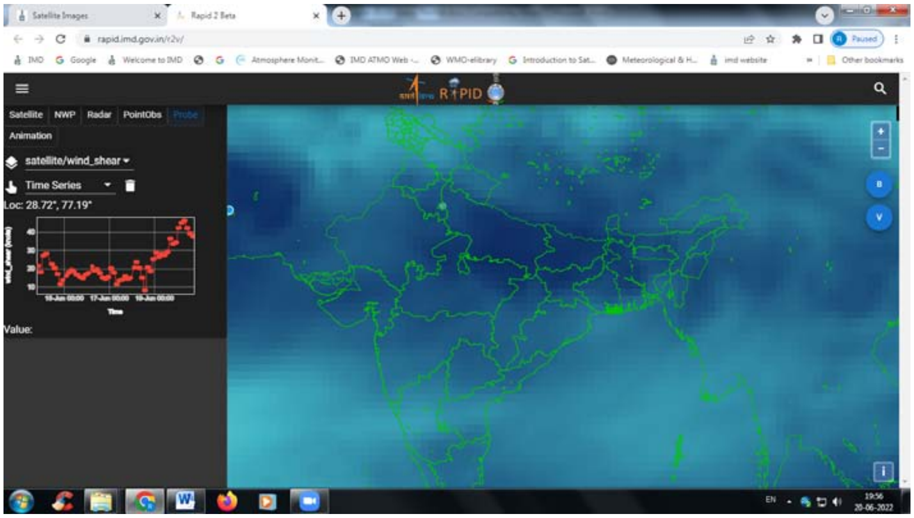

Fig. 5 (f). Wind shear time series of Delhi NCR event on 17 June, 22

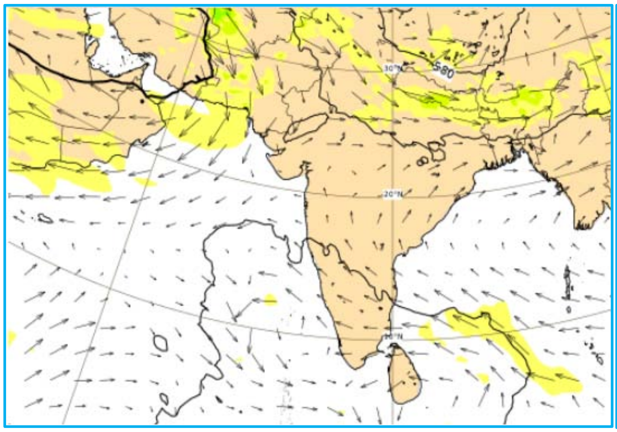

Fig. 6 (a). ECMWF Wind speed at 500 hPa / Geopotential at 500 hPa / Wind at 500 hPa Thursday 16 Jun, 1200 UTC T+0 Valid : Thursday 16 Jun, 1200 UTC (velocity convergence towards NE region (yellow in color)

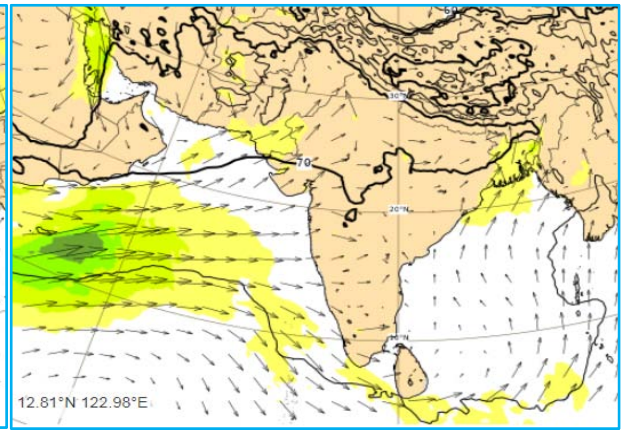

Fig. 6(b). ECMWF Wind speed at 925 hPa / Geopotential at 925 hPa / Wind at 925 hPa, Thursday 16 Jun, 1200 UTC T+0 Valid : Thursday 16 Jun, 1200 UTC (Southerly flow towards NE region generates moisture convergence)

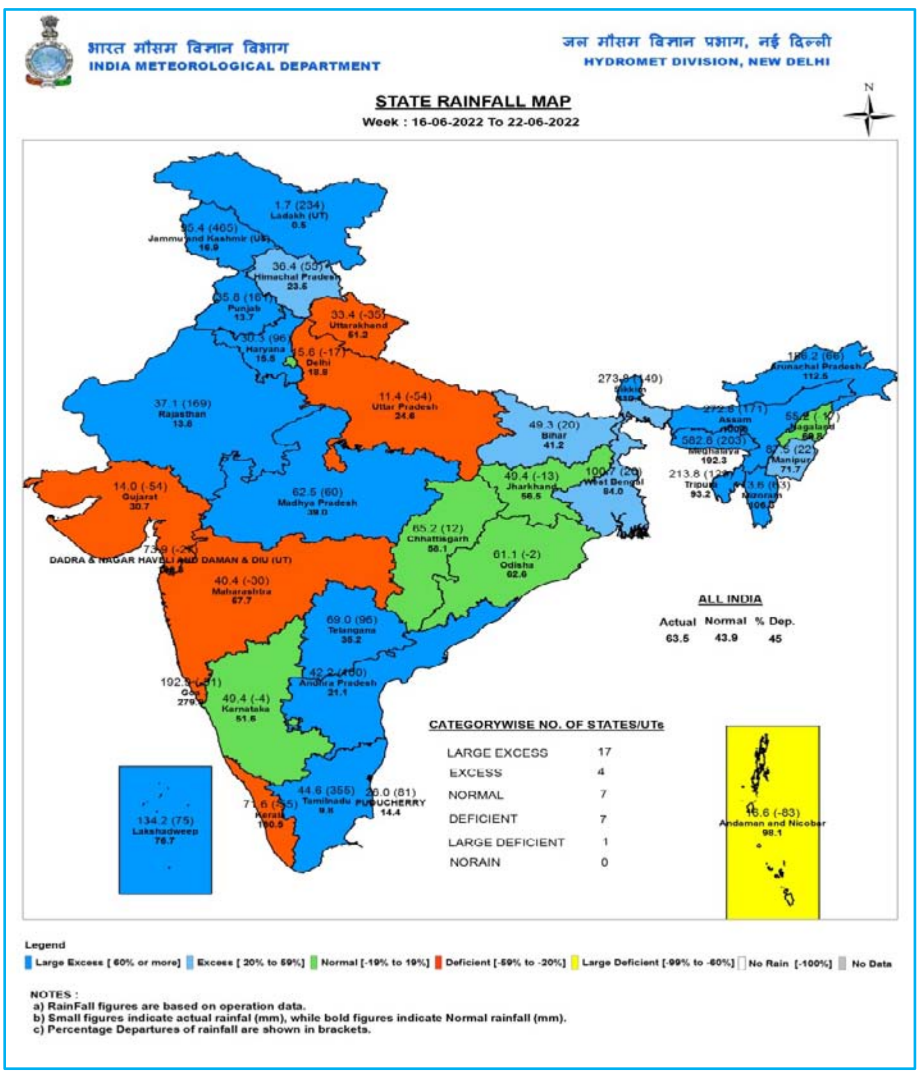

Fig. 6 (c). Actual rainfall recorded by IMD 16-06-22 to 22-06-22 (NE regional shows excess rainfall)

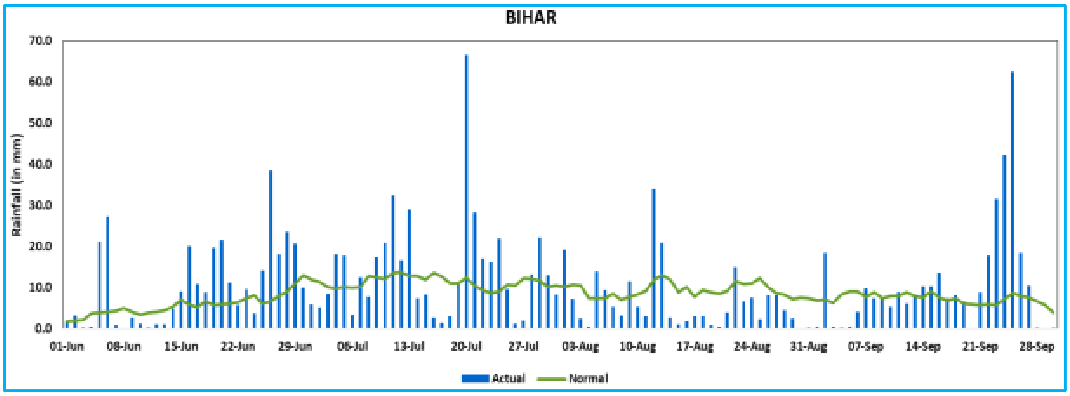

Fig. 6 (d). Sub-divisional rainfall recorded by IMD 16-06-22 to 22-06-22 (NE regional shows excess rainfall) [courtesy-IMD : Rainfall statistics of India: report no. ESSO/IMD/HS/Rainfall Report, page 43]

This indicated the quasi permanent feature of the weather system getting moisture from Bay of Bengal and converges vertically over NE region. The selected region marked in triangular shape, Figs. 3 (a-h) in daily thermal infrared-1, water vapor brightness temperature, daily insolation, daily INSAT

The selected region marked in triangular shape, Figs. 3 (a-h) in daily thermal infrared-1, water vapor brightness temperature, daily insolation, daily INSAT multispectral rainfall (IR), Hydro estimator (HE) rainfall, Daily OLR and UTH products shows the severe convection presidency over the area. Wind derived products like convergence; divergence and shear also support the sufficient building up lower level convergence and upper level divergence confined around NE region. This persistence and low value of shear gain acts as positive feedback to further moisture building up and instability over NE region. Southerly flow and velocity convergence acts as catalyst to spread the convection building up in a wide and short amount of time. The time series analysis through RAPID shown in Figs. 4 (a-h) of different INSAT-3D derived wind parameters (convergence, divergence, vortices, shear etc) and other products line OLR, UTH, IMR and HE rainfall helps to monitor the gradual strengthening or weakling of the system. This information is very useful to the end users and decision makers to make their further planning to save the public in affected areas. Similar daily time series of these products shown in Figs. 5 (a-f) helps to understand the initiation, building up and dissipation stages of the overlying convection and it will be very useful to demarcate the potential impact zone by tracking similar analogues features at different geographical domain. Therefore the case history of any weather event is very important to diagnose the weather system, its development and associated impacts over the area. This information can be further utilized by disaster managers to disaster detection, preparedness and mitigation point of view.

Time to time European Centre for Medium Range Weather Forecasting (ECMWF) reviewed his analysis for better future predictions. In November 2014, ECMWF implemented an intermediate cycle (40r1.1) of its Integrated Forecasting System (IFS) that added the capability to actively assimilate all conventional observational data in BUFR format (binary code). This modification was needed since WMO allowed providers to stop disseminating data in Traditional Alphanumeric Codes (TAC) format in November 2014 (Haiden *et al*., 2014). Recently ECMWF analysis shows improvements in short term forecasting by latest techniques of deep learning algorithms (Frnda *et al*., 2022). The model analysis shown in Figs. 6 (a&b) above shows that at 500 hPa level velocity convergence towards NE region and at 925 hPa (nearly surface) southerly flow was noticed which further enhance the moisture convergence over the NE region.

4. Concluding remarks

Extreme weather events and their occurrence are not uniformly distributed over the Indian domain. There will always a gap of observations, lack of understanding of sudden convective developments. INSAT-3D/INSAT-3DR derived products, images, daily products ad time series generation through in real time mode with the help of RAPID tool contributed significantly. This will further help to build up the understanding and appropriate value addition in furcating as well as decision makers well in advance.

The next generation satellite instruments with enhance capabilities and synergies of complimentary observations (active vertical profiling, hyperspectral imaging, microwave etc) helps further to diagnose and monitor the convective systems more effectively. The development of new solution and techniques like deep learning and artificial intelligence further enhance the usability of remote sensing information's. The compatibility of past, present and future observation will help to maintain long satellite data records and will acts as a resource knowledge base to deal with such convective systems of pre-monsoon season.

Finally, who are affected the public and society and there is always a scope or need of further enhancing the knowledge gap, understanding or infrastructure, so that, we can contribute appropriately to the benefit of the society in sufficient advanced lead time. This study will also be very useful to demarcate the potential impact zone in future by tracking similar analogues features at different geographical domain.

Acknowledgements

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