GNSS Network of IMD and its Applications

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ABSTRACT

India Meteorological Department (IMD) is the nodal agency of Government of India for deploying weather instruments, collection of meteorological data, utilization in daily operational work of weather forecasting and to provide all weather related services to the people of this country and neighborhood and sharing of data with various research institutes all over the world. Improving the quality of operational services is one of the main and important objectives of the Meteorological Department. To meet this requirement, the Department is constantly implementing and upgrading the observational technology and inducting new technology to the maximum possible extent as and when required. IMD has a network of 25 Global Navigation Satellite System (GNSS) ground based stations for measurement of Integrated Precipitable Water Vapour (IPWV) in near real time. This real time IPWV data along with the pressure, temperature and humidity point station data almost all GNSS locations are available for public domain at every 15 minute intervals. In this work the authors presented the brief overview of the utilization of Indian GNSS Network data in various meteorological applications and found very useful input for forecasting the thunder, heavy rainfall and monsoon activities with sufficient lead time from hours to days.

Keywords: *Global Navigation Satellite System (GNSS), Integrated Precipitable Water Vapour (IPWV), GPS Sonde and Numerical Weather Prediction.*

1. Introduction

Integrated Precipitable water Vapour (IPWV) from surface bases GNSS Network is representatives of the atmospheric water vapour present in the atmosphere around 20 km of the stations area. The atmospheric water vapors a major source of precipitation which provide the latent heat for earth's energy balance and a parameter in Numerical Weather Prediction Models (NWP). It has several applications in National Meteorological and Hydrological Services (NMHS). India Meteorological Department (IMD) is currently using the Trimble Pivot Platform (TPP) software for retrieving the IPWV from 25 Indian GNSS Network stations. The locations of 25 Indian GNSS stations are given in Table (1). The near real time information of GNSS derived IPWV and temperature, pressure and relative humidity met parameters are available in public domain at the link http://gnss.imd.gov.in/TrimblePivotWeb/. In the recent past, study conducted by Puviarasan et al. (2015) shows IPWV utility in south West Monsoon activity around the station area.

The GNSS derived IPWV from Indian GNSS network results show that GNSS estimates are generally in good agreement with measurements of radiosondes (Yadav et al., 2020).

The IPWV obtained from satellite measurements can have a global coverage if the satellites fly over every "point" of the Earth within a specified time frame. However, a so called "point" for a satellite observation may mean an area of several hundreds of square kilometres. Therefore, only IPWV averaged over a very large area can be provided by satellite measurements. Depending on what sensors are used, satellite observations may not provide data under all weather conditions. On the other hand, satellite observations give high accuracy over oceanic regions, which otherwise are very difficult to cover efficiently for ground-based measurements.

Table 1. Location of 25 GNSS stations with Lat, Lon, Height (m).

S.No.	Station Code	Stations Name	Latitude	Longitude	Ellipsoid Height (m)
1	JIPR	Jaipur	26.82	75.82	335.37
2	RIPR	Raipur	21.21	81.66	245.56
3	TRVM	Trivandrum	8.51	76.96	-18.44
4	KRKL	Karaikal	10.91	79.84	-79.07
5	KYKM	Kanyakumari	8.08	77.55	-49.23
6	MPTM	Machilipatnam	16.18	81.15	-61.07
7	ITNG	Itanagar	27.10	93.83	66.50
8	DMPR	Dimapur	25.88	93.77	114.78
9	DBGH	Dibrugarh	27.48	95.02	55.76
10	JPGI	Jalpaiguri	26.55	88.71	37.41
11	SMLA	Shimla	31.10	77.17	2021.58
12	SRNR	Srinagar	33.97	74.79	1631.64
13	RANI	Ranichori	30.31	78.41	1930.54
14	DWRK	Dwarka	22.24	68.96	-40.12
15	GOPR	Gopalpur	19.30	84.88	-15.94
16	JBPR	Jabalpur	23.10	79.99	355.09
17	GRPP	Gorakhpur	26.74	83.43	22.19
18	SGGN	Sri Ganga Nagar	29.92	73.89	132.17
19	DELH	Delhi	28.59	77.22	165.06
20	PUNE	Pune	18.54	73.84	487.72
21	BHPL	Bhopal	23.24	77.42	476.22
22	NGPR	Nagpur	21.09	79.06	253.57
23	BWNR	Bhubaneshwar	20.25	85.82	-16.72
24	PNJM	Panjim	15.49	73.83	-23.04
25	ARGD	Aurangabad	19.87	75.39	528.13

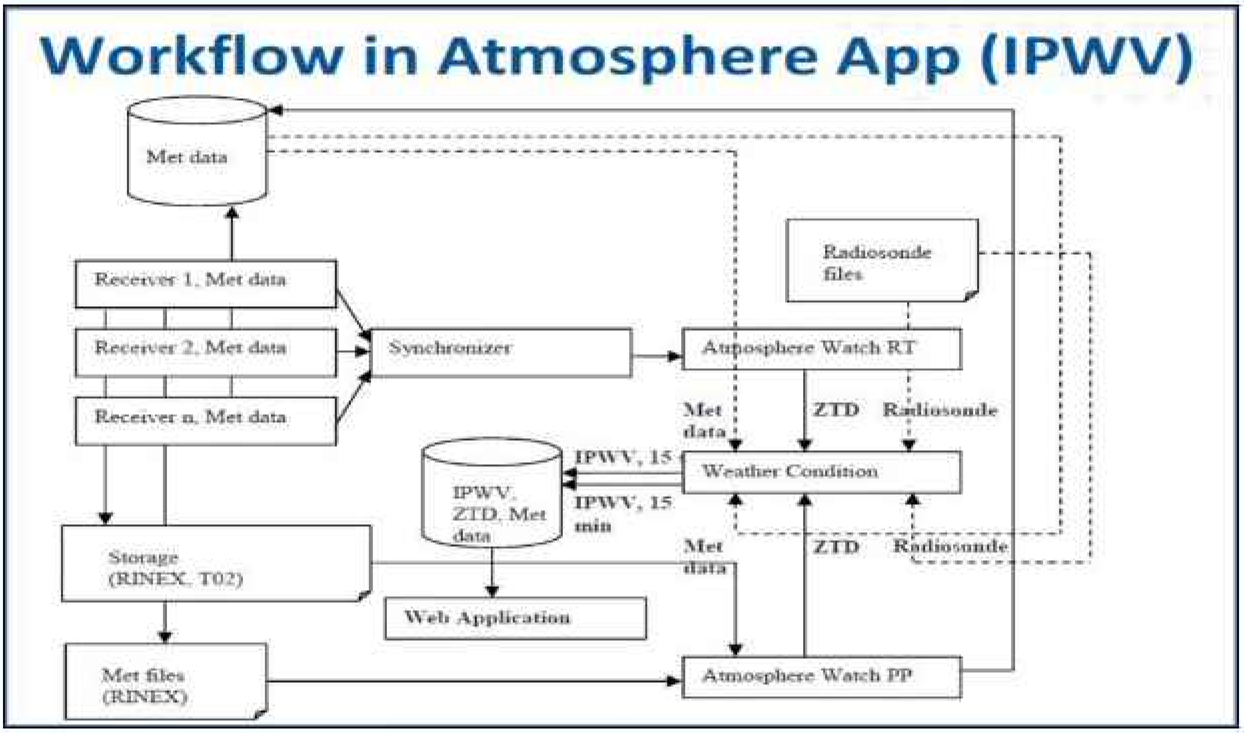

Figure 1: Work Flow in Atmospheric Application for IPWV estimation.

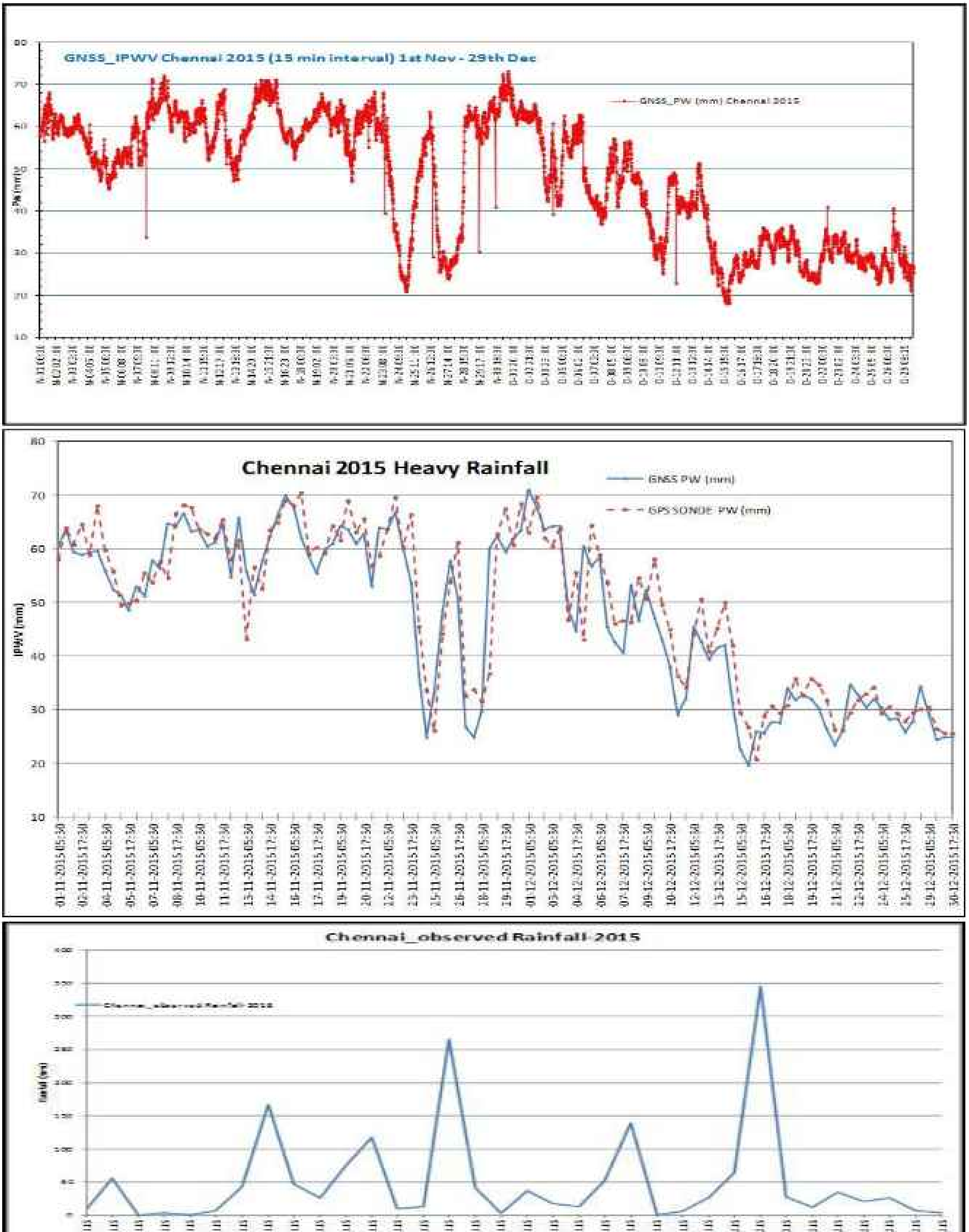

Figure 2 (a): (Top) Continuous observation of GNSS IPWV during 2015 Chennai flood (1st Nov to 29th Dec). (Middle) Comparison with GPS sonde Observation. (Bottom) Observed rainfall. Outliers also observed in GNSS IPWV might be attributed to non-availability of Met data.

2. Data and Methodology

IMD GNSS network data utilized in this study are processed operationally at IMD satellite division by Trimble TPP software. The methodology adopted at IMD is based on Bevis et al. (1992) and Bevis et al. (1994)). The schematic flow diagram of the processing chain is explained in Figure 1. The mapping of the delay of slant path to zenith direction is done by using hydrostatic and wet Mapping Functions (MFs) following Niell (1996).

3. Results and Discussion

3.1 Study of severe weather events and onset

(a) Chennai flood during November-December period (2015)

The major advantages of the GNSS measurements are that they can be performed independently, continuously on all-weather condition, high temporal resolution (a few minutes) and long term observation. Figure 2(a) shows the 2015 South Indian (Chennai) floods resulting from heavy rainfall generated by the annual North East Monsoon in November–December 2015 and the performance of GNSS IPWV observation in Figure 2(a). Figure 2(b) shows the aerial view of the flooded Chennai area.

(b) Usefulness during Cyclone

We all know that a single piece of information is really crucial during cyclone time because of the communication disruption and collection of conventional observations due to bad weather. Sometimes meteorological instruments used have their own limitations of measurements. Figure 3 depicts GNSS IPWV and its comparison with GPS sonde during VARDHA cyclone, 6-13 December-2016 (top panel). In another cyclone Ockhi (observed during 29 November 2017 to 6 December 2017), GNSS IPWV and Vaisala Pressure sensor performance is shown in the middle panel of Figure 3 at Kanyakumari on 29 & 30th November 2017.

This information of temperature and humidity are very useful in day-to-day weather forecasting and especially over those areas where conventional measurements are sparse. Figure 3 shows time series of IPWV, Temperature and Humidity at Dibrugarh station. IPWV reaches 75 mm in Dibrugarh on 4th July 2017 during monsoon time.

Figure 2(b): An aerial view of rain hit area in Chennai. The 2015 South Indian (Chennai) floods resulted from heavy rainfall generated by the annual North East Monsoon in November–December 2015. More than 500 peoples were killed and 1.8 million people displaced. With estimates of damages and losses ranging from nearly ₹200 billion to over ₹1 trillion. 1049 mm of Rainfall observed in the month of November.

(c) Monsoon monitoring studies

IMD has traditionally adopted an objective method to declare onset and withdrawal of monsoon based on rainfall over some specific stations in addition to wind field and Outgoing Longwave Radiation (OLR). An augmentation of existing criteria of monsoon onset using high temporal resolution

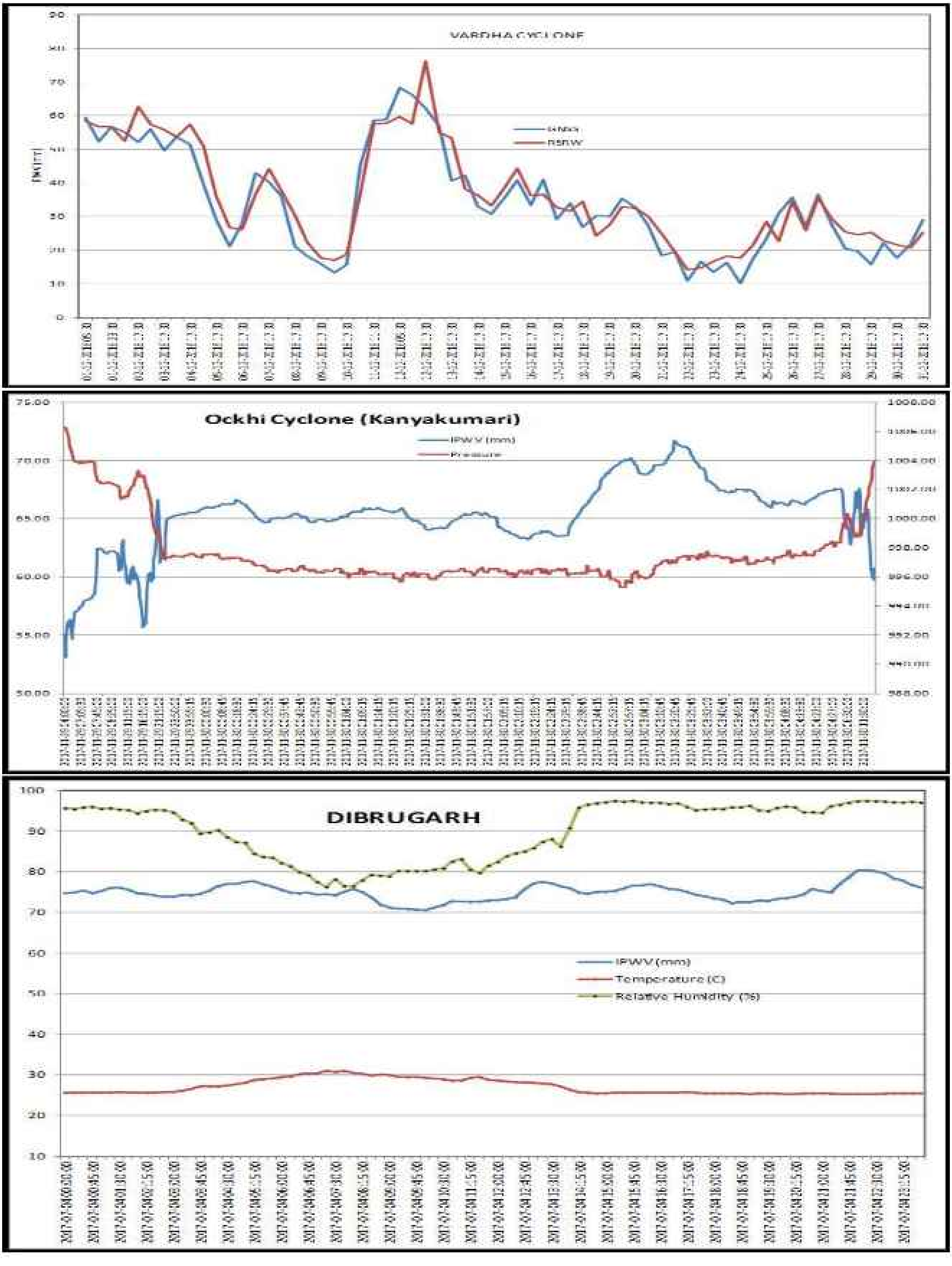

Figure 3: GNSS IPWV and its comparison with GPS sonde during VARDHA cyclone (top). GNSS IPWV and Vaisal Pressure sensor performance during Ockhi Cyclone at Kanyakumari (middle). Time series of IPWV, Temperature and Humidity data (bottom). Note: IPWV reaches 75 mm at Dibrugarh.

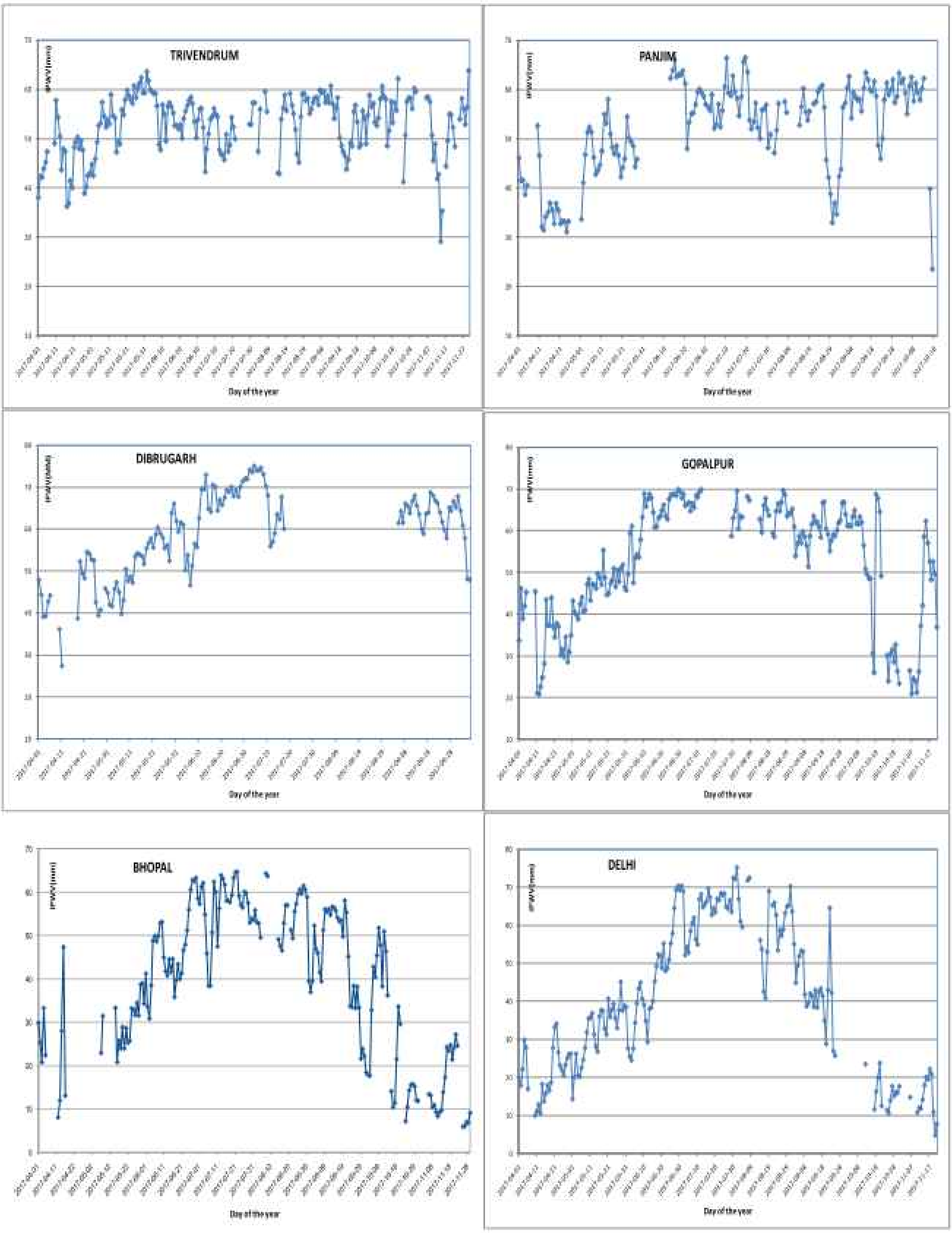

Figure 4 (a): Time Series of IPWV during Pre-monsoon and Southwest Monsoon seasons.

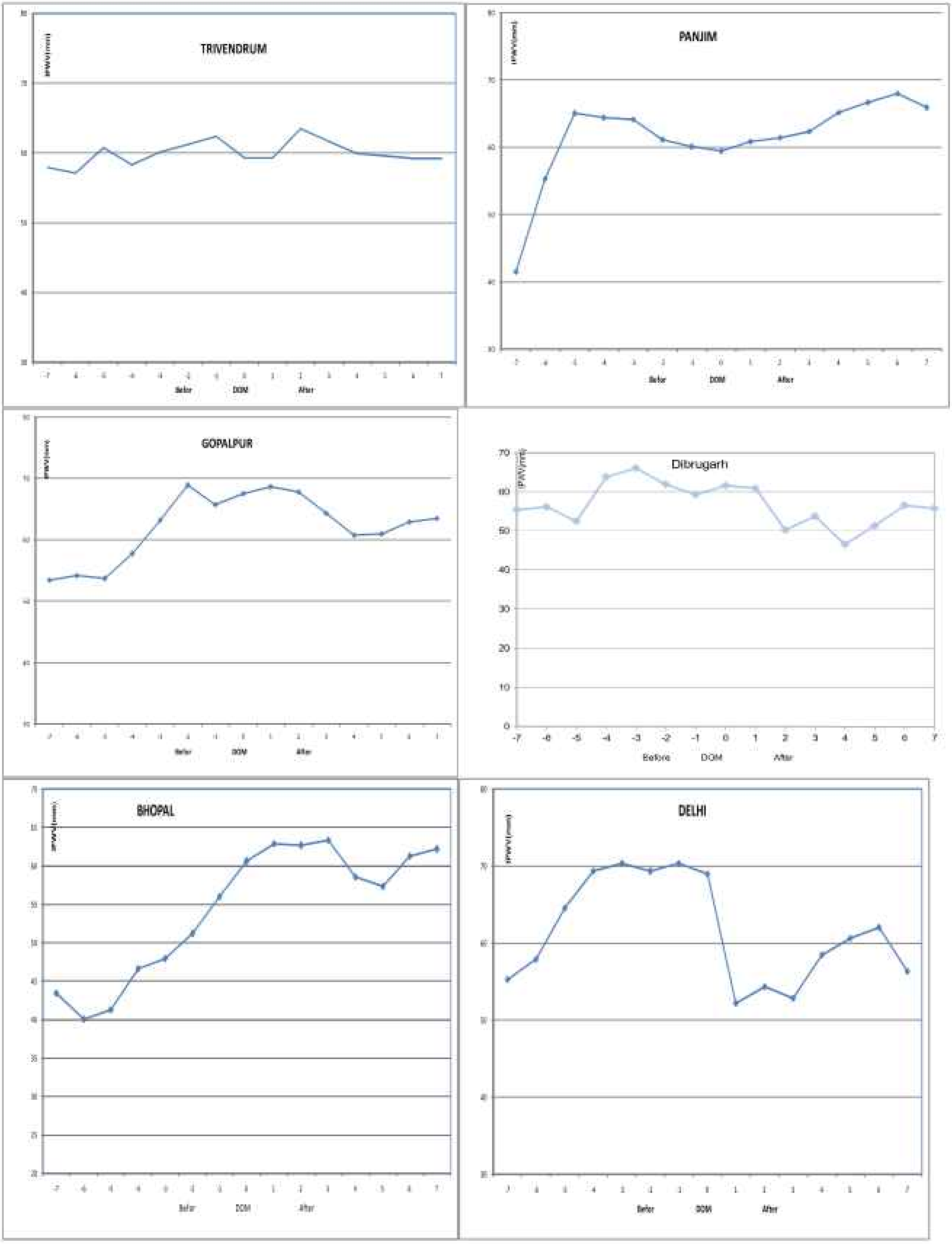

Figure 4 (b): Superposed epoch analysis of IPWV variations for 15 days with arrival date of SWM.

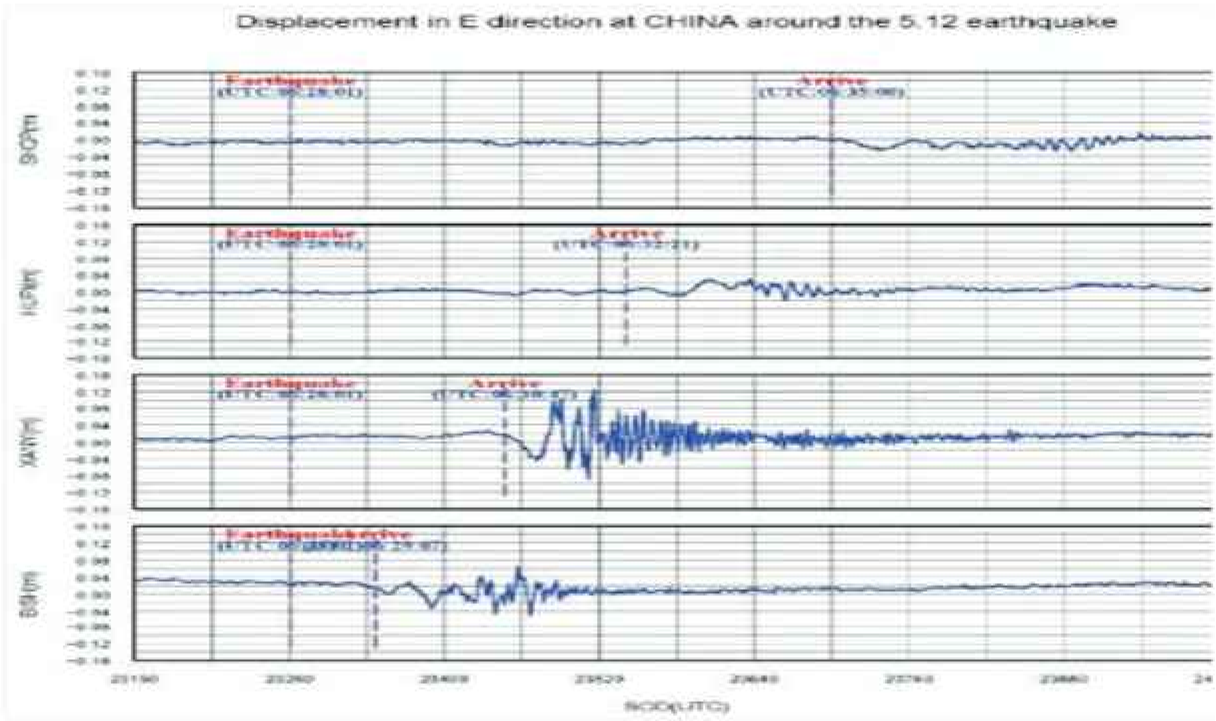

Figure 5: A high rate GNSS receiver used as an instrument to capture co-seismic waves.

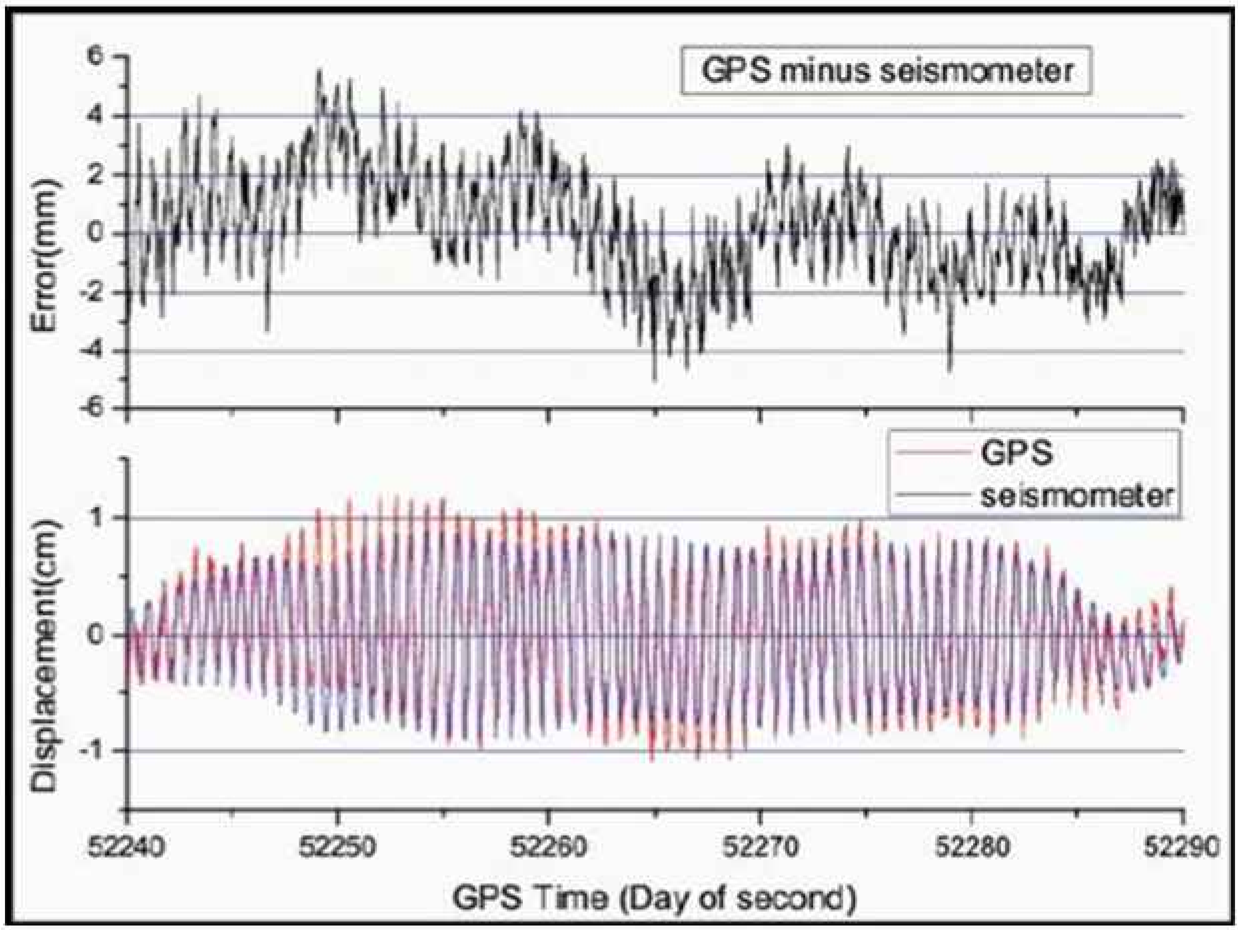

Figure 6: Comparison between GPS and seismometer (bottom) and their differences (top).

tropospheric IPWV content over a station through ground based GNSS receiver is considered for onset of monsoon. The details of onset and withdrawal of 6 stations are given in Table 2. The increase in moisture 3-4 days prior to the onset and sudden decrease during withdrawal around a station area is clearly brought out in Figure 4 (a&b).

3.2 Seismological studies

The GNSS has been widely used to study kinematic deformation. The accuracy of GNSS kinematic positioning has been significantly improved and can reach millimeter level (Elósegui et al., 2006). High-rate GNSS tracking networks have been well established, with which recent earthquakes have been successfully observed (Emore et al., 2007). A high-rate GNSS receiver that is used as an instrument to capture co-seismic waves is called a GNSS seismometer as shown in Figures 5&6.

A GNSS receiver has several advantages over a traditional seismometer. First, when the displacements of ground motions are required, GNSS can directly estimate them by range measurements and the results have no accumulated errors over time, but after integrating seismometer data to displacement, large drifts will occur. Secondly, a seismometer may be saturated in a large earthquake, in which case the instrument cannot record the full amplitude of velocity or acceleration while GNSS will not be saturated in amplitude. Thirdly, a seismometer operates based on the theory of gravity, and a tilt of the instrument can bring about artificial horizontal acceleration, but a GNSS receiver will not be affected in this way. When a seismometer is saturated and unavailable to record large or nearby earthquakes, GNSS can be a feasible tool for earthquake studies.

3.3 Accuracies of GNSS derived IPWV

In in-situ technique, a radiosonde (nowadays GPS sonde) is a balloon-borne instrument which can provide vertical profile of the atmospheric water content at various levels. IMD is taking observations from 55 sites, once/twice in a day. The radiosonde has been one of the most important devices given its long observation history in the field of meteorology. However, the accuracy of the radiosonde-derived IPWV is lower at high altitudes, and major disadvantage of using radiosondes for trend estimation is the systematic errors caused by either calibration uncertainties or sensor changes. This limits its application in the field of climate research (Ross and Elliot, Wang and Zhang (2008).

3.4 Additional capabilities

The current IMD GNSS network receiver is capable of receiving other radio navigation satellite services like GLObal NAvigation Satellite System (GLONASS) Russia, Galileo a European GNSS agency and Indian Regional Navigation Satellite System data also. Apart from 25 GNSS receiver collocated with meteorological sensor, IMD coordinated with National center of Seismology (NCS) and able to get data from their 32 stations in real time. All these 32 stations were integrated with IMD network. 50 more standalone GNSS receiver belongs to various research organization are still unconnected which require communication devices and Meteorological sensor. This work is in pipeline. MoES (Ministry of Earth science) is planning to expand IMD GNSS network with an addition of 500 GNSS receiver The processing software needs some up gradation to process and dissemination of tailor made products from other navigation system data.

4. Conclusions

The current IMD network of GNSS is configured for 25 IMD stations along with 32 NCS stations for monitoring the near real time IPWV data at 15 minutes interval. This information is available and accessible for the user community at IMD website. The information retrieved from the GNSSS network is very useful in now-casting the weather events and monitoring the progress of the monsoon. Preliminary results of six stations (Thiruvananthapuram, Panjim, Delhi, Bhopal, Dibrugarh, Gopalpur) show that IPWV values reach 60 mm or more 3-4 days prior to the onset of monsoon (declared by IMD). The long-term measurement of the IPWV is of great importance due to its role as an independent data source to detect climate changes. Given its long-term stability and high accuracy, the GNSS-derived IPWV is

Table 2. Comparison of SWM arrival/withdrawal date with GNSS IPWV observations.

Station	Arrival of SWM Normal/Declared	Changes in IPWV>60mm	Withdrawal of SWM Normal/ Declared	Changes in IPWV<30mm
Thiruvananthapuram	1st June /30th May	25th May		
Panjim	10thJune/8th June	3rd June	1/2 Oct / 25th Oct	17th Oct
Gopalpur	10thJune/12thJune	9th June	15thOct/ 17thOct	23rd Oct
Dibrugarh	5th June/ 2ndJune	29th May	15thOct ,17/23Oct	18th Oct
Bhopal	5thJune/26thJune	26th June	1st Oct/ 15th Oct	15thOct
Delhi	29thJune/2ndJuly	27th June	15/16thSep 30Sep/10thOct	12thSep

desired for the climate applications in terms of the estimation of linear IPWV trends.

Acknowledgement

Authors are grateful to Director General of Meteorology of IMD for data support to accomplish this task.

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