GNSS Meteorology for Nowcasting

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Introduction to the Problem

- WV is a small fraction of atmospheric gases (fractional volume 0 - 4 %).
- Highly variable in time and space and correlates poorly with surface humidity measurements.
- Distribution and content are critical for the description of the state and evolution of the atmosphere.
- Lack of precise and continuous WV data is one of the major error sources in short-term forecasts of precipitation

Existing PW measurement techniques:

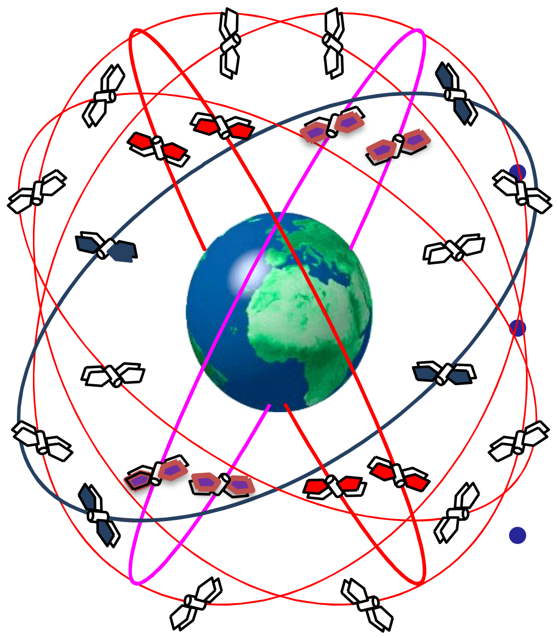
- Radiosondes provide tropospheric moisture profiles, Limited spatial and temporal coverage
- Surface-based radiometers are capable of high temporal resolution high resolution but are costly, require frequent calibration, and their performance is adversely affected by the presence of rain.

- Satellite-based infrared (IR) and microwave sensors offer planetary scale coverage, reliable only in cloud-free regions,
- Microwave sensor-based retrievals, although valid in cloudy regions, reliable over oceans and have limited temporal resolution.
- Less reliable during severe weather condition

A new observational technique

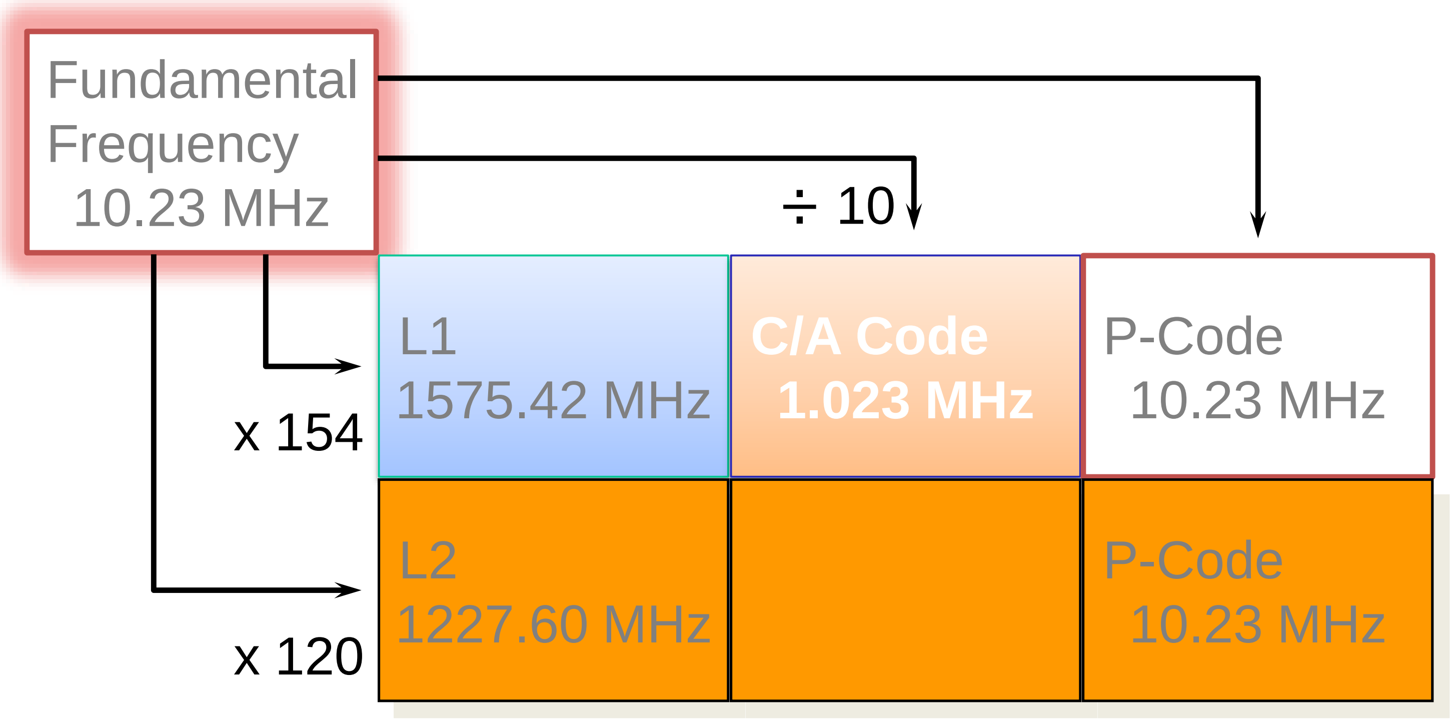
GNSS-IPWV

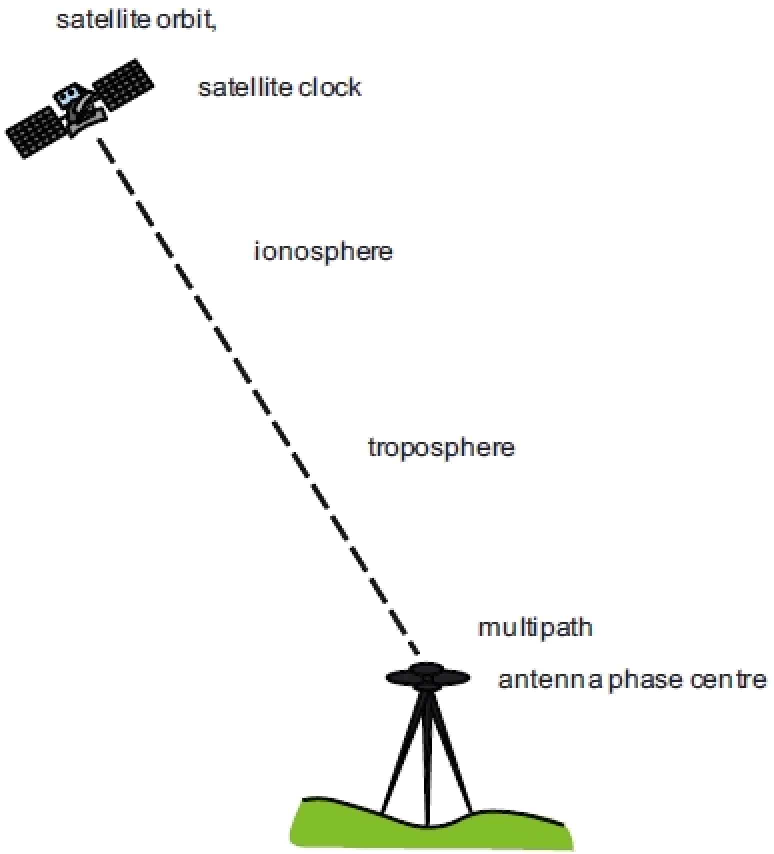
What is GNSS (GPS, GLONASS, GALILEO, COMPASS,NavIC)?

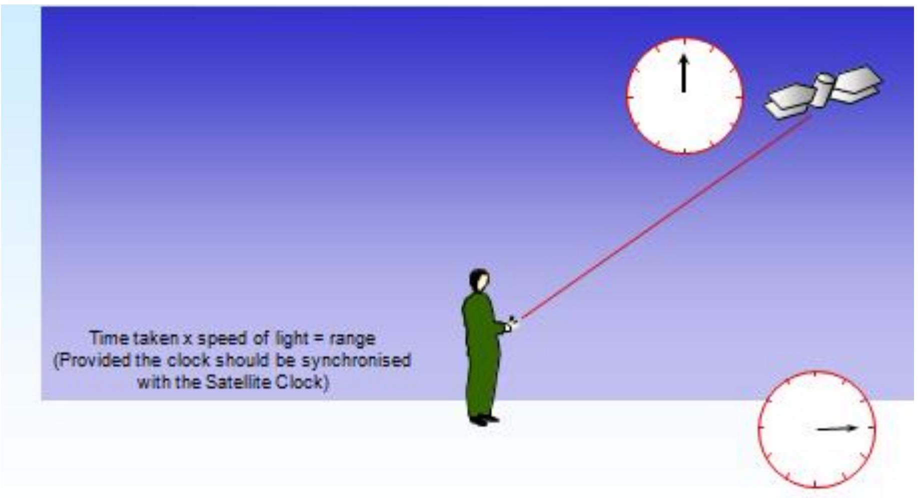


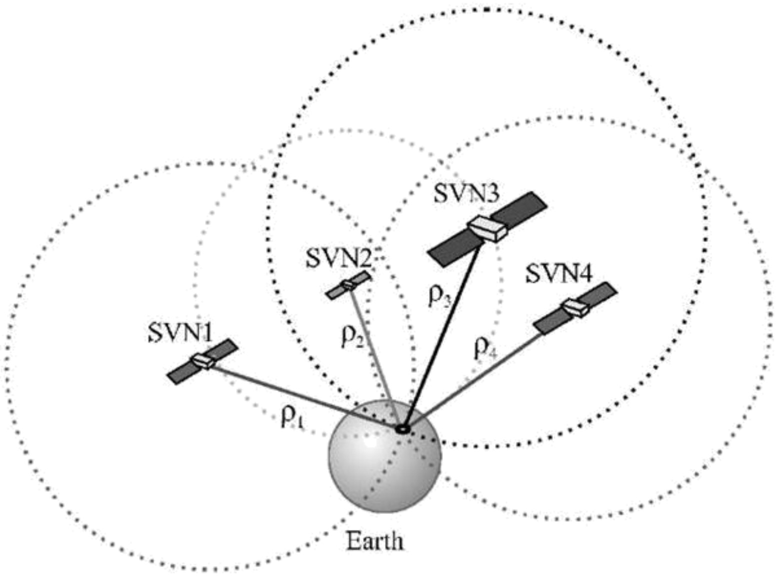
- The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites in Six orbital Plane (US) 20,200 km above Earth
- 55º Inclination to the Equator, Orbital period of 12 hour , 4 Satellite per orbital plane. Total 27 satellites including 3 spares.
- GPS satellites Caries Atomic Clock onboard and transmit two low power radio signals, L1=1575.42 MHz and L2 =1227.60 MHz . Base frequency (L = 10.23 MHz)
- GLONASS, GALILEO and COPASS , each having their own altitudes and inclination and number of Satellites.
- IRNSS/NavIC- 3 satellites in Geostationary orbit & 4 satellites in Geosynchronous orbit.

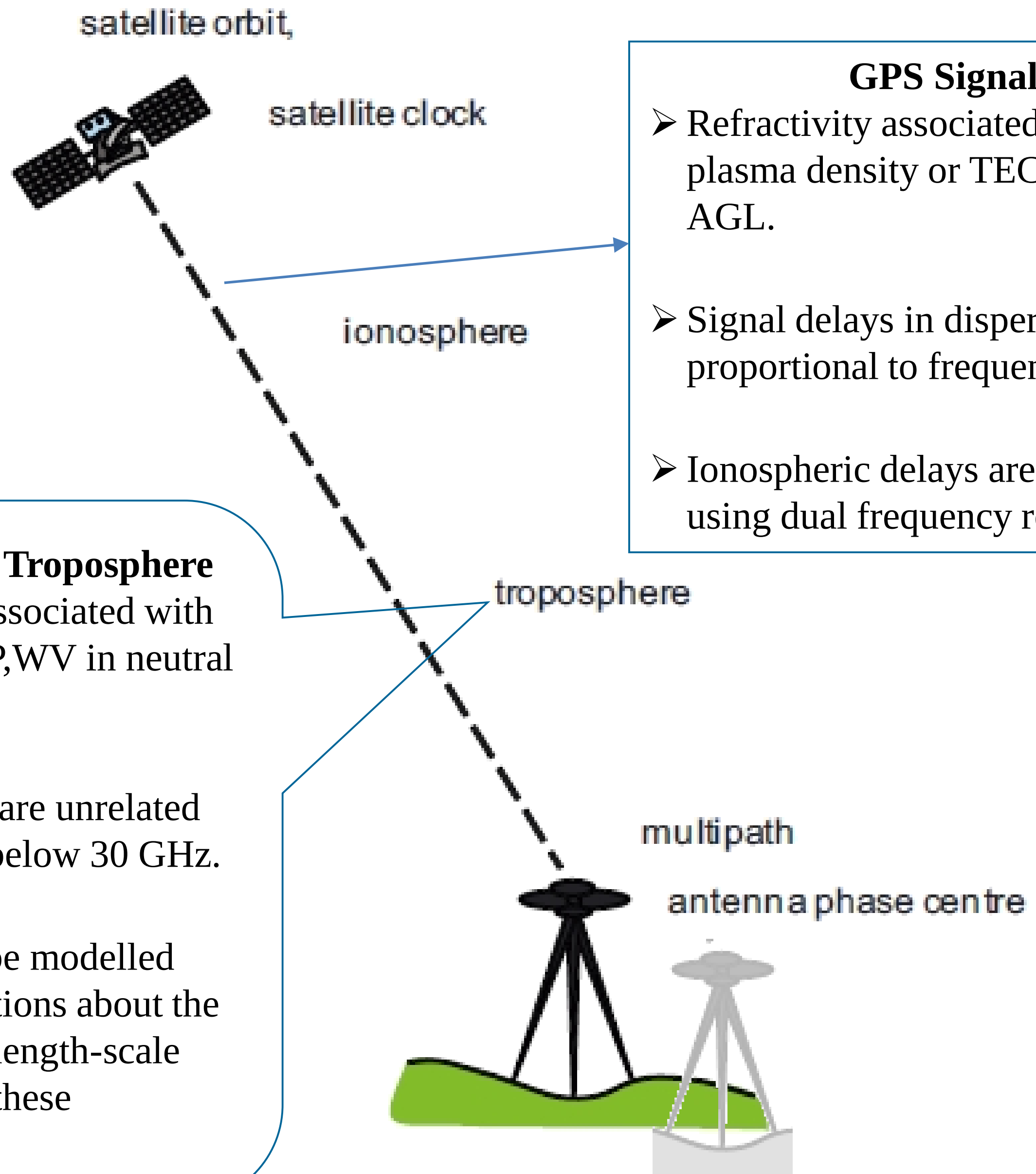
Satellite Signal




satellite orbit,
satellite clock
ionosphere
troposphere
multipath
antenna phase centre


Time taken x speed of light = range
(Provided the clock should be synchronised
with the Satellite Clock)


SVN1
SVN2
SVN3
SVN4
ρ_1
ρ_2
ρ_3
ρ_4
Earth



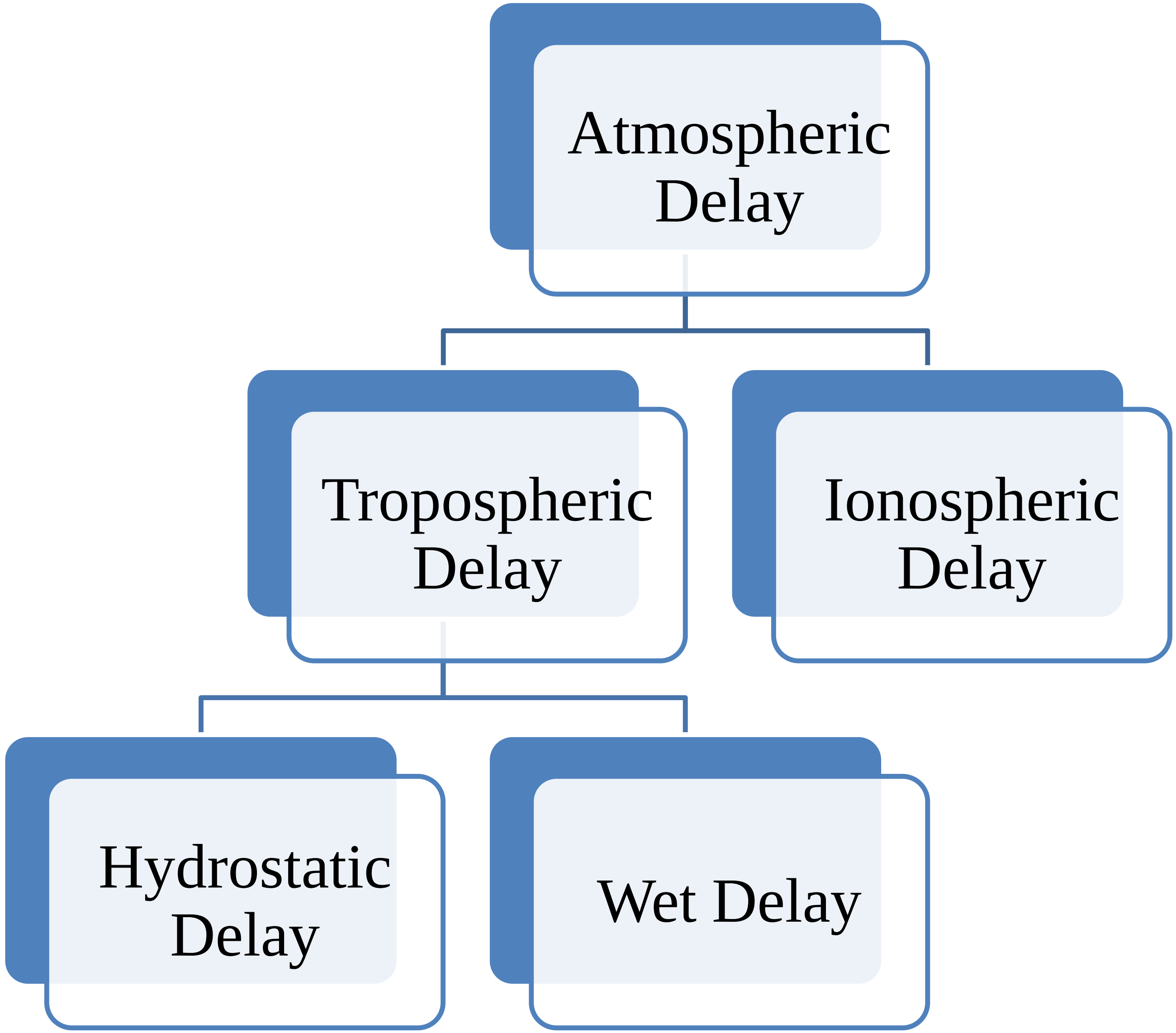
GPS Signal in Ionosphere

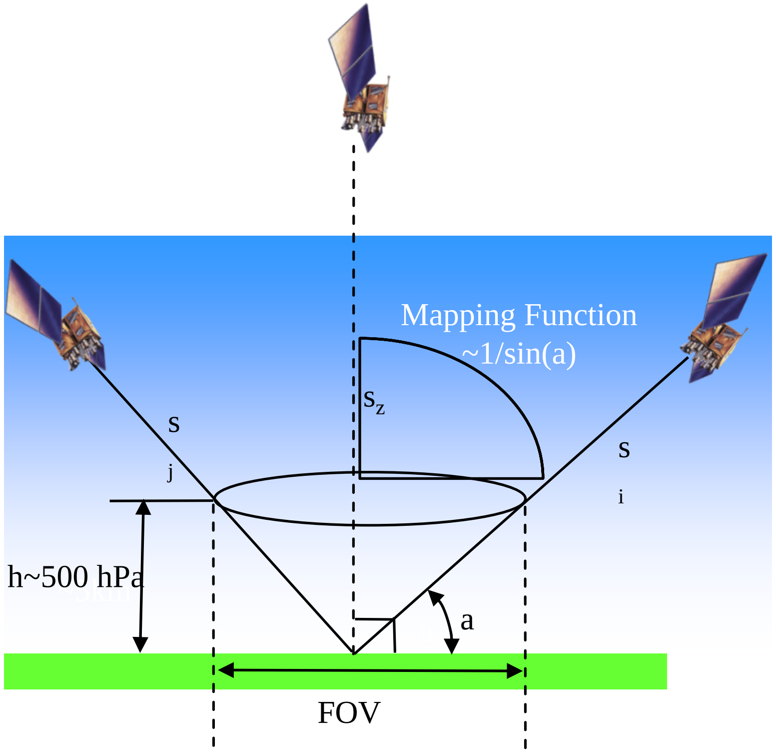
- Refractivity associated with changes in electron plasma density or TEC between 50 and 400 km AGL.
- Signal delays in dispersive media are inversely proportional to frequency.
- Ionospheric delays are estimated (or removed) using dual frequency receivers.

GPS Signal in Troposphere

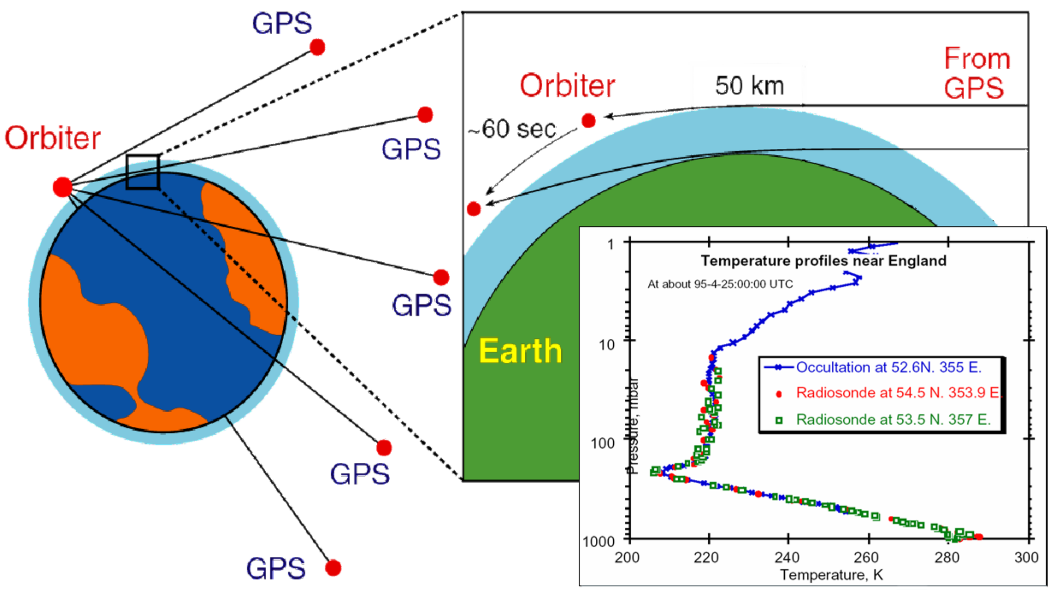
- Refractivity associated with changes in T,P,WV in neutral atmosphere.
- Signal delays are unrelated to frequency below 30 GHz.
- Delays must be modelled using assumptions about the structure and length-scale variability of these parameters.

- GPS was initially designed and developed by the U.S. military for navigation, the use of GNSS for atmospheric remote sensing is a complementary.
- The techniques developed by geodesists to estimate atmospherically induced signal delays as nuisance parameters in the calculation of antenna position, and remove them to improve survey accuracy, were not developed to improve weather forecasts.
- Latter it was proved that ground based and space-based GNSS observations could be used for atmospheric remote sensing with applications in operational weather forecasting, climate monitoring and atmospheric research.


Atmospheric Delay
Tropospheric Delay
Ionospheric Delay
Hydrostatic Delay
Wet Delay



$$\Delta s = 10^{-6}\int_S N(s)ds$$



Tropospheric Delay Or Zenith Total Delay(ZTD)=Zenith Hydrostatic Delay(ZHD)+Zenith Wet Delay(ZWD)

The tropospheric delay of the GPS signal is the integral of the refractivity N along the ray path.
Neglecting liquid water contribution and ionospheric effects (Smith and Weintraub 1953),

$$N = k_1\left(\frac{P_d}{T}\right) + k_2\left(\frac{P_w}{T}\right) + k_3\left(\frac{P_w}{T^2}\right)$$

$$N = N_{hydrostatic} + N_{wet}$$

N=refractivity, k_3 $k_{2,}$ *and* k_2' are physical constant ,T=temperature

ZTD is computed with a formal error of <u>5 mm</u> (Businger et al. 1996) at around <u>10-min</u> interval.

Zenith Hydrostatic Delay

$\int N_{hydrostatic}$ ➡ Zenith Hydrostatic delay (ZHD)

- typical value of 2300 mm at sea level
- accurately modeled if measurements of surface pressure (barometer or a NWP model) are available (Saastamoinen 1972).
- error of 0.4 mb in P_s cause less than 1 mm error of ZHD

Zenith Wet Delay

$\int \mathrm{N}_{\mathrm{wet}}$ → Zenith Wet delay (ZWD)

$$IWV = \int \rho_v dz = k \Delta L_w^0$$

$$1/k = 10^{-6}(k_3 / T_m + k_2^{'}) R_v$$

$$T_m = \frac{\int P_v / T dz}{\int P_v / T^2 dz}$$

$$T_m = 55.8 + 0.77 T_s$$

ΔL is the total delay in the neutral atmosphere

k_3 $k_{2,}$ *and* $k_2^{'}$ are physical constant

ρ is the density of liquid water,

R_v is the specific gas constant for water vapour,

Tm= mean temperature , Ts=surface temperature

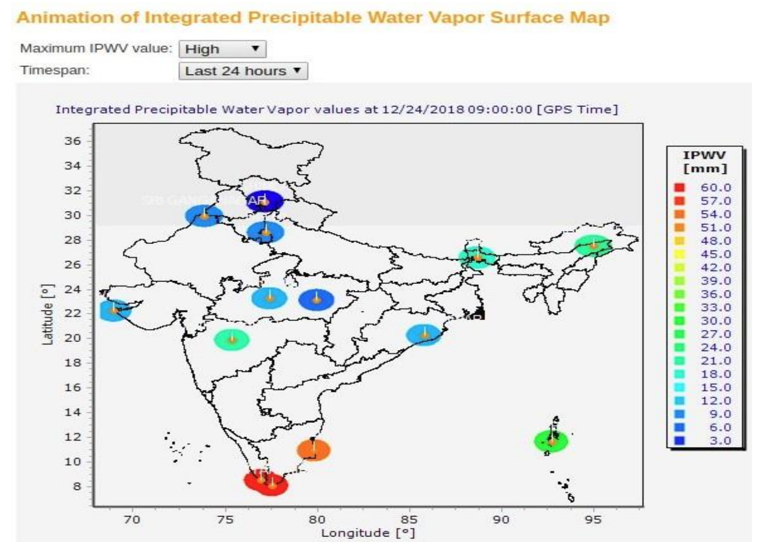
IMD GNSS network (25 number) contains the following major component-

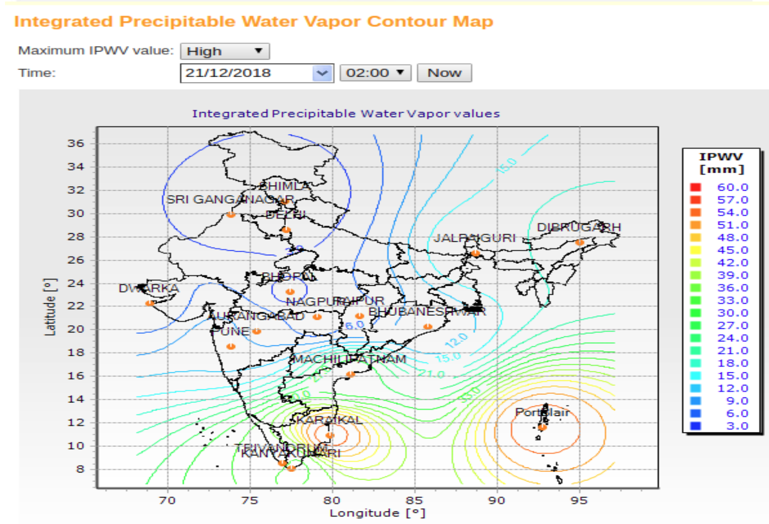
1. GNSS Antenna & Radome
2. GNSS Receiver
3. Surface Meteorological Sensor
4. Mount & Lightning arrestor/surge Protector
5. Communication devices
6. UPS etc.

Fig. Vaisala Meteorological Sensor Co-located with GNSS Antenna. Station - Delhi.

IMD installed 25 GNSS all over India and streaming data near realtime and processing in the network.

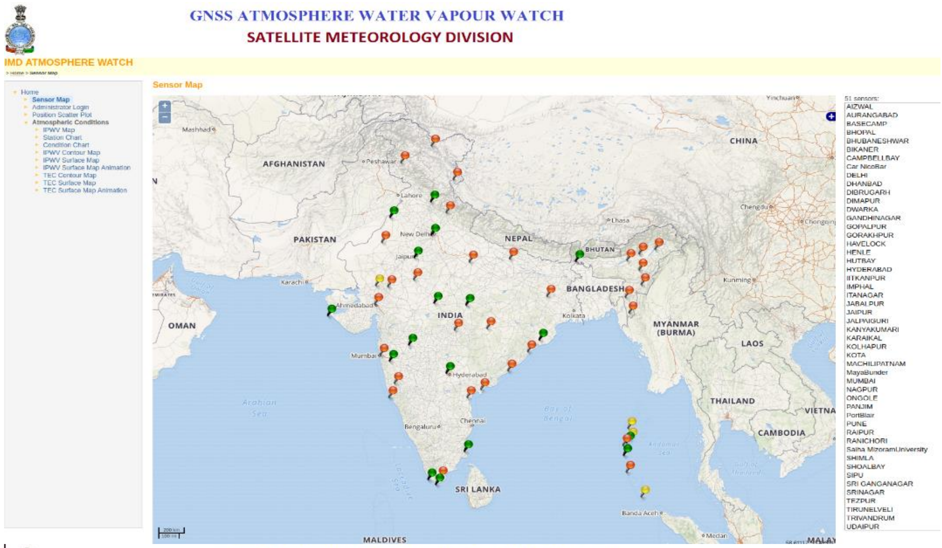
S.No.	Station Code	Satations Name	Latitude	Longitude	Elipsoid Height(m)
1	JIPR	JAIPUR	26.82	75.82	335.37
2	RIPR	RAIPUR	21.21	81.66	245.56
3	TRVM	TRIVANDRUM	8.51	76.96	-18.44
4	KRKL	KARAIKAL	10.91	79.84	-79.07
5	KYKM	KANYAKUMARI	8.08	77.55	-49.23
6	MPTM	MACHILIPATNAM	16.18	81.15	-61.07
7	ITNG	ITANAGAR	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

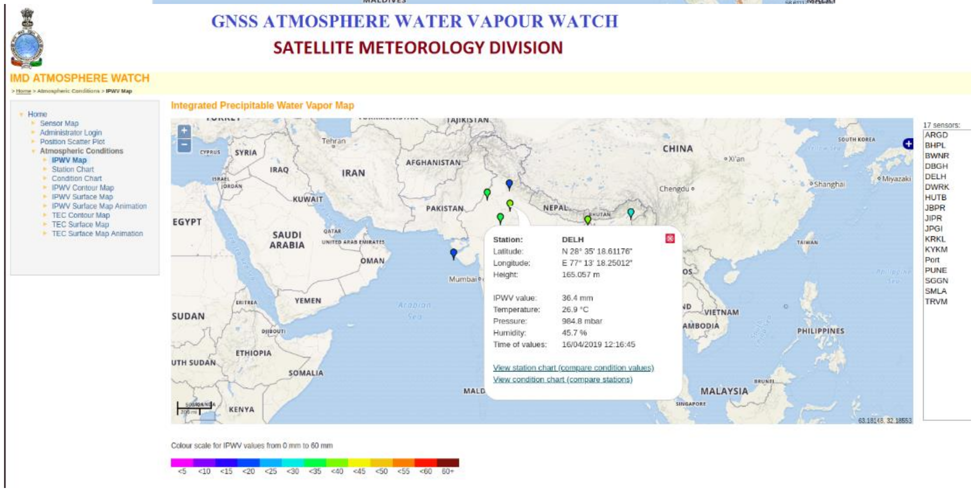




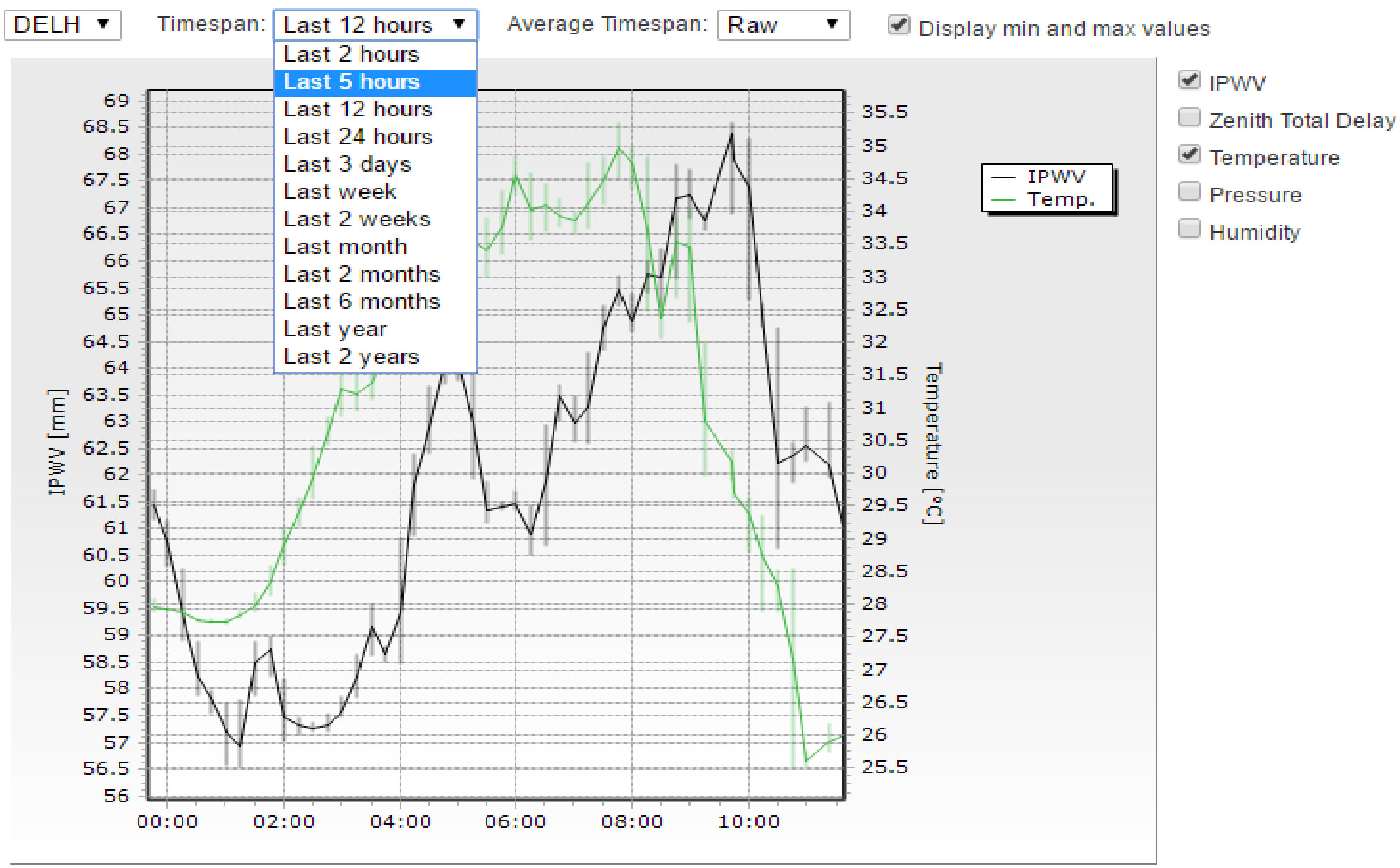
GNSS Data on Public Domain

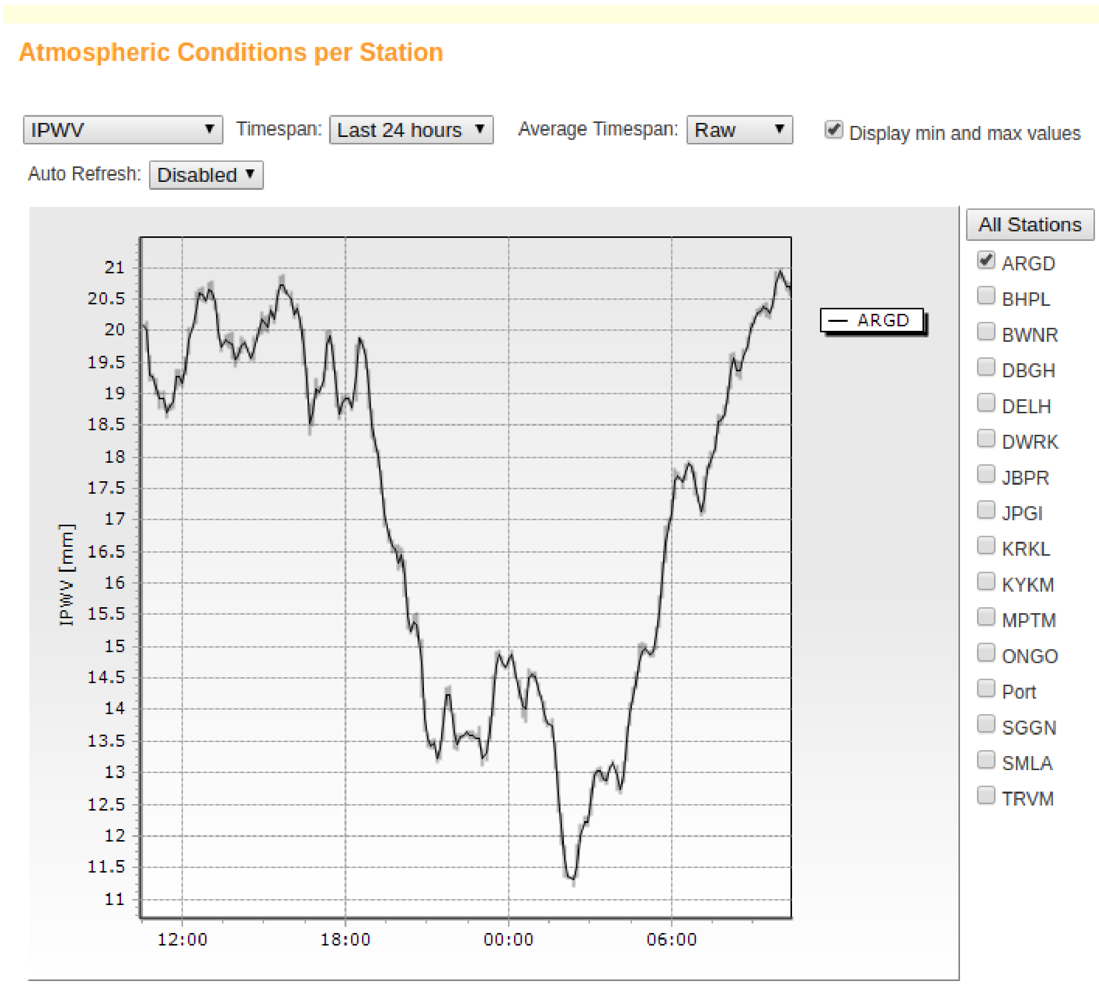
The real time GNSS IPWV estimated from IMD network is available in the public domain. Tools are available to plot real time, daily, weekly and monthly data with maximum and minimum values. The web page also show the status of GNSS. On mouse click it will show the lat/long, time, IPWV, temperature, humidity and Pressure data. Real time PW at every min is possible but less accuracy(Assuming there is no error in the signals).



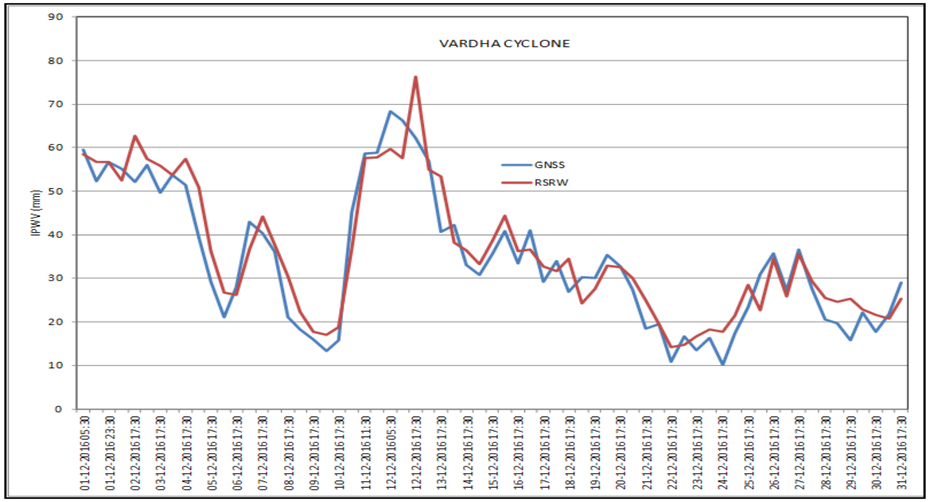


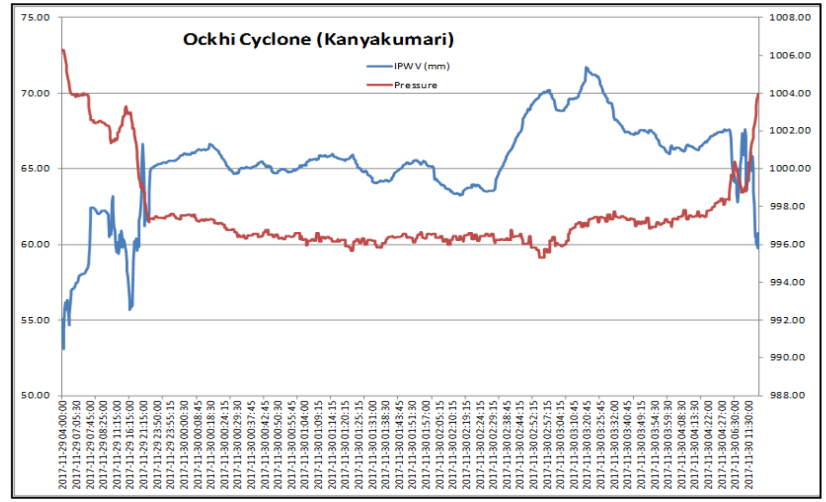
IMD GNSS Network Real Time PWV

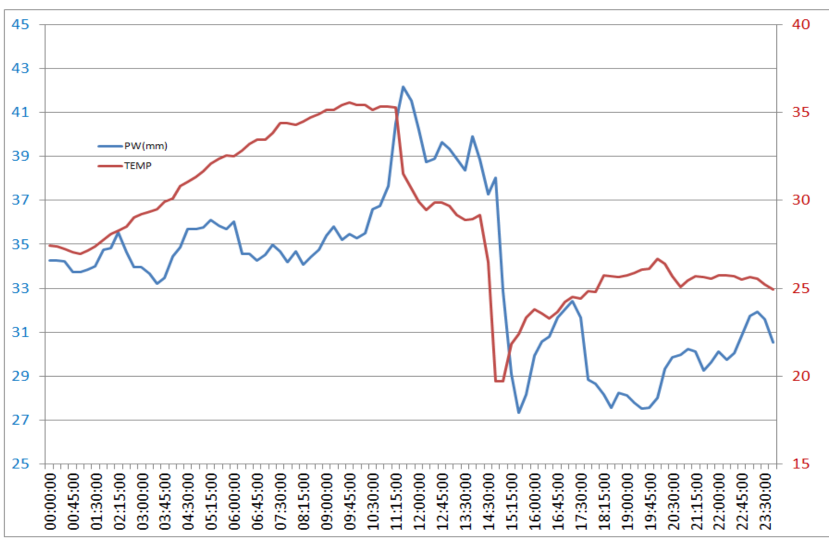



Atmospheric Conditions per Station
IPWV
Timespan: Last 24 hours
Average Timespan: Raw
Display min and max values
Auto Refresh: Disabled
IPWV [mm]
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
12:00
18:00
00:00
06:00
ARGD
All Stations
ARGD
BHPL
BWNR
DBGH
DELH
DWRK
JBPR
JPGI
KRKL
KYKM
MPTM
ONGO
Port
SGGN
SMLA
TRVM

GNSS perfomance during cyclone and Now casting of thunderstorm activity over the station

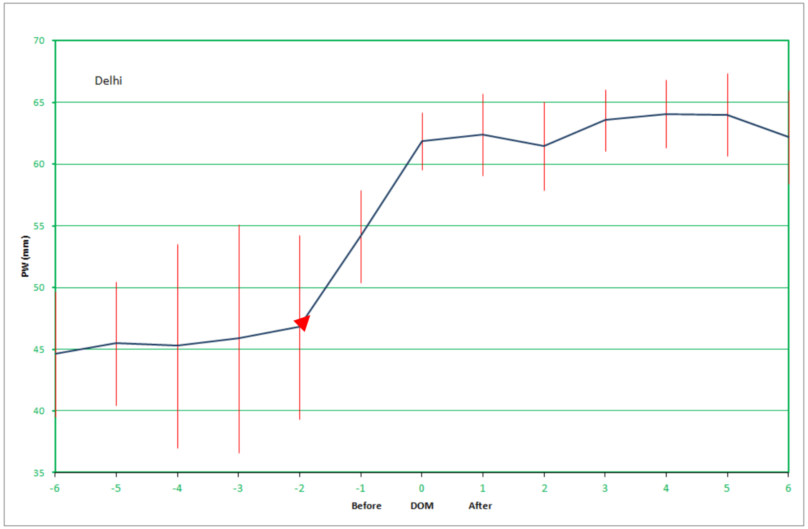






GNSS IPWV and its comparison with GPS sonde during VARDHA cyclone (Right). GNSS IPWV and Vaisal Pressure sensor performance during Ockhi Cyclone at Kanyakumari (Right). Time series of IPWV, Temperature data. (The IPWV reaches 42 mm in Delhi and rain was recorded by ARG 15.2mm on 2nd May 2018)

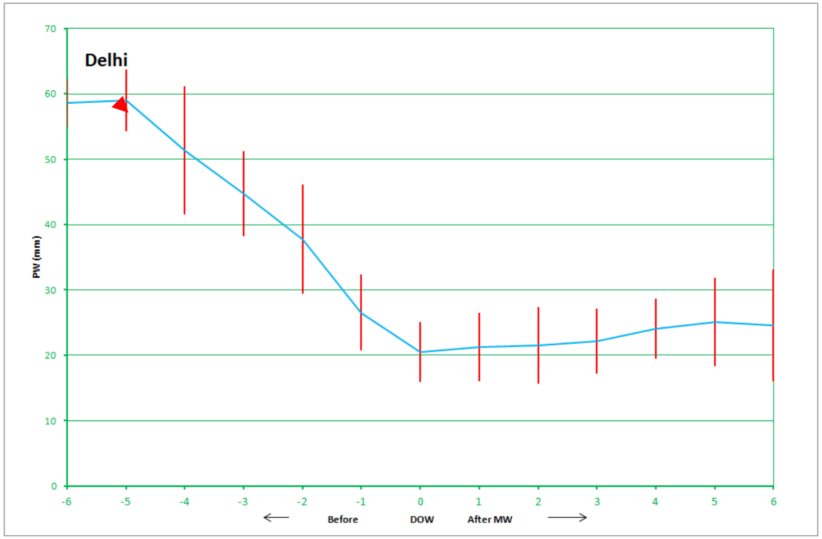
Variation of Water Vapour derived from GNSS at the time of Monsoon (Year 2018)



Monsoon Arrival

- PW/SD increased from 44.6/5.0 mm to 61.88/2.3 mm (monsoon arrived)

Monsoon Withdrawal



- PW/SD Decreased to 20.4/2.6 (monsoon withdrawn)

GPS_PWV IMD NEW DELHI

Accuracy of PWV

- Real time PW at every min is possible but less accuracy (Assuming there is no error in the signals). Standalone system.
- Real time Post processed (15 min int). Requires more than 5 stations data in real time and ultra Rapid orbit information.
- High accuracy PW for climate studies available only after two weeks (for researchers) – Require precise orbital information of the satellites, minimum 5 stations data.
- The accuracy of PW increases provided the coordinate of the stations accuracy increases.
- For better accuracy of PW the distance between any two station not more than 300 KM

Other Major application of Ground based GNSS Receivers

- Reference stations,
- Time transfer,
- Plate Tectonic and Seismic studies
- Land Movement,
- Tsunami studies
- Ionospheric studies etc.,

Conclusion

- IMD installed 25 GNSS all over India and streaming data near realtime and processing in the network.
- IMD also coordinating to receive GNSS data in real time from other organisation such as INCOIS, NGRI, etc.
- All over India more than 100 GNSS stations are existing but most of them are standalone system.
- IMD requires atleast 500 GNSS stations to accurately model the water vapor content in real time.
- The equipment is cheap and easy to install.
- The website for accessing GNSS data is developed and available for general forecasters.

Thank you