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Research Article

DETERMINATION OF PRECIPITABLE WATER VAPOUR USING GLOBAL POSITIONING SYSTEM

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ABSTRACT
Weather Forecast has become an essential component for prediction of occurrence of events like precipitation leading to flood hazards. Global Positioning System is an effective tool for extracting various atmospheric parameters like precipitable water vapour, gradient of water vapour, temperature and pressure etc. The conventional methods of estimating the atmospheric precipitable water vapour (PWV) has some drawbacks. This study focuses on near precise determination of atmospheric precipitable water vapour using Global positioning system technology utilizing GAMIT GPS data processing software. The results indicated that this technology can be effectively used for the determination of precipitable water vapour in near real time.

***Key Words**: Global Positioning System, Precipitable Water Vapour, Radiosonde, Zenith Total Delay, Zenith Hydrostatic Delay, Zenith Wet Delay*

INTRODUCTION
The Global positioning system (GPS) is a satellite navigation system widely adopted for instantaneous position and the velocity at a point anywhere on the surface of the Earth in any weather condition. Atmospheric parameters like precipitable water vapour, gradient of the water vapour, temperature & pressure, total electron content plays an important role in short term weather forecast. This will help in monitoring flood hazards The GPS signals from the satellite are travelling through the atmosphere to reach the receiver (Parkinson & Spilker, 1996; Rabbany, 1997). The signals are delayed due to ionosphere and troposphere. These delays are considered to be the error sources in the GPS positioning, but on the other side, these are taken as signals for atmospheric monitoring. Observed delays can be of two types. One is from the ionosphere and other is from troposphere. The ionosphere is considered to be a dispersive medium, which contain ionized molecules and electrons. The delay from the ionosphere has been found to be inversely proportional to frequency. These delays can be modelled easily using observations at different frequencies. Troposphere is a neutral medium, which contains air in the upper part and water vapour in the lower layer. It has been found that 90% of the water vapour is present in the lower layer of the troposphere. Generation of the bipolar moments due to gases and water vapour are the main cause of signals delay in the troposphere (Shreshtra, 2003). These delays can be modelled from the GPS observables (Neill, 1996). The delay caused due to air and water vapour is termed as hydrostatic and wet delays respectively. The wet delay is converted into precipitable water vapour using "Π" which is the function of atmospheric mean temperature (Moon *et al.*, 1996).
The question of monitoring atmospheric precipitable water vapour with greater accuracy, economically and in real time is troublesome and challenging to the various researchers working in the field of meteorology. The conventional methods like radiosonde for estimating the atmospheric precipitable water vapour (PWV) have some or the other drawbacks. Radiosonde method of PWV determination experiences various limitations like inaccuracy, delay in time of determination due to their release twice daily at a limited number of weather observation stations (jade *et al.* 2005). A second significant flaw involves the flight path of the radiosonde. Ideally, forecasters would desire a straight vertical (zenith) flight path, as the precipitable water over a given location depends only on the atmosphere directly overhead. However, a ballooned instrument like a radiosonde is highly susceptible to drifting off at the

whim of the atmospheric currents and conditions, seldom maintaining its desired flight path. Additional complications are caused by radiosonde surface launch station during its flight through the atmosphere. This flight trajectory can range from minutes to an hour, all depending on how fast the atmospheric conditions permit the ballooned instrument to ascend to its full altitude. The flight time aspect also makes it impossible to achieve the desired real-time capability (David, 2002).

This study has been carried out for the determination of PWV in near real time at GPS permanent station at Indian Institute of Technology (IIT) Bombay using Global Positioning System. The GAMIT GPS data processing software has been used for processing the GPS data for Zenith total delay (ZTD) determination.

MATERIALS AND METHODS

Determination of Zenith Total Delay

The GAMIT is GPS data analysis package developed at Massachusetts Institute of Technology (MIT) and Scripps. It uses the GPS broadcast carrier phase and pseudorange observables to estimate three-dimensional relative positions of ground stations and satellite orbits, atmospheric zenith delays, and earth orientation parameters. The software is designed to run under any UNIX operating system. The main advantage of the software is that it can be effectively used for the real time analysis of the estimates of the parameters. The processing strategies and setting of the parameter has to be improved for getting the more accurate estimation.

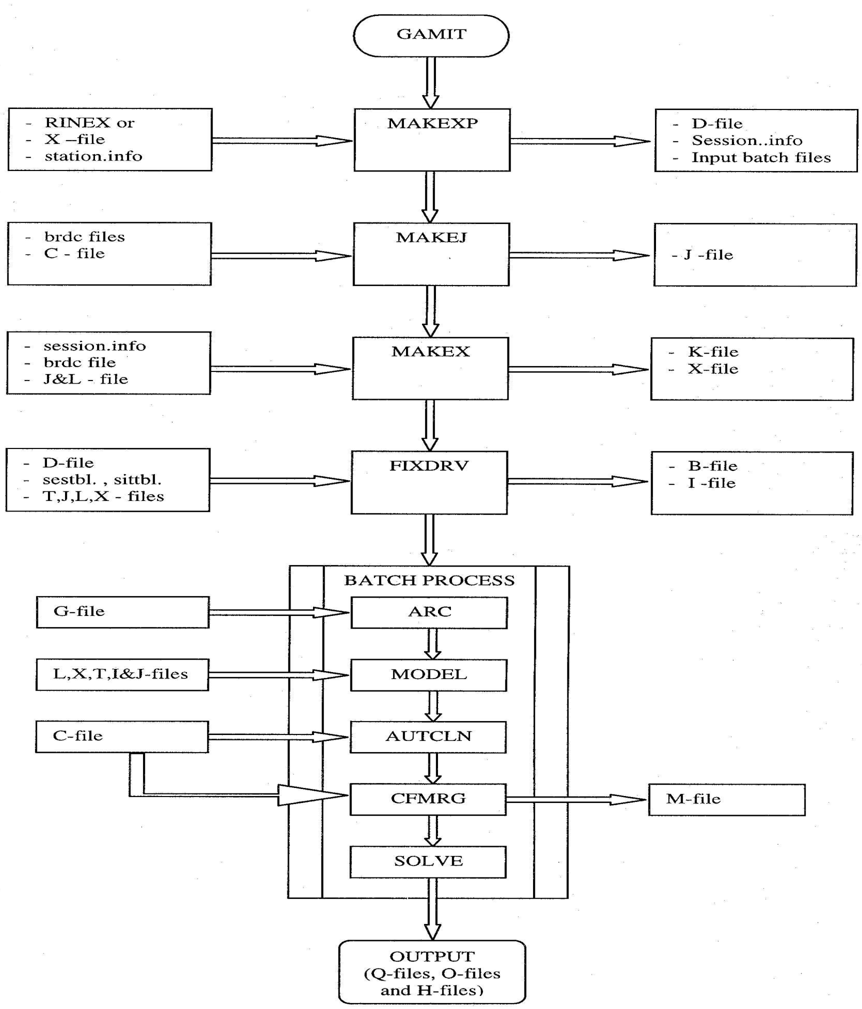

Figure 1: General layout of GAMIT processing

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GPS data was processed for IIT Bombay permanent reference station for the estimation of the ZTD. Due to the automatic batch processing the solutions can be made available in near real time. The estimation of the ZTD was carried out at an interval of every two hours. The GPS data was processed using ultra rapid orbits and G-file (precise orbits). G-file has got the accuracy as the precise orbits. The important input files which are available in the tables and templates were all updated file for the year 2005. The coordinates of the IIT Bombay was loosely constrained where as the International GPS station (IGS) coordinates are tightly constrained. The elevation cut off angle used was 15º **(**Marini, 1972; Yilmaz and Jacob, 2005; Herring *et al*., 2003**)**. The model used for the ZTD estimation was piecewise linear. The procedure that GAMIT follows for the estimation of the ZTD consists mainly of four different modules. The first MAKEXP creates driver file for the session, session information file and batch input files from the rinex observation files and the station information file. Secondly, MAKEJ using the information in global broadcast navigation file and the partial derivative in the observation file creates the satellite clock information file. MAKEX using the session information, satellite clock information and predetermined coordinate information of the station creates values of receiver clock offset during observation span, from pseudorange and input observation file**.** Lastly FIXDRV running with different modules creates the output files of ZTD which is written to the O-file. The general layout of the processing is shown in the Figure 1.

Determination of the Zenith Hydrostatic Delay (ZHD)

Hydrostatic delay was determined using regression model developed for the IIT Bombay reference station. Radiosonde data for the pressure and temperature was analyzed for the year 2005.

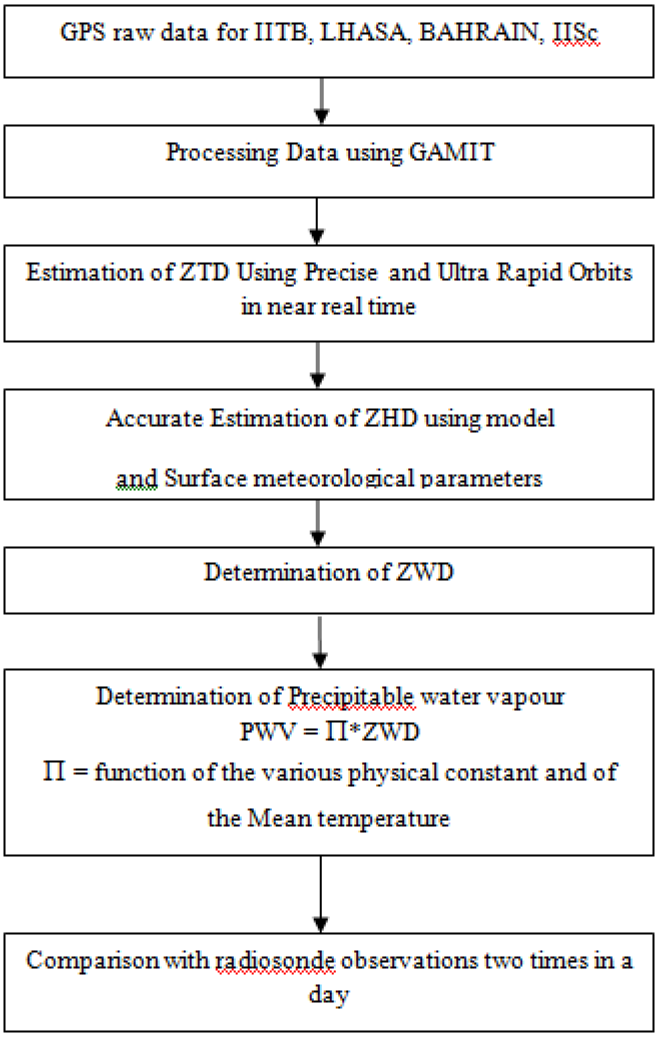

Figure 2: GPS PWV methodology (Jade *et al*., 2005)

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The regression equation used for the atmospheric mean temperature was $267+0.0705*T_s$ where Ts is the surface temperature. The methodology adapted for the estimation of precipitable water is shown in Fig 2.

RESULTS AND DISCUSSIONS

Seasonal Variation in ZTD Computed using GAMIT at IIT Bombay-2005

The seasonal variation in the ZTD computed using GAMIT at IIT Bombay in the year 2005 from January to December is shown graphically in Figure 3 below. It is observed that the ZTD values are high during the rainy months of June- September.

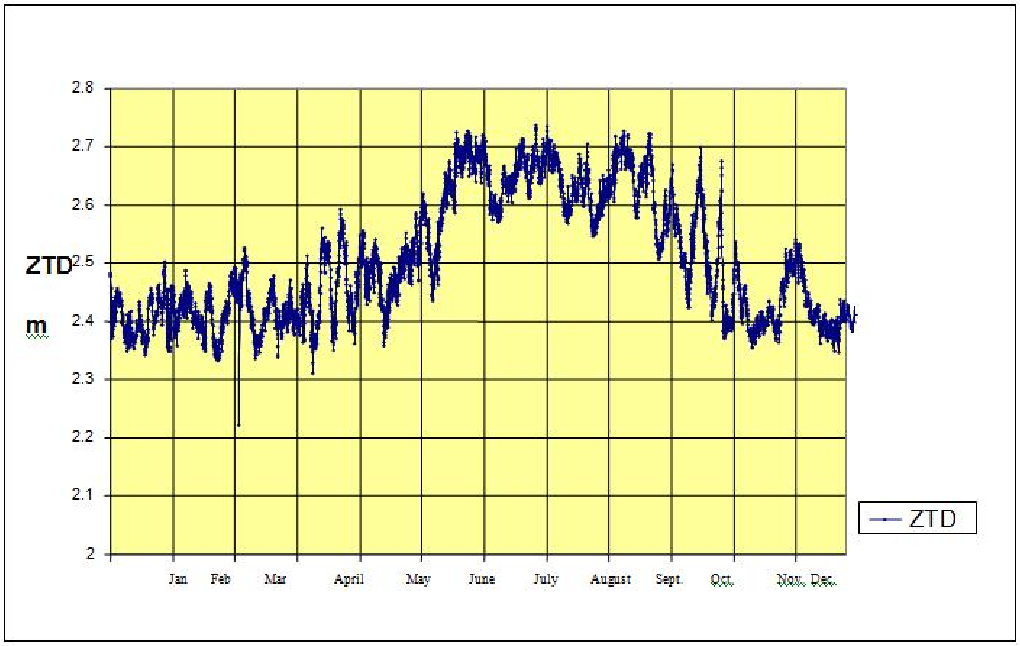

Figure 3: Seasonal Variations in ZTD at IIT Bombay-2005

Determination of the Precipitable Water Vapour

Zenith wet delay is determined over IITB reference station by subtracting the ZHD from ZTD.ZWD is then converted into the precipitable water vapour using atmospheric mean temperature. Then the PWV is compared with the actual values from the Indian Meteorological Department at two epochs. The Root Mean Square of difference between the computed PWV and the radiosonde at 00 GMT (6 AM) and 12 GMT (6PM) were found as 8.5336 mm and 6.8739 mm respectively. The comparison of the PWV estimated and the observed values of radiosonde at 00 GMT is shown in Figure 4.

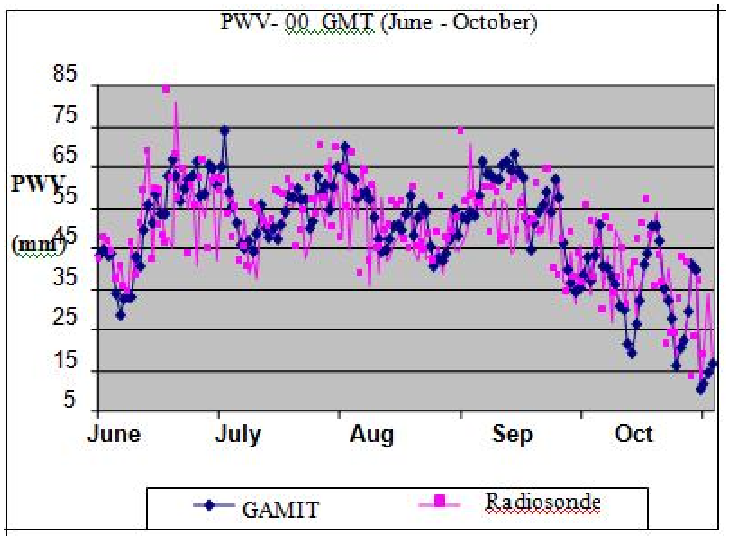

Figure 4: PWV comparisons radiosonde and computed at 6 A.M. IIT Bombay-2005

The comparison of the PWV estimated and the observed values of radiosonde at 12 GMT are shown in Figure 5. Similarly comparison of the PWV for both is shown in Figure 6.

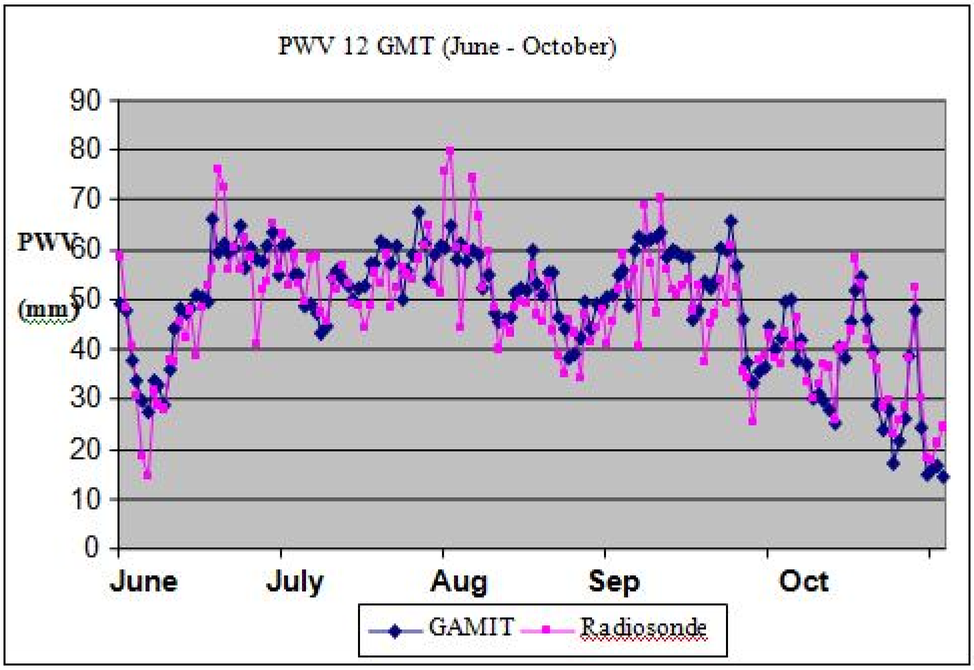

Figure 5: PWV comparisons radiosonde and computed at 6 P.M. IIT Bombay-2005

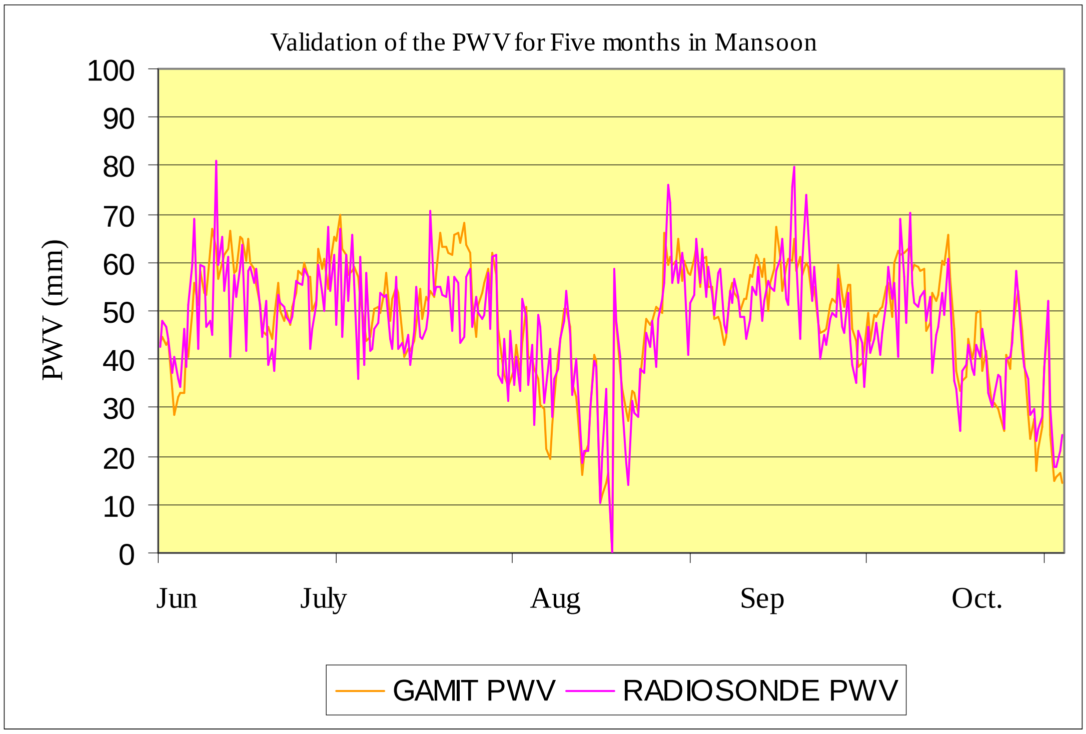

Figure 6: Seasonal Variation of PWV at IIT Bombay-2005

Special case of the event in Mumbai on 26th July -2005, PWV was computed at every two hours. The results obtained are shown in Figure 7.

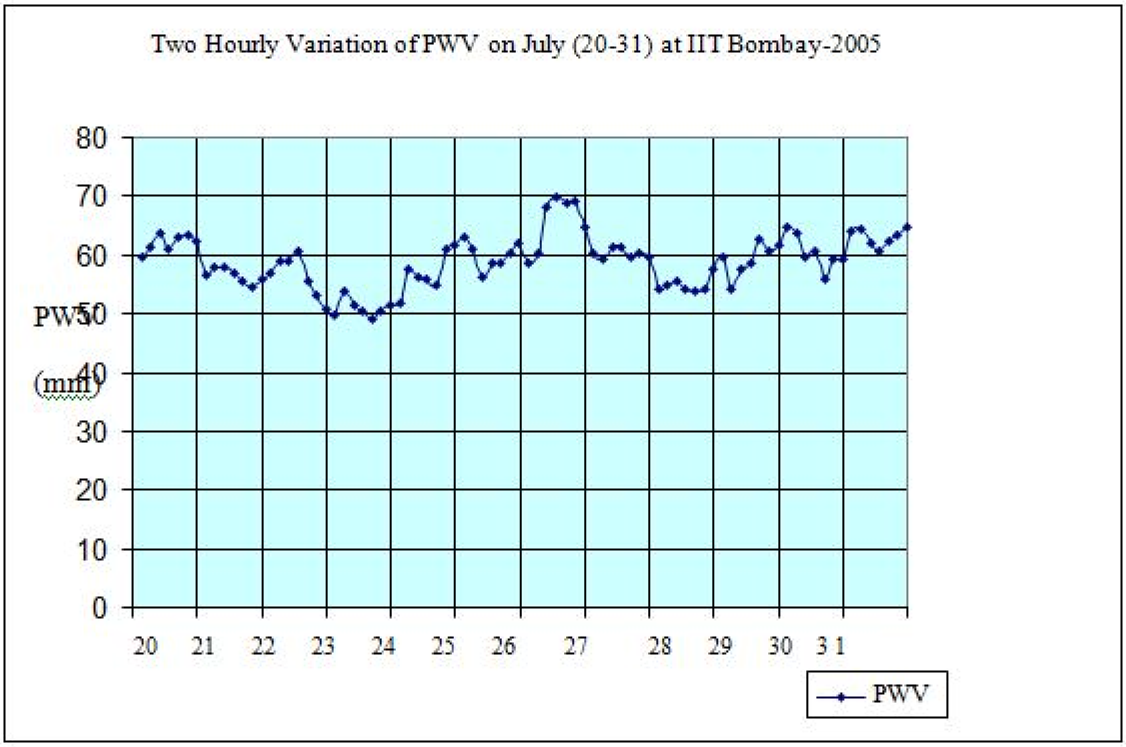

Figure 7: Special case of PWV at IIT Bombay on 26th July-2005

The maximum difference of ZTD using IGS computed values and the ZTD computed using ultra rapid orbits file is found to be ±20 mm. The GAMIT is used for near real time estimate of the zenith total delay but the results for the data analyzed using GAMIT shows the difference in the ZTD computed by IGS and the one Computed using ultra rapid orbits ±20 mm at IISc Bangalore IGS station. The overall accuracy in the estimation of the ZTD depends upon the Station network, Station Coordinates, satellite ephemerides accuracy, elevation angle, various solar, earth pole parameters etc.
The overall accuracy in the estimation of the precipitable water will get improved to the extent of 3-5mm.

CONCLUSION

Global positioning System has got the capability in extracting various atmospheric parameters In this study an attempt has been made to estimate the precipitable water vapour using GPS technology, as it has been the proven fact that GPS radio waves when travelling through the troposphere, due the refractive gradient of the troposphere, wave faces the delay in the direction of their path. These delays are due to the gaseous and the water vapour in the troposphere. By assuming the atmosphere to be in the hydrostatic equilibrium, hydrostatic delay can be modelled easily, but delay due to the wet component cannot be modelled very easily due to the temporal and spatial variation of the water vapour. So the GPS methodology has been used to estimate the precipitable water vapour in near real time. The Study has been carried out on three different components. The first focus was to determine the hydrostatic delay very precisely. Secondly the determination of the zenith total delays to the accuracy standards given by the International GPS service. Last objective was the conversion of the wet delay into the precipitable water vapour. The conclusions are summarized and discussed below.
The regression model for the determination of the zenith hydrostatic delay is given by,

$$ZHD = 0.0023 * Po - 0.0014$$

Fair comparison in the estimation of the PWV by GAMIT and the radiosonde.
Maximum value of the PWV on 26th July has been found out to be 69.90mm.
Zenith total delay analysis has been carried out using GAMIT software. Bernese can compute the zenith delay in post processed mode so the use of the software is limited to the estimate the zenith total delay in post processed mode. It cannot be used in the near or real time solutions of the zenith total delay, so

GAMIT software developed by the MIT has been used for the near real time solutions of the zenith total delay. The accuracy in the estimation of the ZTD was the main objective in the GAMIT processing. After studying the various parameters affecting the ZTD near real time solutions, the impact of the ultra rapid orbits have been tested in the solutions of the ZTD. Similarly G-file which are available with greater accuracy in the ephemerides are used for the processing GPS data for Indian Institute of Technology reference station in year-2005.With the best processing parameters for processing average error in the estimation of the ZTD using g-file has found to be 1.9717 mm with a standard deviation 8.8444 mm. The RMS error has been found to be 9.0604 mm. Similarly the average error in the estimation of the ZTD using ultra rapid orbits has been found to be 1.9717 mm with the standard deviation 9.1964 mm The RMS error has been found out as 9.3134 mm. Ultra rapid orbits can be used over the g-file orbits for the analysis of the ZTD with average error of 0.4432 mm with a standard deviation of 3.2392 mm. The RMS for the same has been found out to be 3.2693 mm.

Lastly precipitable water vapour has been determined for five monsoon months over IIT Bombay reference station. The results of the PWV estimated have been compared with the radiosonde data. ZWD has been calculated by subtracting ZHD from the ZTD.ZWD was then converted into the PWV using atmospheric mean temperature. The linear temperature variation equation was used for depicting the surface temperature at IIT Bombay reference station. PWV has been compared with the observed data from radiosonde at 00 GMT and 12 GMT. The computed values and the radiosonde values show good agreement with each other for the monsoon months. The rarest event was captured by the GPS for PWV and those values for PWV have been plotted separately. On 26th July max value of PWV estimated has been found to be 69.90 mm which has caused flood havoc due to heavy precipitation at Mumbai leading to loss of lives and properties

The data from IIT Bombay reference station has been processed using GAMIT for the estimation of the ZTD. But for better solutions the coordinates has to be constrained tightly so the up gradation of the station coordinates is the important future point to be tested for the solution of the ZTD

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