Effect of broadcast and precise satellite orbits in the estimation of Zenith tropospheric delay and integrated precipitable water vapour from GPS

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ABSTRACT. Global Positioning System (GPS) estimates the total delay in zenith direction by the propagation delay of the neutral atmosphere in presence of water vapour present in the troposphere. This total delay has been treated as a nuisance parameter for many years by the geodesists. The above delay have two parts dry delay and wet delay and known as Zenith Hydrostatic Delay (ZHD) and Zenith Wet Delay (ZWD) respectively. The Integrated Precipitable Water Vapour (IPWV) is estimated through ZWD overlying the receiver at ground-based station. The accuracy of the above said estimates depends on the quality of the predicted satellite orbits, which are not the same for each individual satellite. India Meteorological Department (IMD) is operationally estimating the IPWV on near real time basis at five places and matches fairly well (error ~6.7 mm) with Radisonde (RS) data. This paper examine the effect of International GPS Service (IGS) predicted precise orbits and near real time predicted rapid or broadcast orbits supplied by the Scripps Orbit and Permanent Array Center (SOPAC) on Zenith Total Delay (ZTD) and IPWV estimates by calculating the mean Bias and Root Mean Square Error (RMSE) for ZTD and IPWV in mm for all the five stations. The observed bias for ZTD is almost of the order of less than 1 mm in most cases and RMSE is less than 6 mm. Similarly the bias observed in the case of derived IPWV is almost negligible and RMSE is less than 1 mm.

Key words – Broadcast orbit, Rapid orbit, Zenith total delay and Integrated precipitable water vapour (IPWV).

1. Introduction

In the atmosphere the water vapour content is highly variable in space and time. Conventional method like radiosonde balloon, which carries weather sensors for measuring air temperature, pressure and relative humidity, reaches from earth surface to 20-30 km in the atmosphere thereby resulting in measured vertical profiles. The path of a radiosonde is affected by the wind, which often varies with height, measured twice a day and expensive. Space based geodetic technique like GPS (Bevis et al., 1992) can obtain data continuously with high temporal resolution. Radio signals transmitted from different sources in space are refracted and delayed while propagating through the atmosphere. The refraction effects in the upper atmosphere, the dispersive ionosphere, are frequency dependent and can be removed by using a linear combination of dual frequency data. This is, however, not
Fig. 1. Difference of ZTD values for Chennai on 16 October 2009

Fig. 2. Difference of ZTD values for Guwahati on 16 October 2009

Fig. 3. Difference of ZTD values for New Delhi on 16 October 2009

Fig. 4. Difference of ZTD values for Kolkata on 16 October 2009

Fig. 5. Difference of ZTD values for Mumbai on 16 October 2009

Fig. 6. Difference of IPWV values for Chennai on 16 October 2009

Fig. 7. Difference of IPWV values for Guwahati on 16 October 2009

Fig. 8. Difference of IPWV values for New Delhi on 16 October 2009
the case for the troposphere, which is non-dispersive region. A number of studies for the retrieval of IPWV using ground based GPS observations at the same level of accuracy as radiosondes have shown by (Rocken et al., 1995, Duan et al., 1996 and Tregoning et al., 1998).

Comparative study of GPS derived IPWV data with MODIS, NCEP and Radiosonde data is done by Giri et al. (2007) and validation of GPS retrieved IPWV with radiosonde data for winter season during 2003 using different mean temperatures predictors, Giri et al. (2006)
over Indian region. The processing is done in two ways one is near real time in which we are using rapid or broadcast orbit available daily at 2300 UTC from SOPAC, USA and second, post processing in which precise orbits are available after approximately 10-12 days from the IGS. The accuracy of the GPS satellite orbits is critical for GPS IPWV estimates (Dodson and Baker 1998). The current accuracy level of precise GPS orbits from the IGS is sufficient to provide IPWV estimate on the order of 1 mm, but these orbits are available approximately after
3. Results and discussion

Julian day 260 to 263 (16-19 October, 2008). Precise satellite orbit files respectively for the period of 0.76, 0.75 and 0.77 respectively. The bias (IGS Kolkata, Guwahati, Chennai and Mumbai are 0.83, 0.80, 0.76, 0.75 and 0.77 respectively. The bias (IGS – Broadcast) values are -0.12, 0.47, 0.35, -0.09 and -0.21 respectively. During the processing some of the abnormal values of the data, which is given abnormal peaks, have been omitted. These spikes are systematically occurring at the end of the hour in sliding window GAMIT processing strategy. This is may be due to the data gaps at the end or cycle slip in the signal during period of high tropospheric variability. During the post processing mode same data sets is used as in near real time mode so that the same variance is communicated to the final solution in both cases. The near real - time processing is essential for operational forecasting and Numerical Weather Prediction (NWP) model ZTD or PWV data assimilation, so knowledge of the satellite orbit accuracy is important. This accuracy even is improved when hourly-predicted GPS orbit becomes available (Fang et al., 1998). The comparison of derived IPWV from GPS and Radiosonde (RS) for the year 2007 are shown in Figs. (11-15) along with their statistics indicated on the graphs. Season-wise comparison is also given in Table 2. The RMSE and Bias are more in monsoon season for each station may be due to the variability of the moisture during the season. For Guwahati and Kolkata pre-monsoon data was not available due to the delay of installation of GPS. The other possible source of error is due to the site location because the GPS and Radiosonde observations are not at the same place and local environment can modify the moisture contents.

2. Data and methodology

The observation GPS data in Receiver Independent Exchange (RINEX) format for five stations; namely, New Delhi, Mumbai, Chennai, Kolkata and Guwahati have been processed using GAMIT 10.3.2.1 processing software (King and Bock 1999). The near real time GPS data and Radiosonde data for the year 2007 has been taken from India Meteorological Department, Lodi Road, New Delhi. The data is processed in two modes one is near real time and other is post-processing mode using rapid and precise satellite orbit files respectively for the period of Julian day 260 to 263 (16-19 October, 2008).

3. Results and discussion

The retrieval of ZTD and IPWV from ground base receiver using the precise IGS satellite orbit files and rapid or broadcast near real time orbit files have been computed for five stations. The difference of the two for both ZTD and IPWV is shown graphically from Figs. (1-10) for the Julian day 260 (16 October, 2008). The RMSE and bias in mm of all the five stations for four days is given in Table 1. The observed ZTD RMSE for Mumbai, Kolkata, Guwahati, Chennai and Mumbai are 4.96, 5.09, 5.00, 4.23 and 4.15 respectively. The bias (IGS – Broadcast) values are -1.12, 1.81, 0.64, -0.29 and -0.19 respectively. Similarly, The observed ZTD RMSE for Mumbai, Kolkata, Guwahati, Chennai and Mumbai are 0.83, 0.80, 0.76, 0.75 and 0.77 respectively. The bias (IGS – Broadcast) values are -0.12, 0.47, 0.35, -0.09 and -0.21 respectively. During the processing some of the abnormal values of the data, which is given abnormal peaks, have been omitted. These spikes are systematically occurring at the end of the hour in sliding window GAMIT processing strategy. This is may be due to the data gaps at the end or cycle slip in the signal during period of high tropospheric variability. During the post processing mode same data sets is used as in near real time mode so that the same variance is communicated to the final solution in both cases. The near real - time processing is essential for operational forecasting and Numerical Weather Prediction (NWP) model ZTD or PWV data assimilation, so knowledge of the satellite orbit accuracy is important. This accuracy even is improved when hourly-predicted GPS orbit becomes available (Fang et al., 1998). The comparison of derived IPWV from GPS and Radiosonde (RS) for the year 2007 are shown in Figs. (11-15) along with their statistics indicated on the graphs. Season-wise comparison is also given in Table 2. The RMSE and Bias are more in monsoon season for each station may be due to the variability of the moisture during the season. For Guwahati and Kolkata pre-monsoon data was not available due to the delay of installation of GPS. The other possible source of error is due to the site location because the GPS and Radiosonde observations are not at the same place and local environment can modify the moisture contents.

4. Conclusions

(i) The RMSE values in ZTD and IPWV estimation using precise and broadcast or rapid orbits are less than 6 and 1 mm respectively.

(ii) Similarly the observed bias for precise and broadcast or rapid orbits are less than ±1 in most cases of ZTD estimation and almost negligible in IPWV estimates.

(iii) This study is useful in deciding the quality index for orbit to reject the bad satellite or satellite in manoeuvre and eclipse conditions. Later it can be applied to near-real time basis operationally in order to become usable data source in NWP models.

(iv) The comparison of GPS derived IPWV with RS matches fairly well (~6.7 mm) for all the stations with more variability in monsoon season.

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