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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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सार – भूमंडलीय स्थिति तंत्र मुख्यतः क्षोभमंडल में जलवाष्प तत्वों के फलस्वरूप शिरोबिंदु दिशा में सकल विलंब का आकलन करता है। भूमणितज्ञों द्वारा काफी वर्षों तक सकल विलम्ब के इस प्राचल को निरर्थक माना जाता रहा है। उक्त विलम्ब के दो भाग हैं – शुष्क विलम्ब और आर्द्र विलम्ब जिन्हें क्रमश : शिरोबिंदु जलस्थैतिक विलम्ब (जेड. एच. डी.) और शिरोबिंदु आर्द्र विलम्ब (जेड. डब्ल्यू. डी.) कहा जाता है। समेकित वर्षणीय जलवाष्प (आई. पी. डब्ल्यू. वी.) का आकलन धरातलीय केन्द्र में अभिग्राही के ऊपर स्थित जेड. डब्ल्यू. डी. के माध्यम से किया जाता है। उपर्युक्त आकलनों की सटीकता कक्षीय उपग्रहों की पूर्वानुमानन गुणवत्ता पर निर्भर करती है जो प्रत्येक उपग्रह के लिए समान नहीं है। भारत मौसम विज्ञान विभाग आई. पी. डब्ल्यू. वी. का आकलन पाँच स्थानों पर प्राचालनात्मक रूप से निकट वास्तविक समय के आधार पर करता है जो रेडियोसोंदे (आर. एस.) आँकड़ों से सही मेल (~ 6.7 एम. एम. त्रुटि) खाते हैं। इस शोध पत्र में शिरोबिन्दु संकल विलम्ब (जेड. टी. डी.) के संबंध में स्क्रिप्स ऑरबिट एंड परमानेंट ऐरे संटर (एस. ओ. पी. ए. सी.) द्वारा उपलब्ध कराए गए अंर्तराष्टीय जी. पी. एस. सेवा (आई. जी. एस.) द्वारा पूर्वानुमानित प्रीसाइज ऑरबिटों और निकट वास्तविक समय पूर्वानुमानित रैपिड अथवा ब्रॉडकास्ट ऑरबिटों के प्रभाव का अध्ययन किया गया है। आई.जी.एस. और ब्रॉडकास्ट ऑरबिटों का उपयोग करके पाँच भारतीय केन्द्रों नामतः नई दिल्ली, कोलकाता, चेन्नै, गुवाहाटी और मुम्बई के लिए आकलित जेड. टी. डी. और आई. पी. डब्ल्यू. वी. (मि. मी. में) के लिए प्रेक्षित औसत अभिनति और वर्ग माध्य मूल त्रुटि (आर. एम. एस. ई.) अधिकांश मामलों में 1 मि. मी. से कम रही और आर. एम. एस. ई. में 6 मि. मी. से कम रही। इसी प्रकार, व्युपन्न आई. पी. डब्ल्यू. वी. के मामले में प्रेक्षित अभिनति लगभग नगण्य रही और आर. एम. एस. ई. 1 मि. मी. से कम रही।

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

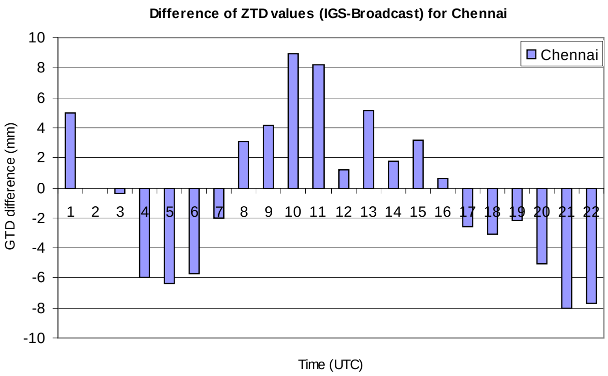

Fig. 1. Difference of ZTD values for Chennai on 16 October 2009

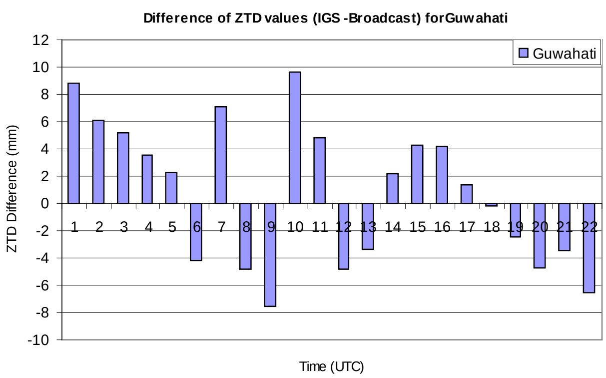

Fig. 2. Difference of ZTD values for Guwahati on 16 October 2009

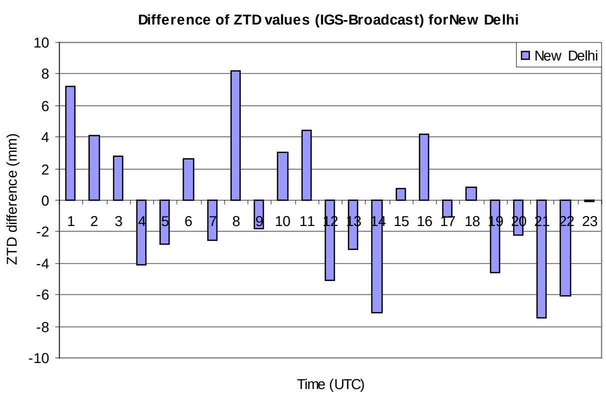

Fig. 3. Difference of ZTD values for New Delhi on 16 October 2009

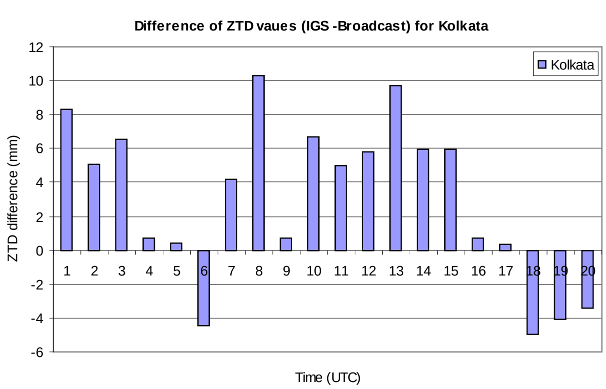

Fig. 4. Difference of ZTD values for Kolkata on 16 October 2009

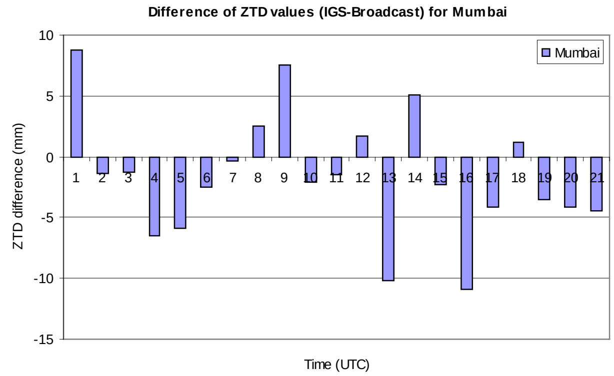

Fig. 5. Difference of ZTD values for Mumbai on 16 October 2009

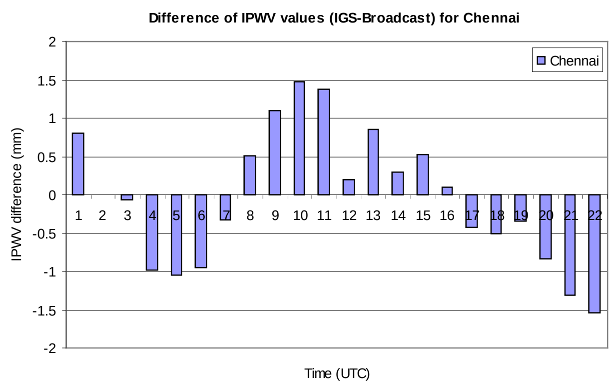

Fig. 6. Difference of IPWV values for Chennai on 16 October 2009

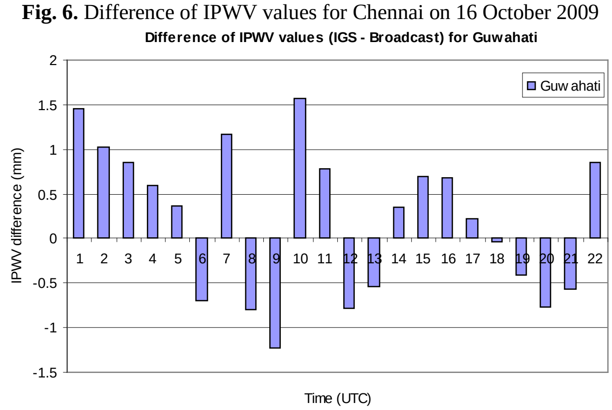

Fig. 7. Difference of IPWV values for Guwahati on 16 October 2009

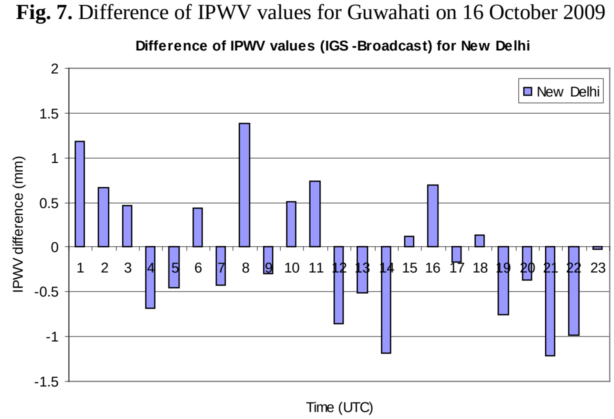

Fig. 8. Difference of IPWV values for New Delhi on 16 October 2009

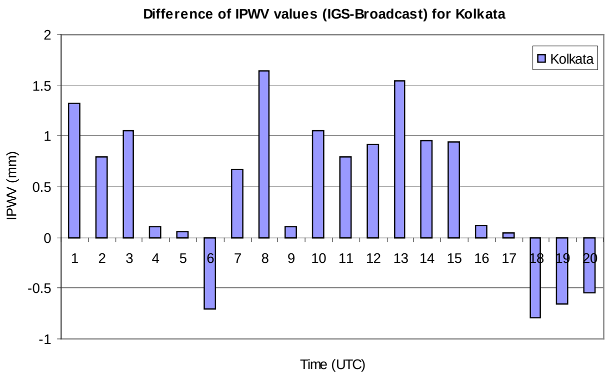

Fig. 9. Difference of IPWV values for Kolkata on 16 October 2009

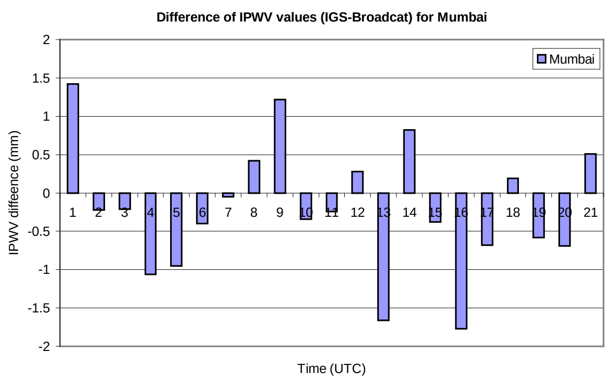

Fig. 10. Difference of IPWV values for Mumbai on 16 October 2009

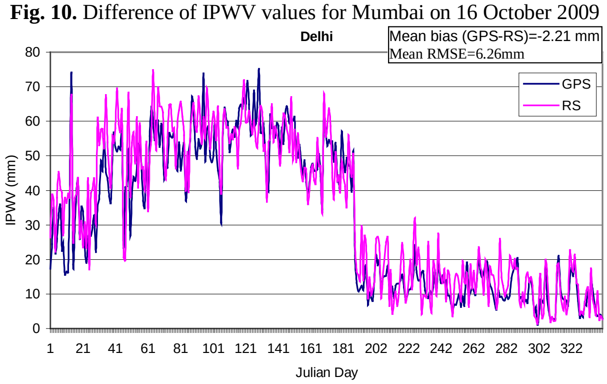

Fig. 11. Comparison GPS *vs* Radiosonde (RS) derived IPWV for Delhi (2007)

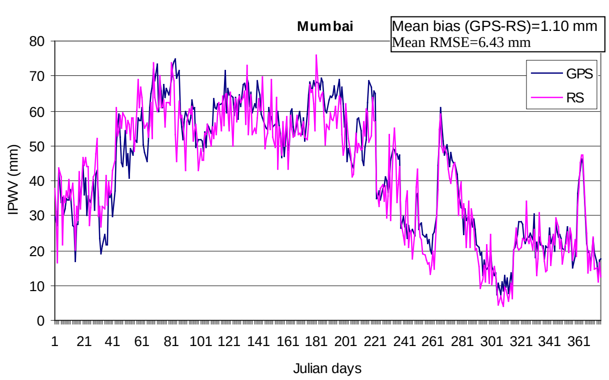

Fig. 12. Comparison GPS *vs* Radiosonde (RS) derived IPWV for Mumbai (2007)

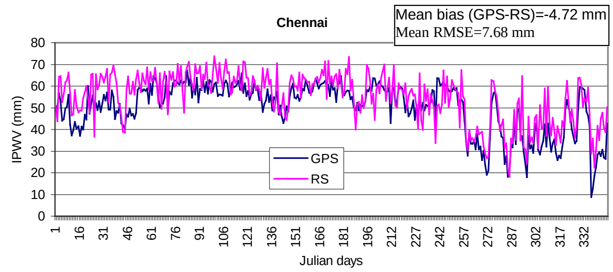

Fig. 13. Comparison GPS *vs* Radiosonde (RS) derived IPWV for Chennai (2007)

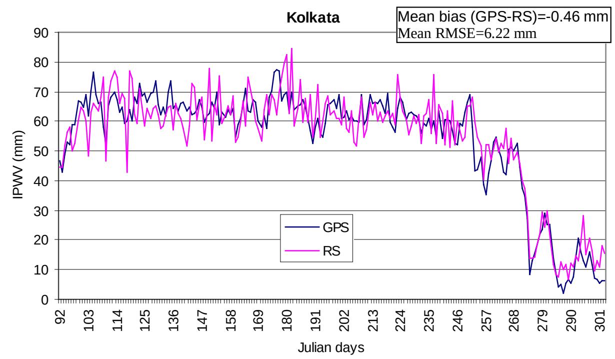

Fig. 14. Comparison GPS *vs* Radiosonde (RS) derived IPWV for Kolkata (2007)

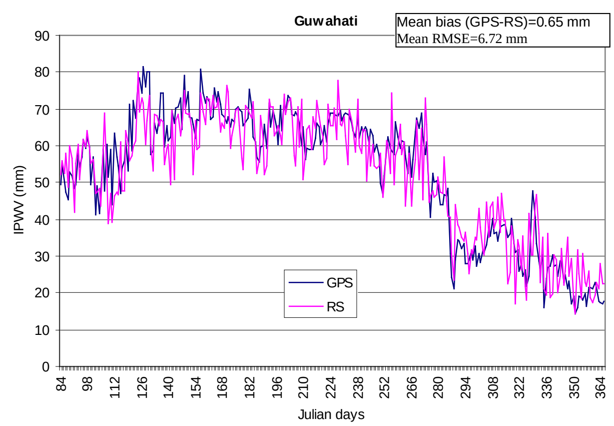

Fig. 15. Comparison GPS *vs* Radiosonde (RS) derived IPWV for Guwahati (2007)

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)

TABLE 1

Mean and Root mean square error (RMSE) for precise and broadcast orbit files

Station Name	Julian Day	Mean bias of ZTD (IGS-Broadcast) in mm	RMSE of ZTD (IGS-Broadcast) in mm	Mean bias of IPWV (IGS-Broadcast) in mm	RMSE of IPWV (IGS-Broadcast) in mm
Mumbai	260	-1.64	5.15	-0.21	0.83
Kolkata	260	2.96	5.49	0.47	0.87
Guwahati	260	0.79	5.04	0.22	0.81
Chennai	260	-0.36	4.87	-0.05	0.85
New Delhi	260	-0.27	4.34	0.12	0.76
Mumbai	261	-1.34	5.06	-0.15	0.79
Kolkata	261	1.35	5.34	0.43	0.84
Guwahati	261	0.56	4.86	0.17	0.77
Chennai	261	-0.31	4.23	-0.11	0.80
New Delhi	261	-0.15	3.98	-0.12	0.72
Mumbai	262	-0.84	4.95	-0.22	0.79
Kolkata	262	1.93	4.75	0.57	0.76
Guwahati	262	0.69	5.24	0.32	0.71
Chennai	262	0.16	3.75	0.25	0.74
New Delhi	262	-0.17	4.24	0.13	0.76
Mumbai	263	-0.69	4.26	-0.11	0.89
Kolkata	263	1.23	4.79	0.41	0.74
Guwahati	263	0.54	1.86	0.67	0.72
Chennai	263	-0.33	4.25	-0.11	0.62
New Delhi	263	0.23	5.21	0.28	0.85

TABLE 2

Season-wise RMSE (mm) and BIAS (mm)

Station	Monsoon season		Post-monsoon season		Winter season		Pre-monsoon season	
Name	Bias GPS-RS (mm)	RMSE (mm)	Bias GPS-RS (mm)	RMSE (mm)	Bias GPS-RS (mm)	RMSE (mm)	Bias GPS-RS (mm)	RMSE (mm)
Delhi	-2.34	7.18	0.33	6.42	-2.54	3.22	-3.32	4.55
Guwahati	3.89	6.98	-1.83	6.14	-1.20	6.42	NA	NA
Kolkata	1.35	6.92	-2.90	4.79	-2.60	5.92	NA	NA
Mumbai	3.55	7.85	3.11	5.70	0.52	4.65	-2.56	7.02
Chennai	-4.65	8.64	-1.56	6.10	-4.54	5.84	-2.32	7.68

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

10-12 days. SPOAC rapid or broadcast near real time orbit also reach the same level of accuracy, but their accuracy is limited to 0.1 to 1.0 meter compared to IGS final orbits (Kouba and Mireault, 1998). Their accuracy decreases with time because of unpredictable non-conservative forces, reaching an average of 0.4 meter after 15 to 39 hours (Rocken *et al*., 1997). In addition, when satellite in maneuver the accuracy of their predicted orbit decreases to a few to hundred meters, when they are in eclipse it decreases 1-2 meters. Marong *et al*., 2000 have implemented the new strategy for predicting the orbits with minimum degradation of the ZTD estimates by estimating three Keplarian parameters, *i.e*., semi-major axis, inclination and argument of perigee. They showed that this implementation shows negligible bias and RMSE less then 6 mm. In this paper authors observed the 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 for the current operationally system working in India Meteorological Department, Lodi Road, New Delhi.

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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