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Estimation of Rain attenuation and Ionospheric delay at a Low-Latitude Indian Station

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Abstract— India falls under low-latitude region and in this study Ahmedabad region (23.0225° N, 72.5714° E) is considered. In satellite link design system rain plays a crucial part and attenuation caused by rain is severe in Ku and Ka bands. This paper involves the rain attenuation estimation using data collected over Ahmedabad region. The data is taken from IMD (Indian Meteorological Department). Rain is dominant over 10 GHz which is a tropospheric phenomenon whereas Ionospheric effects are predominant below 6 GHz. Ionosphere is a dominant source of range errors for the users of Global Positioning System (GPS) satellite signals. This study also focuses on the delay due the Ionosphere in Ahmedabad region along with TEC measurements. The integrated water vapor content in atmosphere is also estimated from the data of GPS receiver. The data is taken from Space Application Centre (SAC-ISRO) and Ahmedabad airport station. The analysis is done for the Monsoon period of year 2016. The platform used for implementation is MATLAB.

Keywords— Global Positioning system, Total electron content, IWV, Rain Attenuation, ITU-R Model, Ionospheric delay, Tropospheric delay

INTRODUCTION

The Earth-Space communication involves many challenges, one of them being the link design for satellite systems. When the radio wave propagates from earth to satellite or vice-versa, it encounters certain kind of delays and disturbances. The attenuation caused above frequency range of 10 GHz is generally categorized into the tropospheric effects and those less than 6 GHz usually comprises of Ionospheric effects. The attenuation caused by troposphere includes rain attenuation, cloud attenuation, scintillation effects, gaseous absorption, melting layer attenuation etc as explained in [1]. This study focuses on attenuation due to rain in Ahmedabad region (2010-2014) in three different climates i.e. pre-monsoon period, monsoon period and post monsoon period. The frequency band taken is Ku (12-18 GHz) and Ka (26-40 GHz).

For climate monitoring and prediction the relative humidity data are useful. In greenhouse gases the atmospheric water vapor is crucial and dominating, so the feedback of water vapor in global warming is substantial. Due to increasing carbon dioxide and other gases the climate gets warmed and the water vapor is increasing rapidly which has effects on heat balance of the earth. The water vapor varies in space and time. The surface based GPS measurements provides high resolution information and also provides data at similar quality under all weather conditions [2]. In the surface based techniques the integrated water vapor and delay is estimated using the signals obtained from the dual frequency GPS receiver. So the integrated water vapor content is estimated in monsoon period of 2016 using the data of dual frequency GPS receivers in Ahmedabad region. Ionosphere being a dispersive medium affects signal proportionally to the inverse of the square of their frequencies. It can thus reveal information about the Total Electron Content (TEC) of the electron density which is a major parameter of the ionosphere. The data collected from receiver is also used to estimate the ionospheric delay at Space application centre (SAC-ISRO) Ahmedabad. Thus signals from GPS satellites encounters delay from ionosphere which results in range errors that can vary from a few meters to tens of meters [3].

2. Methodology

2.1 Calculation of Rain Attenuation by ITU-R model

In satellite communication, for Rain attenuation prediction the standard ITU-R [4] model is used which is applicable to 55 GHz frequency and the input parameters required are: Latitude of earth station φ (deg), point rainfall rate R0.01 (mm/h), altitude of earth station above mean sea level *hs* (*km*), frequency, elevation angle $\theta\ (deg)$. The specific attenuation due to rain is given by

$$\gamma = k(R_{0.01})^{\alpha} \quad \left(\frac{dB}{km}\right) \tag{1}$$

Where k and α are frequency and polarisation dependent coefficients given in [4] [5].

Hence the attenuation can be obtained as

$$A_{0.01} = \gamma L_e \tag{2}$$

Where L_e is effective path length through rain (Km)

The complete procedure is given in [1] and is the most accurate of all models and well tested by ITU-R.

2.2 Calculation of integrated water vapor (IWV) from Zenith path delay (ZPD)

The zenith path delay includes zenith hydrostatic delay (ZHD) and zenith wet delay (ZWD) and the latter is linked to IWV [6].

$$\text{ZPD=ZHD + ZWD} \tag{3}$$

The zenith wet delay (ZWD) directly relates to IWV and is dependent on vertical distribution of water vapor:

$$IWV.\rho_{H2O} = k.ZWD \tag{4}$$

Where ρ_{H2O} is the density of water and k is the proportional constant given as

$$\frac{1}{k} = 10^{-6}\left(\frac{c1}{Tm} + c2\right) R_v \tag{5}$$

Where $c1 = (3.776 \pm 0.03)10^5 \frac{k^2}{hPa}$ and $c2 = (17 \pm 10)10^5 \frac{k}{hPa}$

Tm is the vertically integrated mean temperature and R_v is the specific gas constant for water vapor (461.45 J/kg/K).

2.3 Calculation of Ionospheric delay from dual frequency GPS receiver

To investigate earth's ionosphere, the Total Electron Content (TEC) measurements obtained from GPS receivers is used as an important method. The delay here is determined using code observables at L1 (1575 MHz) and L2 (1227 MHz) GPS frequencies [7]. To estimate the GPS receiver position, the pseudorange measurements are carried out. The position estimate depends on observation, receiver, and satellite measurements.

A GPS operates on two different frequencies f_1 and f_2 which can be derived from fundamental frequency f_0=10.23 MHz as follows:

$f_1=154\ f_0 = 1575.42$ *MHz and* $f_2 =120\ f_0 = 1227.60$ *MHz*

Thus TEC can be estimated by using the below relation:

$$\text{TEC}= \frac{(P1-P2)}{40.3}\ \frac{1}{\left(\frac{1}{f1^2}-\frac{1}{f2^2}\right)} \tag{6}$$

Where P1 and P2 are pseudorange at L1 and L2 respectively

Delay experienced by signal 1 at frequency f_1 can be written as $S_{f1} = \frac{40.3}{f1^2} TEC$ (7)

and similarly

Delay experienced by signal 2 at frequency f_2 can be written as $S_{f2} = \frac{40.3}{f2^2} TEC$ (8)

Hence by estimating TEC using pseudo range, the ionospheric delay can be computed for both the frequencies.

3. Result and Discussions

The surface based GPS-measurements of Zenith path delay can be used to derive vertically integrated water vapor (IWV) of the atmosphere. In this study the data of three months monsoon period is taken from the dual frequency GPS receiver to calculate the tropospheric delay and integrated water vapor content of the atmosphere. The GPS derived values of IWV are used for all operational analysis of IWV. The platform used for implementation is MATLAB.

Fig 1 depicts the analysis of integrated atmospheric water vapor content at SAC-bopal Ahmedabad in the monsoon period of 2016.

It can be observed from the figure that the atmospheric water vapor content has maximum value around 54 mm. In Fig 2 the water vapor content is also ~54 mm since the data is taken for SAC and airport station and the distance between the stations is about 33 km so it is also evident that the delay and water vapor content doesn't change for very smaller distance.

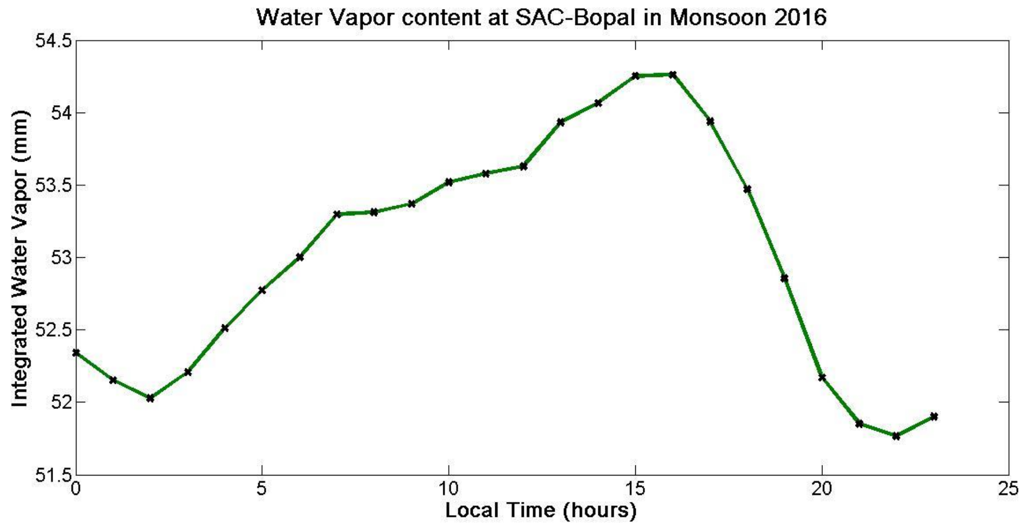

Fig 1: GPS derived integrated water vapor at SAC station

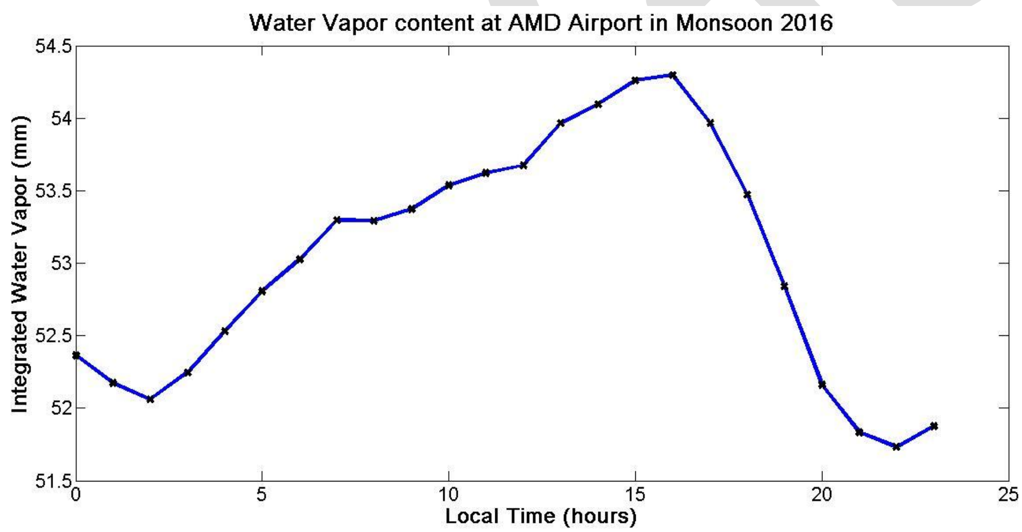

Fig 2: GPS derived integrated water vapor at AMD airport station

Ahmedabad region (23.0225° N, 72.5714° E) is a moderate rainfall zone with station height of 53 meters and average rain rate of about 700 mm. Fig 3 represents the attenuation graph of Ahmedabad in Monsoon period of five years (2010-2014) through ITU-R Model. The x-axis labels rainfall rate and y-axis labels attenuation. It can be observed that with increase in frequency as well as rainfall rate the attenuation is increasing and is highest at 40 GHz. The maximum value of attenuation is about 78 db for rainfall rate of 270 mm at 40 GHZ whereas minimum value corresponds to about 20 db at 12 GHz in monsoon period (July-September). The data is taken from IMD (Indian Meteorological Department).

The post monsoon (October-December) characteristics of Ahmedabad region are shown below in Fig 4. The maximum attenuation estimated is around 9.5 db at 40 GHz. Since it is a low rainfall region the attenuation observed is less as compared with the high rainfall zones. The figure depicts the attenuation observed for 12-40 GHz bands. The rainfall rate (which depends on geographical area) and frequency has much greater impact on attenuation.

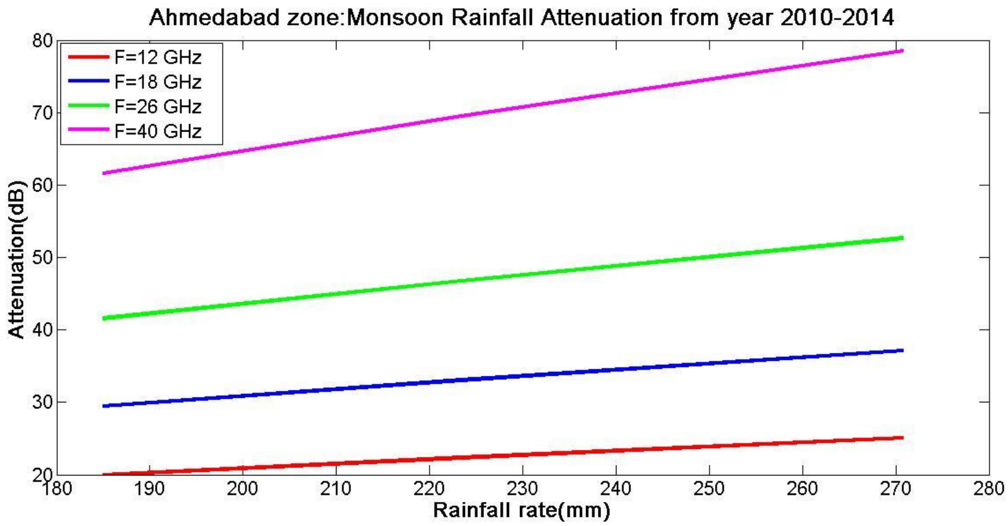

Fig 3: Monsoon Attenuation in Ahmedabad using ITU-R

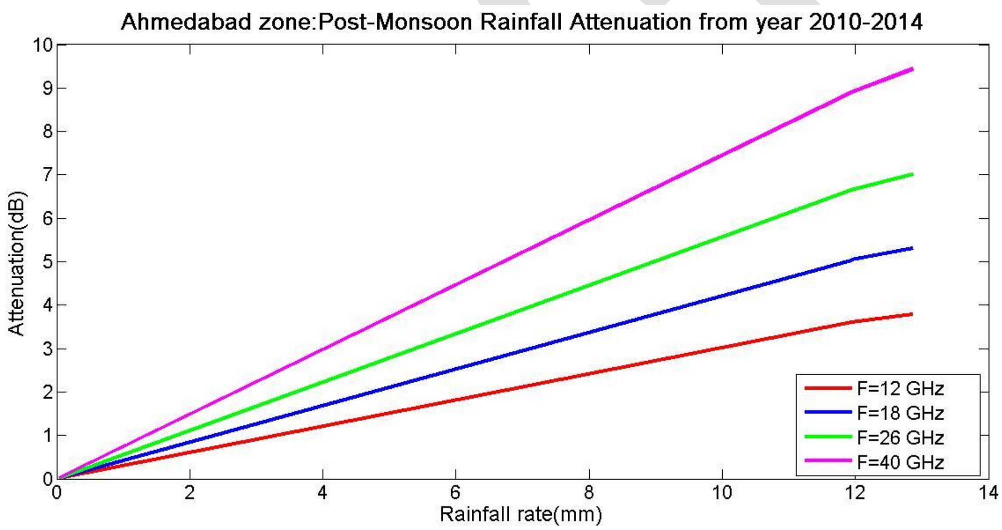

Fig 4: Post-Monsoon Attenuation in Ahmedabad using ITU-R

To determine the ionospheric delay in dual frequency GPS receiver the data is taken from Space Application Centre (SAC-ISRO) (Bopal campus), Physical Research Laboratory (PRL) and Ahmedabad airport station in monsoon period (July to September) of 2016. The given below Fig 5 shows the analysis of GPS data at SAC-bopal station and the estimated delay at both frequencies (f1 and f2) respectively. The first epoch was at 5:30 Hrs. The plot is given with respect to IST (IST=UT +5.5 hrs). The histogram represents the delay at ionosphere at a given time.

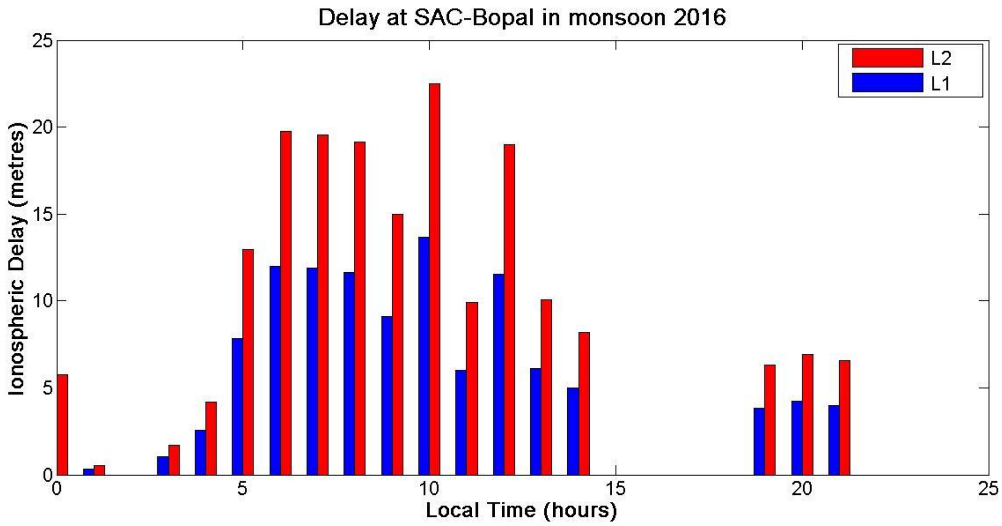

Fig 5: Ionospheric delay vs. IST at L1 and L2 for SAC

The maximum ionospheric delay observed at L1 is around 14 meters and delay at L2 is ~22 meters. It is quite clear from the plot that ionospheric delay starts rising from morning from about 3 meters and achieves a wide range of ~8 to 12 meters around local noon. Then the delay starts decreasing and attains the minimum value at evening. This is due to features of equatorial ionosphere and is known as plasma depletions.

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CONCLUSION

In this study an attempt was made to estimate the delay in Ionosphere and Troposphere at Ahmedabad station. By using the dual frequency code observations the ionospheric delay is estimated. The hourly ionospheric delay is about 1.5 to 16 meters. The GPS measurements are also used to obtain information about water vapor content of troposphere. The atmospheric water vapor content observed is ~ 54 mm. Also the effect of rain is studied in Ku (12-18 GHz) and Ka (26-40 GHz) bands which is a major source of degradation at high frequencies in satellite communication. Rain attenuation is a tropospheric phenomenon and the results are calculated using the standard ITU-R model which is well tested and produces accurate results.

REFERENCES:

[1] Dissanayake A., Allnutt J. and Haidara F., “A prediction model that combines rain attenuation and other propagation impairments along earth-satellite paths”, IEEE Transactions on Antennas and Propagation ,vol. 45, no. 10, pp. 1546-1558, 1997.

[2] Stefan Hagemann, Lennart Bengtsson , Gerd Gendt, “On the determination of atmospheric water vapour from GPS measurements”, Report No. 340,Max Planck Institute for Meteorology, Hamburg, November 2002.

[3] Xu Guochang (2007) GPS Theory, Algorithms and Applications. 2nd edn. Springer, Heidelberg.

[4] ITU–R, “Propagation data and prediction methods required for the design of Earth–space telecommunication systems,” Recommendation ITU–R P.618–8, vol. 12, pp. 1–24, 2015.

[5] ITU *Recommendation* ITU-R RPN.837, 1995.

[6] Bevis, M.S., S. Businger, T.A. Herring, C. Rocken, R.A. Anthes, and R.H. Ware “GPS meteorology: Remote sensing of atmospheric water vapor using the global positioning system” J. Geophys. Res. 97, 15787-15801, 1992.

[7] Kintner P.M. and Ledvina B.M. “The ionosphere, radio navigation, global navigation satellite systems”, Advance in Space Research 35:788-811, 2005.