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Effect of Magnetic Activity on Ionospheric Time Delay at Low Latitude

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Abstract. The purpose of this work is to investigate the effect of magnetic activity on ionospheric time delay at low latitude Station Bhopal (geom. lat. 23.2°N, geom. long. 77.6°E) using dual frequency (1575.42 and 1227.60 MHz) GPS measurements. Data from GSV4004A GPS Ionospheric Scintillation and TEC monitor (GISTM) have been chosen to study these effects. This paper presents the results of ionospheric time delay during quiet and disturbed days for the year 2005. Results show that maximum delay is observed during quiet days in equinoxial month while the delays of disturbed period are observed during the months of winter. We also study the ionospheric time delay during magnetic storm conditions for the same period. Results do not show any clear relationship either with the magnitude of the geomagnetic storm or with the main phase onset (MPO) of the storm. But most of the maximum ionospheric time delay variations are observed before the main phase onset (MPO) or sudden storm commencement (SSC) as compared to storm days.

Key words. Ionospheric time delay—scintillation—TEC—geomagnetic storm.

1. Introduction

The ionospheric refraction remains a major error source in Global Positioning System (GPS) for real-time applications. After integrating the phase and group refractive indices along the path of the GPS signal, the range obtained between the satellite and the receiver is different from the true geometric range by the amount called ionospheric error. This error is negative for carrier phase pseudoranges and positive for the code pseudoranges (Komjathy 1997). The ionospheric delay is proportional to the number of electron content and inversely proportional to the frequency squared. The total delay contains the dispersive ionosphere, transmitter and receiver delays plus non-dispersive delays due to clocks and the troposphere. Therefore, the change of pseudorange measurement caused by the ionospheric refraction may be restricted to the determination of the Total Electron Content (TEC). The ionosphere causes GPS signal delays due to the TEC along the path from the GPS satellite to receiver.

At equatorial and low latitudes, TEC is subjected to dynamical changes owing to the changes in the electric field. For high precision GPS positioning, the ionosphere effect must be estimated so that the more precise position result could be measured.

Owing to the continuous operation and the large number of world wide receivers, GPS is a powerful tool to investigate ionospheric structures, mainly during magnetically disturbed periods when dynamics and energy dissipation processes in the magnetosphere–thermosphere–ionosphere system become extremely complex (Prolss *et al.* 1995; Fuller-Rowell *et al.* 1997). The strong electric fields that are generated cause significant changes in the ionospheric morphology, producing large delays of the propagation of the GPS signals and an advance in the phase of the carrier. The intensity of a magnetic storm is commonly defined by the minimum Dst value during the magnetic storm, which is equivalent to the maximum Dst magnitude at the main phase. As compared to quiet geomagnetic conditions the daytime ionization enhanced at high latitudes and after that it moved to low latitudes. The ionospheric response to magnetic storms is latitude dependent and also varies with the intensity of the storm and its time of occurrence. The present paper stresses especially on the response of the ionospheric time delay in equatorial regions of the ionosphere as it is directly proportional to the total electron content. The data were used for analysis of ionospheric time delay behaviour during the storm. The objective of this paper is to study the effect of magnetic activity on ionospheric time delay at low latitude regions.

2. Experimental data and methodology

GPS data obtained using code a measurement is only used from January 2005 to December 2005 at Bhopal (lat. 23.2°N, long. 77.6°E). From the processed data, elevation angle and TEC are used to estimate the time delay values at elevation cut off 40°. Here the ionospheric delay used is: Δ ion $= 40.3/\text{cf}^2$ TEC. In order to clearly identify the ionospheric time delay, we compute the delay for five international quiet (Q) and disturbed (D) days and during storm conditions.

3. Result

The annual variation of occurrence of ionospheric time delay on quiet and disturbed days during the same period is shown in Fig. 1. It is observed from the figure that the maximum ionospheric time delay occurred in the month of October during quiet period while the maximum delays of disturbed period are observed during the months of winter. The occurrence of ionospheric time delay on Q- and D-days for the three seasons; winter, summer and equinox months and their annual average are shown in Fig. 2. It is obvious from this figure that, under the geomagnetic disturbances, the maximum ionospheric time delay occurred in equinox while minimum in winter and moderate in summer. Result shows that seasonal dependency is one of the major factors of ionospheric time delay under the effect of magnetic activity during low solar activity.

3.1 *Case studies*

The analysis represents the ionospheric time delay for all the storms in relation with Dst respectively for one day before and after the Sudden Storm Commencement (SSC)

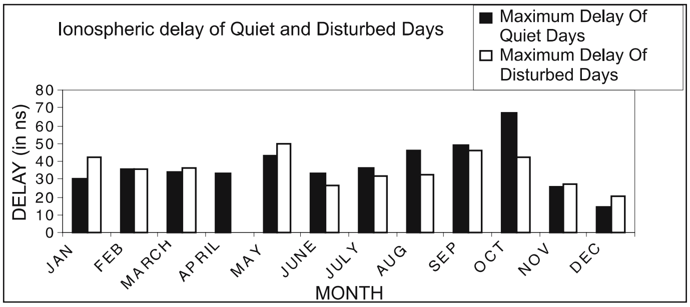

Figure 1. Ionospheric time delay for quiet and disturbed days of 2005.

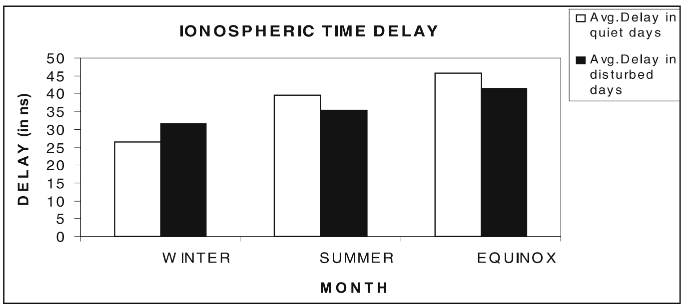

Figure 2. Ionospheric time delay for quiet and disturbed days for the three seasons of 2005.

that describes the ionospheric conditions of Bhopal in response to geomagnetically disturbed conditions for the year 2005.

Case 1. The storm of 7 January 2005, SSC occurred at 0922 UT as mentioned in Fig. 3. The main phase of the storm started about 1500 UT and Dst had its lowest value equal to −96nT on 8 January at 0300 UT. The occurrence of ionospheric time delay was larger on the day before the SSC, i.e., on 6 January 2005. The maximum ionospheric time delay of 31.5173 ns was observed at 0853 UT.

Case 2. On this particular storm day SSC occurred at 1041 UT as mentioned in Fig. 4. The Dst value had its lowest value equal to −96nT at 0300 UT started about 0300 UT on 8 January. The occurrence of ionospheric time delay was larger on the storm day other than the previous day, i.e., on 9 January 2005. The maximum ionospheric time delay was 28.6425 ns at 0925 UT.

4. Summary and discussion

Ionospheric total electron content produces signal delay and refraction that causes range errors that apply to surveillance and GPS navigation. After investigation the result shows that the ionospheric time delay is a function of both season and earth's magnetic field. The maximum ionospheric time delay occurred in equinox during these magnetic days, more significantly at low latitude which is probably due to the

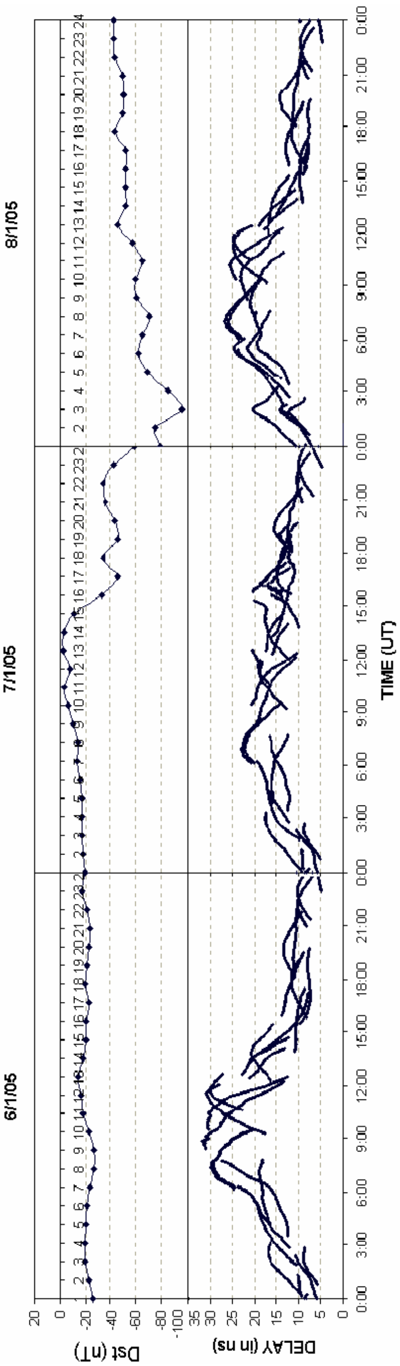

Figure 3. Storm of 7 January 2005 correlated with delay.

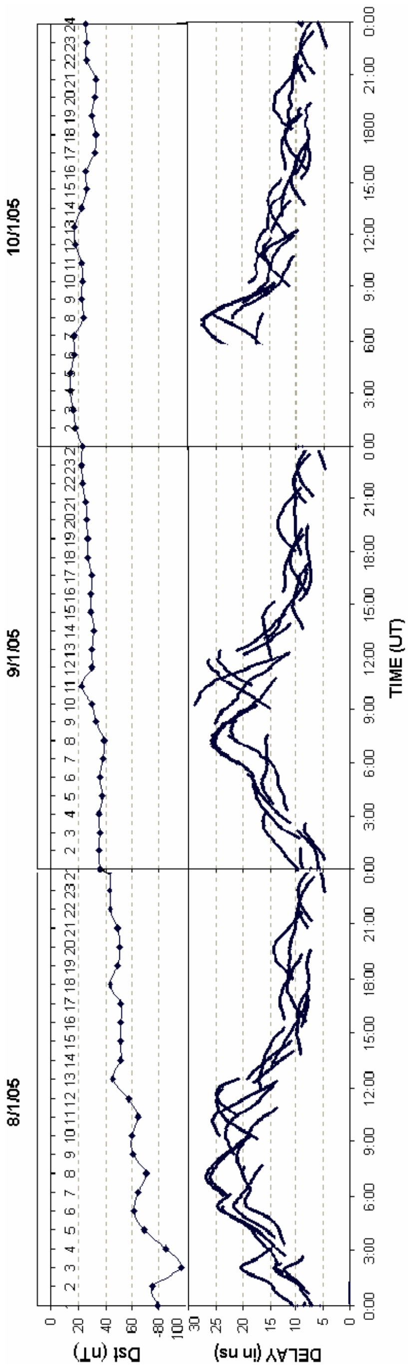

Figure 4. Storm of 9 January 2005 correlated with delay.

downwelling of thermospheric gas. The downwelling of thermospheric gas, mainly caused by storm-induced thermospheric winds (Danilov & Lastovicka 2001), may cause the increase of ionization at low latitudes without any significant change in atom to molecule ratio (Fuller-Rowell *et al.* 1994).

The most favoured mechanisms for the maximum ionospheric time delay are: (a) downward flow from plasmasphere to ionosphere, (b) compression of the plasmasphere by an electric field, (c) upward movement of the F-layer to regions of low loss rate caused either by an electric field or neutral wind, and (d) corpuscular ionization and interhemispheric plasma flow. The relative contribution of different mechanisms could be different at different latitude sectors such as: electric field associated with large pre-reversal height rises during high sunspot equinox at low latitudes and conjugate and protonospheric sources register an increase at high latitudes. During the daytime, equinoctial values, in case of ionospheric time delay is higher than those observed in the winter and summer solstices indicating a semi-annual variation in the whole year of observation irrespective of solar activity condition.

We also observed the maximum ionospheric time delay during magnetic storm condition and the result shows that they do not bear any clear relationship either with the magnitude of the geomagnetic storm or with the main phase onset (MPO) of the storm. But most of the maximum ionospheric time delay variations are observed during quiet days (before MPO or SSC) as compared to storm days. This may be due to changes in electron temperature which have small effect on time delay during disturbed but an appreciable effect during quiet period.

During an ionospheric storm there is heating of the lower part of the thermosphere in the auroral region. The main source of this heating is the joule dissipation of electric currents (Forster & Jakowski 2000; Danilov & Lastovicka 2001) and it should lead to a significant decrease in the atom-to-molecule ratio throughout the entire high latitude atmosphere (Buondanto 1999). Further, the low latitude ionosphere in the Indian region is characterized by large horizontal gradients, intense irregularities and large day-to-day variability. Hence, there is a necessity to thoroughly understand and model the effects of ionospheric time delay on the radio system. And this statistical information would be useful for developing a suitable vertical time delay algorithm for the Indian subcontinent.

5. Conclusion

From the above results we conclude that:

- Under the geomagnetic disturbances, the maximum ionospheric time delay occurred in equinox while minimum in winter and moderate in summer.
- The maximum ionospheric time delay which occurred in the months of equinox, summer and winter was 67.0377 ns, 45.9846 ns and 35.2864 ns during quiet period and 46.0726 ns, 50.0269 ns, 42.6269 ns during disturbed period respectively. While minimum ionospheric time delay was 32.9488 ns, 32.8303 ns, 14.4249 ns during quiet period and 35.9586 ns, 26.2258 ns, 20.1631 ns during disturbed period respectively.
- The average ionospheric time delay in the months of equinox, summer and winter was 45.7875 ns, 39.4716 ns, 26.3558 ns during quiet periods and 41.3250 ns, 35.1827 ns, 31.4715 ns during disturbed periods.

- Result does not show any clear relationship either with the magnitude of the geomagnetic storm or with the main phase onset (MPO) of the storm. But most of the maximum ionospheric time delay variations are observed during quiet days.

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