On the local-time variations of the storm-time TEC at European middle latitudes

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Abstract

Global Positioning System (GPS) measurements of the Total Electron Content (TEC) at European middle latitudes were used to obtain the TEC changes during the geomagnetic storms of the latest solar activity cycle. A common epoch analysis, with respect to geomagnetic storm onset, intensity, season, and latitude, was performed on data representing nearly 300 storm events. Results show that there is also a pronounced dependence of these TEC variations on the local time of the storm onset, as demonstrated for the location of Dourbes (50.1ºN, 04.6ºE).

1. Introduction

An automatic system for real-time specification of the local ionosphere has been developed and installed at the RMI Geophysical Centre in Dourbes (50.1N, 4.6E). The system, named LIEDR (Local Ionospheric Electron Density profile Reconstruction), acquires measurements from collocated digital ionosonde and a GPS receiver and promptly processes the incoming measurements, computes the full-height ionospheric electron density profile, and displays the resulting profilograms [1].

In order to add forecasting capabilities to the LIEDR system, a new procedure is now being developed for TEC forecasting, in which the TEC temporal behaviour is considered as composed of a periodic component and a random component [2]. The periodic component represents the average (annual, diurnal) non-disturbed variation, whereas the random component represents variations inflicted by strong changes in the solar/geomagnetic activity. While the TEC median, periodic behaviour can be predicted by using a TEC climatological model combined with recent measurements for more reliably estimating the forward gradient, the real challenge is to forecast the random component during disturbed ionospheric conditions. During such disturbed conditions, the TEC deviation from its mean/median behavior can be substantial and what further complicates the picture is the fact that the extent of this deviation is much stronger tied to the time elapsed from the storm onset (the so-called storm time). This TEC deviation during storms was proved to vary considerably with season and latitude [3]. Thus, a natural step in the development of forecast procedure was to create an empirical model of the TEC storm-time variations in which the average response pattern is suitably expressed as a function of the storm intensity and time, season and latitude [4].

However, when thoroughly analysing the TEC variability during geomagnetic stroms, it has been noticed that, in addition to the seasonal and latitudinal dependence, there is also a pronounced relation to the local time of the storm onset that should be taken into account when developing the abovementioned empirical model. Reported here is the investigation of this relation. Results are presented for the local ionosphere above the mid-latitude GPS station of Dourbes, Belgium.

2. Data and Method of Analysis

The local TEC observations have been made with a GPS receiver applying a computational procedure based on the 'geometry-free' combination of GPS code and phase measurements for fixing the ambiguities. Receiver and satellite group delays were estimated by modelling the slant TEC with a polynomial depending on latitude and local time. The conversion to vertical TEC was performed by assuming the standard ionospheric thin-shell model at a mean ionospheric height of 350 km. The TEC data base consists of measurements since 1994, i.e. covering more than one complete solar cycle period. Vertical TEC data, retrieved from the CODE (Centre for Orbit Determination in Europe) global ionosphere maps (GIM) generated from IGS (International GNSS Service) measurements, were also utilised as an additional reference and for deducing the latitudinal dependence of the storm-time variations.

For the purpose of this study we considered all geomagnetic storms that occurred between January 1994 and December 2009, i.e. during the entire solar cycle 23. The main reference used for selecting and analysing the geomagnetic storms was the Dst index. The selected storms were classified according to their intensity as Class I (Dst min ≤ -100nT) and Class II (-100nT < Dst min ≤ -50nT). TEC data representing nearly 300 storm events have been analysed with respect to geomagnetic storm intensity, season, latitude, and local time of the storm onset. When

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analysing TEC variations during geomagnetic storms, it is preferable to use the relative deviation (TEC_{rel}) of the observed TEC (TEC_{obs}) from normal (non-disturbed) conditions (in this study, the 27-day running median, TEC_{med}, for each hour of the day): $TEC_{rel} = (TEC_{obs} - TEC_{med})/TEC_{med}$. To correctly deduce the average storm-time changes in the TEC_{rel} behaviour, a superposed epoch analysis (Dst and TEC measurements arranged according to the storm onset, ST=0) was carried out for all storm periods.

3. Results and Discussion

The results of the epoch analysis using hourly medians (with reference to each storm time hour) of Dst and TEC_{rel} are shown here (Fig.1) for equinox Class-I storms for the Dourbes station. The vertical axis corresponds to the Dst index (solid curve) and the relative percentage of TEC (vertical bars). The horizontal axis is the storm time (in hours), ranging from -24ST (i.e. 24 hours before the start) through +120ST (i.e. 120 hours after the start). Results for storm onsets during day are shown on the top, for those during night – at the bottom.

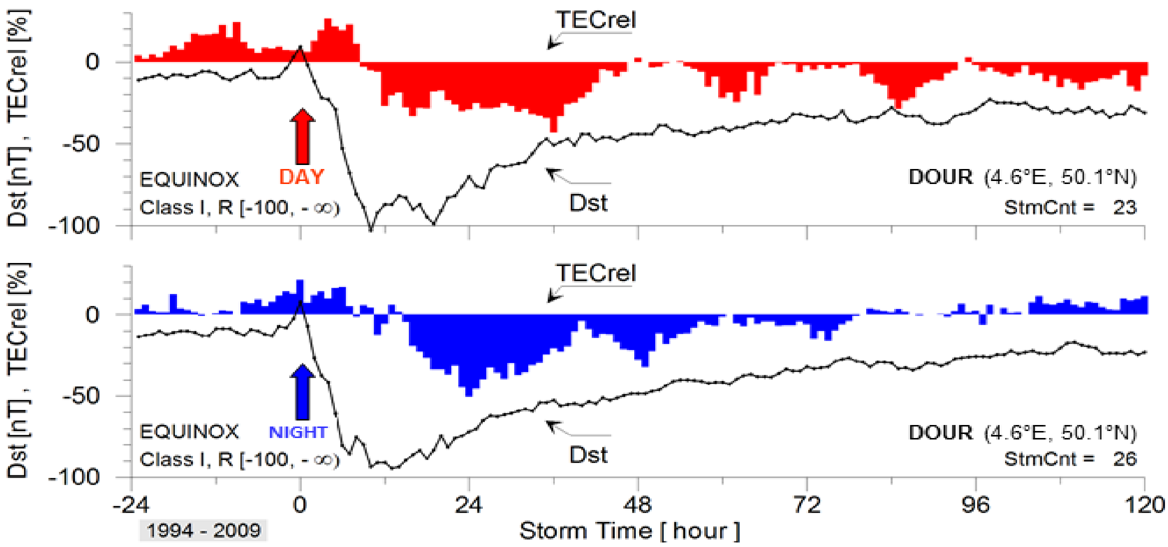

Fig.1. Average GPS TEC relative deviations (TEC_{rel}) from 27-day medians during geomagnetic storms of class I during equinox, for storm onsets during day (top) and night (bottom) for the site of the Dourbes station (4.6°E, 50.1°N) based on data from the 1994-2009 period.

For storms starting during daytime, results show that, with reference to storm time, the TEC relative deviation increases during the onset and peaks a few hours into the main phase. Immediately after that, TECrel decreases sharply to form a long-lasting depression for about 24 hours before starting to increase during the recovery phase and reach values typical for non-disturbed conditions. Interestingly, the relative TEC decreases repeatedly in the following nights. Such behaviour, appearing outside the initial and main phases of geomagnetic storms, are reportedly observed at other longitudes as well, and can be explained with changes in the atmospheric circulation, resulting in upward and downward movements of the ionosphere.

When the storm onset occurs during local nighttime, the TEC relative deviation starts increasing early in the onset phase, peaking at around ST=0, and then slowly decreasing during the main phase. The negative TECrel phase starts near the end of the storm's main phase (ST=12) and reaches an absolute minimum at ST=24. Immediately after that, the TECrel begins a "recovery" to almost pre-storm values, i.e. TECrel = 0, some 12 hours later. Again, the relative TEC decreases repeatedly in the following couple of nights, although the minima are not so pronounced. Note that the minima occur always during the night, for both the daytime and nighttime storm onsets. At the end of the geomagnetic storm, TECrel becomes positive again, a phenomenon known as a "post-storm enhancement".

The results show that the TEC response to geomagnetic storms does indeed depend on local time. There are obvious similarities in the relative TEC behaviour irrespective of the time of the storm onset, for example the occurrence of a positive TEC phase around the onset and a negative phase characterised with several minima in the following nights. However, there are also substantial differences depending on the local time of the storm onset, most notably the timing of the positive phase maximum and the delayed negative phase during storms with nighttime onsets.

4. Conclusion

In relation to an ongoing development of an ionospheric monitoring and forecasting system, the TEC response to geomagnetic storm activity was investigated. The focus here was on the local-time variations of TEC during storms, in particular the differences in the TEC storm-time variations related to the different local time of the storm onset. For the purpose, a superposed epoch analysis of the TEC variations was carried out for all storm periods in the last solar cycle. Although there are similarities in the local-time variations of the storm-time TEC behaviour, some substantial differences were shown, such as the timing and extent of the TEC “positive” phase as well as the delayed “negative” phase during storms with nighttime onsets. Such differences should be taken into account in the TEC empirical modelling and operational forecasting.

Acknowledgments

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