SPACE WEATHER EFFECTS DETECTED BY GPS BASED TEC MONITORING

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Abstract
The world-wide use of GPS satellites for navigation and positioning offers the unique chance for permanent monitoring the total electron content (TEC) of the ionosphere on global scale.
Based on the analysis of GPS-derived TEC maps computed at DLR/DFD Neustrelitz for the European area on a routine base with a time resolution of 10 min the paper demonstrates the power of this new tool to detect and to study the dynamics of large scale horizontal structures in the perturbed ionosphere. Ionospheric storm phenomena are shown to be closely related with Space Weather characterising parameters such as solar radio flux index, solar wind speed and geomagnetic activity indices. Mid-term variations of solar wind speed and related geomagnetic parameters are anticorrelated with GPS-derived TEC data obtained in the first half of 1996, thus showing the potential of TEC maps for studying of upper atmosphere dynamics.
It is expected that GPS radio occultation measurements onboard future satellite missions such as SAC-C, CHAMP and METOP will essentially contribute to monitor the global electron density distribution in near real time.

1. Introduction

Global navigation satellite systems such as GPS and GLONASS offer a unique opportunity to monitor the total electron content (TEC) of the ionosphere on global scale. The information about the ionosphere is derived from dual frequency code and carrier phase measurements on L-band frequencies. The global network of GPS-ground stations as f.i. that of the International GPS Service for Geodynamics (IGS) of the geodetic community (Zumberge et al., 1994) allows a continuous monitoring of the ionosphere with a time resolution of 30s. In this paper we confine our attention to the regional European ionosphere.
The data are processed on a regular base with a time delay of about 2 days since February 1995 (http://www.nz.dlr.de/gps/gps-ion.html).

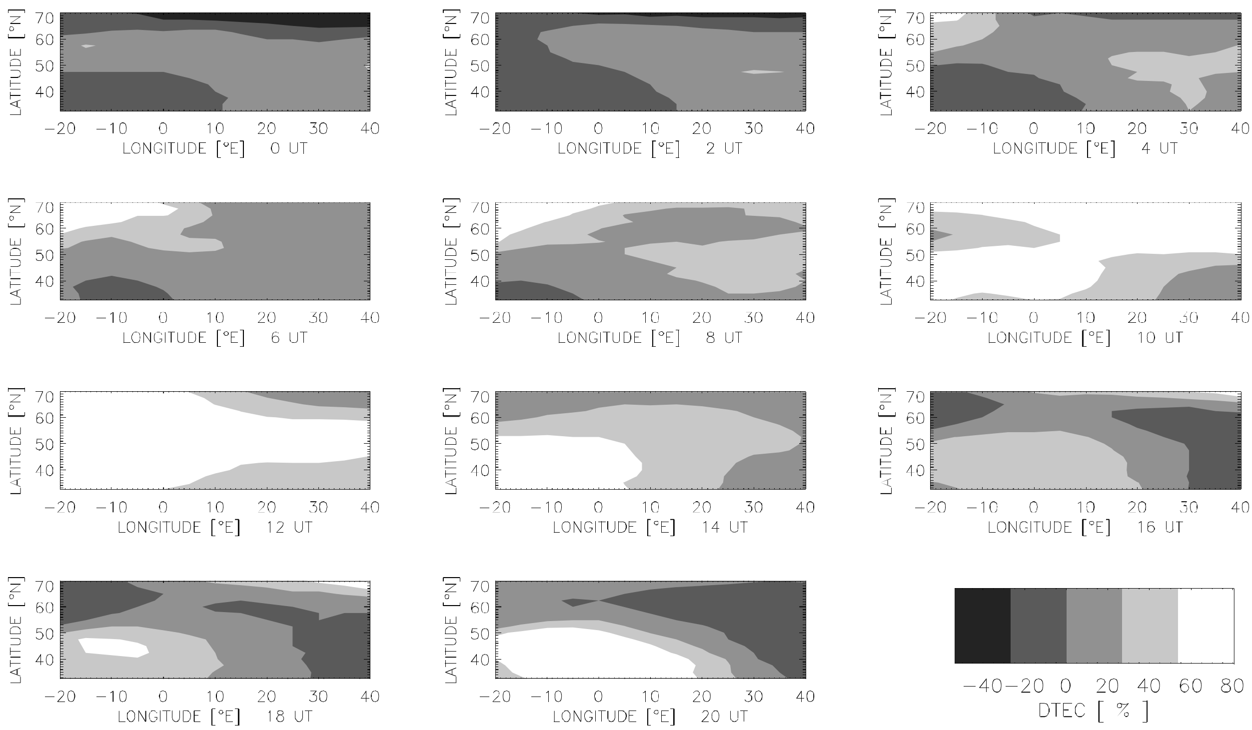

Fig. 1 *Percentage deviations of TEC from monthly medians on 10 January 1997.*

2. TEC Monitoring Procedure

After determining the total electron content along a number of ray path's by using a special calibration technique for the ionospheric delay of GPS signals (Sardon et al.,1994), the slant TEC is mapped to the vertical by using a single layer approximation for the ionosphere at 400 km height. Using the GPS ground stations of the European IGS network, about 60-100 TEC data points are obtained covering the region 20°W $\leq \lambda \leq$ 40°E; 32.5°N $\leq \varphi \leq$ 70°N. To ensure a high reliability of the TEC maps also in case of only a few measurements or at greater distances from measuring points, the measured data are combined with the empirical TEC model NTCM2 (Jakowski, 1998). For each grid point value a weighting process between nearest measured values and model values is carried out. The achieved accuracy is in the order of some 10^{16} electrons/m^2 and therefore high enough to monitor large scale perturbation processes due to Space Weather effects.

3. TEC Monitoring of Ionospheric Perturbations

The geomagnetic/ionospheric storm on 10 January 1997 is well documented by a large number of different observations on global scale. The coordinated measurements were initiated by the observation of large coronal mass ejections (CME) at the sun by SOHO scientists on 6 January 1997.

The variation of TEC during ionospheric perturbations is studied by creating differential maps (TEC = (TEC - TEC_{median})/TEC_{median} x 100%). The two-hourly plots in Figure 1 indicate strong enhancements at high latitudes during the early morning hours around 4 - 12 UT probably due to high particle precipitation rates. It is assumed that equatorward directed neutral winds then cause a plasma uplifting in particular in the 45°N latitude region.

The 10 January storm is characterised by strong longitudinal differences in TEC. Thus North American GPS stations measured a strong enhanced ionisation only during night-time and at high latitudes (Jakowski et al.,1998). In contradiction to North America the European ionosphere shows a significant positive storm phase decreasing from West to East.

The observed simultaneous increase of ΔTEC at different latitudes around 0600 UT shown in Figure 2 indicates the action of an eastward directed electric field which penetrates from high to mid-latitudes. The delayed response of the secondary peak around noon in lower latitudes is consistent with the assumed neutral wind.

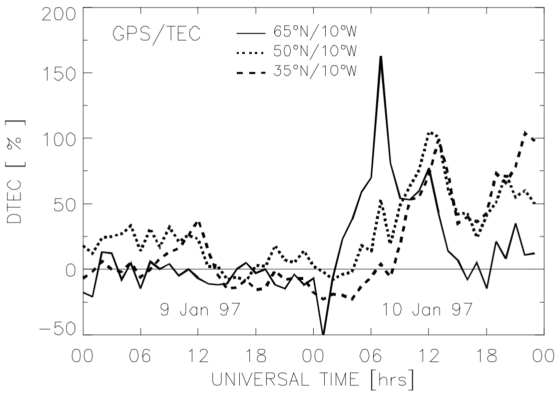

Fig. 2 *Diurnal variation of percentage deviations of TEC from monthly medians on 9/10 January 1997 at different latitudes.*

4. Relationship Between TEC and Solar Wind

Variations of the total electron content (TEC) can be due to variations of the solar radiation and to the solar wind. Since the selected time period (first half of 1996) is before and around solar minimum, the variations of the solar radiation are marginal. Fortunately, the solar wind has recurrent high-speed streams during this time, so that the relationship between TEC and solar wind can be well studied.

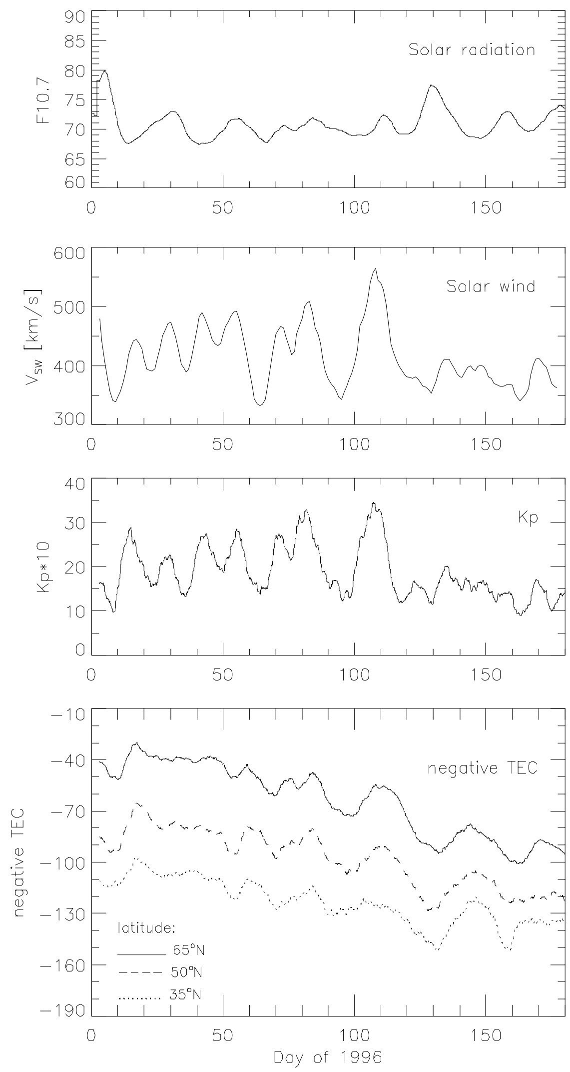

Fig. 3 *Solar, geomagnetic and TEC data during the first half of 1996.*

The time series of F10.7 solar radio flux, solar wind speed Vsw, geomagnetic activity index Kp, and negative TEC are averaged with a sliding 6-day window in Figure 3. The activity of F10.7 was marginal (upper panel), while the time series of Vsw (observed by IMP-8) shows quasi-periodic variations which can be interpreted as high-speed streams from coronal holes (panel 2). These solar wind variations induce highly correlated geomagnetic activity (Kp in panel 3).
TEC observations at different latitudes show a clear anticorrelation to Kp and the solar wind speed (panel 4). The corresponding correlation curves show a maximal correlation of r=0.95 between Vsw and Kp and a correlation of r=0.85 between Vsw and –TEC, respectively.
The delay between Vsw and -TEC by about 2-5 days could be interpreted as a close relationship of the solar wind with the negative phase of ionospheric storms observable 1- 5 days after storm onset, thus indicating a close coupling of solar wind with the ionosphere/ thermosphere systems.

5. Conclusions

It has been shown that TEC is a quite useful parameter to design perturbations in the magnetosphere/ionosphere/thermosphere systems. The GPS technique provides a unique opportunity to monitor this parameter continuously on global scale in near real time. To quantify the strength of ionospheric perturbations, we propose to derive temporal and spatial gradients from the generated TEC maps. In Figure 4 various ionospheric perturbation parameters of this type (3-hourly averaged) are compared with Kp and the F10.7 solar radio flux. In addition to solar and geomagnetic activity indices TEC map derived ionospheric perturbation indices would be helpful especially for system operators to estimate the perturbation degree of the ionosphere.

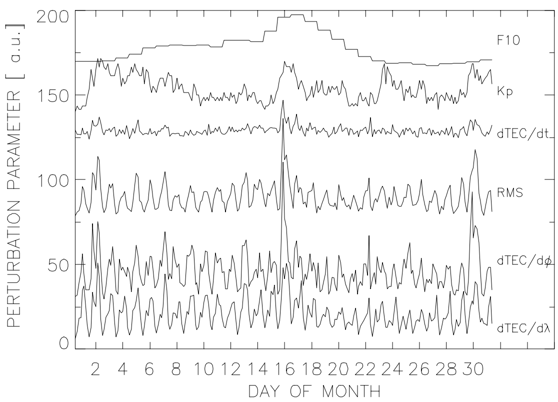

Fig. 4 *Proposed ionospheric perturbation indices in comparison with solar F10.7 and geomagnetic Kp* indices for May 1995.

Great progress for monitoring the ionosphere is also expected by radio occultation measurements onboard Low Earth Orbiting (LEO) satellites. Future satellite missions such as SAC-C, CHAMP and METOP will essentially contribute to monitor the 3-dimensional electron density distribution over the globe.

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References

Jakowski,N., Sardon,E., Engler,E., Jungstand,A. Klähn,D., *Relationships between GPS signal propagation errors and EISCAT observations, Ann. Geophys. 14, 1429 1436, 1996*
Jakowski,N. and Sardon,E., *Comparison of GPS/IGS -derived TEC data with parameters measured by independent ionospheric probing techniques, Proc. IGS 1996 Analysis Centre Workshop, Silver Spring, 19-21 March 1996, 221-230,1996*
Jakowski,N., *Generation of TEC Maps Over the COST251 Area Based on GPS Measurements, Proc. 2nd COST 251 Workshop, Side,30-31 March 1998,51-57, 1998*
Jakowski,N., Schlüter,S., Sardon,E., *Total Electron Content of the Ionosphere During the Geomagnetic Storm on January 10, 1997, J. Atmos. Terr. Sol. Phys., 1998 (in press)*
Sardon,E., Rius,A., Zarraoa N., *Estimation of the Transmitter and Receiver Differential Biases on the Ionospheric Total Electron Content from Global Positioning System Observations, Radio Science, 29, 577-586, 1994*
Zumberge,J., Neilan,R., Beutler,G., and Gurtner,W., *The International GPS-Service for Geodynamics-Benefits to Users., Proc. ION GPS-94, Salt Lake City, September 20-23, 1994.*