# TOTAL ELECTRON CONTENT BEHAVIOR AT HIGH LATITUDES DURING GEOMAGNETIC STORMS

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## ABSTRACT

Using the measurements of the GPS ground station network of the International GPS Service (IGS) at the northern high latitude area polar maps of vertical TEC were derived for a grid consisting of 768 points within the latitude range 50 °N ≤ latitude ≤ 90 °N.
During geomagnetic storms strong enhancements of TEC are observed in particular near the geomagnetic pole accompanied by strong temporal variations of TEC reaching amplitudes of up to 80 $\times 10^{16}$ $m^{-2}$. The observed phenomena are assumed to be correlated with the southward direction of the interplanetary magnetic field.

## INTRODUCTION

Since the high latitude ionosphere is controlled by strong coupling processes with the solar wind and the magnetosphere, its permanent monitoring becomes attractive both for ionospheric research as well as for space weather monitoring.
Based on our experience obtained by monitoring the total electron content (TEC) of the European ionosphere on a routine basis since 1995 (http://www.kn.nz.dlr.de/ , e.g. [ 1] ), we recently started to monitor TEC over the northern polar cap on a routine basis too. The observation data are provided by the permanently growing global network of GPS ground stations of the International GPS Service (IGS).

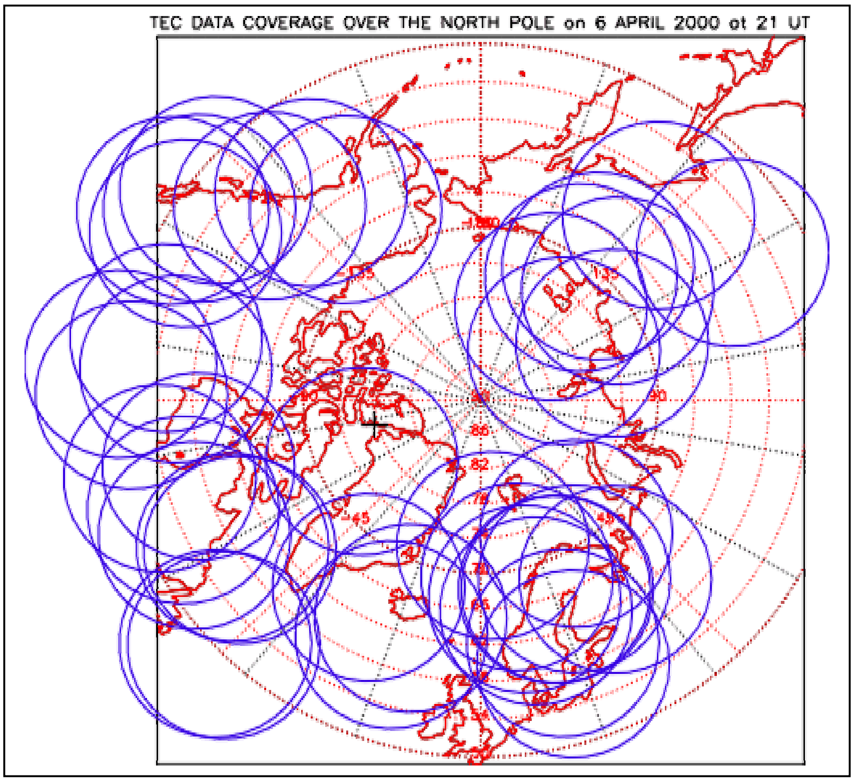


Fig. 1. Coverage of ground based GPS measurements on northern high latitudes on 6 April 2000 at 21:00 UT.
The circles indicate the half width of the weighting function range constructed around ionospheric piercing points.

## MEASUREMENTS

After determining the total electron content along a number of ray path's by using a special technique for calibrating the ionospheric delay of GPS signals [ 2] , the slant TEC is mapped to the vertical by using a single layer approximation for the ionosphere at $h_{sp}$= 400 km height. Using the GPS ground stations of the European and northern high latitude IGS network, about 60 -100 TEC data are estimated for the piercing points of the slant ray paths with the ionospheric layer at $h_{sp}$. The influence of a single measurement is reduced according to a distance depending weighting function. Fig. 1 illustrates the data coverage by plotting circles around the piercing points that correspond with the half width of this weighting function.

For mapping the TEC a preliminary model for the polar TEC (NTCMP-1) was established in the same way as NTCM-2 for the European area (20 °W ≤ longitude ≤ 40 °E; 32.5 °N ≤ latitude ≤ 70 °N, e.g. [ 1]). The regional ionospheric NTCMP-1 model has been iteratively developed by using polar TEC data collected over one year.

So polar maps of vertical TEC were derived for a grid consisting of 768 points within the latitude range 50°N ≤ latitude ≤ 90°. The corresponding actual polar TEC maps are now available in the Web via [http://kn.nz.dlr.de.daily/north](http://kn.nz.dlr.de.daily/north) .

The maps indicate strong spatial and temporal variations in particular during geomagnetic storms.

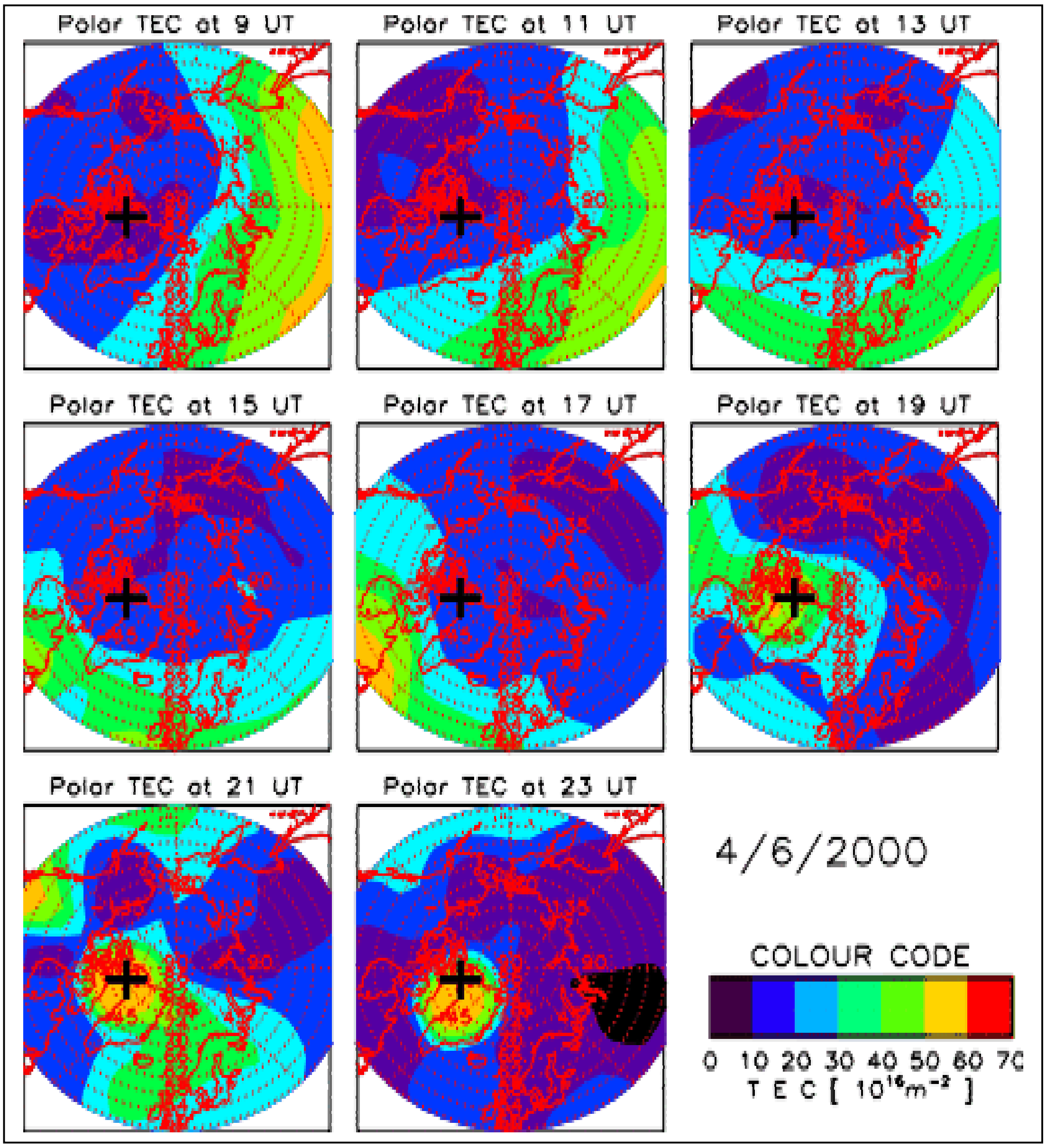


Figure 2. : Vertical TEC plots over the northern polar cap on 6 April 2000 at selected hours

## IONOSPHERIC STORMS

For more detailed studies we have selected some severe storms as e.g. that from 6/7 April 2000 to monitor their development over the northern polar cap. As it has been shown in earlier papers, e.g. [3], TEC is very sensitive to perturbation induced dynamic forces such as particle precipitation, convection electric fields and meridional thermospheric winds.
The polar TEC maps have been computed for 6-7 April 2000 with a time resolution of 10 minutes. Solar wind measurements onboard the ACE spacecraft detected the arrival of the solar wind shock front on 6 April around 16:00 UT.
The polar view on TEC from 9:00 UT until 23:00 UT in Fig. 2 shows a quite normal behavior of the ionosphere with clear day- and night-time sectors before the shock front directly coupled into the Earth's ionosphere obviously more than 1 hour later. However, at 19:00 UT a strongly enhanced ionization is visible directed from the day-time sector towards the geomagnetic pole that is marked by a black cross. A remarkable strong enhancement of ionization is visible near the geomagnetic pole from about 19:00 – 23:00 UT. At 21:00 UT the enhanced ionization spreads over the European area where beautiful polar lights have been seen and other space weather effects such as Geomagnetic Induced Currents (GIC's) on pipelines were detected.
We suppose that the strong impact on the magnetosphere/ ionosphere systems is due to the southward direction of the interplanetary magnetic field. The interplanetary magnetic field turns southward (Bz < 0) from about 17:00 until 24:00 UT with a short break around 22:00 UT.
As pointed out by Buchau et al. already about 20 years ago [4], in case of a southward Bz component the polar cap is populated by so-called ionospheric patches that are characterized by electron densities that exceed the background density by at least a factor of two and extend over at least 100 km. These patches may originate in the day-side and may then move under the influence of high–latitude electric fields through the day-side cusp region toward the polar cap (cf. plot at 19:00 UT in Fig. 2). We assume that both high-latitude convection as well as particle precipitation result in a strong irregular ionization between 17:00 and 24:00 UT. This can also be seen in Fig. 3 where the temporal variation of TEC is plotted at two different latitudes along $\lambda$ = 270° E which is close to the magnetic zero longitude. The 10 min TEC data have been extracted from the corresponding polar maps. The temporal variation indicates a strong irregular structure starting at about 18:00 UT both at the European sector ( $\lambda$ = 0 °E ) as well as at $\lambda$ = 270 °E shown in Fig. 3. The amplitude of TEC reached extreme high values of up to 60 x$10^{16}$ m$^{-2}$.
Similar observations have been made during another storm on 5/6 November 2001 where TEC amplitudes up to 80 x$10^{16}$ m$^{-2}$ were observed.

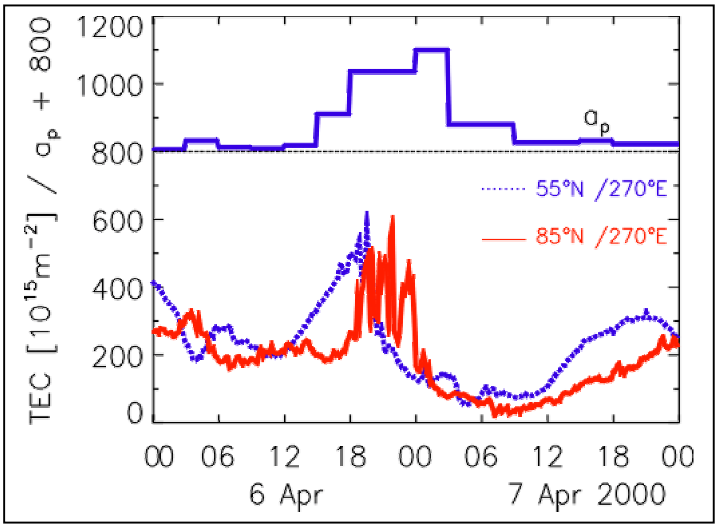


Fig. 3. Temporal variation of TEC at two different latitudes along the 270°E meridian on 6 / 7 April 2000 in comparison with the three-hourly $a_p$ index.

It is interesting to note that the onset of TEC irregularities seen in Fig. 3 is closely correlated with geostationary satellite particle flux data. This fact indicates that polar TEC should be very helpful in monitoring space weather effects.
Both the high absolute TEC level as well as the high temporal dynamics of ionospheric patches may cause serious problems in navigation satellite system applications.

## CONCLUSIONS

It has been shown that a complex space weather event such as that on 6 April 2000 modifies both the electron density as well as the temporal and spatial plasma distribution in a serious and up to now unpredictable manner. Comparing the results of various storm studies, it seems that the southward direction of the interplanetary magnetic field is a key factor for strong disturbances in the high-latitude ionosphere.

Since Global Navigation Satellite Systems (GNSS) such as GPS and GLONASS can seriously be affected by ionospheric perturbations, a permanent monitoring of the global ionosphere is required in particular also for the future European Galileo system.

## ACKNOWLEDGEMENTS

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