INDEX OF LOCAL RESPONSE TO GEOMAGNETIC ACTIVITY FOR USE IN THE SHORT-TERM IONOSPHERIC FORECAST

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Abstract

Investigated is the relationship between the level of geomagnetic activity and the GPS TEC relative deviations from the corresponding monthly medians. The detailed information on this dependence is of crucial importance for developing a new synthetic index quantifying the local response of the GPS TEC to the geomagnetic activity. Also, the new index can significantly improve the quality of the GPS TEC – based short-term forecasting procedure, which is currently being developed. Preliminary calculations of the index coefficients are provided.

Keywords: total electron content, geomagnetic storms, ionosphere-plasmasphere forecast

1. Introduction

One of the ultimate aims of the ionospheric research and service is the reliable short-term prediction of basic ionospheric characteristics, such as foF2 and TEC. Main resulting tasks of the prediction (for use in managing and planning HF Radio Services) is to define: operating frequencies, signal strength, signal-to-noise ratio, multipath probability, etc.

A popular way of predicting the ionospheric characteristics is to employ previously-developed empirical/theoretical models of these characteristics using model inputs that are supposed to adequately represent the conditions in the forecasting period. The problem is that such models are mostly climatological, i.e. they are relevant to undisturbed conditions of large-scale 'slow' dynamics. Recently, new approaches have been proposed to rectify the above-mentioned problem (Houminer and Soicher, 1996; Williscroft and Poole, 1996; Muhtarov and Kutiev, 1999; Kutiev et al., 1999; Kutiev and Muhtarov, 2001; Stankov et al., 2001; Muhtarov et al., 2002). Considering that several procedures, real-time estimates, and predictions of the fundamental geomagnetic activity indices (*Dst*, *Kp*, *Ap*) are now readily available from the World Data Centres (O'Brien and McPherron, 2000; Boberg et al., 2001; Takahashi and Toth, 2001), the proposed auto-regression methods will be better equipped with prediction capabilities because of the proven dependence of the ionospheric characteristics on the geomagnetic activity. Moreover, present and future space missions will help in advancing the knowledge of the solar-terrestrial inter-relationship and thus improving the chances to truly predict the geomagnetic storms (Tsurutani and Gonzales, 1995) and associated phenomena.

A new procedure is being developed for GPS TEC - based forecasting (Stankov et al., 2001), which relates the forecasted GPS TEC behaviour much closer to the past, current and predicted space-weather conditions. Each GPS TEC hourly time series is considered as a sum of two components - periodic and random. The periodic component is non-random and describes the GPS TEC average behaviour (represented here by the 31-day running medians). On the other hand, the random component describes the GPS TEC fluctuations supposedly inflicted by the geomagnetic field disturbances (moreover, it is implicitly assumed that these GPS TEC fluctuations solely depend on the level of geomagnetic activity). These fluctuations are supposed to be a manifestation of a stationary stochastic process. The stationarity hypothesis implies that the mean $E\{n(t)\}$ and the product moment $E\{n(t)n(t+\tau)\}$ are independent on t, where E denotes the mathematical expectation. Such interpretation suggests that the GPS TEC median behaviour is the signal, and the fluctuations are noise. The forecast is therefore performed in two main stages: (i) *Median forecast*: extrapolation of the TEC monthly median values using Fourier series approximation based on actual data from the past twelve months and autocorrelation adjustment over the past thirty days of data. (ii) *Short-term forecast*: extrapolation of the relative deviations (TEC_{rel}) of the measured GPS TEC (TEC_{rel}) from its

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median values, i.e. $TEC_{rel} = (TEC_{meas} - TEC_{med}) / TEC_{med}$, for up to twenty four hours ahead using a classical linear prediction method (Childers, 1978; Muhtarov et al., 2002) based on the current and forecasted values of the geomagnetic activity index *Kp* , equivalently *Ap* (Menvielle and Berthelier, 1991; Takahashi and Toth, 2001).

Thus, the following regression formula is used for forecasting the $(n+1)^{\text{-th}}$ TEC relative deviation value based on the previous *n* values:

$$F_{n+1} = F_{med} + \sum_{i=1}^{n} b_i\left(F_i - F_{med}\right) + \sum_{i=1}^{n+1} b_i\left(G_i - G_{med}\right) \tag{1}$$

where $F(t)$ is TEC_{rel} and $G(t)$ is the 'geomagnetic function', F_{med} and G_{med} the corresponding median values of *F* and *G*. The geomagnetic function $G(t)$, which can be any of the available geomagnetic indices (Mayaud, 1980), say *Kp* , is exactly the random component providing the TEC fluctuations due to the geomagnetic field disturbances. A problem is associated with the short-term forecasting part, arising from eventual non-linear dependence between $F(t)$ and $G(t)$.

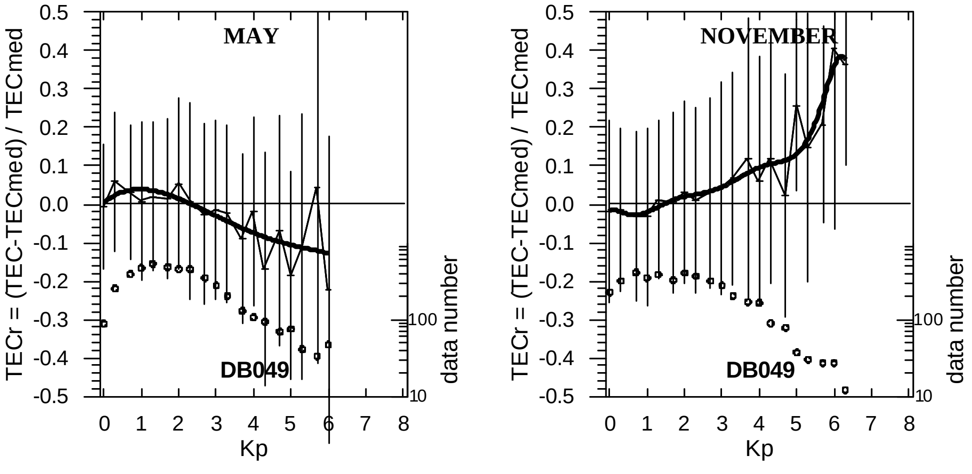

Fig.1 The TEC relative deviations from monthly medians for the site of the Dourbes ionosonde station DB049 (50.1°N , 4.6°E) from 1994–2001 data series obtained at the Royal Meteorological Institute and Royal Observatory of Belgium (Stankov, 2002). Solid lines represent the average dependence of *TECr* on *Kp*. The standard deviations (vertical bars) and data number for each Kp value (circles) are also provided.

The mutual correlation between random variables (*F* and *G*) is highest when these variables are linearly dependent (Childers, 1978; Oppenheim and Schafer, 1989). This is not so in our case: the average dependence between TEC_{rel} and *Kp* is highly non-linear (the solid line in **Fig.1**), which is clearly detected from the GPS TEC measurements at the site of the Dourbes ionosonde station (Stankov, 2002). A polynomial approximation of the mean dependence of TEC_{rel} and *Kp* can perform the role of a synthetic index helping to linearise the above dependence and thus rectifying the above problem. Then, this new index can be used directly in formula (1) instead of the 'geomagnetic function' $G(t)$.

It should be noted, that the behaviour of the foF2 relative deviations have already been analysed and used in modelling studies of the F-region response to storms at middle latitudes (Muhtarov et al., 2002; Kutiev and Muhtarov, 2001; and the references therein). However, significant differences are observed between the behaviour of the GPS TEC relative deviations and the corresponding foF2 relative deviations. These facts are analysed and reported here together with a further analysis of the GPS TEC response to intense geomagnetic activity. Sequentially, it becomes clear that the method of foF2 forecasting cannot be directly applied to the GPS TEC forecasting and modifications in the strategy are needed in the latter case.

This paper presents also results of our work towards creating a synthetic index of local ionospheric response to the geomagnetic activity based on GPS TEC observations and used by the forecast method. Preliminary calculations of the index coefficients for some European stations are provided as well.

2. Analysis – the GPS TEC variations versus geomagnetic activity

The first step in developing the new index is the analysis of the GPS TEC variations induced supposedly by the geomagnetic activity only. The best quantity to be used in such case is the TEC relative deviation TEC_{rel} of the GPS TEC hourly measurements from its median (or mean) value.

$$TEC_{rel} = \frac{(TEC - TEC_{med})}{TEC_{med}} \tag{2}$$

Previous studies involving predictions of the foF2 relative deviations proved the efficiency of this approach of predicting the relative deviations (Houminer and Soicher, 1996; Kutiev et al., 1999; Muhtarov et al., 2002). The relative deviation is calculated by subtracting the monthly mean (or median) value from each hourly value and divided by the monthly mean (median) value. In this way, the diurnal, seasonal, and solar cycle variations are removed. (Note: Another possible way is to use the ratio between the hourly value and the monthly mean (median) value. In this way, the diurnal and longer temporal variations are removed.). Other advantages of using a dimensionless quantity like TEC_{rel} is in the opportunities it offers for comparison of results from different sites (and time), and also for comparison with the behaviour of other characteristic such as foF2. In order to compare the TEC results with the foF2 results from the above publications (Muhtarov et al., 2002; and the references therein), we are also going to use deviations from medians, and the medians will be 31-day running medians. For each 31-day period the 24 (local-time) hourly medians were determined. The TEC relative variability (deviation) for each LT hour was then calculated by subtracting the monthly median value from the corresponding TEC value at the same hour and divided by the median value for the same hour. Thus, for each 31-day period we have 24 values of TEC_{rel}, which are attributed to the 16-th (middle) day of the period.

As mentioned in the introduction, we assume that the GPS TEC fluctuations solely depend on the level of geomagnetic activity; therefore it is necessary to analyze a possible relation (dependence) between TEC_{rel} and an index of geomagnetic activity, e.g. Kp. The Kp index is chosen for the analysis as it provides a larger data set for statistical purposes, its reliability in determination, and traditional use (Menvielle and Berthelier, 1991).

The analysis is made on the basis of 2D-plots of TEC_{rel} versus Kp. All plots are derived in the following manner. For each month of observations, the hourly values of the TEC variability are determined. All values of the characteristic relative deviations in a given month of the year are sorted according to the hourly values of the planetary index Kp, which planetary index is recorded in step values of 0.00, 0.33, 0.67, 1.00, 1.33, ..., 8.67 and 9.00. For higher precision, hourly values of the Kp index are obtained by linear interpolation in-between the neighbouring 3-hour index values. The corresponding hourly values of TEC_{rel} are sorted into bins with width of 0.33 around the above Kp main step values. Then, for each bin (i.e. for each level of Kp) and each 31-day period, the basic statistics are calculated – mean, standard deviation, scattering (twice the standard deviation), number of data in each bin, etc. Examples are given in **Fig.1** for the months of May and November based on GPS TEC observations.

Significant differences are detected in the GPS TEC variability for different seasons and latitude, which will be presented next. Interesting, differences are also observed between the GPS TEC and foF2 variability, which will be discussed as well.

2.1 *Seasonal and latitudinal differences in the GPS TEC relative variations*

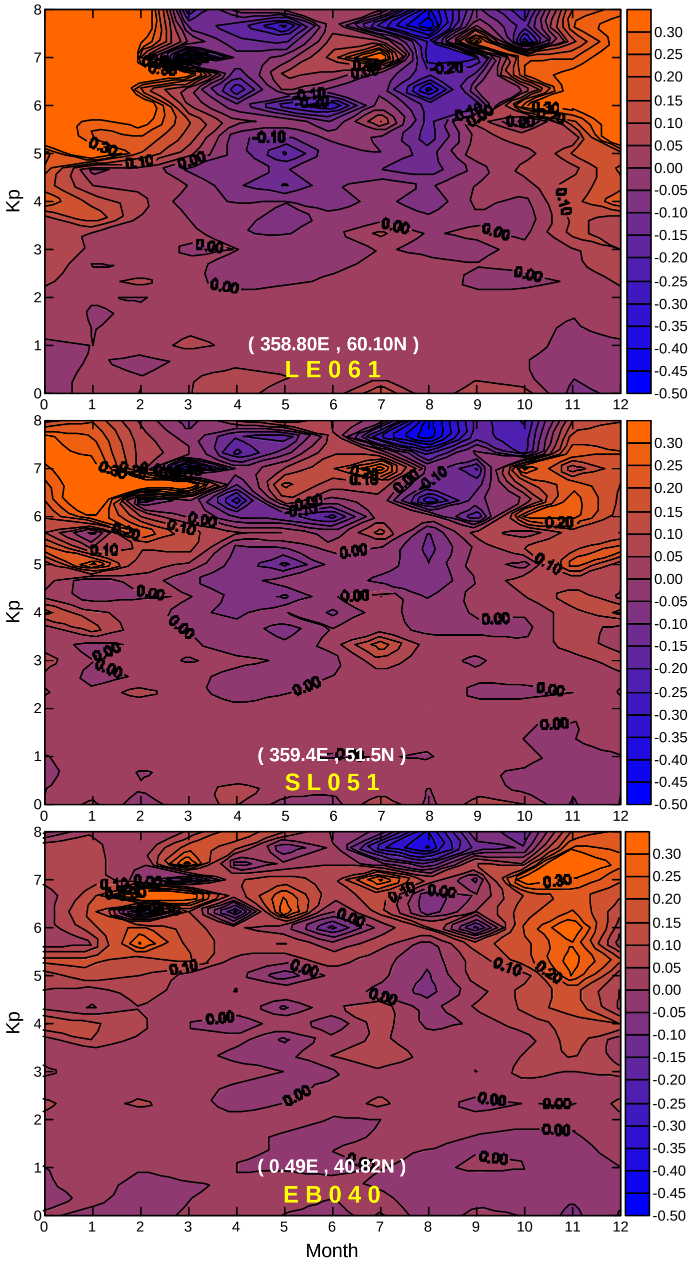

Fig.2 The annual behaviour of the GPS TEC relative deviations from the corresponding monthly medians. Results are obtained and plotted for the sites of the following three ionosonde stations: Lerwick (358.8°E,60.1°N) – top panel, Slough (359.4°E,51.5°N) - middle panel, and Ebro (0.49°E,40.8°N) – bottom panel.

In order to obtain more information on the seasonal and spatial differences in the GPS TEC relative deviations, these deviations are obtained for three stations conveniently situated at three different geomagnetic latitudes: Ebro (43.8°N), Slough (54.3°N), and Lerwick (62.3°N) and within a narrow geomagnetic longitude range between 80°E and 90°E (**fig.2**). The plots are based on the averaged values of the relative TEC deviations plotted using the Kriging method. Differences are observed in both the positive and the negative TEC variability.

First (the positive TEC response), it is obvious that in the winter months of December and January the increase of TEC_{rel} during storms ($Kp>4$) is quite significant: it can be about 20-25% at lower latitudes (**fig.2,** bottom panel) and much more than 35-40% at higher latitudes (**fig.2,** top panel). Therefore, the strength of the positive response is definitely increasing in poleward direction. Also, when heading North, the positive values (for $Kp>4$) are spreading towards the neighbouring equinox months of September and March. Also, positive responses at the Slough and Lerwick sites are observed in summer (June) as well.

Second (the negative TEC response), it is clear from the pictures that pronounced decreases are observed during the equinox periods April-May and September-October for increased geomagnetic activity ($Kp>4$), although not as strong as in the foF2 case (see Section 2.2). Latitude dependence is also observed: at the Northern stations the negative response is much more stronger and starts at lower values of the geomagnetic index Kp .

2.2 *Observed differences between the GPS TEC and foF2 relative variations*

In order to compare the GPS TEC and foF2 relative deviations, the annual response of both characteristics to geomagnetic activity have been calculated in the same manner as described in the previous section. Both types of calculations are performed for the site of the Dourbes ionosonde station DB049 (4.6°E , 50.1°N) using ionosonde and GPS TEC data measurements from the Royal Meteorological Institute and Royal Observatory of Belgium (Stankov, 2002). The results are plotted in **Fig.3** and show that the TEC response is generally stronger and much more complex than the foF2-based observations.

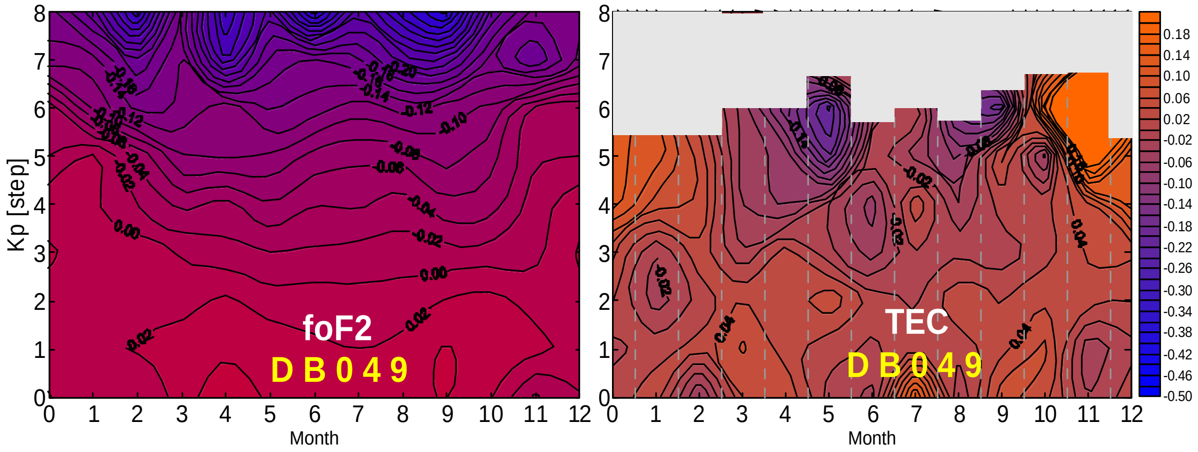

Fig.3. Comparison of the foF2 (left-hand panel) and GPS TEC (right-hand panel) relative deviations from their corresponding monthly medians. All calculations are performed for the site of the ionosonde station DB049 (4.6°E , 50.1°N). The plots are based on the average magnitude of the deviations with respect to the month (horizontal axis) and geomagnetic activity index *Kp* (vertical axis).

First, it is obvious that, for quiet magnetic conditions ($Kp \leq 4$), the dependence of the relative TEC on *Kp* is similar to that of foF2 but, on the other hand, for higher values of *Kp* . Significant differences are observed in the storm-time behaviour of the TEC relative deviations in comparison with the corresponding foF2 relative deviations (**Fig.3**). It is obvious that for foF2 (**Fig.3**, left-hand panel) the relative response to increased magnetic activity is negative throughout the year. Oppositely, for TEC (**Fig.3**, right-hand panel) the relative response to increased magnetic activity may be negative for some months (e.g. May and August –September) but for the rest of the year there are signs of pronounced increases.

Second, let's consider the open question of 'quiet geomagnetic conditions'. It is generally accepted that quite conditions exist if $Kp \leq 4$. However, considering our assumption of sole dependency of the TEC (or foF2) perturbations on geomagnetic activity, the quiet conditions should be defined as those *Kp* for which TEC_{rel} (or $foF2_{rel}$) = 0. It follows from the fact that the median values of a given ionospheric characteristic represent exactly the quiet (undisturbed) conditions; therefore, it should be expected that TEC_{rel} (or $foF2_{rel}$) = 0 for values of *Kp* with highest probability, i.e. where highest number of TEC_{rel} (or $foF2_{rel}$) measurements are recorded. It should be also considered that the magnetic activity is ever-present which in effect leads to TEC_{rel} (or $foF2_{rel}$) = 0 not at $Kp = 0$ but at higher index values. The 'zero' isoline is clearly seen in the plot of the foF2 variability (**Fig.3**, left panel). It is deduced, that for foF2, the 'quiet' behaviour during winter (January and December) can be observed for *Kp* values up to 5, while during equinox – up to 3, and during summer – up to about 2.67. This fact speaks of generally higher sensitivity of the foF2 response to geomagnetic activity during the summer. The picture is much more complicated in the case of GPS TEC values due to the entirely positive response during winter and predominantly negative response at the equinoxes. However, considering both **Fig.2** and **Fig.3**, it can be stated that the overall GPS TEC variability is more sensitive to the level of geomagnetic activity than the foF2.

2.3 *A note on the positive GPS TEC deviations at increased magnetic activity*

It is interesting to analyse also the positive TEC relative deviations (origin and development) at higher geomagnetic activity and also the their differences from the foF2 variability. For this purpose, we need to look into the storm-time behaviour of TEC providing as many concurrent observations as possible.

The positive TEC relative deviations at high values *Kp* are due to the so-called ‘positive phases’ of the ionospheric storms. The positive storm phase is generally accepted to be induced by the strong equatorward thermospheric winds in the expansion phases, reducing the ion loss and effectively increasing the ion production in the day-time hemisphere (Foerster and Jakowski, 2000). The most significant consequence is the plasma uplifting effect – the strong meridional winds push the F2-layer plasma upward, leading to reduced F2-layer peak density and increased hmF2 and TEC. This effect can be easily detected from measurements through the slab thickness shape parameter τ. There is also another possible mechanism – downwelling of molecule rich gas (after summer-to-winter hemisphere transport of composition bulge) causing recombination rate decreases and ‘positive storm effect’ in TEC. The latter mechanism explains also why the positive storms prevail in winter.

A well-known storm event, 31/03/2001–2/04/2001, is investigated in more detail to demonstrate the effects. Provided are values of Dst and *Kp* indices together with the TEC values as observed at the site of station Juliusruh (13.4°E, 54.6°N), **Fig.4**. This storm started at 00:30UT on 31/03/2001 and demonstrated very strong perturbations in the geomagnetic field components: it is clearly defined as ‘severe’, considering also the *Kp* maximum of 9. An extremely sharp decrease of Dst is also observed, reaching the absolute minimum value of –358 nT at 08:00UT on 31/3/2001. It was also a long-lasting event: the main phase (-50 nT→Dst(min)) lasted for 3 hours and the recovery phase (Dst(min)→-50 nT) lasted for about 54 hours.

Both positive and negative storm effects are observed in the GPS TEC measurements. In **Fig.4** (bottom panel), the relative TEC variability is given for the whole storm period. A sharp positive increase (up to 140%) is observed immediately following the SSC, which increase lasted for about 6 hours. During this period, the *Kp* index rises from 6.67 to 8.67 and goes back to the 6.33 mark. This is the period with the highest values of *Kp* and exactly in this period positive TEC_{rel} are recorded. Case studies of other storms reveal similar behaviour (Stankov, 2002), confirming the existence of average positive TEC relative variability at high *Kp*. In contrast to the foF2 positive response, which (if present at all) is very short, the TEC positive response is sustained much longer.

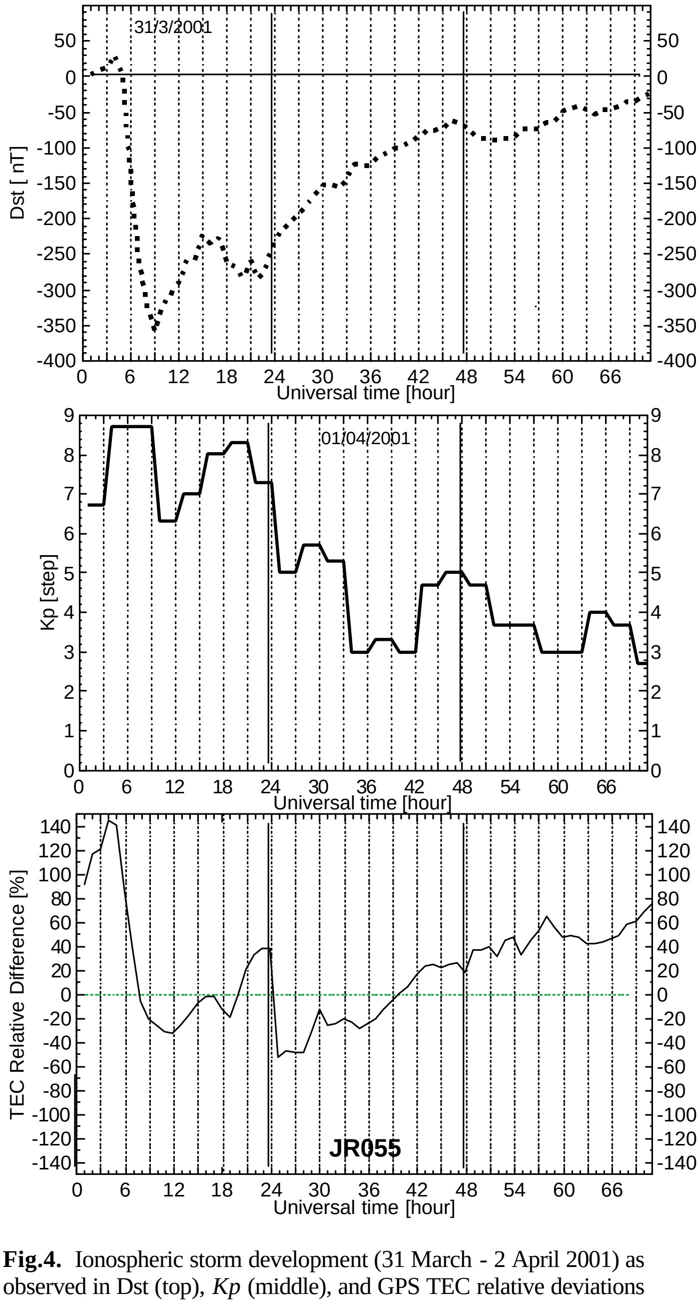

Fig.4. Ionospheric storm development (31 March - 2 April 2001) as observed in Dst (top), *Kp* (middle), and GPS TEC relative deviations (bottom) at the site of station JR055 (13.4°E,54.6°N).

3. SILNORMA - synthetic index of local normalized observations response to magnetic activity

Proposed is a new, synthetic index describing the local ionosphere characteristics (normalized to the median values) response to (intense) geomagnetic activity conditions (SILNORMA). The purpose is to directly apply this index in the short-term forecast of the GPS TEC characteristic based on auto-regression methods.

Essentially, the index will be an approximation of the averaged normalized behaviour of the forecasted characteristic (for example, see the solid line in **Fig.1**). The type of approximation of the mean relative deviation is very important. First, this approximation will provide the actual index values and should be as accurate as possible because it is going to directly affect the linearisation of the connection between F and G (see formula (1)). Second, the function should not be very complex as it will make the above linearisation difficult. Third, a correct separation between ‘quiet’ and ‘storm’ conditions depends on the correctness of the dependence (see the discussion in Section 2.3). Fourth, if possible, the approximation should be of the same type for all ionospheric characteristics, particularly TEC and foF2.

By assuming that the geomagnetic activity is the sole cause of the GPS TEC perturbations (respectively, the GPS TEC relative deviations from the monthly medians), the average behaviour of the above perturbations can be presented as a function of the planetary geomagnetic index *Kp* (alternatively, the *Ap* index). Proposed is a polynomial approximation of this dependence to be used as an index. Considering the analysis in the previous part (Part 2) and the TEC-based calculations, it follows that a second-degree polynomial is not good enough to describe the complex TEC response. Therefore, the following third-degree polynomials are offered for the TEC-SILNORMA (Q), depending on the month of year (m), geomagnetic latitude (j) and longitude (l) :

$$T\left(j\,,l\,,m\right)=\sum_{i=0}^{3}c_i\left(j\,,l\,,m\right).K_p^{\,i} \qquad (3)$$

The analysis shows also that the GPS TEC perturbations induced by the geomagnetic activity demonstrate strong spatial and temporal (seasonal, local-time) variability. Therefore, in order to perform a high-quality forecast, the synthetic index should be deduced for each geographic location separately. However, at this stage, only the European region is considered and TEC-SILNORMA coefficients obtained for its stations. As an example, the calculated polynomial coefficients, obtained for the three middle-latitude sites considered in the analysis (Part 2), are presented here (Table I). In view of further developments in the global storms modelling and TEC short-term forecasting, a global model of TEC-SILNORMA is required.

The GPS TEC relative deviations are expected to depend also on the local time as it was proven for the foF2 relative deviations (F) at middle latitudes (Kutiev and Muhtarov, 2001). The statistical study, based on a full solar cycle period and 26 middle-latitude ionospheric stations, shows that the average foF2 response to geomagnetic forcing is delayed with a time constant of 18 hours and the instantaneous F distribution is sinusoidal. A new model of F is offered, where F is defined by two standing sinusoidal waves with periods of 24 and 12 hours, rotating synchronously with the Sun.

However, it should be mentioned that the relatively short time of collecting GPS TEC data and consequently the limited database doesn’t allow us to perform a full range statistical analysis of the same type as for foF2. TEC data series for an entire solar cycle is a pre-requisite; the TEC variability depending on solar activity is quite strong (Stankov et al., 2001; Stankov, 2002). In addition, the observed differences between foF2 and TEC storm behaviour make the task even more difficult and needs further investigation.

LE061	**Degree 0**	**Degree 1**	**Degree 2**	**Degree 3**
JAN	-0.00315004	0.0508573	-0.0339416	0.00665073
FEB	0.0392457	-0.092586	0.0385024	-0.00282362
MAR	0.0953839	-0.129344	0.0467148	-0.00441373
APR	0.0760262	-0.0291054	-0.00342287	0.000530661
MAY	0.0492617	-0.0219606	-0.00460323	0.000644569
JUN	-0.00789404	0.0840049	-0.0439476	0.00466968
JUL	0.107895	-0.0987833	0.0249447	-0.00183409
AUG	0.0161411	0.0288412	-0.0130401	0.000308943
SEP	0.0646467	-0.035294	0.00519716	-0.00025433
OCT	0.107113	-0.175858	0.0640719	-0.0059002
NOV	-0.052277	0.00189916	0.0154437	-0.00135671
DEC	-0.0427628	0.0604943	-0.0164924	0.00346755

SL051	**Degree 0**	**Degree 1**	**Degree 2**	**Degree 3**
JAN	0.0481981	-0.0228353	-0.00320366	0.00197123
FEB	-0.0197672	0.0409025	-0.0141465	0.00182806
MAR	0.0651627	-0.0742769	0.0254639	-0.00229862
APR	0.0381891	0.00966277	-0.0140484	0.00139891
MAY	0.0178878	-0.0100038	-0.00315998	0.000602891
JUN	-0.034079	0.0889468	-0.0373211	0.00378615
JUL	0.0716682	-0.0716401	0.0269126	-0.00253663
AUG	0.0131134	-0.0196442	0.0117969	-0.00203752
SEP	0.0485791	-0.0409538	0.0136448	-0.00154202
OCT	0.0765764	-0.1523	0.0602785	-0.00574559
NOV	-0.0401791	-0.0149795	0.0210279	-0.0019979
DEC	-0.00814568	0.0217547	-0.00222273	0.000500161

EB040	**Degree 0**	**Degree 1**	**Degree 2**	**Degree 3**
JAN	0.0175217	-0.0285582	0.0146209	-0.00119256
FEB	-0.0189927	0.000941147	0.0082597	-0.000705562
MAR	0.0355263	-0.0567516	0.0216366	-0.00162993
APR	0.0112222	0.0224124	-0.0129707	0.00149852
MAY	0.0478803	-0.0833133	0.0271683	-0.00206908
JUN	-0.0378911	0.0513936	-0.0151496	0.00128453
JUL	0.052472	-0.0766677	0.0330861	-0.00324792
AUG	0.00125327	-0.0374665	0.0226224	-0.00288688
SEP	0.00902681	-0.0296481	0.0151745	-0.0016099
OCT	0.0314029	-0.121016	0.057214	-0.0054803
NOV	-0.0421225	-0.0312555	0.0308677	-0.00263514
DEC	-0.00290052	-0.0010157	0.0113335	-0.00157484

Table.I TEC-SILNORMA : The coefficients for the third-degree polynomial approximation to be used in the development of the new TEC-based synthetic index of local response to geomagnetic activity. The results presented here are for the sites of the following three ionosonde stations: Lerwick (358.8°E,60.1°N) – top, Slough (359.4°E,51.5°N) - middle, and Ebro (0.49°E,40.8°N) – bottom table.

4. Summary

A new procedure is being developed for GPS TEC - based forecasting (Stankov et al., 2001), which relates the forecasted GPS TEC behaviour much closer to the past, current and predicted space-weather conditions. The procedure requires the development of a new synthetic index of local ionospheric response to the geomagnetic activity based on the GPS TEC observations. For the purpose, investigated were the ionospheric TEC relative deviations from the corresponding monthly medians, compared with corresponding foF2 deviations, and preliminary calculations performed for the coefficients of the synthetic index. The main conclusions can be summarized as follows:

- Strong temporal and spatial variability observed in the GPS TEC response to increased geomagnetic activity:
- <u>Season</u>: GPS TEC relative deviations may be negative for some months (equinox) but there are signs of sustained positive response in the remaining months, most noticeably during winter
- <u>Local-time</u>: Indications of day-time and night-time differences in the strength and sign of the GPS TEC relative deviations, but more data required for definite conclusions
- <u>Latitude</u>: GPS TEC relative deviations increasing in poleward direction
- Significant differences are observed between the responses of these values to increased geomagnetic activity; the TEC response is generally stronger and much more complex than the foF2 response:
- Stronger and much more complex response of GPS TEC than foF2
- While the foF2 relative deviations are negative at high magnetic activity (**Fig.3, left**) the GPS TEC relative deviations can be positive as well as negative (**Fig.3, right**).
- A second-degree polynomial approximation might be sufficiently good to represent the mean foF2 relative deviations but higher degree polynomials are necessary for adequately describing the TEC mean relative deviations
- The strength of both the TEC positive and negative responses are increasing in poleward direction.
- Further investigations and more data are needed for global coverage and time-delay analysis.

A new name for the proposed index is proposed, SILNORMA - **S**ynthetic **I**ndex of **L**ocal **N**ormalized **O**bservations **R**esponse to **M**agnetic **A**ctivity.

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