Forecast of Total Electron Content over Europe for disturbed ionospheric conditions

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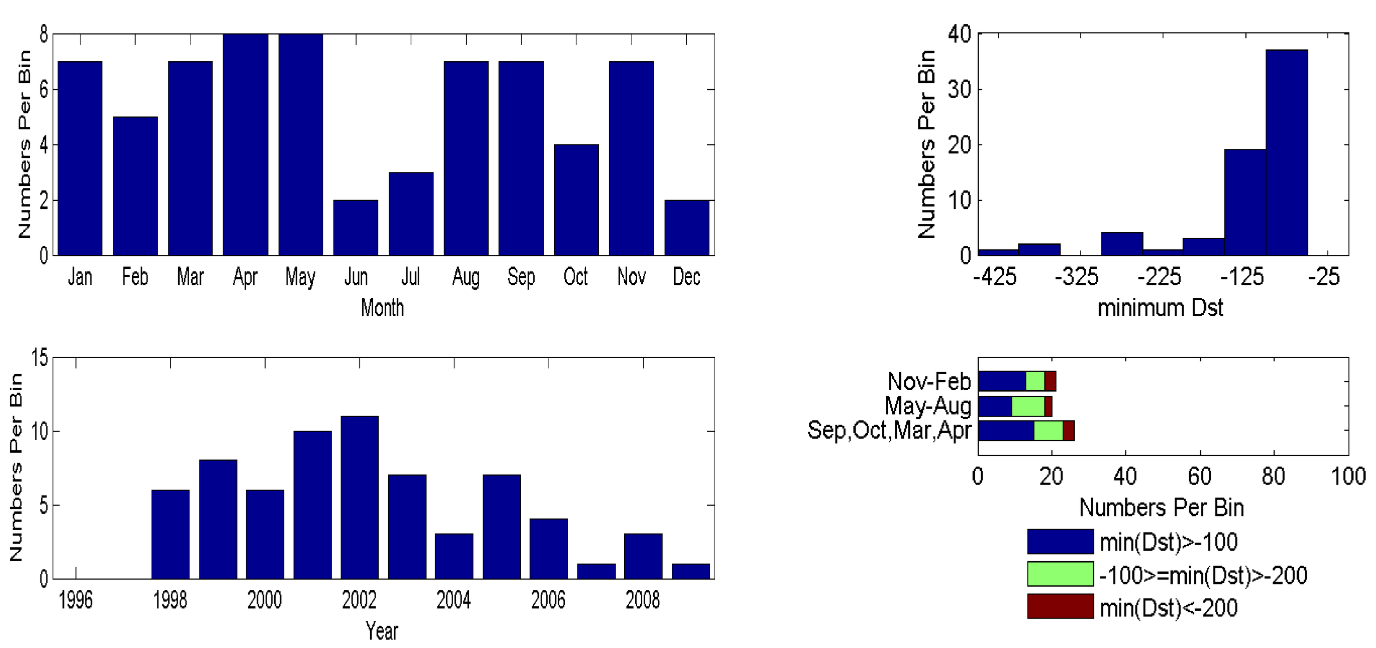
Abstract

A general picture of the occurrence of ionospheric storms as function of local time, season and location is known from numerous studies over the past 50 years. Nevertheless, it is not yet possible to say how the ionosphere will actually respond to a given space weather event because the measurements of the onset time, location of maximum perturbation, amplitude and type of storm (positive or negative) deviate much from the climatology. However, statistical analyses of numerous storm events observed in the Total Electron Content (TEC) since 1995 enable to estimate and predict a most probable upcoming perturbed TEC over Europe based on forecasts of geomagnetic activity. A first approach will be presented here. The forecast of perturbed TEC is part of the Forecast System Ionosphere build under the umbrella of the FP7 project AFFECTS* (Advanced Forecast For Ensuring Communication Through Space). It aims to help users mitigating the impact on communication systems.

Storm characteristics

In order to generate a TEC perturbation model for Europe, a proper selection of archetype ionospheric storms, representing the general behaviour of a strongly perturbed ionosphere, has been done. The analyses of ionospheric storms over the past decades allow a general picture of their occurrence depending on local mean time, season and location.

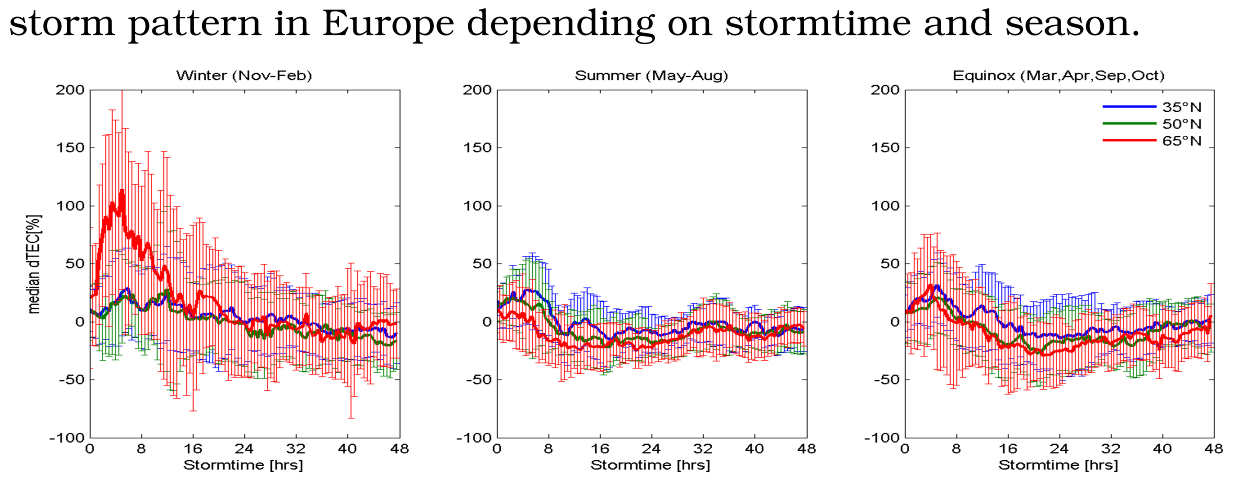


Distribution of the occurrence of 67 selected geomagnetic storms in the period from 1995 till 2009 depending on season (left upper panel) and year (left lower panel). On the right hand side the storms are classified due to their minimum in Dst with respect to season and strength (lower panel), where moderate storms (minimum Dst > -100 nT) are indicated with blue, strong storms (minimum Dst between -100 nT and -200 nT) with green and extreme storms (minimum Dst below -200 nT) in red color.

The disturbance of the ionosphere can be well described using ΔTECrel, the relative difference between TEC and the 27days median of TEC (TECmed) obtained by

$$\Delta\mathrm{TEC_{rel}} = \frac{\mathrm{TEC} - \mathrm{TEC_{med}}}{\mathrm{TEC_{med}}} \cdot 100\%.$$

The superposition of the European TECrel maps reveal not a general picture of TEC perturbation pattern during geomagnetic/ionospheric storms, but shows quite different storm pattern in Europe depending on stormtime and season.

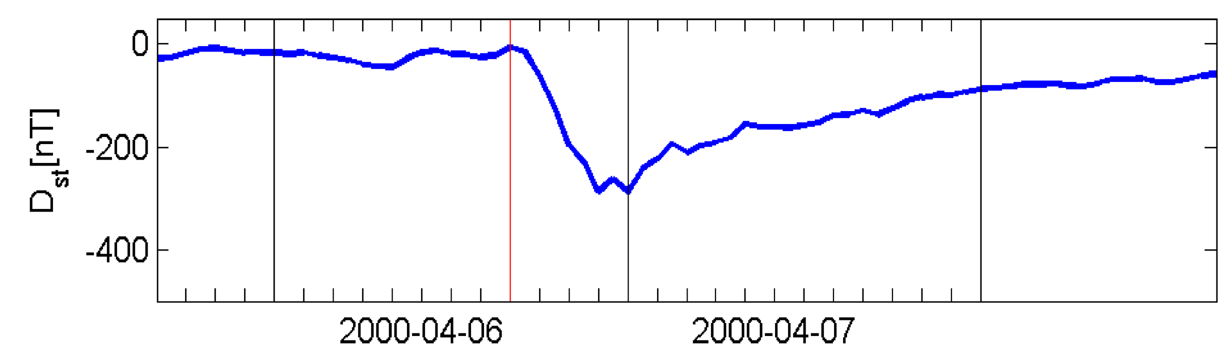


Superposition of $\Delta\mathrm{TEC_{rel}}$ for selected storms depending on season, stormtime and latitude.

Due to the close connection of the Dst index to solar and geomagnetic storms, i.e. also to ionospheric storms, we have selected in a first approach the Dst index to define the onset of ionospheric storms.

Storm onset definition

The storm onset time is defined by the positive change in the Dst rate ($\Delta\mathrm{Dst}/\Delta t$) in combination with the interpretation of the subsequent Dst behaviour at the very beginning of the main phase.



Example for Dst index, showing the geomagnetic storm 2000-04-06 16: UT. The red line indicates the storm onset.

If the Dst rate reaches a local maximum and exceeds a certain threshold value $\Delta\mathrm{Dst}/\Delta t_{\mathrm{ons}}$ (e.g. $\Delta\mathrm{Dst}/\Delta t_{\mathrm{ons}} >$ 4nT/1h) then it is checked whether the predicted Dst value after subsequent 3 hours falls below another threshold Dstmph (e.g. Dstmph < -40 nT) which characterises the initial strength of the expected storm. If this value is not reached, no storm onset is declared. To avoid misinterpretation due to an erroneous prediction, the estimations are always controlled by observed Dst values to allow the onset definition with a delay. The TEC forecast model will base on the forecasted Dst and Kp parameters, provided by the National Academy of Sciences and National Space Agency of Ukraine, being implemented in the Forecast System Ionosphere of the AFFECTS project.

TEC storm-model for the European Area (NTCM-EU-SM)

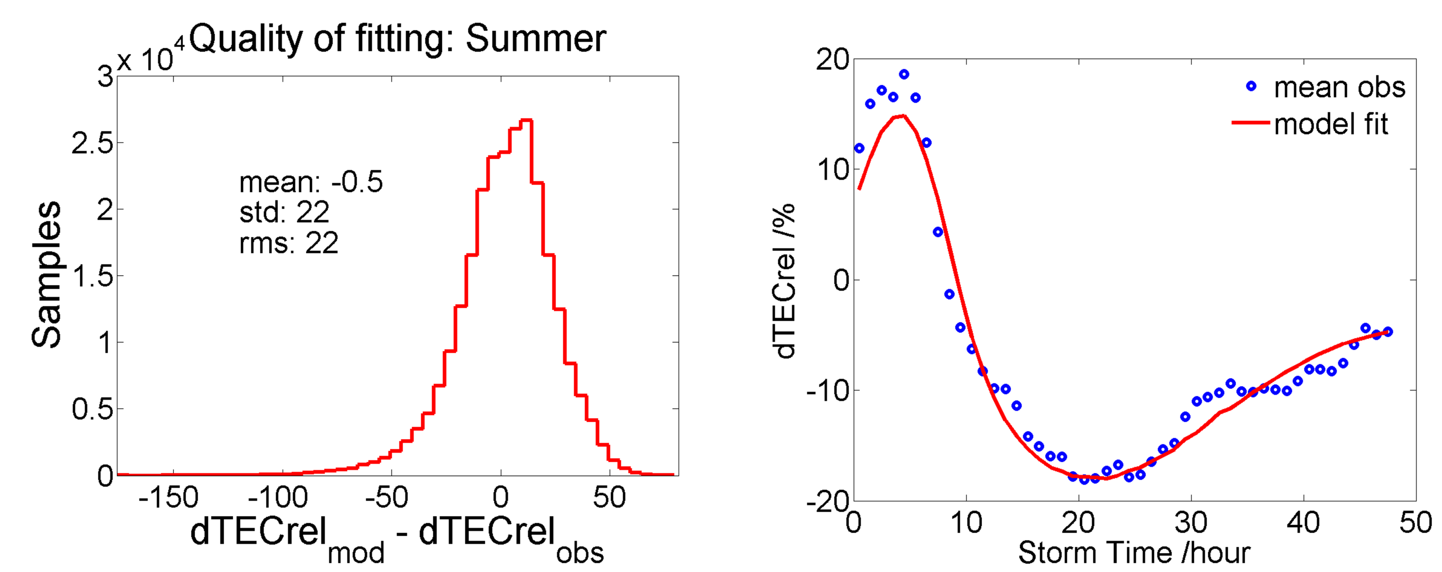
Using the mean storm characteristics obtained from the superposed epoch analyses of TEC maps based on the unique data base analysed by DLR, an empirical model of storm related TEC disturbances has been developed. The TEC storm model computes the percentage or absolute deviation of TEC from the corresponding average value. If a storm and its onset has been identified the storm model will be added to an useful reference value representing the average behaviour of TEC at a given location and time (e.g. to a climatological model the 27 days medians).

$$\mathrm{TEC_{SM}} = \mathrm{TEC_{ave}} + \Delta\mathrm{TEC_S}$$

The TEC storm-model for the European area (NTCM-EU-SM) provides $\Delta\mathrm{TEC_S}$ as a function of the storm time beginning with the storm onset, which is measured in universal time (UT).

$$\mathrm{t_{SM}} = \mathrm{t_{ons}} + \mathrm{t_S}$$

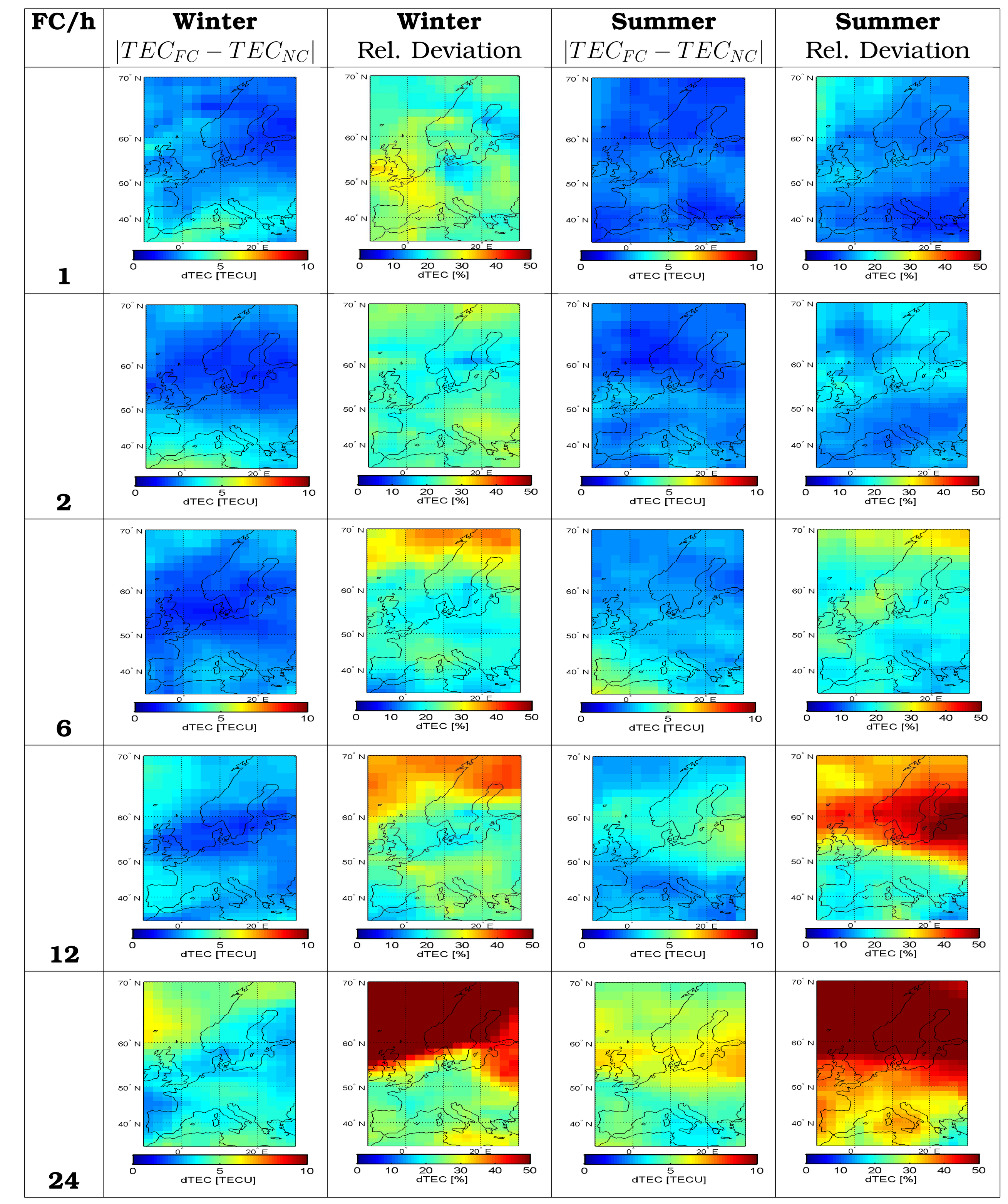
The perturbation induced TEC deviations or storm pattern have to be modeled in an effective way. The present results belong to a prototype using a multiplicative approach invented at DLR for TEC, NmF2 and hmF2 models. Here $\Delta\mathrm{TEC_S}$ depends in a first order on stormtime, local time, season, geomagnetic latitude and storm power. The model coefficients are derived via a least squares fitting.



Quality check of the TECrel model for summer storms. The difference between model and observation are shown in the left panel. In the right panel the progression of the TECrel in respect to the storm time is shown and compared to the mean observation value from the selected storm sample are shown for summer storms (left panel)

As one can see in the Figure a good agreement between model and observation is reached, enabling a forecast of perturbed TEC in the ionosphere.

Prototype results



Median absolute deviations between TEC forecast and nowcast for summer and winter storms over Europe

Summary

A software tool has been developed at the DLR, which computes the forecast of TEC up to 24 hours in advance taking into account perturbations due to space weather events. A prototype, to demonstrate its capabilities, has already been implemented. The recent results indicate range errors less than 1.5m on L1 GNSS frequency in average for predictions up to 24 hours in advance.

Acknowledgement

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SEVENTH FRAMEWORK PROGRAMME

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