Observation of large scale waves in the thermosphere-ionosphere system

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Objectives

This paper deals with large scale oscillations in the F2-region ionosphere, having periods between 2 and 30 days and wavelength exceeding 10000km, referred to as PWTO. PWTO forced by periodic solar signals are identified and supressed. The question adressed in this paper is whether the remaining PWTO are forced by stratospheric planetary waves. Hence , to point out similarities, the variations in the filtered ionospheric signal are compared to stratospheric planetary wave activity.

Data Base and Algorithms

TEC Maps

Ground based GNSS measurements, provide by the International GNSS Service (IGS), are used to compute regional maps of Total Electron Content (TEC). The hemispheric North Pole TEC maps (50°N to the North Pole), analysed in this paper, are provided by the DLR Neustrelitz as a continuous data set since 2002. The perturbations of TEC are studied by creating relative differential TEC maps (subsequently referred to as dTEC) as follows

$$dTEC = \frac{(TEC - TEC_{med})}{TEC_{med}} \cdot 100\%$$

Solar and Geomagnetic Data

We use the F10.7cm radio flux (F10.7 index), which is still a common proxy of the solar EUV radiation, the Kp-index, which is as a measure for planetary scale geomagnetic disturbances, and measurements of the Solar Wind Experiment onboard the WIND satellite. For the spectral analyses hourly mean values of the absolute solar wind speed are calculated.

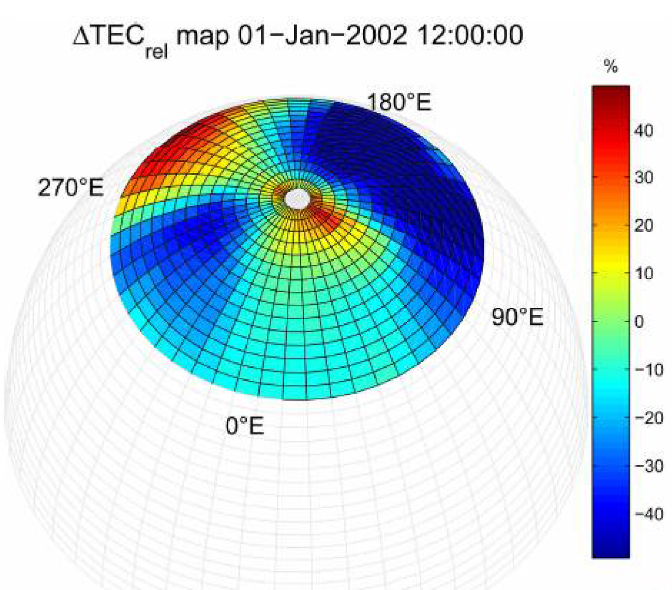

Fig: Example for a dTEC-map

Wavelet Analyses

For spectral analyses this paper mainly uses the wavelet transform

$$W_\psi f(s,\tau) = \frac{1}{\sqrt{s}} \int f(t)\psi_0^*\left(\frac{\tau - t}{s}\right) dt$$

Using the Frequency-Wavenumber analyses, the TEC maps can be zonally decomposed in wave components described by wavenumber, frequency and propagation direction.

Excluding Solar Forced Variations from TEC Records

The sun strongly controls the dynamics and variability of the upper atmosphere and its ionization. Main drivers for the ionization are the solar EUV radiation and solar wind. The aim is to identify concurrent oscillations localized in time and frequency in the solar EUV, solar wind, Kp and dTEC.

Therefore, we estimated the wavelet power spectra of the four data sets. The 95% significant coefficients in the wavelet power spectra of F10.7, solar wind and Kp identify and localize the solar forced variations. The dTEC signal is filtered such that its wavelet coefficients having the same location as the solar forced variations are set to zero and the filtered signal is reconstructed from the reduced wavelet spectrum. This method largely excludes variations owing to solar variability at all time scales under consideration.

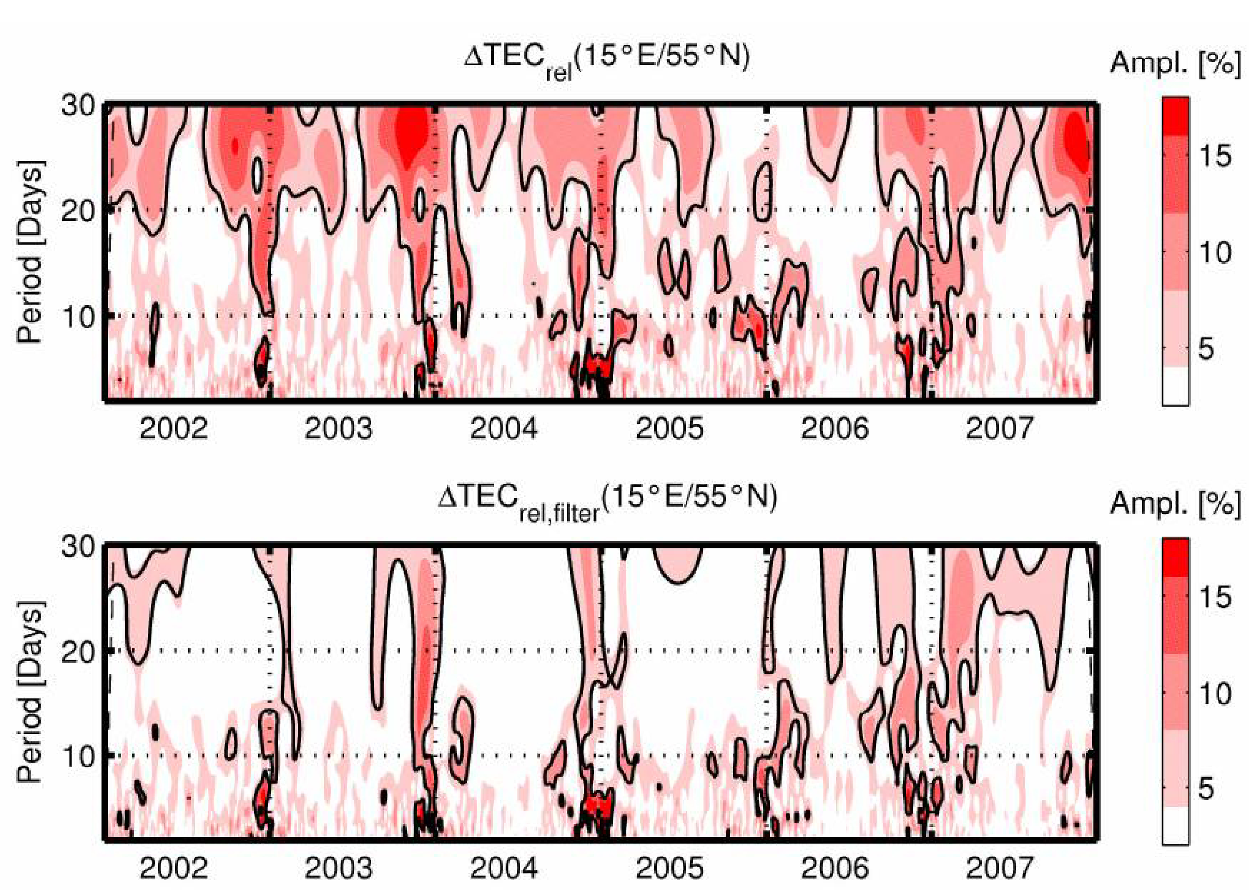

Fig: Upper Panel: Example of a wavelet amplitude spectrum of dTEC at 15°E/55°N.

Lower Panel: Wavelet amplitude spectrum of the filtered signal.

The estimation of the relative difference between the power of dTEC and the power of the filtered dTEC (not shown here) reveals that on average 38-42% of the periodic variability of dTEC is forced by solar variations. On average EUV and solar wind have the same contribution to the ionospheric variability with periods similar to PW. But, the impact of the EUV is stronger during solar maximum (2002-2004), whereas the contribution of the solar wind is higher during solar minimum (2006-2008). Thus, a large fraction of the PWTO observed in dTEC has to be allocated to solar variability.

Similarities of Stratospheric PW and Ionospheric PWTO

Wavelet FK-spectra are calculated for the wavenumbers 1 to 5 (not shown here). The 95% significant amplitudes $\widetilde{W}_\psi^{(95)} f(s,\tau)$ in the FK-spectra indicate all PWTO occurring in the filtered dTEC.

$$RMS(s) = \sqrt{\int_{[0T]} |\widetilde{W}_\psi^{(95)} f(s,\tau)|^2 \, d\tau}$$

The RMS global wavelet amplitude spectrum, represents the strongest and most frequent PWTO observed in the filtered dTEC.

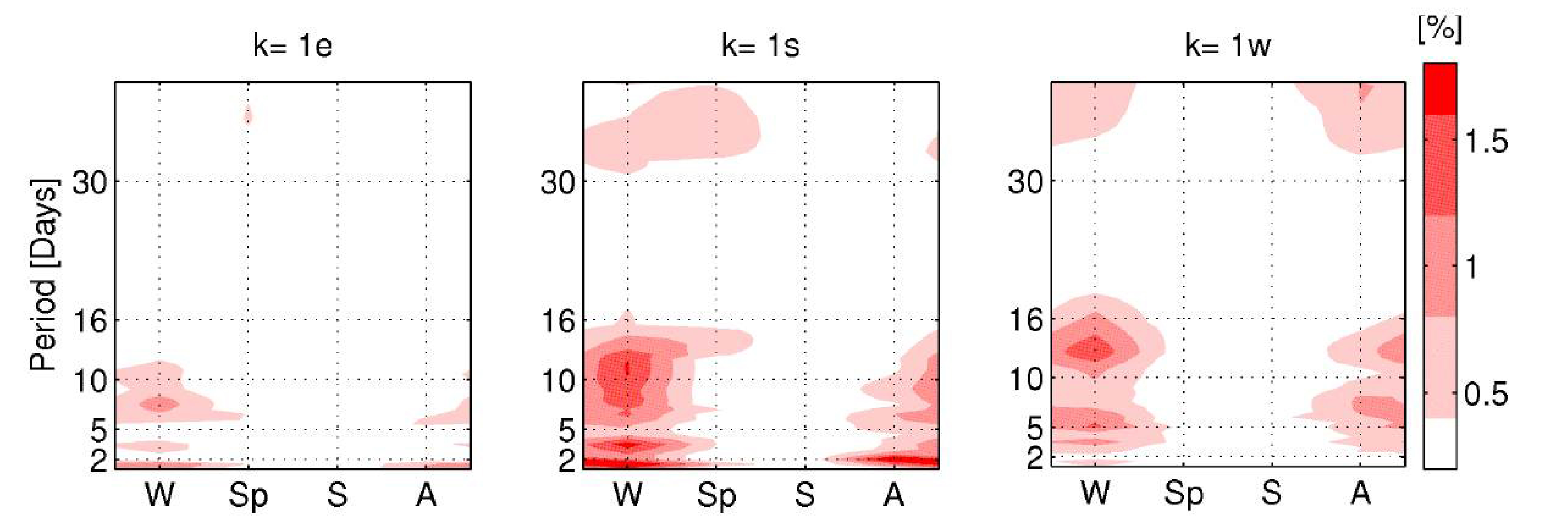

Fig.: RMS global amplitudes of PWTO with wavenumber 1 (left panel: eastward; middle panel: standing; right panel: westward propagating) at 70°N, 2002-2008. The RMS amplitudes are calculated and displayed separately for each season (W: Dec-Feb; Sp: Mar-May; S: Jun-Aug; A: Sep-Nov).

Because PW are considered as free oscillations, typical periods are associated with the atmosphere's Eigenfrequencies. The Eigenfrequencies of oscillations with zonal wavenumber 1 in the atmosphere are 1.17, 5, 8 and 12 days. The periods of the prevalent PWTO with zonal wavenumber 1 observed in the filtered dTEC agree with the Eigenfrequencies of the thermosphere and the PWTO can be accounted to free oscillations. This supports the assumption that the PWTO observed in the F2-region ionosphere correlate with PW of the lower and middle atmosphere.

Upward propagating stationary PW (SPW) strongly affect the dynamics of the middle atmosphere. During winter their amplitudes are largest in the stratosphere. Strong stationary waves like the stratospheric SPW at midlatitudes (an example is shown in the right figure for the zonal wind at 10hPa from NCEP reanalyses, green lines) cannot be observed with similar strength in the filtered dTEC (red lines).

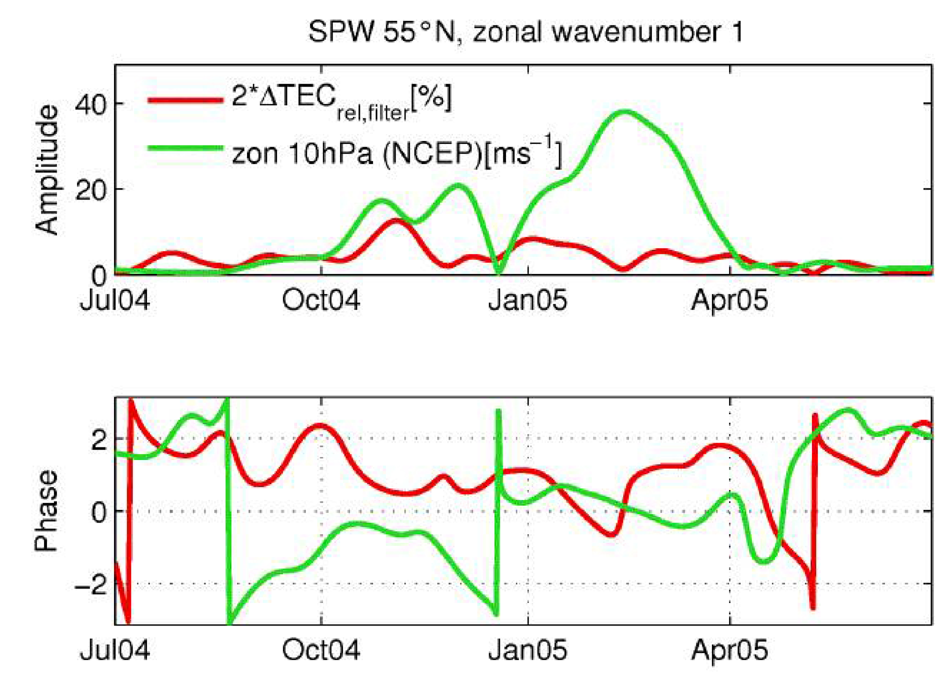

Fig.: Example of stationary waves with wavenumber 1 at 55°N

Often, amplitudes and phases of the stationary PWTO in the filtered dTEC vary with time. However, for example during the November 2004 the amplitude of the stationary component of the waves with zonal wavenumber 1 in the filtered dTEC is larger than usual and also the phase remains quite constant. Moreover, the phase is close to the one of the SPW in the stratospheric zonal wind. This suggests, that energy of the stratospheric SPW might leak from time to time into the ionosphere. Further investigation is needed to identify the conditions for such a leakage.

Summary and Conclusions

TEC maps have been analysed for large scale oscillations, denoted as PWTO. The origin of a large part (38-42%) of these PWTO has been attributed to variations in the solar signal, as seen in EUV and solar wind. A wavelet transform filter has been used to minimize the solar impact on the TEC signal.

In summary, spectral analyses revealed a good agreement between the properties of the PWTO in the filtered dTEC and stratospheric PW. The PWTO observed in the filtered dTEC show the same seasonal dependency and periods corresponding to the atmosphere's Eigenfrequencies. SPW are not common in the ionosphere. Nevertheless, from time to time there seems to be energy leaking from stratospheric SPW into the F2-region ionosphere.

Finally, the analyses revealed a few hints for a correlation between PW in the middle atmosphere and the PWTO observed in the filtered dTEC. Because PW cannot directly penetrate into the F2-region ionosphere, there must be other processes transporting their energy upwards. Further investigation is needed on these mechanisms. The SWARM mission may deliver new essential data supporting these analyses.