DETECTION OF THE WAVE-LIKE STRUCTURES IN THE F-REGION ELECTRON DENSITY: TWO STATION MEASUREMENTS

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ABSTRACT

Comparative studies of short-term ionospheric variability in the F region ionosphere during rapid sequence sounding campaign "HIRAC/SolarMax" (23–29 April 2001) are presented. The ionospheric short-term fluctuations have been studied in detail using measurements from vertical sounding at Ebro (40.8°N, 0.5°E) and Průhonice (49.9°N, 14.5°E) in the period range from 15 minutes to 2 hours. The electron density measurements contain variations that indicate the possible presence of propagating gravity waves. Regular wave-like bursts were found during quiet days at both stations in electron concentration in F region, with an increase of the oscillation activity after sunrise and then during late afternoon, and at sunset and after sunset. Solar Terminator is assumed to be one of the sources of the regular wave bursts detected in the ionosphere during campaign HIRAC. As expected, substantial intensification in longer period gravity waves was found to occur during the disturbed period on April 28. Particular enhancement of the wave-like activity during disturbed day is discussed, being significant evidences of a change of the wave-like activity pattern at a height around 200 km.

Keywords: HIRAC campaign, ionospheric variability, gravity waves, Solar Terminator, TID

1. INTRODUCTION

Wavelike disturbances in the ionosphere were described by *Hines (1960)* and other authors as being signatures of acoustic gravity waves passing through the neutral atmosphere and they are commonly classified into three groups: large scale, medium scale and short scale waves. Their main distinction is the phase speed that is much larger than speed of sound in the lower thermosphere in case of large-scale waves and considerably smaller in case of medium scale waves. Large scale waves are believed to be predominantly related to sources in the auroral zones during magnetic storms and auroral

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activity and are often observed propagating horizontally from the auroral region with horizontal wavelengths of several thousand km. Medium and short scale waves have shorter wavelength, have a continuous spectrum, and are much more common than large scale waves. Gravity waves are generated and present in practically all regions of the neutral atmosphere (*Alexander, 1998*; *Chang et al., 1997*; *Tsuda et al., 1990*; *Wan et al., 1998*). The interaction of the gravity waves in the neutral atmosphere with ionospheric plasma is described, for instance, in *Clark et al (1971)*, *Davis (1990)*, *Hook (1968), Huang et al. (1998)*, *Meyer (1999)* and other publications. The quasi-periodic behaviour in measurements of the electron density is supposed to be signature of the gravity waves in the ionosphere. A complicated fact of each study is that monochromatic waves are rarely, if ever, observed. The detected disturbances are composed of waves with different wavelengths, amplitudes, phase velocities and propagation directions. The study is limited by the fact that using vertical ionospheric sounding measurement we can see only vertical component of each wave comprising the propagating wave structure.

In the present work we deal with medium and short scales gravity waves in the period range 15 minutes to 2 hours. A considerable part of the short-term variability of the thermosphere and ionosphere is connected with variations in neutral gas, especially with gravity wave activity. The gravity waves play an important role in controlling the overall dynamics of the middle atmosphere. Medium-scale waves are assumed to be generated in all regions of the neutral atmosphere (troposphere, stratosphere etc.) and propagate through the atmosphere before their detection in the ionosphere. After being generated in different source regions of the atmosphere, gravity waves transport their momentum and energy over large horizontal and vertical distances (*Clark et al., 1971*; *Hines, 1960*). Other sources of acoustic-gravity waves (AGW) in the ionosphere come from turbulent wind shear regions in the lower and middle atmosphere (*Hocke and Schlegel, 1996*).

The gravity waves produced by Solar Terminator, as discussed by *Somsikov (1991)*, are of special interest of the presented paper. The Solar Terminator is defined using the optical view of the situation as a border between dayside and night side of the ionosphere. Its width, determined by the Solar disc, is about 0.5° corresponding to ~ 500 – 1000 km in the thermosphere changing from the equator to the Earth's pole. Above the equator the Solar Terminator moves with velocity ~ 450 m s^{-1} in the thermosphere. The moving border between the night side and the dayside of the Earth's atmosphere is a region of strong gradients in temperature, electron concentration, pressure etc. As the temperature is increasing and decreasing, the transition level for the loss coefficient and the height of the peak of electron production is changing. *Somsikov (1991)* reported that gravity waves at dawn hours have dominantly periods shorter than at dusk hours since the region of gradients is sharper in the morning hours. Changes in the parameters of the background neutral atmosphere cause the ionospheric plasma to seek for a new equilibrium state. The processes that will bring the ionosphere to a new equilibrium are probably wave activity in the plasma. The moving transition region between the night side and day side of the atmosphere thus acts as a source region of AGW (*Boška et al., 2003*; *Chimonas and Hines, 1970*; *Somsikov, 1995*).

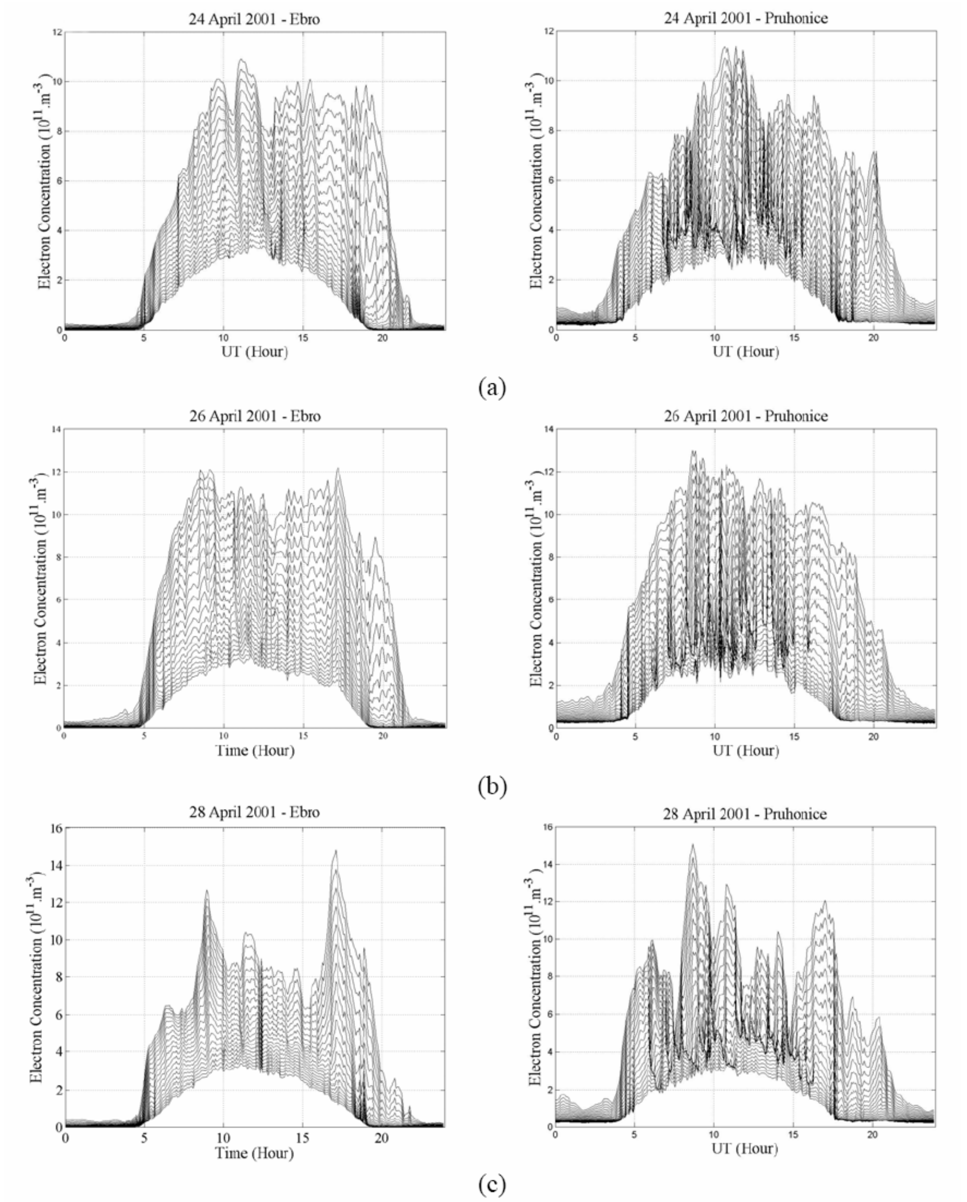
Similar processes were studied as well during several Solar Eclipses. As the lunar shadow sweeps at supersonic (700 m s^{-1}) speed across the Earth during a solar eclipse event, the cooling of the atmosphere acts as a contributor of gravity waves and builds up a bow wave. Enhancement of the waves is supposed to be attributed to the rapid cooling of the atmosphere, variations of the height of the transition level for the loss coefficient, and the height of the peak of electron production. The decrease in the temperature causes reductions of the scale height of the plasma and neutral gas, which result in the plasma and neutral gas readily diffusing downward and vice versa (*Chimonas and Hines, 1970*; *Davis, 1990*). Investigations of solar eclipses show bursts of wave activity excited by the rapid cooling and heating the atmosphere (*Cheng et al., 1992*; *Fritts and Luo, 1993*; *Altadill et al., 2001*; *Galushko et al., 1998*).

The ionosphere reflects all manifestations of solar activity (e.g., Coronal Mass Ejection (CME), Solar proton flares (SPE), etc.) by different ways in a broad range of time scales from a few hours to several days. Similarities and differences were detected in the responses of the lower ionosphere and F region to the passage of SPE-related travelling ionospheric disturbances (TID) (*Boška and Laštovička, 1996*).

2. DATA AND ANALYSES

The aim of this work is to investigate the regular manifestation of wave-like bursts in the F region electron density in relation to the Solar Terminator passages during geomagnetic quiet periods, to study the day-to-day variation similarities and differences of the GW activity in the F region, its vertical structure, and how its structure is modified during disturbed periods at two mid-latitude ionospheric stations. The study is limited by the fact that we can see only vertical component of each wave composing the propagating wave structure from the vertical sounding measurements we are using.

In order to carry out this study, we use data from two mid-latitude ionospheric stations, Ebro (Spain, 40.8°N, 0.5°E) and Průhonice (Czech Republic, 49.9°N, 14.5°E), recorded at a time sampling rate of 5 minutes during the world campaign “HIRAC/SolarMax” (*Feltens et al., 2001*) 23–29 April 2001. The ionograms from Průhonice (ionosonde IPS 42) and Ebro (ionosonde DGS 256) were converted into a sequence of a true height electron density profiles by POLAN (*Titheridge, 1985*) and NHPC (*Huang and Reinisch, 1996*) methods respectively. The ionograms’ traces were carefully revised for both stations in order to avoid any mistake of scaling methods. For both stations, data sets of 1D-time series are extracted from profiles consisting of the time variations of the electron density at fixed heights from 155 km to the electron density peak (*hF2*) at 5 km step. However, our study is restricted to the altitude range 155–255 km. Fig. 1 shows the resulting time series in that altitude range (with Ebro on the left panels and Průhonice on the right panels) on 24, 26 and 28 April of 2001. So that, pre-sunrise and late after-sunset analyses are out of the scope of this work. The latter is due to the fact that, in order to evaluate the vertical structure of the electron density variations, we are using data at fixed heights and the ionospheric regime is quite different from nighttime to daytime at a same altitude due to the diurnal variation of the ionosphere. The latter can be easily seen from Fig. 2a, where the bottom side of the daytime ionosphere ranges from 110 to 270 km and that of the nighttime ranges from 300 to 400 km. Also, Fig. 2b shows the sharp variation of the of the virtual reflection height, derived directly from the ionograms measured at Průhonice observatory, from night time to day time for two different radio frequencies of emission. The top plot of Fig. 2b (3.06 MHz) shows that at daytime we are observing E layer, whereas F region apply for nighttime.



(a)

(b)

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Fig. 1. Diurnal variation of electron density in the F region ionosphere at heights 155 km to 255 km on 24 April, 26 April and 28 April 2001.

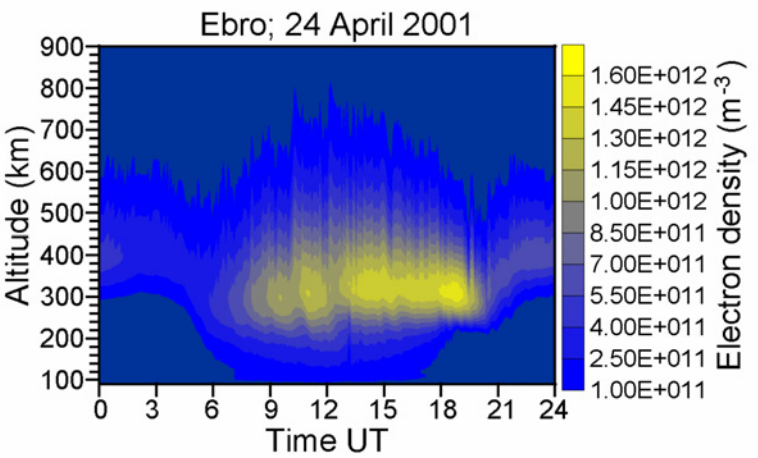


Fig. 2a. Cross-section plot of electron density as function of time and altitude recorded at Ebro during 24 April of 2001. Note the absence of significant electron density (navy blue colored) below 200 km during night time as result of daily variation of the ionosphere.

Our analyses are made during 5 days of the HIRAC campaign, from 24 to 28 April of 2001, containing information about the ionosphere behaviour under different geomagnetic conditions in a period of high solar activity (near sunspot cycle maximum; $R12 = 108$). The geomagnetic activity during HIRAC campaign changed from very quiet conditions into a minor geomagnetic storm. The beginning of the campaign was during a period of low geomagnetic activity characterized by $Ap < 7$ from 24 till 27 April of 2001. At the beginning of the campaign ionosphere was quiet without any significant perturbation from its regular features. On 28 April of 2001, the ionosphere responded to an energy input from auroral zone. The geomagnetic activity increase on 28 April ($Ap = 40$, minor storm) was caused by the interaction of a Coronal Mass Ejection (CME) with the magnetosphere. The CME, as well as the enhanced flux of high-energy protons, had their source in the M7/2b flare at 13:12 UTC on 26 April (NOAA NGDC Boulder). The absolute values of the electron concentration reached values of about 30% larger than previous days of low and moderate geomagnetic activity at the same height (Fig. 1), and more electron density variability is observed on 28 April of 2001 compared to previous days. As an example, Fig. 3 shows the time variations of the electron density residuals obtained at fixed heights (155–255 km) by a 3-hour running mean filter. The observed magnitudes of the oscillations are twice as large on 28 April as on the previous quiet day. Moreover, an enhancement of the short-term variation of virtual reflection height on 28 April is clearly seen in Fig. 2b for both sounding frequencies selected, at 3.06 MHz during night-time (F-region) and at 8.37 MHz. The strong wave-like activity starting during night from 27 to 28 April we straight attribute to the CME caused minor geomagnetic storm (NOAA NGDC Solar Geophysical Data Centre). On 28 April we observe two main TID events also in Fig. 1c, at both stations and at almost the same time, at about 8:00 UT and 15:00 UT. These two main TID events are also found in the raw data in the virtual reflection height variation at 8.37 MHz in Fig. 2b.

Since most of the wave-like structures in ionosphere are of a burst nature, with an onset and a limited duration, we use the Wavelet spectral analysis approach for our purpose that yields to good results in the detection and classification of the wave-like structures (*Torrence and Compo, 1998*). The 1D-time series of electron density at fixed heights (155–255 km) were analysed using Wavelet Transforms (Morlet mother wavelet with parameter 6). They are used to detect wave-like structures and to characterize them with respects to occurrence times. The wave-like enhancements are studied in the period ranges 10 to 55 minutes to see detail and fine structures and detect likely periodic structures. Wave-like variations were studied during quiet and disturbed days.

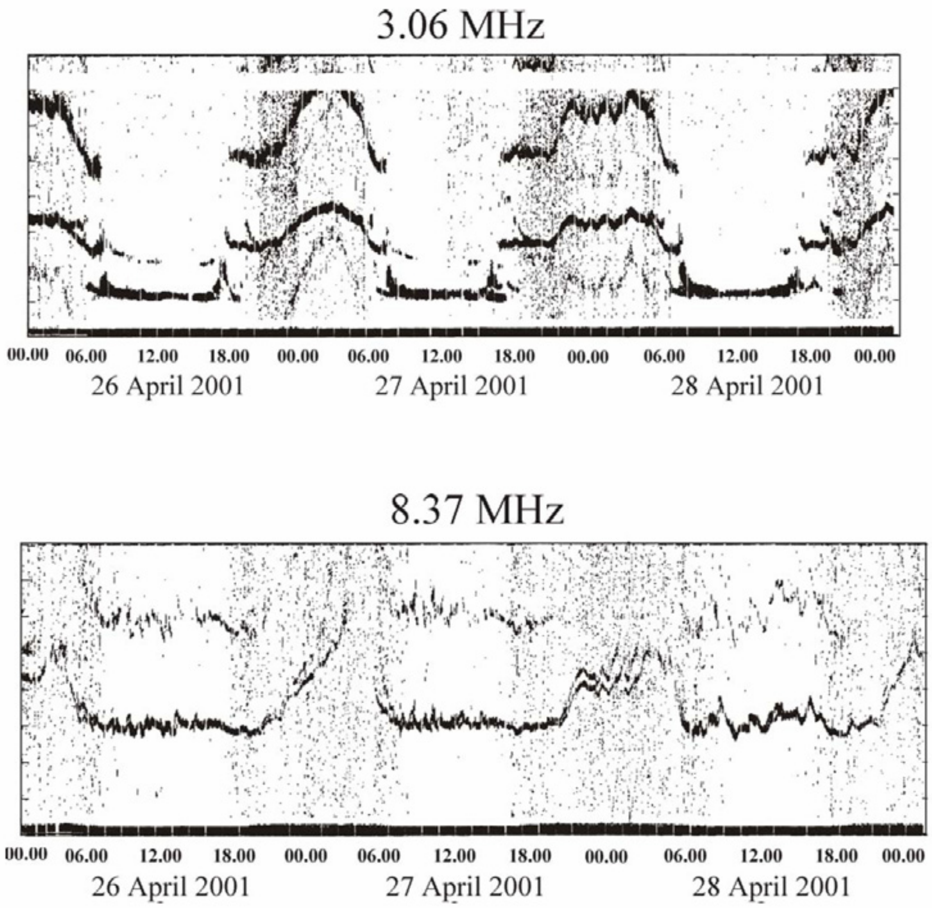


Fig. 2b. Variation of virtual reflection height at 3.06 MHz and 8.37 MHz from 26 April till 28 April 2001 extracted from ionograms.

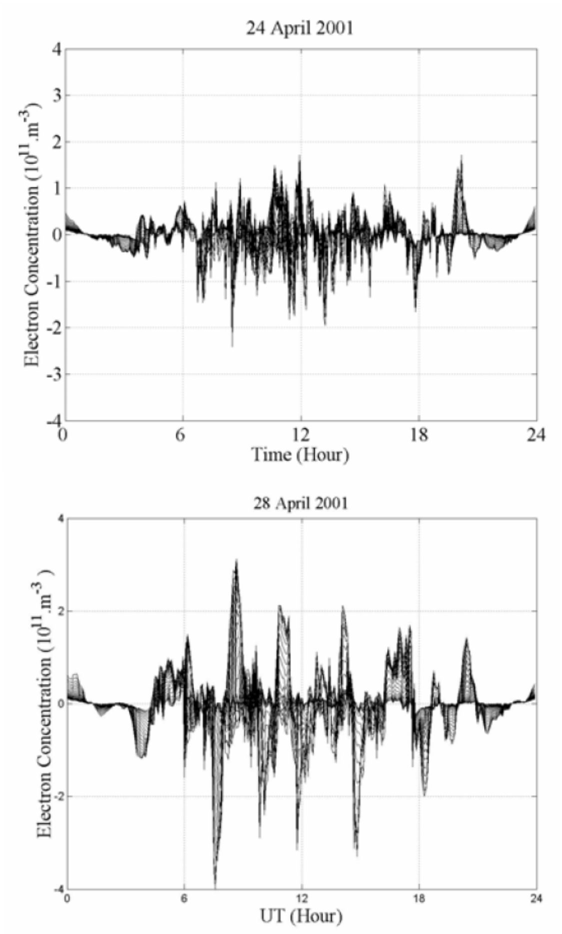


Fig. 3. Oscillation of electron concentration round 3-hour mean value on 24 April and 28 April 2001, Průhonice station.

3. RESULTS

During days of rather low geomagnetic activity, a large family of oscillations exists in all studied data sets (Fig. 1a,b) at both stations. The longitudinal difference of about 15° between stations is clearly seen in the 1-hour time-shift of the sunrise and sunset changes of electron concentration. The wave bursts appear to be more pronounced in the data from Průhonice than from Ebro. The latter may be likely an effect of the latitudinal difference of the 10° between both stations and/or as a result of the different methods of ionogram’s inversion to the true-height electron density profiles. The electron density measured in Ebro seems to vary smother than in Průhonice, and they increase/decrease sharper after sunrise/sunset than in Průhonice. Large wave-like oscillations are observed between dawn and dusk that are seen in the electron concentration variation in Fig. 1. Large part of these wave bursts contributes to the irregular wave enhancements in the midlatitude ionosphere and may be caused by local sources. We call the latter enhancements 'irregular wave bursts' and they seem to be the dominant wave activity occurring during day time. In addition the so called 'regular wave bursts' occur during sunrise/set time and may be caused by "ST" passages. In order to distinguish both above wave burst types we apply Wavelet analyses, this way we may discern them by considering the regular starting time (related to ST) for both ionospheric stations.

As already noted on previous section, one expects a quite different pattern of the ionospheric behaviour from quiet days of the campaign to the disturbed day. That should be considered in order to distinguish the 'irregular' and 'regular' wave burst as described above. That is why our results of detection of wave-like structures are classified into results for quiet and disturbed days.

In general, more short-period oscillations were detected in the data series measured at Průhonice Observatory. Figs. 4 and 5 show wavelet power spectra of the electron concentration at fixed heights in the period range 10 minutes to 80 minutes for a quiet and a disturbed day, respectively. Wavelet power spectra are normalized. In these diagrams a dark red colour refers to maximum and a blue colour to minimum values. The spectra are computed at 95% significance level (*Torence and Compo, 1998*). Significant change of the oscillation pattern is characteristic for the day of low geomagnetic activity as well as for the day of geomagnetic storm for both stations.

3.1. Geomagnetically quiet days, 24–27 April 2001

The inspection of diurnal variation of the electron concentration in Fig. 1 shows similarities and differences in the variation of the electron density in the two observatory data sets. In the sets of electron concentration measured in Ebro we observe sharper increase of the electron density after sunrise and sharper decrease of electron concentration before sunset due to faster change of zenith angle. Electron concentration at Ebro shows two maxima followed by the sharp decrease of electron concentration at the dusk hours. The electron concentration at Průhonice station has a slightly different behaviour that is likely caused by the geographic and geomagnetic positions of the station.

As already mentioned, the data measurements from Průhonice observatory show more oscillations than within the time series corresponding data sets from Ebro station. On the plot of electron concentration at fixed heights on 24 April 2001 in Fig. 1a in the Průhonice data, there are intense short period AGW oscillations between 7 UT and 15 UT preceded and followed by a smoother period of longer period activity. On 26 April 2001 (Fig. 1b), the wave-like activity increase in electron concentration variations at fixed heights starts again at about 7 UT. Two intense bursts are visible between 9 UT and 12:30 UT followed by another burst from 13 UT till 14:30 UT. Similar wave bursts are evident after 17 UT during both days at the data sets measured in Průhonice observatory. The electron concentration at fixed heights measured at the Ebro observatory show a smoother diurnal course at all heights compared to the corresponding Průhonice measurements. In the wavelet power spectra (Fig. 4) there are almost no wave bursts showing similar features within the observatories. The wavelet power spectra of the electron concentration

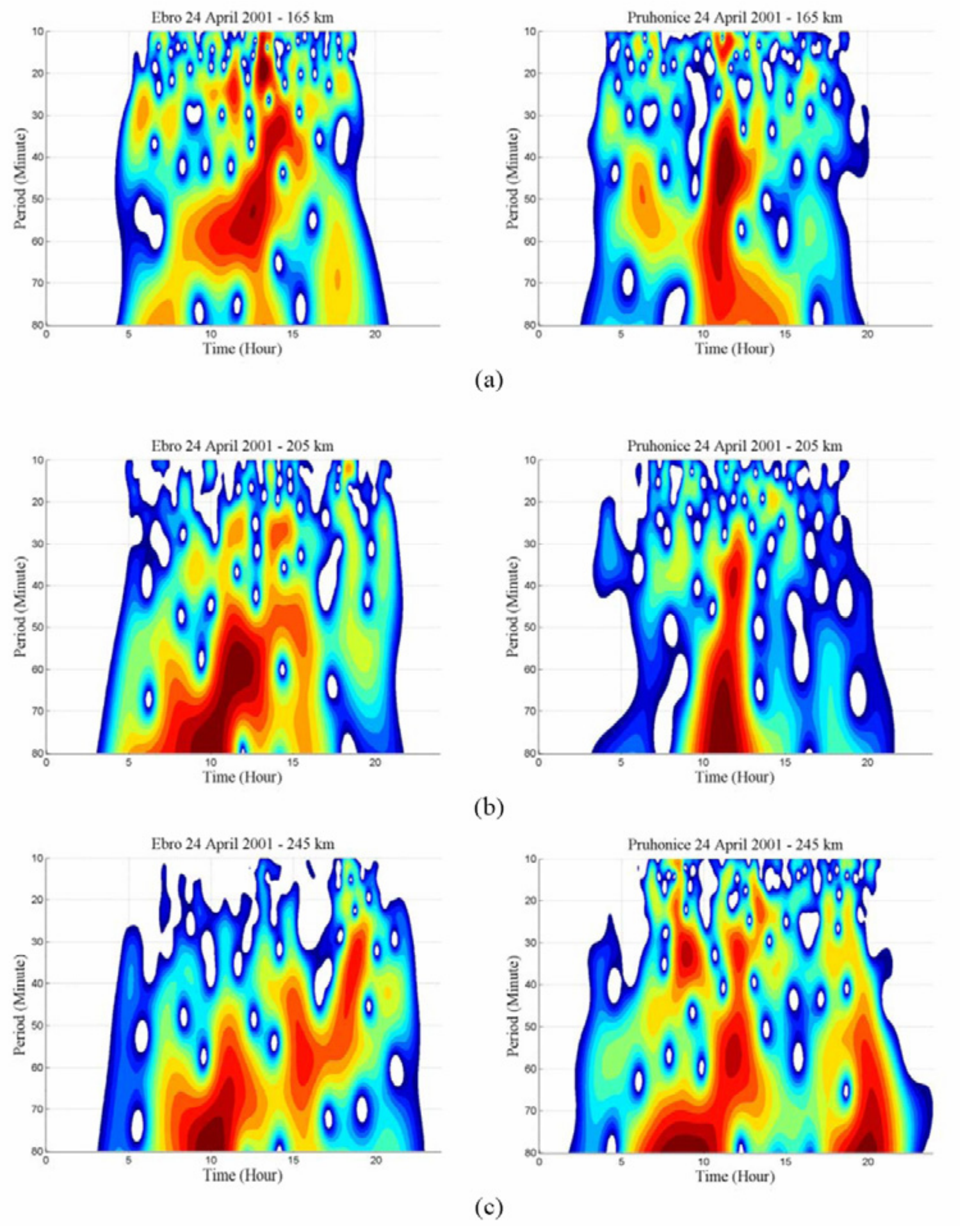
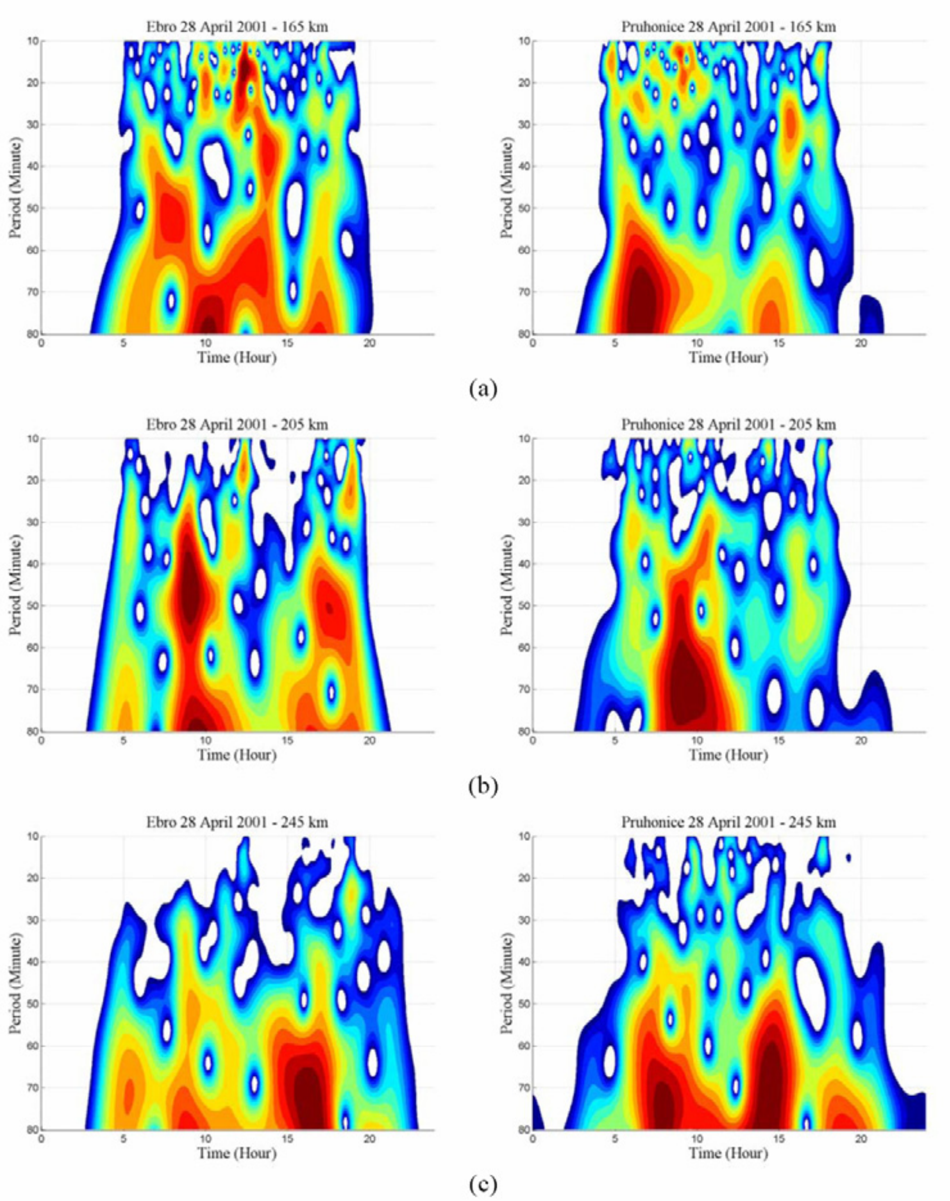


Fig. 4. 24 April 2001 - Wavelet Power Spectra 5 minutes to 55 minutes at **(a)** 165 km, **(b)** 205 km and **(c)** 245 km.



(a)

(b)

(c)

Fig. 5. 28 April 2001 - Wavelet Power Spectra 5 minutes to 55 minutes at **(a)** 165 km, **(b)** 205 km and **(c)** 245 km.

variations are significantly different at all studied heights between 7 UT and 17 UT. The mid-day wave-like oscillation observed during the HIRAC campaign seems to be generated irregularly in the atmosphere. All the longer-period oscillations are modulated by short-period activity. Strong wave-like activity is generally visible at a height of about 200 km. The amplitude of the wave-like bursts is found to increase with increasing height as predicted by AGW theory (*Hines, 1960*).

3.2. Day of minor geomagnetic storm, 28 April 2001

The behaviour of electron concentration at F-region ionospheric heights on 28 April 2001 is controlled mainly by the energy input from the auroral zone due to a minor geomagnetic storm. The absolute peak values of electron concentration increase from 200 km up to the peak of the F2 layer by about 30% at both stations. The sudden increase of electron concentration corresponding to the TID events is visible below 200 km down to 180 km height. Strong long-period variation is dominant feature of the wave activity seen in electron concentration variation at fixed heights in Fig. 1c. Strong oscillations begin during the night and last until 21 UT at both observatories. Above 200 km, the higher the altitude, the greater the electron density perturbation that is detected. In the morning hours from 6:00 UT to 8:00 UT in the variation of the electron concentration at fixed heights there is wave-like structure on the background of the long-period variation of electron concentration (see Fig. 1c, Průhonice observatory). Amongst the larger oscillations, there are signs of a slightly downward progressing TID-like disturbance between 8.30 UT and 11 UT and around 16 UT to 17 UT. An impulsive burst of TID is seen at the same time at all heights before 17 UT. In the data sets measured at Ebro station there are three TID events between 8.30 UT and 11 UT and around 16 UT to 17 UT. All these TID events correspond to the events observed at Průhonice observatory. However, strong wave bursts (at around 6 UT and from 12 UT to 15 UT) in Průhonice have no corresponding events visible in the Ebro measurements. Electron concentrations at levels below 200 km vary remarkably less compared to levels above this height. This finding corresponds to the F1-layer behaviour during geomagnetic storm reported by *Mikhailov and Schlegel (2003)*.

In agreement with the results of *Boška and Laštovička (1996)* wave-like activity during the day of the magnetospheric response to the sharp increase of solar wind dynamical pressure significantly increases at longer periods (larger than 70 minutes) the same way at both station. Wave bursts detected at 8-10 UT in the electron concentration at fixed heights are found in the wavelet power spectra (Fig. 5). Short-term variability, at periods up to 40 minutes, are also found in the wavelet power spectra at heights below and around 200 km in data sets from both stations.

As expected, wave-like variations (their wavelet power spectra, Fig. 5) observed in the data measured at both observatories, coincide during the day of minor geomagnetic storm on 28 April 2001 at all studied heights above 200 km, so that the oscillations could be straight attributed to the auroral energy impact (originated in minor geomagnetic storm) on the midlatitude ionosphere. Several TID-like bursts are evident on measurement on both observatories, mainly in the region above 200 km. There are signs of downward progressing TID-like disturbances (9 UT - better developed in case of Průhonice data) amongst the larger oscillations, but an impulsive burst is seen at the same time at all altitudes but the highest level first before 17 UT at both stations. These results are consistent with theory of TIDs of auroral origin propagating through the ionosphere. The correlation analysis shows almost no time delay between the effects seen at the two distant stations above 200 km.

There is little evidence of the TID bursts or any strong disturbance under 180 km height in data sets taken at Průhonice station. Small effects of the geomagnetic storms, positive and mainly negative with respect to the previous quiet day, in the F1 layer reported *Mikhailov and Schlegel (2003)*. The photochemical processes are possible physical mechanism of the observed F1-layer storm effects. The transition level between F1 and F2 ionospheric regions occurs in the region 170–210 km according to a model computation (POLAN). However, the absence of the corresponding variation could be caused by the limitation of the method, since we are using only ordinary trace reflection (*Titheridge, 1988*).

3.3. Solar Terminator

To study the possible Solar Terminator effect in the electron concentration we will concentrate on the sunrise hours before the occurrence of large wave-like oscillation. The regular wave enhancements occurring during sunrise and sunset time are of lower amplitudes than the irregular wave bursts appearing in the data sets. The wavelet analysis is applied to the data sets in which the 3-hour mean average is filtered out. Particular groups of wave bursts appear regularly immediately after sunrise beginning at 4 UT and somewhat stronger wave-like structure enhancements in the dusk sector in the Průhonice data after about 18 UT with a 1 hour shift from the Ebro data. Fig. 6 shows the wavelet power spectra during sunrise hours at both stations at heights 175 km and 185 km from 2 UT to 10 UT (Průhonice) and 3 UT to 11 UT (Ebro) with respect to 1-hour shift of the sunrise. Fig. 7 presents the same analysis performed on the data during afternoon and sunset time from 16 UT to 22 UT (Průhonice) and 17 UT to 23 UT (Ebro) at 205 km on 24 April and 28 April 2001.

Fig. 6 shows wave-like structures in the data sets of the variation of the electron concentration with respect to 3-hour mean on 24 April 2001. Immediately after sunrise wave-like structure with a dominant period about 30 minutes occurs in the wavelet power spectra that generally remain significant in 10 consecutive levels (about 50 km). The similarities in periodicities of wave-like structures, within observatories and from day to day data series, in wave bursts occur mainly up to 220 km. During sunset we observed wave bursts with dominant period about 30 minutes and waves enhancements with periods round 60 minutes. In the Fig. 7b, the ST wave bursts are partly covered by preceding TID events. However the 30-minute wave-like structure is well developed in the spectra at 18 UT in Průhonice data and structure of about 25 minute at 19 UT in Ebro data. We suppose, that the Solar Terminator movement causes these two structures. Similarities in the wavelet power spectra are seen mainly above 180 km in the studied range of heights.

Morning Solar Terminator wave bursts are better pronounced in the region below 220 km compared to higher levels. Similarities in wavelet power spectra appearing in the distance of about 1500 km (latitudinal difference ~ 9°, longitudinal difference ~ 14°) points to the global phenomenon affecting the ionospheric electron concentration in a similar way at two different positions. The mechanism of heating and cooling of the

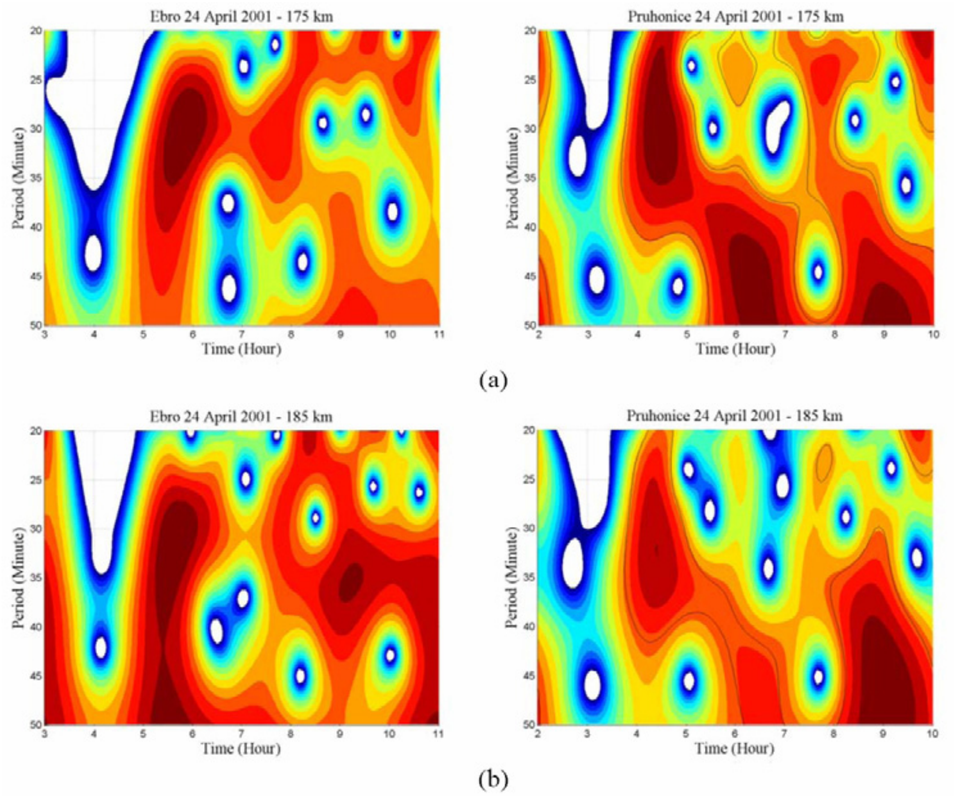
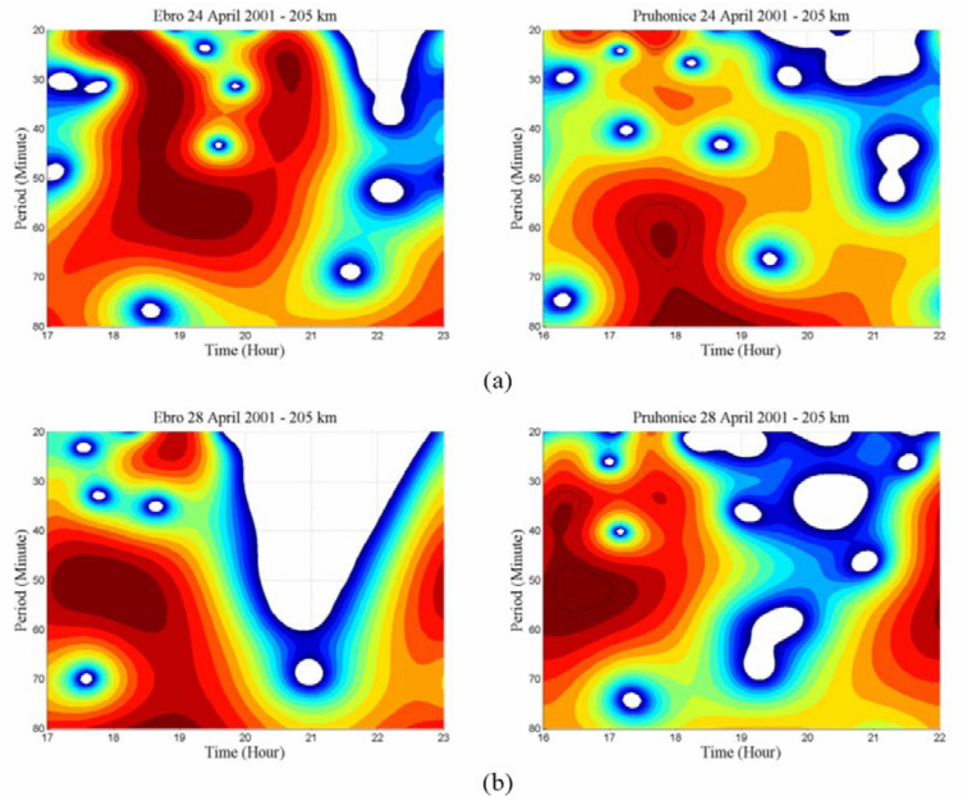


Fig. 6. Detail Wavelet Power Spectra (20 minutes to 50 minutes) on 24 April 2001 at **(a)** 175 km and **(b)** 185 km (3–11 UT - Ebro; 2–10 UT - Průhonice).

atmosphere associated with the movement of the Solar Terminator (*Chimonas and Hines, 1970*) can explain these observations (*Somsikov, 1990*). In the sunset hours the observed wave enhancement as well on the longer periods about 60 minutes was observed, this fact corresponds to the results of *Somsikov (1991)*.

4. CONCLUSIONS

There are many irregular wave bursts observed in ionospheric data measured in Ebro and Průhonice Observatories during quiet days 24–27 April 2001. The wide range of structures is presented on the wavelet power spectra (Fig. 4). The smoother variation of the electron concentration in the case of the Ebro data compared to the Průhonice measurements can be caused by the different positions of observatories. The two different techniques of deriving the true height $N(h)$ profiles that were used also likely contribute to the differences between corresponding data sets. Among random wave bursts we found similarities in the wave-like activity at the two stations even though no global impact of geomagnetic origin was reported. Part of the detected oscillations may contribute to



(a)

(b)

Fig. 7. Detail Wavelet Power Spectra (20 minutes to 80 minutes) **(a)** on 24 April 2001 at 205 km and **(b)** on 28 April 2001 at 205 km (17–23 UT - Ebro; 16–22 UT - Průhonice).

a regular pattern of AGW activity while the rest of wave-like enhancements are likely generated by irregular local sources. During sunrise and sunsets wave bursts are found to occur in the series of electron concentration. Intensification of the wave activity in the dusk and down hours with short periods mainly in the range of about 20 minutes to 50 minutes (peak frequencies vary slightly from day to day) is seen in the Wavelet power spectra of a quiet day (Fig. 6). There are wave bursts appearing in the sunset time at periods 10 to 80 minutes.

Figs. 6 and 7 clearly shows similarities of the wavelet power spectra at local sunrise and local sunset at both observatories. The oscillations detected during morning and evening hours are of smaller amplitudes compare to irregular wave bursts. These particular wave-like effects seem to be attributed to the same agent as they are appearing regularly. These wave bursts could be attributed to the Solar Terminator passage. Similar results based on Fourier spectral analysis and Correloperiodogram analysis reported *Boška et al. (2003)*. Previous studies of group and phase velocities show that typical source region of these oscillations are located in the altitude range 180–210 km (*Boška et al, 2003*). The waves propagate upward and downward and that confirms the hypothesis of the Solar Terminator excitement of the detected waves. The waves related to the Solar Terminator observed during HIRAC campaign are likely excited by movement of the transition region between the night side and the day side of the atmosphere (*Somsikov, 1991*). Enhancement of the waves is supposed to be attributed to the rapid heating and cooling of the atmosphere, variations of the height of the transition level for the loss coefficient, and the height of the peak of electron production. The decreases in the temperature cause reductions of scale height of plasma and neutral gas, which cause the plasma and neutral gas to diffuse downward and vice versa. Such a mechanism, namely gradients in atmospheric parameters, is believed to form the waves associated with the movement of the Solar Terminator.

On 28 April 2001 wave-like activity in the electron concentration at the short periods (few minutes) is dominated by strong longer-period wave-like oscillations with a period 1 to 2 hours. Oscillations of shorter periods remain in Wavelet power spectra but are of lower amplitude than the longer-period variations, which most probably result from geomagnetic disturbance. Substantial intensification of the gravity wave activity at longer periods around 8−10 UT was associated with response of the magnetosphere to the sharp increase of solar wind dynamical pressure on 28 April. The amplitudes of the oscillations are significantly larger than during days of lower geomagnetic activity. Wave-like activity in electron concentration, recorded on the short periods is of lower importance than the dominant long period variation. Variation of electron concentration above 200 km is significantly larger than below this level especially on 28 April 2001.

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