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Influence of meteorological systems on the ionosphere over Europe

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ABSTRACT

Ionosphere represents weakly ionized plasma that reflects both solar, geomagnetic activity and processes in the neutral atmosphere. Correlation coefficients of long time series of the critical frequencies from European stations measured by means of vertical sounding are analyzed with respect to latitudinal and longitudinal difference and surface distance of stations. Time series of critical frequencies are highly correlated reflecting the dominant solar influence. Correlation coefficients are high not only for raw data and subtracted mean courses but for fluctuations around mean as well. At the surface distance exceeding 1000 km and/or about 10° of latitudinal difference between stations, the correlation coefficient of fluctuations decrease rapidly. Such effect is less visible on the latitudinal dependence, where the correlation coefficients decrease with increasing distance with less pronounced threshold. We explain the existence of the 'break point' at 10° in longitude and/or 1000 km by the 'local' influence of the neutral atmosphere and the wave activity. As a possible source of the common influence on scale 1000 km/10° we propose tropospheric systems that are known to be an important source of atmospheric waves in a broad period range. Large tropospheric mesoscale systems have typically up to 2000 km in diameter.

1. Introduction

Earth's atmosphere consists of neutral and ionized particles. Neutral atmosphere particles undergo ionization and form weakly ionized plasma called the ionosphere. Bottom border of the ionosphere is located in the upper part of the atmosphere at heights above ≈ 50 km during day-time and above ≈ 90 km during night-time, where the concentration of the ions is sufficiently high to significantly affect the radio waves propagation. Ionized particles remain present below the lower level in whole atmosphere. Their importance increases with rising height due to growing ratio between ions and neutral particles with height.

The most important factors that affect the ionosphere are related solar and geomagnetic activity (e.g. solar irradiation, solar wind coupling, through the magnetosphere). Ionosphere reflects external forcing in variability on scales from minutes to a solar cycle. However, the influence of the lower atmosphere through thermospheric chemistry and dynamics cannot be neglected because the number of neutrals highly exceeds the ionized particles by several orders of magnitude. The fact that lower atmosphere influence cannot be neglected was confirmed by ground based and satellite measurements. During the exceptionally low solar activity during solar minimum between 23 and 24 solar cycles, large ionospheric variability has been observed. High day-to-day changes in the electron concentration are observed for instance by means of ground-based measurements. Fig. 1 illustrates large difference in the diurnal course of critical frequency foF2 representing the maximum frequency of reflected electromagnetic wave from ionospheric F2 layer. Solar and geomagnetic activity are characterised by solar flux $F10.7=75–80$ sfu and max(Kp)$=2$. Critical frequency is manually scaled from ionograms measured by Digisonde DPS 4 (Reinisch et al., 2005), in the Observatory Pruhonice (49.9N, 14.6E).

At heights of the ionosphere neutral particles and ions exist together and due to strong coupling the behaviour of neutral particles is reflected by the ions. Hence, state of the neutral atmosphere plays a significant role in the behaviour of the ionosphere. Despite the fact that the ionosphere significantly affects the radio waves propagation (reflection, modification and absorption) it is very weakly ionized medium. At maximum of ionospheric electron concentration of the *F* layer the ion to neutral ratio is less than 0.01. However the degree of the influence of neutrals varies with height and season. Within regions with collision dominated plasma (D and E regions) the influence is stronger than in the above laying regions F1 and F2 where the magnetic field influence dominates the collisions. However, the neutral atmosphere remains as an important agent.

Processes in the lower laying atmosphere such as UV radiation absorption by the stratospheric ozone, severe meteorological formations in the troposphere, and/or generation of wide range of

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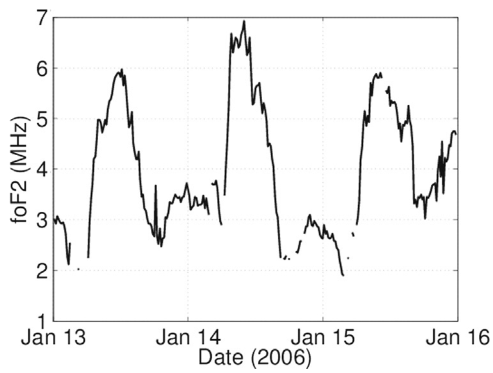

Fig. 1. Diurnal course of critical frequency foF2 representing the maximum frequency of reflected electromagnetic wave from ionospheric F2 layer. Solar and geomagnetic activity are characterised by solar flux $F10.7=75$–80 sfu and max (Kp)=2.

atmospheric waves by the orography, earthquakes, waves related to human activity and other sources, play an important role in the ionospheric behaviour. As the atmospheric waves propagate upward from the source region, their energy tends to be conserved and consequently the amplitude grows due to the decreasing atmospheric density. The propagation conditions change in the thermosphere where the temperature rapidly grows and atmospheric molecular viscosity increases. Hence, most of the atmospheric waves do not reach higher heights than mesosphere and lower thermosphere. However, it has been proven experimentally that some atmospheric waves are able to penetrate up to the F2 layer height (Altadill et al., 2001; Altadill et al., 2004; Boska and Sauli, 2001; Forbes and Leveroni, 1992; Lastovicka and Sauli, 1999; Pancheva et al., 1994; Radicella et al., 2009; Sauli and Boska, 2001; among others). Under geomagnetic quiet conditions Forbes et al. (2000) attributed ≤ 25–35% (at periods of a few hours to 1–2 days) and ≤ 15–20% (at periods of approximately 2–30 days) about the mean of ionospheric variability to meteorological influence.

Vadas and Fritts (2006) investigated the propagation of gravity waves generated by the severe tropospheric convection. They modelled propagation of the gravity waves from a small region of convection in the troposphere into a much larger volume in the thermosphere, where they dissipate in a spatially localized and intermittent manner. Gravity waves with large vertical scales and small amplitudes would propagate through the mesopause and into the thermosphere, while those with small vertical wavelength break at lower heights. They also pointed out the importance of the secondary gravity waves of a broad spectrum which propagate upward and downward.

Chang et al. (2014) reports anomalies in the zonal winds in the MLT region in the low and middle latitudes following the quasi two day wave events observed instruments on board of the TIMED satellite. They concluded that the observed anomalies in the MLT region and ionosphere are related to the dissipation of the quasi two day wave originating in the lower atmosphere.

Large ionospheric variability has been well documented by satellite measurements during exceptionally low solar minimum between cycles 23 and 24. Special attention has been paid to the stratospheric warming and its influence on the ionosphere. Pancheva and Mukhtarov (2011) analyzed global spatial structure and temporal variability of the mean ionospheric response to Sudden Stratospheric Warming events (SSWs) in winters of 2007/2008 and 2008/2009 on the COSMIC foF2, hmF2 and electron density data. They prove experimental evidence that the low and middle latitude ionosphere regularly responds to almost all SSW stratospheric temperature pulses at high latitudes and confirm the importance of lower-laying atmospheric systems. Using GPS Total Electron Content (TEC) and atmospheric temperature from 20 to 100 km altitudes measured by TIMED satellite. Phanikumar et al. (2014) reported observation of the upward progressing wave with period 3–5 days originating in stratosphere during SSW event. Pancheva and Mukhtarov (2012) reviewed progress in the ionospheric response to the upward propagating atmospheric tides based on satellite measurements.

2. Atmospheric waves

The ionosphere is highly dependant on the chemistry and dynamics of the thermosphere and is strongly coupled with regions below down to the troposphere. Meteorological processes in the lower-lying layers, particularly in the troposphere, affect the ionosphere predominantly through the upward propagating waves and their modifications and modulations. Atmospheric waves are highly variable in spatial and time scale. They range from large-scale planetary waves with periods of days to small scale acoustic waves with periods of minutes. Tides are atmospheric waves with period with harmonics of 1 solar day (24h, 12 h, and 8 h). Origin of the atmospheric waves is in periodic heating and cooling of the Earth atmosphere and surface and/or dynamics. When the atmospheric waves reach the condition when they break and dissipate they could further form the secondary waves. An important subset of atmospheric waves are acoustic-gravity waves with periods up to several hours. Sources of acoustic-gravity waves are related to meteorological phenomena, transitions of solar terminator and many others.

Atmospheric waves propagate into the ionosphere mostly directly but the planetary waves can propagate upwards to the F region heights only indirectly, via various potential ways like modulation of the upward propagating tides. The waves may be altered during upward propagation via non-linear interactions, particularly in the MLT region. The upward propagating waves of the neutral atmosphere origin are important both from the point of view of vertical coupling in the atmosphere–ionosphere system, and for applications in radio propagation/telecommunications, as they are responsible for a significant part of uncertainty of the radio wave propagation condition predictions. A review of the ionosphere forcing from lower laying atmosphere is provided by Lastovicka (2006). Recent knowledge of the internal wave coupling process in Earth's atmosphere can be found in Yigit and Medvedev (2015). The paper focuses primarily on the atmospheric waves generated by meteorological processes. It summarizes the observational evidence of wave signatures at different regions of the atmosphere up to the thermosphere.

The MLT region is the most crucial/important coupling region as it is formed by collision dominated plasma. The neutral motions drag ions across the magnetic field lines via ion-neutral collisions. It creates small charge displacements with the electrons that consequently give rise to relatively weak electric fields. With the increasing height the importance of collisions decreases and plasma becomes geomagnetic field dominated. Dissipating atmospheric waves in the mesosphere/lower thermosphere (MLT) region affect dynamics and composition of the system.

Nguyen and Palo (2014) investigated modulation of turbulent mixing near the turbopause with respect to the propagation of the atmospheric waves and their dissipation. Using NCAR TIE-GCM they investigated variability in the upper atmosphere composition and density. They found that varying the amount of turbulent mixing at discrete planetary wave periods induces similar periodicities in neutral and electron density. This process is driven by species diffusive flux through isobaric levels, resulting in atmospheric contraction or expansion. They have shown that the mechanism is dependant on period and is more effective for long