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Ionospheric disturbances under low solar activity conditions

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Abstract

The paper is focused on ionospheric response to occasional magnetic disturbances above selected ionospheric stations located at middle latitudes of the Northern and Southern Hemisphere under extremely low solar activity conditions of 2007–2009. We analyzed changes in the *F2* layer critical frequency *foF2* and the *F2* layer peak height *hmF2* against 27-days running mean obtained for different longitudinal sectors of both hemispheres for the initial, main and recovery phases of selected magnetic disturbances. Our analysis showed that the effects on the middle latitude ionosphere of weak-to-moderate CIR-related magnetic storms, which mostly occur around solar minimum period, could be comparable with the effects of strong magnetic storms. In general, both positive and negative deviations of *foF2* and *hmF2* have been observed independent on season and location. However positive effects on *foF2* prevailed and were more significant. Observations of stormy ionosphere also showed large departures from the climatology within storm recovery phase, which are comparable with those usually observed during the storm main phase. The IRI STORM model gave no reliable corrections of *foF2* for analyzed events.

Keywords: Ionosphere; Solar minimum; Magnetic storms; Ionospheric variability

1. Introduction

Solar energy and magnetic disturbances are the main sources of ionospheric variability. Solar ionizing flux varies with the solar cycle, the quasi-27-day rotation of the Sun and even on a day-to-day basis and shorter time scales. Solar flux-induced variations in the neutral composition, neutral temperatures and winds, and conductivities manifest also to ionospheric plasma densities and heights.

The minimum of the solar cycle 23/24, as for solar ionizing fluxes, has been described as unusually long, deep and complex. Araujo-Pradere et al. (2012) pointed out that solar irradiance for the years 2008–2009 was depleted in comparison to past minima. The number of spotless days in 2008 was highest since 1913 and the magnetic field at the solar poles was by about 40% weaker compared to the prior minimum. The authors also mentioned that measurements from several spacecraft showed a drop in solar brightness and solar wind pressure. Nanan et al. (2012), when performing simulations with model SUPIM, revealed extremely low O^+/H^+ transition height during the extreme solar minimum. Solomon et al. (2010) analyzed the extremely low thermospheric neutral densities in the solar minimum year 2008 compared to 1996 and concluded that the decrease of the solar EUV flux by 13–15% (SOHO and TIMED observations) can account for this decrease of thermospheric density. A more recent analysis by Solomon et al. (2013) estimated a global average *NmF2* decline between solar minima 1996 and 2008–2009 by ∼15%; a 10% reduction of solar EUV played the largest role in causing the ionospheric change, with a minor contribution from lower geomagnetic activity and a very small

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additional effect from anthropogenic increase in CO_2 (Solomon et al., 2013). Lean et al. (2011) used structural equation modeling with the EUV level in 2008 by 15% lower than in 1996 and found this model to provided implausible total electron content (TEC) trend; a plausible trend was obtained for EUV models with comparable EUV levels in 2008 and 1996. Deng et al. (2012) took into account also the decrease of geomagnetic energy. Their simulations with TIEGCM model indicate that about 75% of thermospheric density decrease was caused by EUV and 25% by the geomagnetic energy decrease. This reduced the 1996–2008 EUV difference to some 10–12%. Lastovicka (2013) estimated the decrease of EUV flux by 7–9% in 2008–2009 compared with 1996 based on Juliusruh *foF2* data. Araujo-Pradere et al. (2013) evaluated the performance of the International Reference Ionosphere (IRI) model in predicting *hmF2* for similar geomagnetic latitudes of the Northern (NH) and Southern (SH) hemispheres during the solar cycle 22/23 minimum. Model outputs for 1996 agreed reasonably with observations, whereas in the solar cycle 23/24 minimum (2008) IRI mostly overestimates *hmF2* values. This is probably a consequence of substantial cooling and contraction of the thermosphere due to very low level of the solar EUV flux. Also Lühr and Xiong (2010) compared the IRI-2007 outputs with measurements. Since 2005 (not before) onward to 2009 the IRI-2007 model overestimates electron densities compared to measurements of CHAMP and GRACE (topside ionosphere) – this overestimate in 2008 is by about 50%, in 2009 even by more than 60%. Liu et al. (2011) pointed out that worldwide recorded low *foF2* and TEC may be in principle explained in terms of decline of solar EUV as observed by SOHO/SEM and the low solar EUV is the main contributor to the unusually low electron density in the last solar minimum (23/24).

On the other hand, as it was mentioned by Araujo-Pradere et al. (2012), the Whole Heliosphere Interval (WHI), an international coordinated observing and modeling effort, reported that solar wind speed and radiation belt flux were high compared to minimum of the 22/23 cycle. Fig. 1 shows the monthly means of daily summary *Kp* index (Kp_{sum}) for the previous minimum year 1996 and for part of the declining branch and minimum of the solar cycle 23/24. The figure indicates that geomagnetic activity was markedly depleted from the second half of 2008 throughout 2009. The period of 2007–2009 did not exhibit strong magnetic storms (with $Dst < -100$ nT), and the number of moderate events (-50 nT $< Dst < -100$ nT) was decreasing (5 events in 2007; 4 events in 2008; 1 event in 2009) till 2010, when it increased again (7 events). Nevertheless, numerous cases of minor magnetic disturbances ($Dst > -50$ nT) where observed, which began with well-pronounced rapid increase of positive *Dst*.

It is well known fact that ionospheric storms are nearly always associated with magnetic storms. Particularly severe magnetic storms create complicated changes in the complex morphology of the electric fields, temperature, winds and

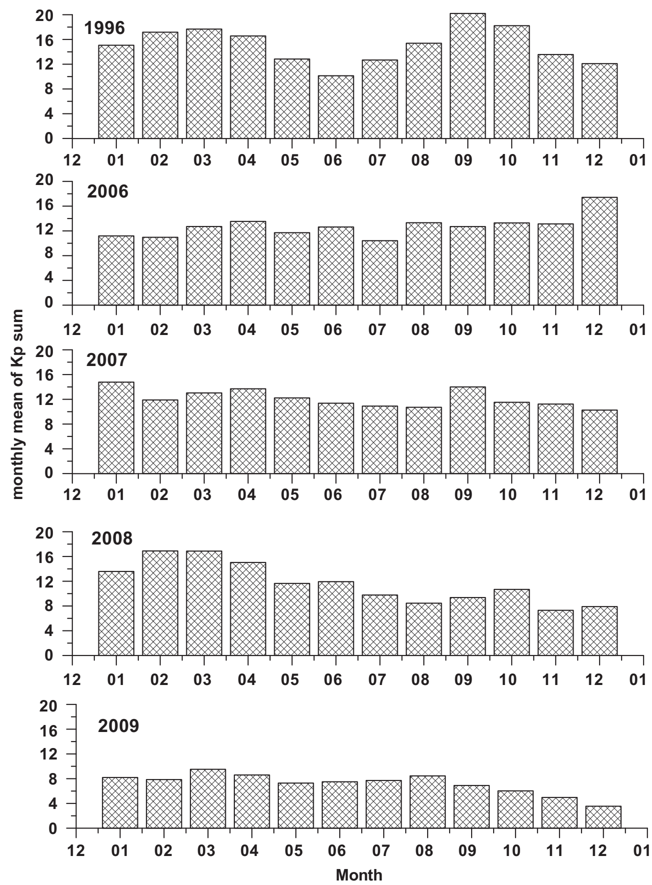

Fig. 1. Monthly mean of daily Kp_{sum} for years of low solar activity 1996 and 2006–2009.

composition and affect all ionospheric parameters. The main feature of the stormy ionosphere is a great degree of irregular variability, which persists from several hours to days. There is a broadly accepted opinion in scientific community that only large magnetic storms induce a global ionospheric storm.

Many years of continuous studies of magnetic storm effects on the ionosphere gave a typical course of the *F* region response at middle latitudes as described by Rishbeth and Field (1997) and summarized by Prölss (2004) with an initial phase with enhanced peak electron density lasting a few hours after the start of the magnetic storm. The subsequent main phase with electron density depletion usually lasts a day or more. A recovery phase of the storm could last from several hours to several days. Strong dynamical effects (heating and winds) occur during the initial phase, leading to fluctuations of *F2* layer height. Most of extra ionization is produced at heights below the *F2* layer, and the *F2* layer ionization is not greatly enhanced. However, during some storms the topside ionospheric electron content is much more enhances than the bottomside electron content (Zhao et al., 2012). The electron concentration at heights near the *F2* layer maximum could be more sensitive to changes of neutral composition, temperature and horizontal winds, whereas effects of