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Comparative study of high-latitude, mid-latitude and low-latitude ionosphere on basis of local empirical models

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Abstract

The analysis of the regular features of the high-, mid- and low-latitude ionosphere characteristics has been carried out using local empirical models. The local empirical models were derived from the manual scaled ionogram data recorded by DPS-4 Digisondes located at Norilsk (69 N, 88E), Irkutsk (52 N, 104E) and Hainan (19 N, 109E) for a 6-year period from December, 2002 to December, 2008. The technique used to build the local empirical model is described. Primary focuses are diurnal, seasonal and solar cycle variations of the peak electron density and the peak height under low solar activity and their changes with increasing solar activity. The main objective of the paper is to reveal both common and specific features of high-, mid- and low-latitude ionosphere. Based on earlier comparisons with the International Reference Ionosphere model, we analyze how the common and specific features are reproduced by this model.

Keywords: High-latitude, mid-latitude and low-latitude ionosphere; Local model; Digisonde; IRI model; Diurnal–seasonal–solar activity behavior

1. Introduction

The Earth ionosphere may be divided into three latitude zones that have rather different properties according to their geomagnetic latitude (GLAT): low-latitude zone (GLAT $< 30°$), mid-latitude zone ($30° <$ GLAT $< 60°$) and high-latitude zone (GLAT $> 60°$) (Hunsucker and Hargreaves, 2003; Schunk and Nagy, 2009). At the all latitude zones, the diurnal–seasonal variations of ionospheric electron density are caused by the change of the ion-production rate proportional to the cosine of the solar zenith angle; the neutral composition controlled by global thermospheric circulation and neutral temperature; and the plasma transport associated with neutral winds (Rishbeth, 1998). In addition to mentioned factors, the low-latitude ionosphere is strongly influenced by the low-latitude system of electric field, and the high-latitude ionosphere is affected by particles and electric fields controlled by the magnetosphere (Hunsucker and Hargreaves, 2003).

Local empirical models (LEMs) of the ionosphere are important tools for many research efforts (Zhang et al., 2005). These models are based on long-term data sets of incoherent scatter radars (Zhang et al., 2004, 2005; Lei et al., 2005) or ionosondes (Blanch et al., 2007; Altadill et al., 2008; Ratovsky and Oinats, 2011; Ratovsky et al., 2013). The LEM accounts for the regional specifics of the ionospheric plasma distribution and so can be used for validating theoretical and empirical global models. The comprehensive pattern of the diurnal, seasonal and solar activity variations of ionospheric characteristics provided by the LEM is useful for understanding the physical mechanisms of these variations.

In this paper we compare the regular features of the high-latitude, mid-latitude and low-latitude ionosphere characteristics using LEMs. The LEMs were derived from

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the manual scaled ionogram data recorded by the DPS-4 Digisondes (Reinisch et al., 1997) located at Norilsk (69 N, 88E; 60 N GLAT, 166E GLON), Irkutsk (52 N, 104E; 42 N GLAT, 177E GLON) and Hainan (19 N, 109E; 8 N GLAT, 179E GLON) for a 6-year period from December, 2002 to December, 2008 (GLON is geomagnetic longitude). All ionogram data have been manually scaled using an interactive ionogram scaling software, SAO Explorer (Reinisch et al., 2004; Khmyrov et al., 2008). The electron density profiles were inverted from all suitable ionogram traces using the NHPC method (Reinisch and Huang, 1983). The technique used to build the LEMs of ionospheric characteristics is described in Section 2. For the comparison, we selected two F2 layer parameters: the F2 peak density (NmF2) and the peak height (hmF2).

The main objective of the paper is to reveal both common and specific features of high-, mid- and low-latitude ionosphere. Based on earlier comparisons (Ratovsky et al., 2009, 2013; Wang et al., 2009) with International Reference Ionosphere (IRI) (Bilitza, 2001; Bilitza and Reinisch, 2008), we analyze how the common and specific features are reproduced by this model.

2. LEMs construction technique

The source data for the empirical model representation are the ionospheric characteristics obtained by the Norilsk, Irkutsk and Hainan Digisondes at 15-min cadence. Each measured characteristic P is considered as a function of local time (LT), day of year (D) and year (Y), i.e. P(LT,D,Y). In order to represent the regular part of the observed P(LT,D,Y) behavior that we expect to be associated with climatological specifics of the diurnal, seasonal, and long-term solar activity variations, we used the 27-day sliding window median Pmed(LT,D,Y) for each combination of LT, D, and Y in the sets {P(LT,D-13,Y),. . .,P(LT,D + 13,Y}. As is shown in numerous data analysis applications, use of the median filtering instead of a classic averaging preserves strong gradients in the source data while suppressing the short-term variability with periods below the filter length (27 days in our case).

The LEM construction technique worked out for the mid-latitude station of Irkutsk is described in details in Ratovsky and Oinats (2011). Here we give the main steps of the technique.

1. Calculation of the 27-day running medians of the ionospheric characteristics Pmed(LT,D,Y).
2. Transformation of Pmed(LT,D,Y) to Pmed(LT,M,Y_S) at equal month steps using linear interpolation, where Y_S is the solar year equal to = 365.25 days, M is the month equal to 1/12 of Y_S. The Y_S starts from the winter solstice of leap year (December 21). The month continuously varies from 0 to 12, with the 0th month corresponding to the beginning of Y_S.
3. Calculation of the two sets of model parameters, (a) low solar activity set P_0(LT, M) and (b) slope of the linear dependence on F10.7, P_D(LT, M), using the linear regression of Pmed (LT,M,F10.7) on 1-year running mean of F10.7, where F10.7 is the 10.7 cm solar radio flux used as a solar activity proxy, whose daily values are available from WDC-A in Boulder, Colorado (ftp://ftp.ngdc.noaa.gov/STP) in the solar flux units, s.f.u. (1 s.f.u. = 10^{-22} W m^{-2} Hz^{-1}). The selection of one year running mean of F10.7 is caused by previously performed (Ratovsky and Oinats, 2011) testing different sliding window averaging periods for F10.7 (from 27 days to 1 year) in order to minimize the linear regression RMS error.
4. Calculation of the B-spline coefficients for P_0 and P_D sets with local time step ΔLT = 0.5 h and month step ΔM = 1.

Hereinafter, we will use traditional month names, implying that the zero month is December, the 1st one is January, the 2nd one is February, the 3rd one is March, and so on. The beginnings of December and June correspond to the winter and summer solstices and the beginnings of March and September refer to the spring and autumn equinoxes.

According to Ratovsky and Oinats (2011), the relative root mean square deviations (ΔNmF2) between 15-min time step medians of NmF2 and the LEM values are from 5 to 15% depending on season and local time: the largest ΔNmF2 are in the winter evening and morning hours and the smallest ΔNmF2 are in the summer daytime.

3. Results and discussion

3.1. Comparison of NmF2 under low solar activity

The Hainan, Irkutsk and Norilsk diurnal–seasonal behaviors of NmF2 under low solar activity (F10.7 = 70 s.f.u.) as a function of local time LT and month M are shown in Fig. 1.

Here and after we analyze seasonal variations of NmF2 in terms of annual and semi-annual harmonics (Fourier components):

$$\mathrm{NmF2(M)} = \mathrm{A0}(1 + (\mathrm{A1}/100)\cdot\cos((\pi/6)(\mathrm{M} - \Phi1)) + (\mathrm{A2}/100)\cdot\cos((\pi/3)(\mathrm{M} - \Phi2))),$$

where M is month, A0 is the annual mean, A1 and A2 are the amplitudes (in percents relatively to annual mean), and Φ1 and Φ2 are the phases (in months) of annual and semiannual harmonics, correspondingly. We used 10–14 LT averaging for the daytime and 22–02 LT averaging for the nighttime.

The daytime seasonal variations of all three stations show pronounced semiannual anomalies (NmF2 is greater at equinox than at solstice, (Rishbeth, 1998)). The largest NmF2 are seen in October for all three stations; the secondary peaks are seen in February at Norilsk, in March