Comparison of Polar, Sub-polar and Mid-latitude Ionospheric Variability Using Ionosonde and SuperDARN Data

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Abstract— We study ionospheric variability using HF radio facilities within three latitudinal regions: polar zone (Norilsk ionosonde; 69.4N, 88.1E), sub-polar zone (Ekaterinburg SuperDARN radar; 56.4N, 58.5E) and mid-latitude zone (Hokkaido East SuperDARN radar; 43.53N, 143.61E). As characteristics we select the peak electron density (NmF2) measured with the ionosonde and the ground backscatter range corresponding to the skip distance (Rmin) from HF radar measurements. The disturbances of characteristics are the deviations of characteristics from their 27-day running median values. The variability is considered as the root mean square of disturbances. For different tasks we used different types of averaging. Annual averaging was used for studying year-to-year changes in the variability (solar cycle variations). To obtain the seasonal pattern of the variability we performed averaging over years for the daytime of each day of year. In the paper we discuss similarities and differences between the selected characteristics and between the polar, sub-polar and mid-latitude ionospheric variability.

1. INTRODUCTION

In [1] authors analyzed the 2003-2012 dataset of the Irkutsk ionosonde (52.3°N, 104.3°E). They obtained the diurnal, seasonal and solar activity pattern of the NmF2 variability for both high- and low-frequency parts of the variability.

In the current study we analyze the data of the Norilsk ionosonde (69.4N, 88.1E), the Ekaterinburg SuperDARN radar (56.4°N, 58.5°E), and the Hokkaido East SuperDARN radar (43.53°N, 143.61°E). Following [1], we analyze the variability of ionospheric characteristics in the same manner. As an ionosonde characteristic we selected the F2 peak density NmF2 calculated from the ionogram critical frequency. As a SuperDARN radar characteristic we selected the minimum slant range (Rmin) extracted from the HF radar ground backscatter data. Due to double HF focusing effect near the skip distance, the corresponding slant range can be surely determined as a slant range related to the maximum of the registered ground backscatter power. The main idea of minimum slant range extraction technique from SuperDARN radar data is described in [2]. However, in contrast with [2] in the current study we used an improved version of this technique which utilizes elevation angle information for more accurate identification of ground backscatter echoes corresponding to F2 ionospheric layer.

The main objectives of this paper are the following:

(1) to analyze the seasonal pattern and the solar cycle variations of the NmF2 variability from the Norilsk ionosonde and make comparison with the NmF2 variability from the Irkutsk ionosonde;

(2) to analyze the seasonal pattern and the solar cycle variations of the Rmin variability from the Hokkaido East SuperDARN radar and to make a comparison with the Rmin variability from the Ekaterinburg SuperDARN radar;

(3) to compare the seasonal pattern and the solar cycle variations of the NmF2 and Rmin variability and discuss the reasons of the obtained distinctions.

2. TECHNIQUE OF VARIABILITY CALCULATION

A disturbance of an ionospheric characteristic is considered as deviation of the observed value from a regular behavior. The regular behavior associated with climatological specifics of the diurnal, seasonal, and long-term solar activity variations can be represented by 27-day running medians. The 27-day running median of ionospheric characteristic $\mathbf{P}$ for given local time (LT), day of year (D) and year (Y) is the median value for the set $\{\mathbf{P}(\mathrm{LT, D} - 13, \mathrm{Y}), \ldots, \mathbf{P}(\mathrm{LT, D} + 13, \mathrm{Y})\}$. Thus, the $\mathbf{P}$ disturbance is the difference between observed $\mathbf{P}_{\mathrm{OBS}}$ and the 27-day median $\mathbf{P}_{\mathrm{MED}}$ value:

$$\Delta\mathbf{P} = \mathbf{P}_{\mathrm{OBS}} - \mathbf{P}_{\mathrm{MED}}, \tag{1}$$

$$\Delta_{\mathrm{R}}\mathbf{P}(\%) = \Delta\mathbf{P} \;/\; \mathbf{P}_{\mathrm{MED}} 100\%, \tag{2}$$

where $\Delta\mathbf{P}$ and $\Delta_{\mathrm{R}}\mathbf{P}$ are the absolute and relative disturbances, respectively.

The next step is separation of low- and high frequency components of the $\mathbf{P}$ disturbances. For the separation we used low-pass filtering with a cutoff period of 6 hours. The high-frequency part with periods less than 6 hours (denoted further as $\Delta\mathbf{P}_{\mathrm{TID}}$, $\Delta_{\mathrm{R}}\mathbf{P}_{\mathrm{TID}}$) is related to traveling ionospheric disturbances (TID) caused by internal gravity waves (IGW). The cutoff period was selected basing on [3] statistics that showed existence of TIDs with periods up to 5 hours. The low-frequency part with periods more than 6 hours (denoted further as $\Delta\mathbf{P}_{\mathrm{LONG-TERM}}$, $\Delta_{\mathrm{R}}\mathbf{P}_{\mathrm{LONG-TERM}}$) is related to day-to-day variability and tidal variations with diurnal, semidiurnal, and terdiurnal components.

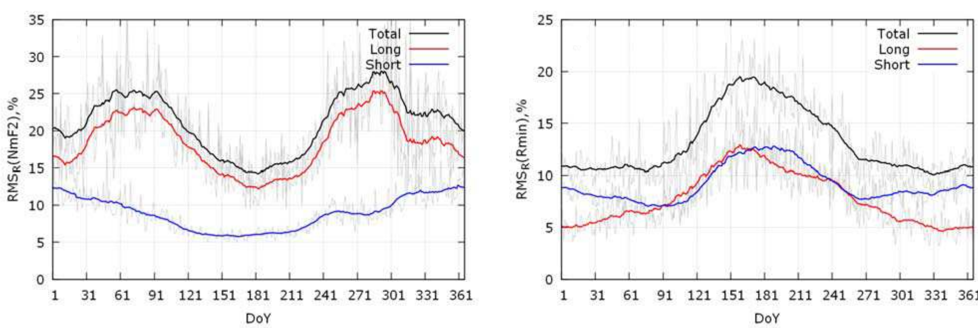
The variability is considered as the root mean square of $\mathbf{P}$ disturbances:

$$RMS(P) = \sqrt{\langle \Delta P^2 \rangle}, \quad RMS_R(P) = \sqrt{\langle \Delta_R P^2 \rangle}, \tag{3}$$

where brackets denote some averaging. For different tasks we used different types of averaging. Annual averaging was used for studying the year-to-year changes in the variability (solar cycle variations). To obtain the seasonal pattern of the variability we performed averaging over years for the daytime of each day of year. In this study we consider only the daytime variability (using ground terminator as a day-night boundary) due to the fact that the nighttime SuperDARN radar ground backscatter echoes are regularly observed only in summer period.

3. RESULTS AND DISCUSSION

Figure 1 shows the seasonal behaviors of the daytime relative NmF2 and Rmin variability. In the case of the peak electron density variability (RMS(NmF2)), the long-term variability provides the main contribution to the total variability, and their seasonal variations are similar. These seasonal variations are characterized by the largest values at equinoxes and the smallest values in summer with intermediate values in winter. The equinoxes/summer ratio is 1.7 and the winter/summer ratio is ∼1.3. The short-term variability shows clear seasonal behavior with maximum in winter and minimum in summer, and the winter/summer ratio is ∼2.3. For all the kinds of the NmF2 variability, the main features of the seasonal behavior at polar Norilsk are close to those at mid-latitude Irkutsk [1]. The difference is that the variability in winter and equinoxes is somewhat larger at Norilsk than at Irkutsk, and as a result the winter/summer ratios are somewhat larger at Norilsk.



(a) (b)

Figure 1: Seasonal behavior of daytime relative NmF2 (a) and Rmin (b) variability. Total, long-term and short-term variability averaged by running 27-day mean are shown by black, red and blue lines respectively. Grey lines are initial dependencies.

In the case of the Rmin variability (RMS(Rmin)), the long-term variability is smaller (in winter) or comparable (in summer and equinoxes) to the short-term variability, and hence we can not make a conclusion on the main contribution to the total variability. For all the kinds of the variability, the largest RMS(Rmin) is seen in summer. The smallest RMS(Rmin) is seen in winter for the long-term variability and at equinoxes for the short-term variability. The winter/summer ratio is ∼0.4 for the long-term variability and ∼0.7 for the short-term variability. For all the kinds of the Rmin variability, the main features of the seasonal behavior for the mid-latitude Hokkaido SuperDARN radar are close to those for the sub-polar Ekaterinburg SuperDARN radar with somewhat grater variability for the sub-polar radar.

The main distinction between the RMS(NmF2) and RMS(Rmin) seasonal behaviors is the opposite winter-summer difference. A similar difference between the seasonal behaviors of NmF2 and peak height (hmF2) variability was reported in [4]. Thus, we can assume that the Rmin variations are mainly caused by hmF2 variations and to a lesser extent by NmF2 variations. Under the same electron density (Ne) variations, the amplitude of hmF2 variations strongly depends on the background Ne profile thickness: the larger the thickness, the higher the amplitude. Thus, the higher hmF2 and Rmin variability in summer is most likely explained by the larger Ne profile thickness in summer compared to winter.

The other distinction between the NmF2 and Rmin variability is the different relation between the long- and short-term parts of the variability. This distinction may be explained by that the short-term part most likely corresponds to the variations with shorter vertical wavelengths that cause the higher hmF2 and Rmin variability compared to the longer wavelength variations.

The only similarity between the RMS(NmF2) and RMS(Rmin) seasonal behaviors is that the short-term part of the variability characterized by the higher winter/summer ratio compared to the long-term part.

Figure 2 demonstrates the year-to-year variations of the daytime relative NmF2 and Rmin variability. In the case of the NmF2 variability, the long-term part (as well as total variability) shows a clear increase with the solar/geomagnetic activity, whereas the short-term part does not show a clear dependence on the solar/geomagnetic activity. Both these features of the solar/geomagnetic activity dependence of the NmF2 variability at polar Norilsk are close to those at mid-latitude Irkutsk [1]. The short-term part of the Rmin variability (as well as in case of NmF2) does not show any increase with the solar/geomagnetic activity, whereas the long-term part shows some correlation with F10.7 excluding the case of 2007 when the long-term Rmin variability is the largest under enough low level of the solar/geomagnetic activity. From Figure 2 we can see that the long-term NmF2 variability noticeably exceeds the short-term NmF2 variability and the largest difference is seen under the highest solar/geomagnetic activity (2003); whereas the short-term Rmin variability is larger or comparable to the long -term Rmin variability and the largest difference is seen under the lowest solar/geomagnetic activity (2009).

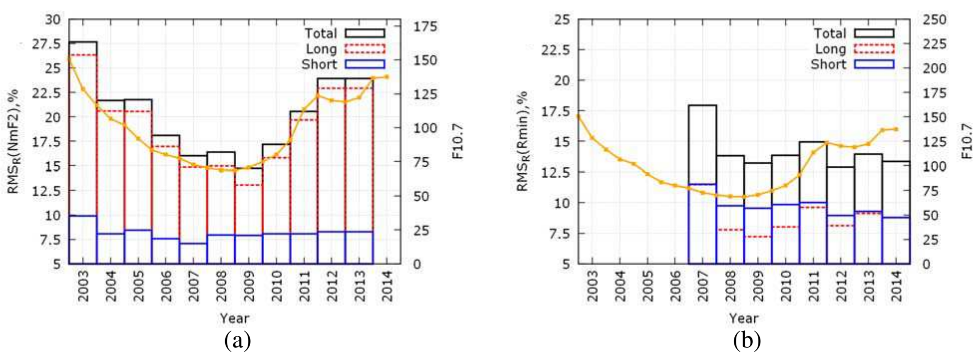


Figure 2: Year-to-year variations of daytime relative NmF2 (a) and Rmin (b) variability with variations of annual running mean F10.7 index (orange line with squares). Total, long-term and short-term are shown by black, red and blue colors respectively.

4. CONCLUSIONS

The performed analysis of the daytime relative NmF2 and Rmin variability revealed both distinctions and similarities in the seasonal behavior and year-to-year variations.

The main distinction between the seasonal behaviors is the opposite winter-summer difference. The proposed explanation is that the amplitude of Rmin variations strongly depends on the background electron density profile thickness: the larger the thickness, the higher the amplitude; and so the higher Rmin variability in summer is most likely explained by the larger profile thickness in summer compared to winter.

The long-term NmF2 variability noticeably exceeds the short-term NmF2 variability; whereas the short-term Rmin variability is larger or comparable to the long -term Rmin variability. The different relations between the long- and short-term parts of the variability may be explained by that the short-term part most likely corresponds to the variations with shorter vertical wavelengths that cause the higher Rmin variability compared to the longer wavelength variations.

The only similarity between the seasonal behaviors is that the short-term part of the variability characterized by the higher winter/summer ratio compared to the long-term part.

In solar cycle variations there are more similarities than differences. The short-term part of both the NmF2 and Rmin variability does not show any increase with the solar/geomagnetic activity, whereas the long-term part of the NmF2 variability clearly increases with the solar/geomagnetic activity and the long-term Rmin variability shows some correlation with F10.7 excluding the case of 2007.

The comparison between the NmF2 variabilities from the Norilsk and Irkutsk ionosondes as well as the comparison between the Rmin variabilities from the Ekaterinburg and Hokkaido SuperDARN radar showed that: (1) the main features of the seasonal and solar cycle behavior at polar and mid-latitudes are close to each other; and (2) the variability is somewhat larger at higher latitudes.

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