Short-period variability in the ionosphere and the stratosphere related to winter jet stream

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Abstract

In the study, we carried out a joint analysis of the spatio-temporal dynamics of ionospheric and stratospheric short-period variability. We analyze the periods of winters of 2008–2009, 2012–2013, and 2018–2019, when strong midwinter sudden stratospheric warmings (SSW) occurred. During quiet winter periods, the stratospheric variability index is shown to be increased at a limited latitudinal interval of 40-65°N. Under SSW condition, the generation of disturbances in the stratosphere stops and a decrease in the stratosphere disturbance index appears. The index keeps low values for up to a month. The latitudinal-temporal distributions of the ionospheric TEC variability index vrTEC also show similar dynamics. The level of ionospheric variability decreases after the SSW onset in the stratosphere. The decrease in the short-period ionospheric variability can be explained by reduction of wave generation in the stratosphere, associated with the destruction of the jet stream during SSW periods.

1. Introduction

It is well-known that processes in the underlying atmospheric layers strongly impact the ionospheric plasma state [1]. Internal gravity waves (IGWs), propagating from the lower and middle atmosphere can intensify variations in the ionosphere [2]. One of the sources for wave generation in the winter polar stratosphere and lower mesosphere is the circumpolar vortex and associated jet stream [3, 4]. Shpynev et al. [5] showed that the jet stream transfers up to 10-15% of its energy to generate IGWs.

The level of ionospheric variability of IGW periods is shown to depend on seasons at high- and mid-latitudes [6-8], with a maximum in winter months. Frissell et al. [7] and Yasyukevich et al. [9] showed a significant correlation between the seasonal variations in the short-period ionospheric variability and the dynamics of the circumpolar vortex. Chernigovskaya et al. [10] noted a possible relation between the increase in winter ionospheric variability and the dynamics of the stratospheric jet stream over Eurasia.

The configuration of the jet stream and its parameters crucially change during the winter, being characterized by a significant spatial inhomogeneity. As a result, the generation of IGW disturbances in the stratosphere also occurs unevenly.

In the study, we carried out a joint analysis of the spatio-temporal dynamics of ionospheric and stratospheric short-period variability during the development and transformation of the circumpolar vortex to reveal a possible relation between variabilities in these atmospheric layers. To study, we chose the periods of winters of 2008–2009, 2012–2013, and 2018–2019, when strong midwinter sudden stratospheric warmings (SSW) occurred. During such warmings the most significant transformation of the circumpolar vortex occurs.

2. Data

To analyze the variability in the stratosphere in the Northern hemisphere during the winter periods we used the ECMWF ERA-5 global reanalysis data [11]. The reanalysis provides high spatial data resolution (up to 0.25º or ~ 30 km) in latitude and longitude up to a pressure level of 1 hPa (corresponding to ~50 km of altitude). We considered the fields of vertical and horizontal velocities of atmospheric gas.

Figure 1 shows an example of the horizontal wind field (top) and vertical velocity (center) distribution of the atmospheric gas at the stratopause level (1 hPa, about 52 km) on December 27, 2012. Well-defined medium-scale wave disturbances are observed; the highest intensity of disturbances is recorded in areas corresponding high horizontal wind speeds in the jet stream.

The lower panel shows the spatial Fourier spectrum of the observed variations. The variation spectra show the stable region of disturbance generation at 40–65°N. Spectrum maximum is at 500–1000 km of horizontal wavelengths (zonal component) – that correspond to IGW.

To analyze short-period ionospheric variability, we used total electron content data provided by the World-wide GNSS Receiver Network database Madrigal [12]. The initial data of the vertical TEC were binned into 1x1 degree cells in latitude and longitude and with a time step of 5 minutes. Then, in each cell, the short-period variability index vrTEC was calculated [9].

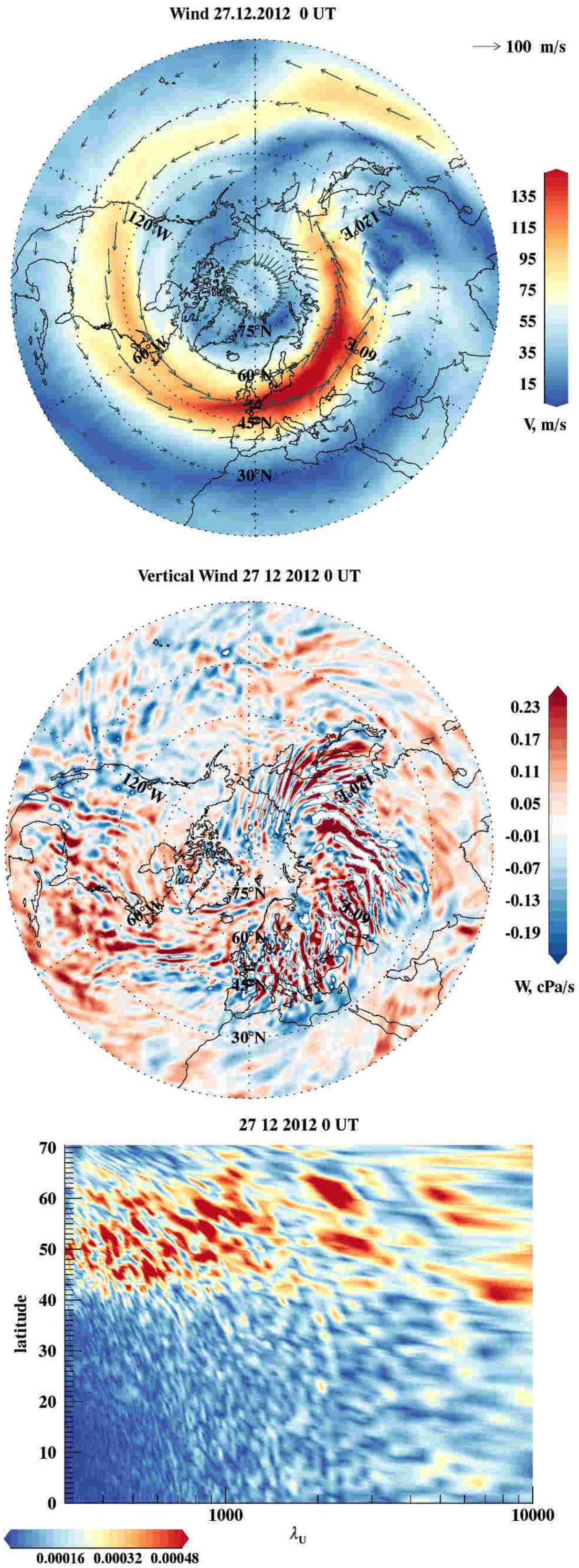

Figure 1. Fields of horizontal (top) and vertical (center) atmospheric gas velocities in the upper stratosphere at the level of 1 hPa on December 27, 2012, and corresponding spatial Fourier spectrum of observed variations (bottom).

VrTEC is the standard deviation of the vertical TEC in a window, normalized to the mean value of the TEC in this window. Normalization makes it possible to compare the nighttime and daytime TEC variability. In order for the index to reflect the level of IGW disturbance, the averaging interval should be limited to a value of several hours (4 hours). Calculations were made only for windows that included more than 50% of the data. This is necessary to increase the volume of vrTEC data, since a specific grid cell is not always filled with the value of the vertical TEC due to satellite movement. On the basis of the index values obtained, the latitude-time distributions of ionospheric variability in the studied winter periods were constructed.

The index of small-scale wave disturbances in the stratosphere was calculated to compare the dynamics in the ionospheric and stratospheric variability. The index is based on the vertical gas velocity fields at given latitude at a pressure level: it is a normalized standard deviation of the vertical gas velocity from its zonal average [9].

3. Results

Figure 2 shows the latitude-time distributions of the short-period variability indices in the stratosphere (left) and ionosphere (right) during the winters of 2008-2009 (top), 2012-2013 (center) and 2018-2019 (bottom). Strong sudden stratospheric warmings developed during the considered periods. The central warming days were recorded on January 24, 2009, January 6, 2013, and January 1, 2019.

During quiet winter periods, the dynamics of the stratospheric variability index shows an increase in the disturbance at a limited latitudinal interval of 40-65°N. The maximal disturbance appears in the regions with the well-developed polar vortex. During periods of strong SSWs, the jet stream first shifts to the pole. Around a warming maximum the jet stream significantly weakens or even destroys. Under that, the generation of IGW disturbances in the stratosphere stops - so a decrease in the stratosphere disturbance index appears. The index keeps low values for an extended period (up to a month).

The latitudinal-temporal distributions of the ionospheric TEC variability index vrTEC also show an increase in the disturbance at the beginning of the considered winters. However, the level of variability decreases after the onset of SSW in the stratosphere. Thus, the dynamics of variability indices in the stratosphere resemble those in the ionosphere.

The reduction in the generation of wave disturbances in the stratosphere, associated with the destruction of the polar vortex and jet stream during SSW periods, could explain the decrease in short-period variability in the ionosphere. The result obtained indicates a connection between processes in these two atmospheric layers.

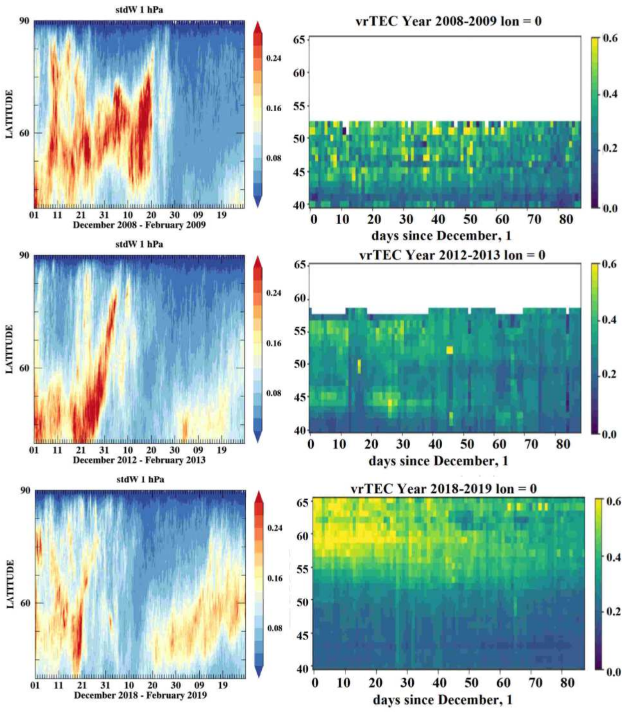

Figure 2. Latitudinal-temporal variations in the short-period variability indices in the stratosphere (left) and ionosphere (right) for the winters of 2008-2009 (top), 2012-2013 (middle) and 2018-2019 (bottom).

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