Ionosphere Response to Stratospheric Circulation in High-midlatitudes

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Abstract— The paper investigates the impact of the neutral atmosphere dynamical processes on the high-midlatitude ionosphere during winter sudden stratospheric warming (SSW) in January 2009. For this purpose we use the ECMWF Era Interim reanalysis data and the data from high-midlatitude chain of Russian ionosonde stations. The results show that the ionospheric response to the SSW event at high-midlatitudes depends on the position of the ionosonde stations relatively to the stratospheric circulation jet-stream.

1. INTRODUCTION

The middle atmosphere dynamics in winter is dominated by large-scale stratospheric high midlatitudes polar jet which forms a circumpolar vortex (CPV). The physical mechanism which is responsible for CPV acceleration is the cooling and lowering of the atmospheric gas during polar night and the transformation of gas gravity potential to kinetic energy of the vortex. Due to planetary wave (PW) activity CPV cannot be stable and the interaction of the PWs with CPV zonal flow can alter the middle atmosphere dynamics dramatically, as it happens in sudden stratospheric warming (SSW) events.

Recent studies have clearly identified large perturbations of the ionosphere, particularly in the ion drift measured at Jicamarca, and total electron content at low latitudes during SSW events [1, 3, 4]. The global spatial (latitude and altitude) structure of the mean ionospheric response to SSWs was for the first time investigated in paper [5]. The authors studied the SSW events in the winters of 2007/2008 and 2008/2009. To elucidate the effect of the SSWs on the ionosphere the FORMOSAT-3/COSMIC f_oF2, h_mF2 and electron density at fixed altitudes have been analyzed. Both the mean f_oF2 and h_mF2 parameters and the mean electron density at fixed heights indicated negative responses to the SSW temperature pulses at high latitudes. Similar response was found also for the diurnal variability of the COSMIC electron density. These effects were confined to low and middle latitudes. In our recent study [7] we have made an attempt to analyze ionosphere response to SSW events by using of ionosondes chain in eastern part of Russia. The study showed that during the developing of SSW event and breaking of CPV structure in the ionosphere there forms regions with higher electron density above stratospheric cyclone and regions with low electron density above the border of cyclone/anticyclone cells where circulation is directed poleward.

In the present paper we present new results of this study where we extend the high-midlatitudes chain of Russian ionosondes by new western stations that allows us to investigating the ionospheric response above the CPV main stream with large longitudinal coverage.

The modern version of Era Interim reanalysis from European Centre for Medium-Range Weather Forecasts (ECMWF) [2] gives a new possibility for analysis of fine structure of stratosphere dynamics. We use ECMWF Era Interim for demonstration of coupling between stratosphere/mesosphere circulation and ionosphere response associated with this dynamics.

2. USE OF RUSSIAN IONOSONDES CHAIN FOR SSW STUDIES

In order to investigate the ionospheric response to SSW events at high-middle latitude we used data from the chain of Russian ionosonde stations which are usually situated under the CPV jet-stream. We considered the temporal variability of the main ionospheric parameters: the critical frequency of F2 layer (f_oF2) and the F2 layer maximum height (h_mF2), measured by ionosonde stations in Kaliningrad (KAL) (54.7°N, 20.6°W), Moscow, (MSK) (55.5°N 37.3°E), Yekaterinburg (EKB)(56.5°N 60°E), Novosibirsk (NSK)(54.6°N, 83.2°E), Irkutsk (IRK)(52°N, 104°E), Yakutsk (YAK)(62°N, 129.7°E) and Paratunka (PAR)(53°N 158°E).

The longitudinal coverage of this chain is about 140° and for SSW-2009 event, described in this paper, we can investigate ionospheric response over different zones of stratospheric circulation. The longitudinal resolution of the ionosonde chain is about 20° that gives a good possibility for analyses of ionospheric response.

In the present study, to investigate the day-to-day variability of the ionosphere in different geographical points, we have made an averaging of f_oF2 and h_mF2 data over four hour interval in the vicinity of local noon and local midnight in every site. Typical time resolution of ionosondes was 15 minutes or one hour, so from 5 to 17 data points in day and in night were averaged. From 3% to 30% of data were missed on different sites due to data quality. Standard deviation on plots presented below characterizes variability of parameters in considered time intervals. For SSW event presented in the paper we considered ionosonde data for time interval from December 1 to January 31.

Observatories in Irkutsk, Yakutsk and Moscow are equipped by modern DPS-4 ionosondes and their software can provide real height of maximum h_mF2. Observatories in Yekaterinburg, Novosibirsk, Kaliningrad and Paratunka used old generation ionosondes, so in standard mode these equipments provide only virtual height of F2 layer (i.e., h'F2) determined from ionograms. This difference is not critical for purpose of our paper as we study variations of these parameters, but absolute values of h'F2 on plots may differ from h_mF2. Further in the text we will use h_mF2, implying h'F2 for old generation equipment. Also, data processing on Kaliningrad ionosonde did not included the h'F2 calculation during SSW-2009 event, so these data for this station are missed.

3. COMPARISON OF STRATOSPHERE AND IONOSPHERE DYNAMICS DURING SSW-2009

In the present study for investigation of stratosphere/lower mesosphere dynamics we use ECMWF Era Interim reanalysis data and particularly the fields of horizontal wind speed that clearly identify the structure of atmospheric circulation at different pressure levels. For this purpose the special software for wind field mapping was developed. We use the data from highest pressure level 1 hPa ($\sim$ 50 km) from ECMWF Era Interim reanalysis which is closest to thermosphere region and well represents mesosphere dynamics in winter time. Due to close relation of mesosphere and lower thermosphere we suggest that observed mesosphere dynamics also has significant influence on global ionosphere dynamics.

Figure 1 shows four patterns of CPV structure in the latitudinal interval 30°–90° of Northern hemisphere during different stages of SSW in January 2009. Fig. 1(a) is 05 Jan. 2009; Fig. 1(b) is 15 Jan. 2009; Fig. 1(c) is 21 Jan. 2009; Fig. 1(d) is 25 Jan. 2009. Intensity of gray scale corresponds to horizontal wind strength. Arrows show the wind direction and length of arrows is also proportional to wind velocity. Positions of Russian ionosondes are pointed on maps and we can see that ionosondes cover different zones of stratospheric circulations. Dark regions on plots correspond to jet-streams that transfer air from warm equator to polar region and sometimes form pronounced circumpolar vortex.

Figure 2 shows variations of ionospheric parameters foF2 (left column) and hmF2 (right column) measured by chain of Russian ionosondes from 1 December 2008 to 31 January 2009. Right upper plot shows F10.7 and summary Kp indexes during this period. As it can be seen, the geomagnetic activity during the event was quiet (summary Kp does not exceed 25) and solar activity index F10.7 was less than 70. This provided best conditions for analysis of atmosphere-ionosphere coupling.

Left vertical line on Fig. 2 corresponds to time of circulation pattern on Fig. 1(a) and this is the time of beginning of CPV increasing. Middle and right lines show the period of CPV splitting and destroying. From analysis of f_oF2 variations in every site we can see some common features as regular day-to-day variations with periods 3–5 days that sometime correlate with each other and sometime are not correlated. In our paper we consider differences between variations of ionospheric parameters in different sites depending on their position relatively to the circulation pattern. We analyze relatively long trends (5–10 days) that appear on each site in time interval from January 5 (day 35 on Fig. 2) to January 30 (day 60 on Fig. 2).

First time interval under consideration is January 5–20, when in the beginning of the interval the western group of ionosondes Kaliningrad, Moscow, Ykaterinburg and Novosibirsk were to the south of jet-stream. Eastern group Paratunka, Yakutsk and partially Irkutsk were under the jet-stream (Fig. 1(a)). In these conditions we see on Fig.2 higher f_oF2 in the western group and lower f_oF2 in the eastern group. The f_oF2 difference between Kaliningrad and Paratunka is about 1.5 MHz, that is significant for quiet solar and geomagnetic conditions. Here we can make a reasonable suggestion that under the jet-stream the lower thermosphere has higher concentration of molecular particles N_2 and NO that provides higher recombination rate and decreases the electron density. We used classical approach [6] for explanation of ionospheric variations by changing of molecular gas density in lower thermosphere. In diffusion equilibrium conditions, if some process transports molecular gas to the lower thermosphere, then it produces lowering of f_oF2 and increasing of h_mF2. If molecular gas density in lower thermosphere decreases then we have a reverse effect.

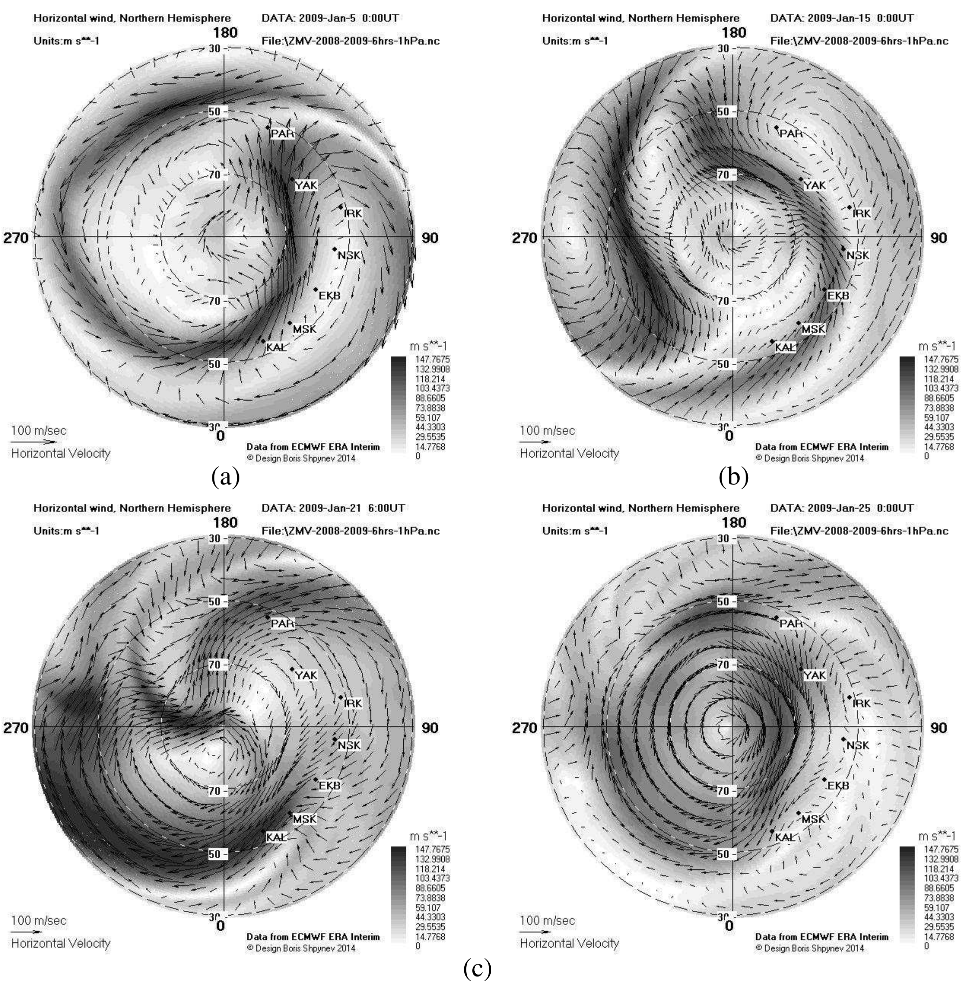

Figure 1: Circulation patterns on 1hPa pressure level during different phases of SSW developing. (a)05 Jan. 2009; (b)-15 Jan. 2009; (c)-21 Jan. 2009; (d)-25 Jan. 2009.

During the interval January 5–20 the jet-stream changes from Fig.1a to Fig.1b and western group of ionosondes shifts under the jet-stream while eastern group appears out of jet-stream position. Again we can see obvious f_oF2 decreasing in western group and f_oF2 increasing in eastern group.

Middle dashed line on left panel of Fig. 2 corresponds to time of circulation pattern on Fig. 1(c) when western group was under very strong jet-stream ($\sim$ 140 m/s) and we can see in this time the lowest f_oF2 in Kaliningrad and Moscow for all considered period. Destroying of circulation in period January 20–25 makes the jet-stream weaker and again changes the relative ionosondes positions. We see f_oF2 growing in western group and f_oF2 decreasing in Yakutsk and Paratunka.

Finally f_oF2 come back to usual dynamics after SSW finishing.

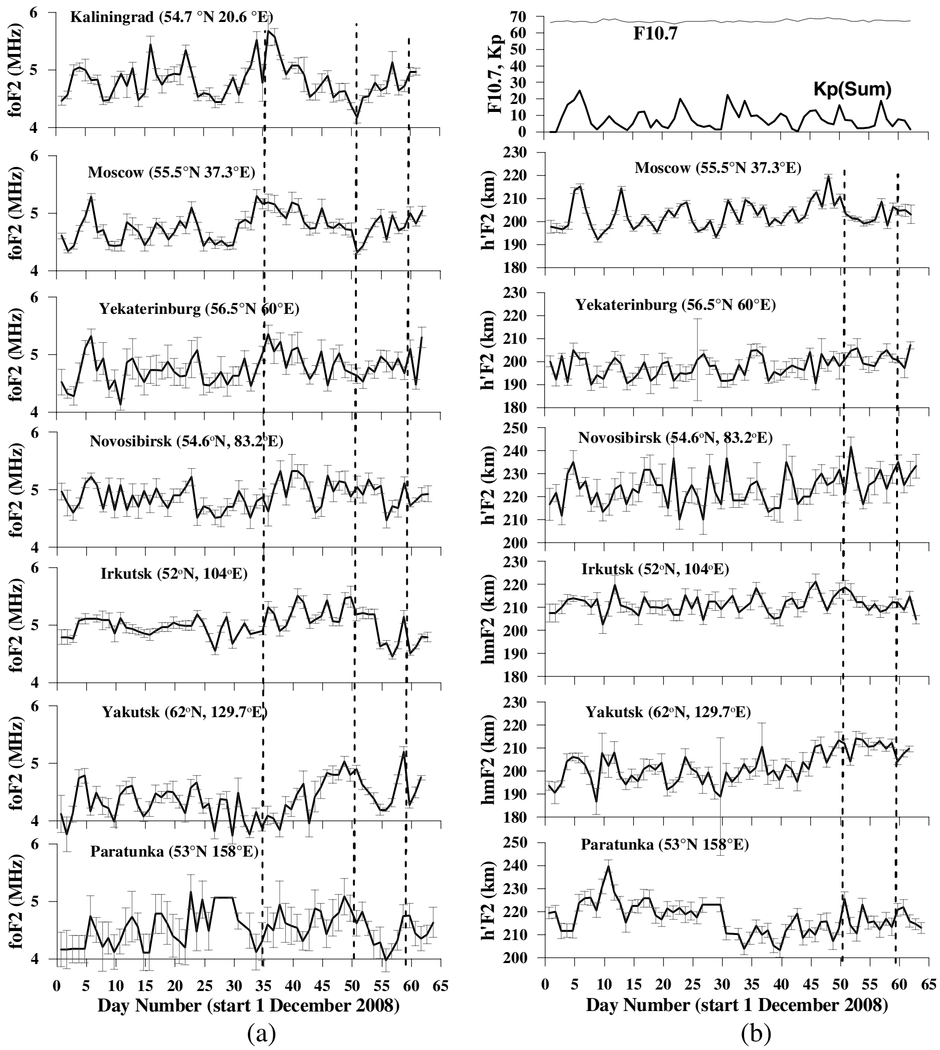

Figure 2: Variations of ionospheric parameters foF2 (left column) and hmF2 (right column) measured by chain of Russian ionosondes from 1 December 2008 to 31 January 2009. Left upper plot shows F10.7 and summary Kp indexes during this period.

If we compare h_mF2 dynamics with considered f_oF2 dynamics we see usually some negative correlation which confirms our suggestion about origination of observed variations due to some process of molecular gas transport to the lower thermosphere. Only Yakutsk data shows different dynamics of h_mF2 because it has higher latitude and more often appear under circulation than other sites. Format of this paper does not allow us to show the night ionosphere variation. In our recent study [7] we did such analysis for eastern group of ionosondes. In Yakutsk the night time variations show very high increasing of h_mF2 on ~ 50 km which were observed during six days. We discussed this unusual effect in the previous paper and suggested the existing of some effective transport mechanism (perhaps some fountain effect) that increased N_2/O^+ ratio.

4. DISCUSSION

Comparing with our previous study [7] the extending of Russian ionosondes chain by additional western station give us a new possibility for studying of global ionosphere middle atmosphere coupling, especially during major SSW events. We also have the agreement to involve into joint analysis the data from European Juliusruh (54.6N, 13.4E) and Chilton (51.5N 0.6W) ionosondes that will allow us to overlap almost whole Eastern hemisphere along 50–60 latitudes. We can see that the spatial resolution of such chain is good enough for investigating of large scale irregularities formed in the ionosphere by atmospheric processes from below and by geomagnetic activity. For the present study it is very important that Russian ionosones chain is continuous and it is not critical that some observatories use the old generation equipment.

The main conclusion that results from present study is the presence of obvious dependence between stratospheric jet-stream structure and ionosphere dynamics. We can see that the midlatitude ionosphere in winter may be affected by large scale stratospheric processes and its longitudinal structure may be significantly uneven during the period of several days.

From results of the present study we cannot surely determine the stratosphere-mesosphere-ionosphere transport processes that responsible for observed ionosphere-neutral atmosphere coupling. To make a definite conclusion we have to analyze the mesosphere data on vertical drift and gravity waves.

Comparing with the previous [7] study we found clear dependence of background f_oF2 on jet-stream position, not only fact of being over stratospheric cyclone or anticyclone that are formed by jet-stream.

In any case the results of this study require additional investigations of SSW phenomena with involving of new experimental data on stratosphere, mesosphere and lower thermosphere.

ACKNOWLEDGMENT

This work was supported by the Grant of the Russian Scientific Foundation (Project No. 14-37-00027).

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