2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Changes in the stratosphere and ionosphere parameters during the 2013 major stratospheric warming

Anna S. Yasyukevich*(1), Yury Yu. Kulikov(2), Maxim V. Klimenko(2,3),
Vladimir V. Klimenko(2), Fedor S. Bessarab(2), Yury N. Korenkov(2), Valery N. Marichev(4), Konstantin G. Ratovsky(1),
Sergey A. Kolesnik(5)
(1) Institute of Solar-Terrestrial Physics SB RAS, 664033, Irkutsk, Russia, annpol@iszf.irk.ru
(2) Kaliningrad Branch of N. V. Pushkov IZMIRAN RAS, 236010, Kaliningrad, Russia
(3) Immanuel Kant Baltic Federal University, 236016, Kaliningrad, Russia
(4) V.E. Zuev Institute of Atmospheric Optics SB RAS, 634055, Tomsk, Russia
(5) Tomsk State University, 634050, Tomsk, Russia

Abstract

The paper presents the results of the complex experiment (lidar and ozonometric observations), carried out during the period of the 2013 major sudden stratospheric warming (SSW) in the North Asia region. The data of this experiment were supplemented by the ionospheric parameters observations. We considered variations in the critical frequency and peak height of the ionospheric F2-layer (foF2) from ionosonde measurements in Tomsk and Irkutsk, as well as the behavior of the total electron content (TEC) based on the phase dual-frequency GPS/GLONASS receivers' data. We revealed significant variations in the stratosphere ozone concentration, ionospheric electron density, as well as in the thermosphere O/N_2 ratio with the similar pattern during the SSW. The ionospheric response to SSW in the middle and high-latitude regions is suggested to be caused by changes in the neutral composition at the thermosphere altitudes.

1. Introduction

The period of December 2012 - January 2013 is of special interest for the study of solar-terrestrial and atmospheric-ionospheric relations physics, due to the almost simultaneous increase in solar activity and the formation of sudden stratospheric warming (SSW). Stratospheric warming is a strong increase in the temperature of the polar and subpolar stratosphere in winter lasting for several days or even weeks. The warming is characterized by the "explosive" nature and the phenomenon intensity can reach up to 50°C or more. The influence of stratospheric warming on the meteorological parameters distribution in the troposphere, surface atmospheric layer and, consequently, on the weather has a rather extensive experimental and theoretical background [1]. Studies of the possible SSW-related effects in the upper atmospheric layers, such as the mesosphere, thermosphere and ionosphere, need carrying out on a wider scale. Experimental and modeling results demonstrated SSW-related global changes in the atmosphere dynamics and composition at all the heights from the stratosphere to the thermosphere [2-3]. The consequences of modern works have also shown that SSW could have a considerable effect on the ionospheric plasma distribution [4-9]. However, there have been only a few attempts of complex studying the SSW effects simultaneously in different atmospheric layers so far. In this work we present the results of observations of various parameters in the middle and upper atmosphere in the Northern Asia region during the period of December 2012 - January 2013, when the major SSW event took placed.

The basis of our study was a complex experiment (lidar and ozonometric observations), conducted during the period considered in Tomsk. The data of this experiment were supplemented by the ionospheric parameters observations. We considered variations in the critical frequency and peak height of the ionospheric F2-layer (foF2) from ionosonde measurements in Tomsk (56°N, 85°E) and Irkutsk (52°N, 104°E), as well as the behavior of the total electron content (TEC) based on the phase dual-frequency GPS/GLONASS receivers' data. The vertical TEC were calculated from the initial series by the method described in [10].

2. Results and discussion

Figure 1 shows the distribution of the stratospheric temperature at the 10 hPa (~ 30 km) level, as well as the isolines of geopotential height from the NCEP/NCAR reanalysis data. The temperature of the stratosphere began to rise from December 21, 2012. The maximum temperature increase exceeded 70°C during January 3-6, 2013 and was registered in the Northern Asia region. The reverse of the zonal mean zonal wind direction at 60°N latitude occurred on January 6, the warming was considered to become the "major" type on this day One can also clearly observe the displacement and splitting of the circumpolar vortex during this event. The stratospheric circulation returned to normal mode by the end of January.

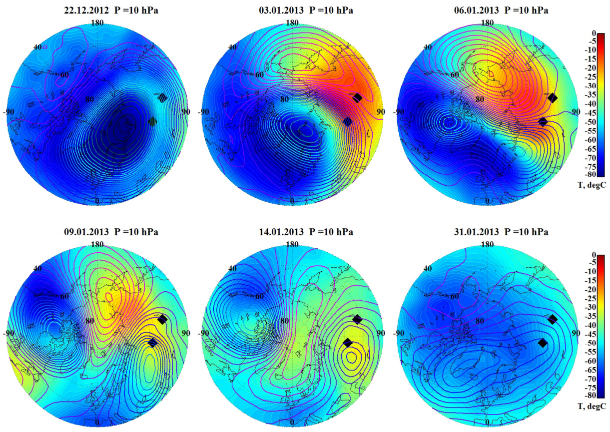

Figure 1. Distribution of the stratospheric temperature, as well as isolines of the geopotential height at the 10 hPa (~ 30 km) level. Rhombuses mark the Irkutsk and Tomsk locations.

During the period under consideration, stratospheric ozone measurements were carried out in Tomsk using a mobile microwave (MMW) ozonometr [11, 12], as well as lidar observations of the stratospheric temperature. The obtained results are shown in Fig. 2 jointly with the distributions of the parameters from satellite MLS/AURA measurements and ERA Interim reanalysis data. One can see significant variations in the ozone concentration and temperature of the stratosphere during the SSW. After the SSW warming peak (January 6) the ozone concentration was observed to increase up to 1.5-2 times at 25 and 60 km altitudes (Fig. 2 a, d). On the contrary, at the lower stratosphere during the SSW evolution phase (December 21 - January 2) one can see a considerable decrease in the O_3 concentration by approximately 50% compared to previous days (Fig. 2 a). There was also an increase in the amplitude of ozone fluctuations. The observed period was featured also by the absence of a correlation between the stratospheric temperature and O_3 concentration behavior at the 25 km altitude (Fig. 2 a, b).

The revealed ozone behavior in the lower stratosphere is, probably, associated with the processes of destruction of the circumpolar vortex during the SSW and the transfer of cold air masses from the North Atlantic. At the upper stratosphere the ozone concentration changes are caused basically by variations in the temperature. The obtained significant ozone fluctuations during the SSW indicate the origin of a tidal wave that can affect the ionosphere.

Significant variations were also observed in midday ionospheric critical frequency and TEC behavior (Fig. 2 c, f). TEC variations are given for receivers in Irkutsk and Novosibirsk, which is close to Tomsk. The difference between foF2 and TEC values before and after the SSW peak was 1.5 and 2 times, respectively. The analysis showed that the recorded increase in the ionospheric electron density during the considered period cannot be completely explained by changes in the solar activity level. Increased values of solar activity were observed from December 29 till January 18 with a maximum on January 11. However, a significant enhancement in the value of ionospheric parameters was still observed for more than 20 days after the $F_{10.7}$ had decreased down to the mean level. However, the SSW-related stratospheric dynamic disturbances lasted until early February, which matched the duration of the ionospheric variations observed.

Similar changes were registered for the neutral composition of the thermosphere. There was a significant increase in the O/N_2 ratio, measured by satellite GUVI/TIMED instrument, during the SSW peak and within 20 days after it. The positive O/N_2 response was recorded at latitudes greater than 30°N and was most pronounced in the high-latitude region where the warming development took place. This O/N_2 behavior correlated with the revealed variations in the ionospheric electron density.

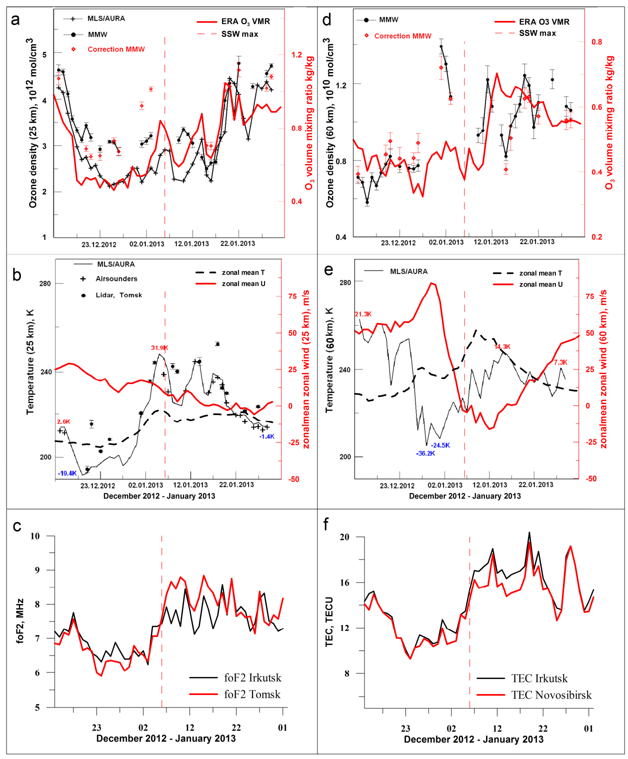

Figure 2. Distributions in: ozone concentration at 25 km (a) and 60 km (d) altitudes, temperature of lower (c) and upper stratosphere (e) in Tomsk from experimental and reanalysis data (see the legends); midday critical frequency of ionospheric F2-layer (c) as well as total electron content (f) in Tomsk and Irkutsk. Vertical dashed lines on the panels indicate the SSW peak.

The obtained results indicate that the ionospheric response to SSW in the middle and high-latitude regions is caused by changes in the neutral composition at the thermospheric altitudes. Variations in the neutral composition of the thermosphere can be related either to changes in direct penetration of wave disturbances (mainly tides), which are amplified during SSW at the mesosphere/lower thermosphere height; or be the result of neutral gas vertical transfers produced by SSW-induced secondary circulation. This issue requires further detailed studies, involving experimental data and modeling efforts.

3. Acknowledgements

The work is supported by the RFBR grants No. 16-35-60018 (Yasyukevich A.S. – data treatment and analysis) and 18-05-00594 (Ratovsky K.G., Klimenko M.V – ionosondes' data), and the RSF grant No. 17-17-01060 (Korenkov Yu.N., Klimenko V.V., Bessarab F.S. – the model problem statement). The authors enclose their gratitude to the NOAA/OAR/ESRL PSD, USA and to European Centre for Medium-Range Weather Forecasts for the Reanalysis data, to the Aerospace Corporation, to the Johns Hopkins University, USA for GUVI/TIMED data, and to the International GNSS Service (IGS) for GPS/GLONASS receivers' data. Irkutsk Station vertical sounding data were recorded by the Angara Multiaccess Center facilities at ISTP SB RAS.

4. References

1. J. Kidston, A. A. Scaife, S. C. Hardiman, D. M. Mitchell, N. Butchart, M. P. Baldwin, L. J. Gray, "Stratospheric influence on tropospheric jet streams, storm tracks and surface weather", *Nature Geoscience*, 2005, doi:10.1038/ngeo2424.

2. H.-L. Liu, R. G. Roble, "A study of a self-generated stratospheric sudden warming and its mesospheric–lower thermospheric impacts using the coupled TIME-GCM/CCM3", *J. Geophys. Res.*, **107,** D23, 4695, 2002, doi:10.1029/2001JD001533.

3. I. Medvedeva, A. Medvedev, K. Ratovsky, A. Shcherbakov, M. Tolstikov, "Comprehensive study of disturbances of the neutral atmosphere and ionosphere parameters over Eastern Siberia during the 2013 January major sudden stratospheric warming", *Adv. in Space Res.*, **56**, pp. 1877–1885, 2015, doi:10.1016/j.asr.2015.06.008.

4. L. P. Goncharenko, J. L. Chau, H. L. Liu, A. J. Coster, "Unexpected connections between the stratosphere and ionosphere", *Geophys. Res. Lett.*, **37**, L10101, 2010, doi: 10.1029/2010GL043125.

5. M. V. Klimenko, V. V. Klimenko, F. S. Bessarab, Yu N. Korenkov, H. Liu, L. P. Goncharenko, M. V. Tolstikov, "Study of the thermospheric and ionospheric response to the 2009 sudden stratospheric warming using TIME-GCM and GSM TIP models: First results", *J. Geophys. Res. Space Physics*, **120**, 2015, doi:10.1002/2014JA020861.

6. D. Pancheva, P. Mukhtarov, "Stratospheric warmings: The atmosphere –ionosphere coupling paradigm", *J. Atm. Solar-Terr. Phys.*, **73**, 2011, pp. 1697–1702, doi: 10.1016/j.jastp.2011.03.006.

7. A. S. Polyakova, M. A. Chernigovskaya, N. P. Perevalova, "Ionospheric effects of sudden stratospheric warmings in Eastern Siberia region", *J. Atm. Solar-Terr. Phys.*, **120**, 2014, pp. 15-23, doi: 10.1016/j.jastp.2014.08.011.

8. B. G. Shpynev, V. I. Kurkin, K. G. Ratovsky, M. A. Chernigovskaya, A. Yu. Belinskaya, S. A. Grigorieva, A. E. Stepanov, V. V. Bychkov, D. Pancheva, P. Mukhtarov, "High-midlatitude ionosphere response to major stratospheric warming", *Earth Planets and Space,* **67:18**, 2015, doi:10.1186/s40623-015-0187-1.

9. E. Yiğit, P. K. Knížová, K. Georgieva, W. Ward, "A review of vertical coupling in the Atmosphere–Ionosphere system: Effects of waves, sudden stratospheric warmings, space weather, and of solar activity", *J. Atmos. and Solar-Terr. Phys.*, **141**, 2016, pp. 1–12, doi:10.1016/j.jastp.2016.02.011.

10. Yu. V. Yasyukevich, A. A. Mylnikova, A. S. Polyakova, "Estimating the total electron content absolute value from the GPS/GLONASS data", *Results in Physics*, **5**, 2015, pp. 32-33, doi:10.1016/j.rinp.2014.12.006.

11. Y. Y. Kulikov, A. A. Krasilnikov, V. G. Ryskin, V. N. Shanin, A. M. Shchitov, "Ground-based microwave instrument to research of stratospheric ozone (some results of observations)", *Proc. XXX Annual Seminar, Apatity,* 2007, pp. 218 – 221.

12. V. N. Marichev, G. G. Matvienko, A. A. Lisenko, D. A. Bochkovsky, Yu. Yu. Kulikov, A. A. Krasilnikov, V. G. Ryskin, V. M. Demkin, "Microwave and optical observation of ozone and temperature of the middle atmosphere during stratospheric warming at Western Siberia", *Atmos. Ocean. Opt.,* **27,** 6, pp. 499-505, 2014, doi:10.1134/S1024856014060141.