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Comprehensive study of disturbances of the neutral atmosphere and ionosphere parameters over Eastern Siberia during the 2013 January major sudden stratospheric warming

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Abstract

We investigated variations in the neutral atmosphere and ionosphere parameters within a large range of heights in the Eastern Siberia region during the 2013 January sudden stratospheric warming (SSW). The analysis is based on: the data from spectrometric measurements of OH (~87 km, 834.0 nm, (6–2)) and At O_2 (~94 km, 864.5 nm, (0–1)) upper atmospheric emissions, the data from the Irkutsk DPS-4 Digisonde, the data on electron and ion temperatures and the meridional component of the neutral wind from the Irkutsk Incoherent Scatter Radar, the satellite data on the vertical temperature distribution in the atmosphere from Aura MLS v3.3, and the MERRA reanalysis data.

We detected the disturbances of the neutral atmosphere temperature from the stratosphere to the mesosphere and lower thermosphere (MLT). The temperature at 10 hPa (~32 km) increased by ~70 K up to ~270 K, the temperature at 0.01 hPa (~80 km) decreased by 50 K, and reached ~170 K. At the MLT heights, an increase in the intensities of the OH and O_2 emissions by a factor of 2–2.5 relative to the undisturbed conditions was revealed. At the F2-layer height, the plasma parameter disturbances were found. After 2013 January 10, interruption of the correlation between NmF2 and hmF2 occurred. Ion temperature cooling reaching 50 K was observed on January 1–10, changing to a quick increase by 50 K for several days after January 10. The neutral wind meridional component and the electron temperature decreased over January 1–21.

The observed effects can be probably caused by atmospheric circulation disturbances and amplification in the vertical transfer. The disturbances in the upper atmospheric and in ionospheric parameters during SSW can evidence the coupling between the lower and upper atmosphere.

Keywords: Sudden stratospheric warming; Atmosphere; Ionosphere; Hydroxyl airglow; Incoherent Scatter Radar; Atmosphere–ionosphere coupling

1. Introduction

A sudden stratospheric warming (SSW) is one of the most dramatic meteorological phenomena that impact the dynamics of the wintertime middle atmosphere. During SSWs, zonal circulation weakens considerably, and the stratosphere temperature increases by tens of degrees within a short time. According to World Meteorological Organization's definition, a stratospheric warming can be said to be major when the zonal-mean zonal winds at 60°N and 10 hPa become easterly during winter and the 10-hPa zonal-mean temperature gradient between 60°N and 90°N becomes positive (Labitzke and Naujokat,

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2000). If no reversal of the westerlies is observed, but only a rapid temperature increase (at least, 25 °C within one week in the upper stratosphere in any area of the winter time hemisphere), the event is defined to be a minor warming (Labitzke, 1977).

The commonly accepted primary mechanism leading to SSW is interaction of planetary waves with zonal mean flow (Matsuno, 1971). Quasi-stationary planetary waves (SPWs), due to contrasts in the surface temperature of the continents and oceans, as well as to the orographic effect, affect the winter circulation of the atmosphere, extending from the troposphere to the stratosphere and disturbing the latter. Large-amplitude SPWs disturb the circumpolar vortex in winter, which leads to weakening of eastward zonal winds or changing them to westward ones. The interaction decelerates and/or reverses the eastward winter stratospheric jet and also induces a downward circulation in the stratosphere causing adiabatic heating and an upward circulation in the mesosphere causing adiabatic cooling.

As classified by Charlton and Polvani (2007), there are two types of SSW events: vortex-displacement events, when the stratospheric polar vortex displaces from its climatological position over the pole while preserving its integrity, and vortex splitting events, when the vortex splits into two parts. Displacement events occur as a result of an increase in the amplitude of SPW with zonal number 1 (SPW1). Splitting events are a consequence of an increase in the amplitude of SPW with zonal number 2 (SPW2). Splitting events occur more rarely than displacement events, and cause stronger disturbances of temperature and zonal wind in the upper atmosphere (Miller et al, 2013). According to Matthewman et al. (2009), during vortex-splitting events, the vortex remains nearly barotropic with the vortex split occurring near-simultaneously over a large altitude range. A major sudden stratospheric warming impacts the state of the atmosphere within a large height range.

Experimental results corroborating the SSW impact on the mesosphere and thermosphere (MLT) region were presented in numerous observational studies. SSW effects at the MLT altitudes were revealed by using the data on the OH airglow rotational temperature (Myrabo et al., 1984; Walterscheid et al., 2000; Medvedeva et al., 2012), lidar, meteor radar (Hoffmann et al., 2002, 2007), SABER, and MLS Aura temperature data (Siskind et al., 2005; Manney et al., 2009; Tolstikov et al., 2014), etc. The data on radio physical measurements of the ionospheric plasma parameters detect manifestations of SSW effects even at ionospheric heights (Goncharenko and Zhang, 2008; Pancheva and Mukhtarov, 2011).

Investigation into the manifestation of stratosphere warmings at the heights of the upper atmosphere and ionosphere was also performed through numerical work by using different models. TIMEGCM simulations (Liu and Roble, 2002) predicted mesospheric cooling extending up to the heights of ~110 km with a secondary warming between 110 km and 170 km. The extended CMAM-CIN simulations explain dynamical effects of SSW on the MLT and the coupling between the thermosphere and the stratosphere through the NO_X and CO transport (Shepherd et al., 2014). Korenkov et al. (2012), by using GSM TIP model, suggested that the main formation mechanism for the global ionospheric response during the 2008 minor SSW event is due to the disturbances in the $n(O)/n(N_2)$ ratio. At low latitudes an important mechanism for the ionospheric response to SSW events is the change in zonal electric field through amplification of tides (Jin et al., 2012; Wang et al., 2014).

Ionospheric response to the 2013 SSW was investigated in a number of works (Goncharenko et al., 2013; Polyakova et al., 2014; Shpynev et al. 2015). Goncharenko et al. (2013) revealed that anomalous variations in vertical ion drift measured at Jicamarca (12°S, 77°W) were observed for over 40 days. They reported strong perturbations in the total electron content (TEC) that reached 100% of the background value. Shpynev et al. (2015) analyzed ionospheric response to the 2009 and 2013 SSWs by using the data from the high-midlatitude chain of the Russian ionosonde stations. They showed that the intensity and sign of SSW effects depend on the observation point position relative to a stratospheric circulation zone. Polyakova et al. (2014) investigated ionospheric effects of SSWs in the Eastern Siberia region by using the TEC data. They revealed a decrease in the amplitude of the TEC diurnal variation, and an increase in intensity of TEC deviations from the background level.

Despite the recent progress in studying SSW effects at the upper atmosphere heights, many questions remain. The association between SSW events and the MLT region is not fully understood. The link between MLT disturbances and ionospheric variations during the SSW event is not clarified, either. Thermodynamic regime disturbances during significant winter stratospheric warmings cover a wide range of atmospheric heights, which makes SSW a convenient, nature-provided event to study connections between the stratosphere, MLT region, and the ionosphere.

Therefore, it is important to provide a comprehensive approach to experimental research that allows one to trace manifestations of SSW event within a large height range analyzing the parameters of both neutral atmosphere and ionospheric plasma.

The goal of this paper is to comprehensively analyze the disturbances of parameters of the neutral atmosphere and the ionosphere during the 2013 January major sudden stratospheric warming evolution and function. The analysis is based on the experimental data of coordinated measurements with the instruments at the Institute of Solar-Terrestrial Physics of the Siberian Branch of the Russian Academy of Sciences (ISTP SB RAS). Also, we used the reanalysis and satellite data.