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Statistical Inhomogeneity of Dates of Sudden Stratospheric Warmings in the Wintertime Northern Hemisphere

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Abstract—Using the data of meteorological information reanalysis, a statistical analysis of dates of the main sudden stratospheric warmings observed in 1958–2014 has been performed and their inhomogeneous distribution in winter months with maximums in the beginning of January, from the end of January to the beginning of February, and in the end of February has been shown. To explain these regularities, a climatological analysis of variations in the amplitudes and vertical components of Eliassen–Palm fluxes created by large-scale planetary waves (PWs), as well as of zonal-mean winds and deviations of temperature from their winter-average values in high northern latitudes at heights of up to 50 km from the surface has been carried out using the 20-year (1995–2014) collection of daily meteorological information from the UK Met Office database. During the aforementioned intervals of observing more frequent sudden stratospheric warmings, climatological maximums of temperature perturbations, local minimums of eastward winds, and local maximums of the amplitude and Eliassen–Palm fluxes of PWs with a zonal wavenumber of 1 in the high-latitude northern stratosphere were found. Distinctions between atmospheric characteristics averaged over two last decades have been revealed.

Keywords: climatology, sudden stratospheric warming, zonal-mean wind, temperature, planetary waves, stratosphere dynamics

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1. INTRODUCTION

Strong (up to 30–40 K) and fast increases in temperature in the wintertime polar stratosphere at heights of 30–50 km are known as sudden stratospheric warmings (SSWs) and occur mainly in the Northern Hemisphere. During major SSWs, reversals of stratospheric zonal fluxes take place.

Atmospheric perturbations related to SSWs can descend to the troposphere during time intervals from weeks to months [1] and produce significant weather phenomena, e.g., intense invasions of cold air in winter [2]. SSWs can have an effect on photochemical processes in the stratosphere [3], on the transfer of climatically active gases and contaminants [4, 5], and on the ozone variability in the Arctic and Antarctic regions [6].

From the date of the first discovered SSWs in 1952 [7], they are widely observed and classified by the World Meteorological Organization. The analysis involves, in particular, meteorological information reanalysis databases (see the survey in [8]) applicable for studying climatic changes [9]. In [10], the NCEP/NCAR and ERA meteorological reanalysis databases were used, different methods of identifying SSWs were applied, and dates of main SSWs observed in 1958–2013 were tabulated. When considering these tables, there appears a hypothesis that dates of main SSWs can be inhomogeneously distributed in winter months and there can exist climatologically preferable intervals of occurrence of these phenomena.

To verify this hypothesis, analysis of climatological atmospheric characteristics related to the development of SSWs is carried out in this investigation using 20-year (1995–2014) collections of daily meteorological data in the assimilation system of the United Kingdom Met Office (UKMO) [11] at heights of up to 50 km. We have analyzed amplitudes and Eliassen–Palm fluxes (EP fluxes) created by modes of planetary waves (PWs) with zonal wavenumbers $m = 1$ and 2, as well as the longitude-average zonal wind and temperature deviations from winter-average values at heights of up to 50 km from the Earth's surface. These climatic data were compared with results of the statistical analysis of observed dates of main SSWs.

2. METHODS AND DATA

The climatic 20-year average atmosphere characteristics responsible for the formation of SSWs were obtained using daily values of meteorological variables from the UKMO meteorological reanalysis database [11] for the winter month (from December to February) of 1995–2014 in the height range of 0–50 km. For the aforementioned interval, the zonal wind and deviations of temperature from its winter-average values were calculated and averaged. To obtain parameters of PWs responsible for SSWs, the Fourier analysis was performed with the decomposition of hydrodynamic variables into zone-average values and superposition of harmonics with zonal wavenumbers $m = 1–4$; below they are called PW1–PW4.

Mechanisms of the SSW formation are often analyzed using Eliassen–Palm fluxes which characterize the PW energy [12]. The EP-flux vector represents the zonal-mean direction of wave activity propagation in the meridional plane. The meridional and vertical components of the EP-flux include heat and momentum fluxes created by PWs. In this study, climatological mean values of the vertical component of EP fluxes for PWs with zonal wavenumbers 1 and 2 were found using the usual formula [13]

$$F_z = \rho_0 a \times \cos\varphi \left\{ \left[f - \frac{1}{a\cos\varphi}\frac{\partial}{\partial\varphi}(\bar{u}\cos\varphi) \right] \frac{\overline{v'\theta'}}{\bar{\theta}_z} - \overline{w'u'} \right\}, \quad (1)$$

where a and f are the Earth's radius and Coriolis parameter, respectively; ρ_0 is the background density; φ is the latitude; u, v, and w are the zonal, meridional, and vertical components of the wind, respectively; and θ is the potential temperature. The overbar and primes denote zonal-mean values and deviations from them, respectively.

3. RESULTS

In what follows, the climatology of SSW dates and associated atmospheric characteristics are studied by data of reanalysis of the UK Met Office meteorological information for winter seasons of 1995–2014.

3.1. Statistics of SSW Dates

Figure 1 shows 20-year averaged amplitudes and vertical components of the EP flux for PW1 and PW2, zonal-mean wind, and deviation of temperature from its winter-average values for every day in December–February in middle and high latitudes of the Northern Hemisphere. The descending cold and warm layers shown in Fig. 1f reflect seasonal changes in temperature at heights of up to 50 km caused by the decrease in the surface temperature to its minimum in January–February and seasonal variations in radiation heat inflows and circulation in the stratosphere during the polar night. Studying height–latitude distributions of monthly average temperatures at heights of 5–35 km by data of the low-orbit CHAMP GPS satellite [14, 15] shows considerable minimums of temperature at heights above 30 km near the North Pole in November–December. Then, these minimums become less deep and descend by analogy with Fig. 1f. The maximums in the zone of positive temperature deviations in Fig. 1f become stronger below 40 km, where main SSWs often occur.

Inside the warmer layer in Fig. 1f, in addition to seasonal variations, one can see local temperature maximums in the beginning of January, from the end of January to the beginning of February, and in the end of February. These maximums can reflect the SSW contribution averaged over 20 years. The presence of several local maximums in Fig. 1f suggests that SSW dates can be distributed inhomogeneously with a higher frequency of occurrence of warmings in certain intervals of dates in January–February.

To verify the hypothesis about the inhomogeneous distribution of SSW dates during winter, dates of all stratospheric warmings were determined, including the main (major) and weaker (minor) ones we found in the reanalysis database of the UKMO meteorological information during 1995–2014. We used the standard SSW definition (an increase in temperature and weakening or reversal of the zonal wind in polar latitudes [10]), but took a wider height interval of up to 50 km. The table presents the number of major and minor SSWs recorded in subsequent 10-day intervals during winter. Since the total number of SSWs recorded in 1995–2014 is not very large, we completed the table with numbers of dates of major SSWs that were accompanied by the zonal wind reversal and identified during 1958–2013 [10] using different methods and NCAR/NCEP meteorological reanalysis database. We also added numbers of SSWs in 1980–1995 from the MERRA meteorological reanalysis database developed by NASA in the United States [16].

For the last row of the table, probabilities of the hypothesis about the homogeneous distribution of SSW dates were determined using the χ^2 statistical test [17]. This probability turned out to be less than 0.01, which justifies the inhomogeneity of the SSW date distribution in winter time intervals shown in the table. The SSW number distribution in the last row of the table has local maximums in the beginning of January, from the end of January to the beginning of February, and in the end of February. To verify the significance of these local maximums, additional χ^2 tests for the homogeneity of the probability distributions of dates inside fragments of the last row of the table were carried out. The fragments consisted of 2–4 intervals and contained neighboring maximum and minimum values of the SSW numbers. For the abovementioned three local maximums in the last row of the table, probabilities of accepting the hypotheses of homogeneity in their neighborhoods do not exceed 0.03–0.07. This gives grounds to believe that the maximums of recorded SSW events in the last row of the table are significant.