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ВЗАИМОДЕЙСТВИЕ ТРОПОСФЕРЫ И СТРАТОСФЕРЫ ПРИ СОБЫТИЯХ ВНЕЗАПНЫХ СТРАТОСФЕРНЫХ ПОТЕПЛЕНИЙ

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STRATOSPHERE–TROPOSPHERE INTERACTION DURING SUDDEN STRATOSPHERIC WARMINGS

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Одним из наиболее ярких динамических процессов, во время которых проявляется динамическое взаимодействие тропосферы и стратосферы, являются события внезапных стратосферных потеплений (ВСП). Выполненный нами на основе данных UK Met Office анализ динамических процессов в стратосфере показал, что с точки зрения климатической изменчивости за последние десятилетия (1992–2012 гг.) происходит переоценка относительной роли различных механизмов возникновения событий ВСП. Внутренние процессы, связанные с нелинейным взаимодействием стационарных планетарных волн (СПВ) со средним потоком, начинают играть преобладающую роль. Для анализа динамического взаимодействия стратосферы с тропосферой во время зарождения и развития события ВСП были рассчитаны трехмерные потоки волновой активности и их дивергенция с использованием усредненных по 13 событиям данных UK Met Office. Нелинейное взаимодействие СПВ со средним потоком эффективнее при условиях восточной фазы квазидвухлетних колебаний, что объясняется более сильной модуляцией условий распространения СПВ из тропосферы в стратосферу.

One of the most intense processes of a stratosphere dynamics are sudden stratospheric warming events (SSW) when the dynamic interaction between the troposphere and stratosphere becomes apparent. On the basis of UK Met Office analysis, we consider the dynamical processes in the stratosphere from the point of view of climate variability over the last decades (1992–2012). The relative role of the various mechanisms of the SSW events changes in recent decades. Internal processes due to the nonlinear interaction of stationary planetary waves (SPW) with a mean flow have a predominant role. Three-dimensional wave activity flux and its divergence were calculated using an averaged for 13 SSW events to analyze the dynamical interaction between the stratosphere and the troposphere before and during SSW. Nonlinear interaction of SPW and mean flow is more effective under the easterly phase of QBO when modulation of SPW propagation conditions from the troposphere into the stratosphere is stronger.

Sudden stratospheric warming (SSW) event is one of the most prominent processes, during which the troposphere and stratosphere demonstrate the dynamical coupling. According to existing notions [Stan and Straus, 2009] SSW events may develop due to two reasons: increase of wave activity flux from the troposphere into the stratosphere [Matsuno, 1971], and/or caused by the internal dynamical processes, i.e., as a result of the nonlinear interaction of planetary waves with the mean flow at the stratospheric heights [Pogoreltsev, 2007]. The interest in the investigation of the SSW events has increased substantially during the last years. This increase is primarily due to the fact that the results obtained have shown a significant influence of the SSW on the formation of the weather and climate anomalies in the troposphere [Woolings et al., 2010]. During the last decades the growth of amplitude of stationary planetary wave with zonal wave number one (SPW1) is observed in the stratosphere [Pogoreltsev et al., 2009] and, as a consequence, the nonlinear interaction of this wave with the mean flow increased that results in rising intensity of irregular fluctuations, the so-called stratospheric vacillations [Holton and Mass, 1976]. Last years, internal processes associated with the nonlinear interaction of the planetary waves with the mean flow plays a predominant role. Another important result obtained from the analysis of the UK Met Office data shows that main SSW events were observed quite high (altitude between 40 and 60 km) and adopted classification of these events based on the analysis of the behavior of the zonal flow and/or temperature at 10 hPa (altitude of about 30 km) [Labitzke et al., 2005] should be reconsidered. Thus, to investigate of the preconditions, origin, and development of the SSW events not only the dynamical coupling between the troposphere and the stratosphere should be considered but the nonlinear wave-mean flow and wave-wave interactions of SPW and a mean flow in the upper stratosphere have to be taken into account. That is why UK Met Office data are currently unique in terms of the location of the upper boundary at 0.01 hPa. To investigate the SSW distinctive features observed during the winter months in the Northern Hemisphere, the initial meteorological UK Met Office were presented at each latitude and altitude in the form of Fourier-series expansion in zonal harmonics with wave numbers m=0÷4. Figure 1 shows that during the winter of 2011–2012 there have been two SSW events, at the beginning and in the middle of January 2012. In the first case there was only a weakening of the polar vortex, while in the second one there was not only a sign change of the zonal flow, but there was a very strong zonal flow directed to the west. During these events enhancement of the SPW amplitudes with zonal wave numbers m=1÷3 (SPW1-SPW3, respectively) was observed, however, it is not evident that this enhancement is connected with an increase of wave activity in the troposphere. It can be assumed that the reason was in the nonlinear SPW1-mean flow interaction and nonlinear self-interaction of SPW1. The observed SPW2 enforcing can be explain by the so-called doubling of the wave number due to the quadratic nonlinearity. SPW3 can be excited in result of the nonlinear SPW1-SPW2 interaction. In principle, one could carry out a detailed analysis of the SSW events, observed during the 2011–2012 winter, but it seems more useful to understand the preconditions and evolution of the SSW to develop the statistical model of these events. The 13 cases of explicit SSW events that were observed in January-February of 1992–2012 years were

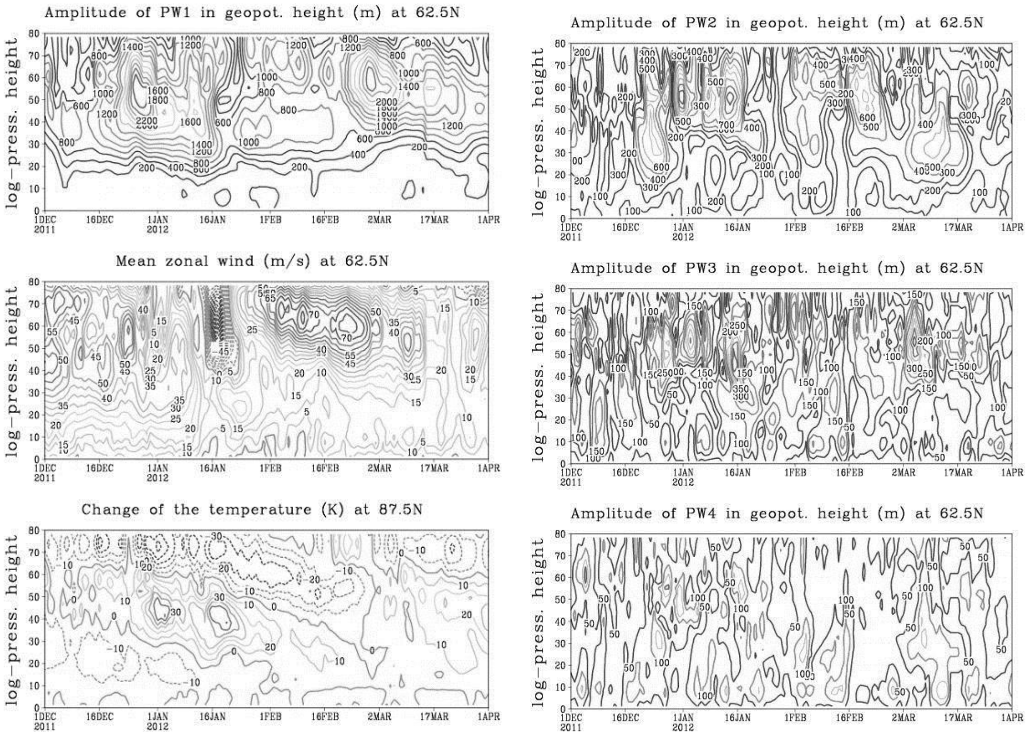

Fig. 1. The time-altitude cross-sections of the amplitude of the zonal harmonic with m=1÷4 in the geopotential height and the mean zonal wind at latitude 62.5° N (upper and middle panels, respectively). The changes of the zonal mean temperature during December–March at latitude 87.5° N are shown in the lower left panel.

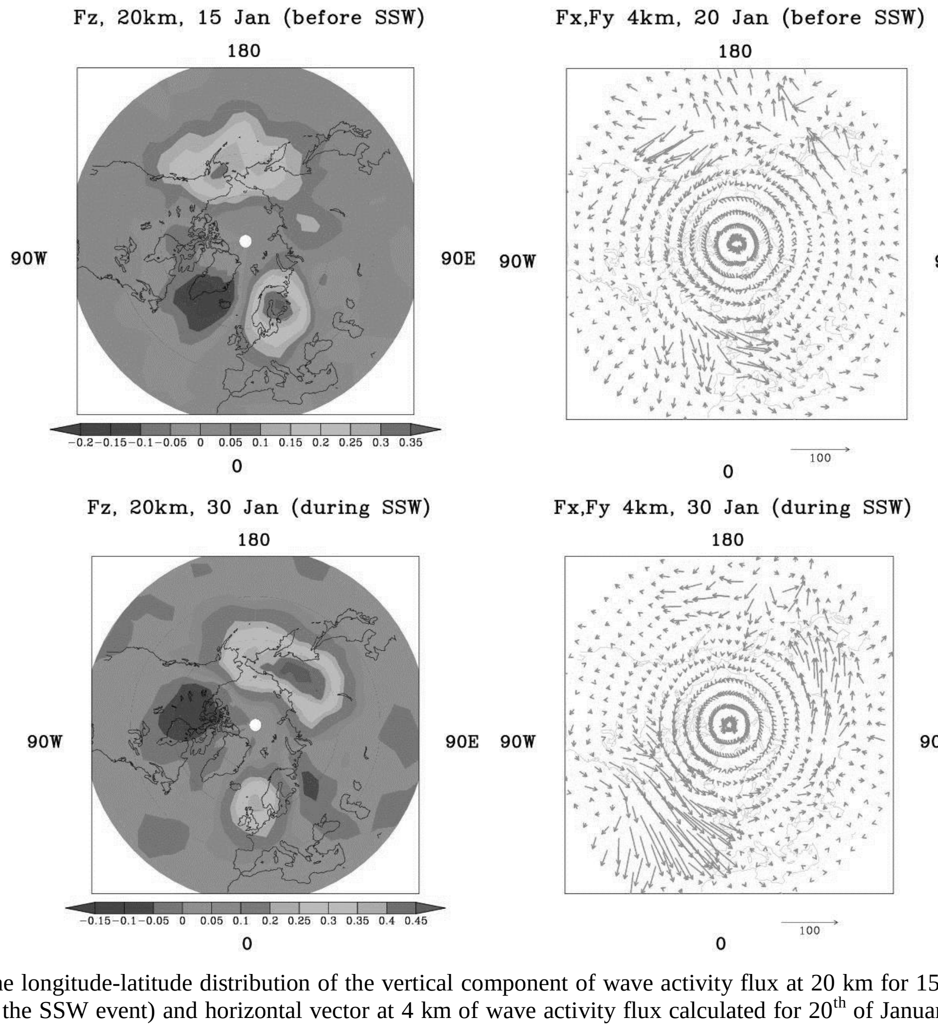

Fig. 2. The longitude-latitude distribution of the vertical component of wave activity flux at 20 km for 15th of January (two weeks before the SSW event) and horizontal vector at 4 km of wave activity flux calculated for 20th of January (10 days before the SSW event) and during the SSW event.

selected. To obtain the statistical model, the composite of these 13 events was calculated. The selected date of each event was shifted to January 31 and composite distributions of meteorological fields for 61 days (30 days before the event, that is, from January 1, and 30 days after the event) were calculated by averaging over all events. All fields were separated into the zonal mean components and zonal harmonics with m=1÷4. Three-dimensional wave activity flux and its divergence [Plumb, 1985] were calculated to estimate the dynamical coupling between the stratosphere and troposphere during the initiation and development of the SSW event.

Fig. 2 shows the distribution of the vertical component of wave activity flux at 20 km for 15 January (of about one week after the first SPW1 enhancement in the stratosphere). It is evident that there exists a relatively strong downward flux of wave activity from the stratosphere into the troposphere over the Atlantic. This flux reaches the troposphere and then redistributes within the horizontal plane. The horizontal flux is directed from the area of maximum wave activity downstream to Europe, where its convergence is noticeable with a delay of about 5 days. Thus, at this time we can expect significant changes in the weather conditions over Europe, including European region of Russia. Noticeable enhancement of the wave activity flux from the troposphere into the stratosphere and weakening downward flux from the stratosphere into the troposphere during the SSW event are shown in Fig. 2. Simultaneously horizontal vectors of wave activity flux from the downstream area in the direction of Europe are amplified. Our results indicate that about 2–3 weeks before SSW we observe the enhancement of wave activity flux from the stratosphere into the troposphere. Thus, the primary reason of the wave activity enhancement at stratospheric altitudes is the nonlinear interaction between the SPW1 and mean flow during the vacillation cycles.

Thus, suggested scenario of the SSW development (at least in terms of statistically meaning, averaged over 13 events) is the following:

– The enhancement of the SPW1 in the upper stratosphere takes place because of an amplification of the nonlinear interaction between the SPW1 and mean flow. This enhancement is accompanied by a subsequent increase in the wave activity flux from the stratosphere into the troposphere;

– The wave activity in the troposphere is redistributed in the horizontal plane and in the future has been increasing its flow from the troposphere to the stratosphere (at this time may develop weather anomalies in the troposphere, mainly over the European territory);

– Secondary enhancement of the planetary wave activity in the stratosphere, which is accompanied by the heating of the polar region and the weakening or even the reverse of stratospheric jet.

The results obtained point to an importance of the nonlinear processes in the stratosphere that took place before the enhancement of wave activity flux from the troposphere. To understand the processes of the SSW events initiation and development it is necessary to consider features of dynamic processes behavior in stratosphere with long lead time – at least 2-3 weeks, or even longer. Stratospheric nonlinear processes play an important role in providing a favorable situation for the SSW initiation or probably initiate this event themselves.

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