The influence of the Madden-Julian oscillations on dynamic processes in the stratosphere and mesosphere

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To estimate the influence of the Madden-Julian oscillation (MJO) on atmosphere the atmospheric general circulation model (MUAM) was used. The model adequately reproduces the circulation processes during the sudden stratospheric warming (SSW) - the dependence on the phase of the quasi-biennial oscillation (QBO), the dynamics of the zonal velocity and the zonal temperature. In the western phase of the QBO the variations in circulation in the tropical and polar stratosphere have a time scale of about 20-30 days and move from the mesosphere to the stratosphere. When MJO is included, variations in meteorological parameters become less regular, perturbation transfer from top to bottom is broken. In the eastern phase of QBO, the difference in the mean zonal velocity in the extratropical latitudes changes sign, decreases and shifts to the south by 10-15 degrees. The temperature anomalies weaken and change sign in the polar region.

Dynamic processes in the winter stratosphere and the mesosphere differ from those in the summer. The intensification of circulation in the middle of winter is interrupted by episodes of destruction of the Polar vortex and strong stratospheric warmings (so-called sudden stratospheric warming - SSW). The causes of these phenomena are natural oscillations in the average atmosphere [3, 4, 9] and external forcing due to orographic planetary waves, quasi-biennial oscillations, tropospheric blockings and fluctuations travelling in the meridional direction [2, 5]. A comparison of SSW and travelling fluctuation showed that sudden stratospheric warming are preceded by periods of increased activity in the tropical stratosphere. The causes of this activity may be convective anomalies in the troposphere caused by the El Niño-Southern Oscillation (ENSO) phenomenon and the Madden-Julian oscillations. MJO is a wave of deep convection moving eastward with an average velocity of 5 m/s over the regions of the Indian and Pacific Oceans [7, 8].

An analysis of the complex multifactor picture of the development of circulation anomalies in the lower and middle atmosphere, according to observations, presents great difficulties. The
useful tools for analysis are models of general atmospheric circulation, which could to evaluate "individually" each of the possible factors of influence. In order to study the role of the Madden-Julian oscillations at various QBO phases, we used the model of the middle and upper atmosphere (MUAM) [6] in the altitude region 0-293 km, realized on a grid of 5.625 degrees longitude, 5 degrees latitude, 56 altitude levels. The effect of the QBO phase was set by the additional term in the prognostic equation for the zonal component of the velocity in the latitudinal interval of 17.5S. - 17.5N at altitudes of 0-50 km. An additional heating source simulating MJO in the tropical region was represented as a wave disturbance with zonal number m = 2 moving with an average phase velocity of 5 m/s (oscillation period T = 45 days). The theoretical model of the heat source MJO was studied in [1]. It is established that a similar shape of the heating source makes it possible to describe the main characteristics of the MJO oscillation.

Calculations were carried out separately for the eastern and western phases of QBO with and without MJO. The duration of each experiment was 400 model days. The inclusion of the diurnal variations and the gradual inclusion of the additional equation for the geopotential at the lower boundary of the computational domain occurred after 120 days. From 331 to 400 days the calculations were carried out taking into account the change in the zenith angle of the sun. Gradual inclusion of the additional equation on 121, 122 ..., 130 day allowed us to obtain ensembles of fields of hydrodynamic quantities, consisting of 10 model realizations. The objects of the analysis were the average zonal values of the temperature and the zonal component of the wind. Trends and high-frequency oscillations were eliminated by moving averaging in windows 5 and 20 days. The series of quantities were then normalized to the difference between the maximum and minimum values, which made it possible to get rid of latitudinal and vertical dependence of the amplitude variations of the studied quantities. The resulting distributions were then plotted on height-time diagrams.

Figure 1 shows an example of the constructed diagrams for the mean zonal velocity above the latitude circle 62.5 degrees at the levels 15.6, 25.8, 37.2, 49.9, 62.7, 74.0, 83.6, 91.9, 100.2 km in the log-isobaric coordinate system in the western QBO phase without MJO (left) and with MJO (right). The average zonal velocity at levels of 25.8 km (blue) and 83.6 km (red) are plotted on the diagrams. The x-axis represents the model days, and the y-axis represents the heights in the log-isobaric system.
Figure 1. Vertical distributions of the zonal average wind speed for the western phase of QBO without MJO (left) and MJO (right) for the latitude 62.5N.

The figure shows that the main feature of the evolution of distributions is the transfer of anomalies from the mesosphere to the stratosphere. However, without MJO this transfer is stronger than with MJO. This is seen in the graphs of the correlation coefficients calculated with a shift from -40 days to +40 days between changes of the mean zonal velocity at the different heights (Fig. 2). The graphs of the correlation coefficients between the variations at the level of 15.6 km and the variations of the values at the levels 25.8, 37.2, 49.9 and 62.7 km are blue, color shades of red - graphs of correlation coefficients between the variations at the level of 15.6 km and the variations at the levels 74.9, 83.6, 91.9 and 100.2 km. Near + 20 day, the graphs of the correlation coefficients in the mesosphere are regularly shifted one relative to the other, which indicates the vertical perturbation transfer. Below in Fig. 2 are graphs of root-mean-square deviations of correlation coefficients, calculated from 10 realizations. The values of the correlation coefficients near + 20 day shift exceed 1.5-2σ, which confirms the statistical significance of the effect. A similar but slightly less pronounced effect of violation of vertical disturbance migration can be observed in the diagrams of the mean zonal velocity and the mean zonal temperature above the equator.

Calculations of meteorological fields in the eastern phase of QBO show another picture. In the absence of additional heat sources at the equator, the effect of the QBO phase on the circulation of the polar stratosphere turned out to be very strong: at the western phase of QBO, the velocities of the stratospheric jet stream at altitudes of 30-60 km were 20-25 m / sec lower than the velocities at the eastern phase of the QBO. The differences in the mean zonal temperatures were also quite high and amounted to about +10 degrees at altitudes of 20-30 km and -10 degrees at altitudes of 60-70 km. The inclusion of MJO changed the character of the distributions - the difference in the mean zonal velocity in the extratropical latitudes changed
sign, became smaller in magnitude and shifted to the south by 10-15 degrees. The temperature anomaly weakened and changed the sign in the polar region.

**Figure 2.** Correlation coefficients (upper panel), calculated with a shift from -40 days to +40 days, between variations of the mean zonal velocity at different levels of the atmosphere, averaged over 10 model calculations. The graphs to the left refer to the western phase of the QBO without the MJO, the graphs to the right refer to the western phase of the QBO with the inclusion of MJO; bottom panel - standard deviation of correlation coefficients, calculated from 10 model calculations.

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