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Proceedings of International Conference "Atmosphere, ionosphere, safety" (AIS-2018) include materials reports on: (1) — response analysis of the atmosphere — ionosphere to natural and manmade processes, various causes related geophysical phenomena and evaluate possible consequences of their effects on the human system and process; (2) — to study the possibility of monitoring and finding ways to reduce risk. Scientists from different countries and regions of Russia participated in the conference. Attention was given to questions interconnected with modern nanotechnology and environmental protection. Knowledge of the factors influencing the atmosphere and ionosphere can use them to monitor natural disasters and to establish the appropriate methods on this basis.

Content of the reports is of interest for research and students specializing in physics and chemistry of the atmosphere and ionosphere.

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4. J. L. Chau, L. P. Goncharenko, B. G. Fejer, and H. L. Liu, Equatorial and low latitude ionospheric effects during sudden stratospheric warming events, 2012, *Space Sci. Rev.*, doi:10.1007/s11214-011-9797-5.

5. E. A. Araujo-Pradere, T. J. Fuller-Rowell, M. V. Codrescu, and D. Bilitza, Characteristics of the ionospheric variability as a function of season, latitude, local time and geomagnetic activity, *Radio Sci.*, 2005, 40, RS5009, doi:10.1029/2004RS003179.

Numerical Simulation of Sensitivity of Meridional Circulation to Impacts of Orographic Gravity Waves and QBO Phases in The Middle and Upper Atmosphere

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Introduction. The energy and momentum transport by internal atmospheric waves are considered as one of the important factors of dynamical interactions between the lower and upper atmosphere. For numerical modeling of the general circulation and thermal regime of the middle and upper atmosphere, it is important to take into account accelerations of the mean flow and heating rates produced by dissipating internal waves. One of the most important sources of atmospheric waves is the interaction between Earth's topography and upcoming atmospheric flow [1]. Propagation of the orographic gravity waves (OGWs), generated at the Earth's surface, into the middle and upper atmosphere can significantly affect the general circulation of the middle and upper atmosphere. Gavrilov and Koval [2] showed importance of the Earth's rotation for theoretical description of stationary OGWs. They developed a parameterization of dynamical and thermal effects of stationary OGWs, generated by the surface topography and propagating into the middle and upper atmosphere. This parameterization was implemented into a model of atmospheric general circulation [3]. The authors showed that OGW may produce substantial changes in the zonal circulation of the middle and upper atmosphere.

The influence of planetary waves (PW), OGW and gravity waves of other origin on meridional circulation in the atmosphere, was studied and evaluated in various models of general circulation (e. g., [4, 5]). The general circulation of the atmosphere in the middle and high latitudes can also be influenced by quasi-biennial oscillations (QBO), which create changes in the direction of the zonal wind in the low-latitude middle atmosphere with a period of about two years (see, for example, [6]).

In this study, we focus on the sensitivity of meridional and vertical circulation to OGW dynamical and thermal effects and to the changes in the QBO phases. The sensitivity numerical experiments are essential for better understanding of the roles of different factors in formation of global dynamical processes, in transport and mixing of atmospheric gas components, and in dynamical coupling of different layers of the lower, middle and upper atmosphere.

Numerical model and parameterizations. For numerical experiments studying dependencies of the atmospheric circulation on OGW parameterization and QBO phases we use the middle and upper atmosphere model (MUAM) [7]. Gavrilov et al. [8] described briefly the main equations and physical processes used in the model. The horizontal grid spacing is 5° and 5.625° in latitude and longitude, respectively. The model has 48 vertical levels the log-isobaric coordinate covering altitude range from 0 to 135 km.

The MUAM does not involve entire mechanisms forming QBO. To assimilate empirical data for years with different QBO phases, Pogoreltsev et al. [9] introduced additional terms to the MUAM equations for zonal wind and temperature, which are proportional to the deviations of the simulated wind and temperature from their zonal-mean climatic values at latitudes between 17.5° S and 17.5° N. Pogoreltsev et al. [9] used the UK Met Office meteorological reanalysis data [10] for January during years 1992—2011 to analyze signs of deviations of annual-mean and climatological (averaged for 20 years) zonal velocities over the equator. The positive and negative deviations correspond to the westerly and easterly QBO phases, respectively. In order to study the OGW influence on atmospheric dynamics, the recently developed parameterization of dynamical and thermal effects of stationary OGWs [2] was implemented. To calculate vertical profiles of the total vertical wave energy flux and the associated accelerations of the mean horizontal winds by stationary OGWs with ground-based observed frequencies $\sigma = 0$, the parameterization uses wave polarization relations that take into account rotation of the atmosphere.

Results of simulations. We used the MUAM model with included parameterizations of OGW dynamical and thermal effects for numerical simulations of the changes in the meridional and vertical velocities in the middle and upper atmosphere. In the experiments, the meridional and vertical components of wind velocity were simulated with and without inclusion of the OGW parameterization for conditions corresponding to the easterly and westerly QBO phases. The differences in values between these calculations demonstrate effects of OGW and QBO, respectively. Positive or negative differences indicate, respectively, increases or decreases in the corresponding quantities due to OGW effects or changes in QBO phases.

Figure 1a presents the simulated height-latitude distribution of the zonal-mean meridional velocity, averaged over January for the easterly QBO phase without OGW parameterization. Lines with arrows correspond to schematic zonal-mean streamlines calculated using the values of vertical velocity *w* multiplied by a factor of 100 for the sake of illustration. A global meridional cell ascending at high and middle latitudes of the summer (southern) hemisphere and descending in winter (northern) hemisphere exists in Fig. 1a above 50—60 km. Below these altitudes, in Fig. 1a one can see additional ascend at latitudes 50—70◦N and descend at 50—70◦ forming local circulation sub-cells in both hemispheres.

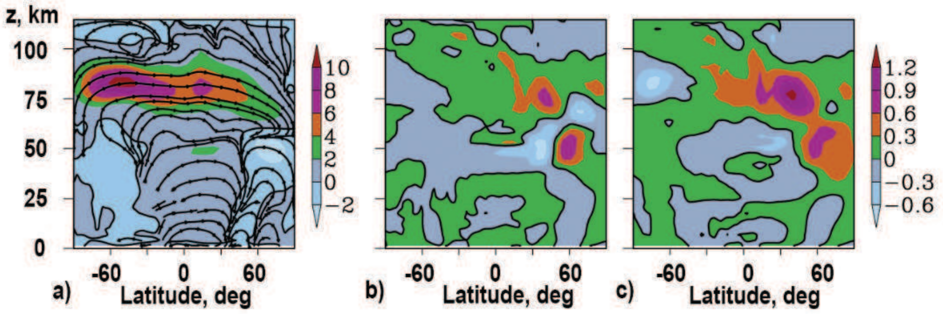

FIGURE 1. The simulated January zonal-mean meridional velocity (in ms^{-1}) and schematic streamlines for easterly QBO phase without OGW effects (a) and meridional velocity differences (in ms^{-1}) caused by inclusion of OGW effects (b) and change from easterly to westerly QBO phase (c).

Figure 2b shows simulated differences (MVD) zonal-mean meridional velocity, which are caused by the inclusion of OGW parameterization into the MUAM for the easterly QBO phase. One can see regions of increases or decreases (positive or negative MVD) in the meridional velocity after inclusion of the OGW effects. Hypotheses about nonzero differences in the meridional winds in Fig. 1b was verified using the statistical Student's t-test. Paired t-tests showed higher than 95% confidences of nonzero monthly mean meridional wind differences in latitude-altitude grid points used for plotting Fig. 1b, where their absolute values are larger than 0.1 ms^{-1}. In many cases in Fig. 1b, MVD signs are opposite to those of the meridional velocity in Fig. 1a. Therefore, OGW dynamical and heating effects may lead to a weakening of simulated zonal-mean meridional circulation fluxes. Peak MVDs in Figure 1b can reach ±(30—40)% of the zonal-mean meridional velocities at respective heights and latitudes in Fig. 1a. Simulated MVDs caused by the change from the easterly to westerly QBO phase without inclusion of OGW effects are shown in Fig. 1c. Application of paired t-tests for verification of nonzero MVDs in Figure 1c gave the same results as those described above for Figure 1b. There is the main maximum at high latitudes of the Northern Hemisphere at altitudes 40 — 60 km in Fig. 2c. This corresponds to significant weakening of the simulated southward meridional flux (up to 60%) there. The MVD minimum at altitudes 80—100 km at high latitudes of Southern Hemisphere corresponds to a decrease in the zonal-mean northward meridional velocity up to about 10%.

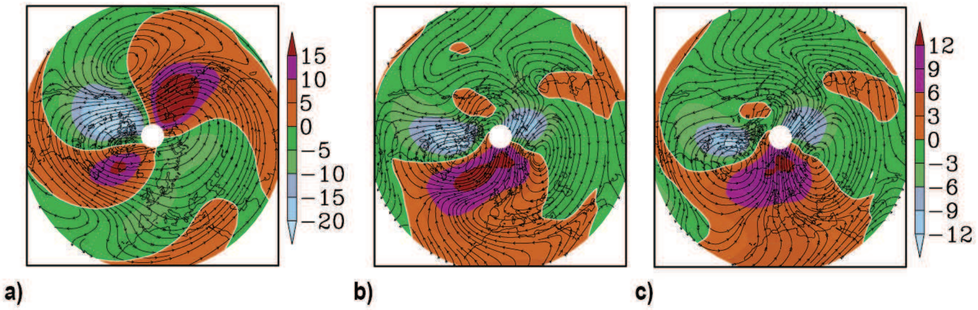

FIGURE 2. The North Pole stereographic projection at altitude 25km and latitudes 20—80 N of the simulated January mean meridional velocity (in ms^{-1}) for easterly QBO phase without OGW effects (a), meridional velocity differences (in ms^{-1}) due to inclusion of OGW effects (b) and change from easterly to westerly QBO phase (c). Contours with arrows show respective streamlines.

Figure 2a shows the North Pole stereographic projection of the simulated meridional wind (shaded areas) at altitude 25 km averaged over January without OGW effects and respective (including the zonal wind) streamlines. Fig. 2b and 2c give differences in meridional winds caused by inclusions of the OGW parameterization and change from the easterly to the westerly QBO phase. There are areas of northward meridional flux at high latitudes above Far East and North-West Atlantic and southward jets above Canada and Europe. These features make corresponding horizontal circulation cells. Inclusion of OGW parameterization as well as change of the QBO phase leads to the enhancement of northward jet above Atlantic Ocean and southward — above Canada. Fig. 3 is similar to Fig. 2 and indicates the simulated January mean vertical velocities and their differences produced by OGW effects and changes in QBO phases. Peak values of the differences in Fig. 2b, and 2c, 3b and 3c can reach up to ±(50—100)% of the respective peak values shown in Fig. 2a and 3a. Therefore, inclusion of OGW dynamical and thermal effects and changes in QBO phases in our experiments may produce substantial changes in vertical and meridional velocities in the middle atmosphere simulated with the MUAM model at middle and high latitudes.

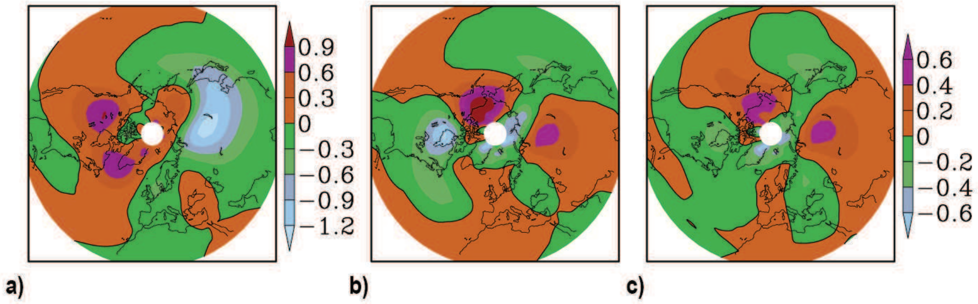

FIGURE 3. Same as Fig. 2, but for the vertical velocity (in cms^{-1}).

Conclusion. In this study, we performed numerical experiments with the MUAM model simulating the general circulation in the middle atmosphere using ten-year average meteorological information. We focused on the sensitivity of the meridional and vertical circulation in the middle and upper atmosphere to inclusion of recently developed parameterization of OGW dynamical and thermal effects for the initial and boundary conditions typical for the easterly and westerly QBO phases. The main goal was to understand the role of the processes associated with dynamical coupling between different atmospheric layers in general circulation model.

Results of numerical experiments show that global-scale meridional and vertical circulation in the MUAM model is very sensitive to OGW dynamical and thermal effects, as well as to the changes in QBO phase. Changes in meridional velocity in the middle atmosphere can reach +/- (30—40)% at high latitudes of the northern hemisphere. In the years with QBO easterly and westerly phases, the differences in meridional velocities can reach 60% at altitudes of 40—60 km. The corresponding changes in vertical velocities can reach 20—50% in the Northern Hemisphere at altitudes of 10—40 km. In addition to directly influencing dynamic and thermal processes in the atmosphere, changes in circulation at these altitudes can lead to changes in ozone fluxes, significantly changing its concentration. OGW effects and changes in QBO phases, can have a similar effect on meridional circulation in the middle atmosphere, despite the different physical mechanisms.

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1. E. E Gossard, W. H. Hooke, Waves in the atmosphere, Elsevier Sci. Publ. Co., Amsterdam-Oxford-New York, 1975.

2. N. M. Gavrilov, A. V. Koval, Parameterization of mesoscale stationary orographic wave impact for usage in numerical models of atmospheric dynamics, *Izv. Atm. and Ocean Phys.*, 2013, 49(3), pp. 244—251.

3. N. M. Gavrilov, A. V Koval et al., Numerical simulation of the response of general circulation of the middle atmosphere to spatial inhomogeneities of orographic waves, *Izv. Atm. and Ocean Phys.*, 2013, 49(4), pp. 367—374.

4. F. Li, J. Austin, and J Wilson, The Strength of the Brewer–Dobson circulation in a changing climate: Coupled chemistry–climate model simulations, *J. Climate*, 2007, 21, pp. 46—57, doi: 10.1175/2007JCLI1663.1.

5. N. Butchart, A. A. Scaife, M. Bourqui et al., Simulations of anthropogenic change in the strength of the Brewer-Dobson circulation, *Clim. Dyn.*, 2006, 27, pp. 727—741.

6. M. P.Baldwin, L. J. Gray, Dunkerton et al., The quasi-biennial oscillation, *Rev Geophys,* 2001, 39(2), pp. 179 — 229.

7. A. I. Pogoreltsev, A. A. Vlasov, K. Froehlich and Ch. Jacobi, Planetary waves in coupling the lower and upper atmosphere, *J. Atmos. Solar-Terr. Phys.*, 2007, 69, pp. 2083—2101.

8. N. M. Gavrilov, A. I. Pogoreltsev, and Ch. Jacobi, Numerical modeling of the effect of latitude-inhomogeneous gravity waves on the circulation of the middle atmosphere, *Izv. Atm. and Ocean Phys.*, 2005, 41 (1), pp. 9 — 18.

9. A. I. Pogoreltsev, E. N Savenkova, and N. N Pertsev, Sudden stratospheric warmings: the role of normal atmospheric modes, *Geomagnetism and Aeronomy*, 2014, 54(3), pp. 357—372.

10. R. Swinbank, A. O'Neill, Stratosphere-troposphere assimilation system, *Mon Weather Rev*., 1994, 122, pp. 686—702.

Numerical Simulation of Wave Propagation from Atmospheric Pressure Variations Registered with the Microbarographs Net in Moscow and Environs

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In this paper, the propagation of waves from pressure variations on the Earth's surface recorded in observational experiments using a network of microbarographs is numerically modeled. On the basis of the experimental data of pressure variations on the net of microbarographs, pressure variations on the Earth's surface near the microbarograph net are approximated. These approximations of pressure variations are used in the simulations as the lower boundary condition. In the performed simulations, the effect of dissipated acoustic-gravity waves (AGWs) on all layers of the atmosphere is investigated. Simulations of wave propagation from wave pressure variations on the Earth's surface, recorded experimentally, were performed for the first time.

The propagation of AGWs originating at tropospheric heights to the upper atmosphere is one of the causes of the change in atmospheric parameters [1, 2]. Waves affect the motion of the plasma in the ionosphere and the propagation of radio waves. An investigation of the vertical propagation of AGW from the lower layers of the atmosphere and their effect on the atmosphere due to wave dissipation is necessary for describing the interaction of the layers of the atmosphere.

The processes of heating/cooling the atmospheric gas during phase transitions of water in the atmosphere are of the most important causes of generation of waves in the atmosphere [3—5]. The complexity of simulation waves from meteorological sources lies in the fact that these sources are very diverse, have a complex evolving internal structure. The available experimental information is usually not enough for a detailed description of these heat sources of waves. Uncertainty in the parameters of the wave sources, as a consequence, significantly affects the accuracy and reliability of calculations.
