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GLOBAL STRUCTURE OF GRAVITY WAVE EXCITATION IN THE TROPO-STRATOSPHERE FROM CHAMP SATELLITE OBSERVATIONS AND ITS IMPACT ON GENERAL CIRCULATION OF THE UPPER ATMOSPHERE

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Abstract. An analysis of variances of the atmospheric refraction index measured with CHAMP satellite receiving radio signals from GPS satellites has been performed. The height-latitude-longitude distributions of the variances up to altitudes 35 km and their annual and inter-annual variations were studied. A simplified parameterization of wave dynamical and thermal impacts for inclusion into general circulation models was developed. A study of sensitivity of the mean general circulation of the middle and upper atmosphere to the horizontal inhomogeneity of IGW sources is made using the COMMA-SPBU numerical model. Taking account of IGW sources inhomogeneity gives a better reverse of the zonal wind near the mesopause. Overall structure of the mean zonal wind distribution is most sensitive to the distribution of wave variance at middle latitudes.

Introduction

Mesoscale wave processes, which are mainly contributed by internal gravity waves (IGWs), play a significant role in the dynamics of the middle and upper atmosphere. Recent results of observations and numerical modeling suggest that IGWs propagating from sources located in the troposphere and stratosphere make the predominant contribution to the energy of wave motions up to heights of about 100 km. Satellite measurements of the mesoscale variability of the atmospheric radiation, temperature, and refractive index displayed a substantial inhomogeneity of the latitude--longitude distributions of IGW characteristics and their seasonal variability in the troposphere and stratosphere. Therefore, the problem of accounting for the observed inhomogeneity of wave source distributions in numerical models of the general circulation of the middle atmosphere has become urgent.

In this paper we analyze global inhomogeneity of IGW activity and sources using data of low-orbit satellite CHAMP, which receives signals of high-orbit satellites of the Global Positioning System (GPS). Parameterizations of horizontally inhomogeneous IGW sources in the tropo-stratosphere are used to study the response of the COMMA--SPBU numerical model of the general circulation of the middle atmosphere to typical distributions of latitudinal inhomogeneities of IGW sources observed in the lower atmosphere.

Method of data analysis

Low-orbital satellite receiving radio signals of GPS system usually gives height profiles of the refractive index for radio waves n. Refractivity of electromagnetic radiation, N, at radio frequency f is connected with the atmospheric parameters with the following expression:

$$N = (n-1)\times 10^6 = 77.6\,\frac{p}{T} + 3.73\times 10^5\,\frac{e}{T^2} + 4.03\times 10^7\,\frac{N_e}{f^2}, \quad (1)$$

where p is atmospheric pressure [hPa], T is atmospheric temperature [K], e is partial pressure of water vapor [hPa], N_e is numerical electron density [m^{-3}]. Generally, N decreases versus height as exp (- z/H) and creates difficulty for evaluating the small deviations of refractive index. More sensitive to the small changes it is so-called "dry temperature", which can be obtained from (1):

$$T_{dry} = 77.6\, p / N. \quad (2)$$

Dry temperature is good estimation of atmospheric temperature at altitudes from 10 to 30 km. Below 10 km, the term, connected with humidity becomes important in (1), and the approximation of dry temperature loses force. Above 30- 35 km, the errors of the exception of the contribution of the ionosphere become large. Dynamic processes in the atmosphere lead to the variations δp, δT and other parameters in (1). For small-scale turbulence and low-frequency short IGWs usually $|\delta p/p| << |\delta T/T|$, and we have $|\delta N / N| = \alpha\, |\delta T_{dry} / T_{dry}|$, where $\alpha \approx 1$ in the stratosphere. In the troposphere, where the humidity is high, it is possible to expect $\alpha > 1$.

In this work we examine the results of analysis of the measurements of the refractive index of radio waves by low-orbit satellite CHAMP. Polynomial least-square fits are used to estimate smoothed values and standard deviations of mesoscale variations for each vertical profile of refractivity (1) and dry temperature (see [Gavrilov et al., 2004; Gavrilov and Karpova, 2004]).

Results of analysis

Left plot of Fig. 1 represents altitude-latitude distribution of zonal mean standard deviations of refractivity mesoscale variations averaged for the winter months December–February of the years 2001 – 2008. Respective summer distribution for June–August is shown in right plot of Fig. 1. The main maximum of the standard deviation is located above equator at altitudes 15 – 25 km and is possibly connected with deep convection there. Secondary maxima are located at altitudes of 5 – 10 km due to convection and instabilities of jet streams.

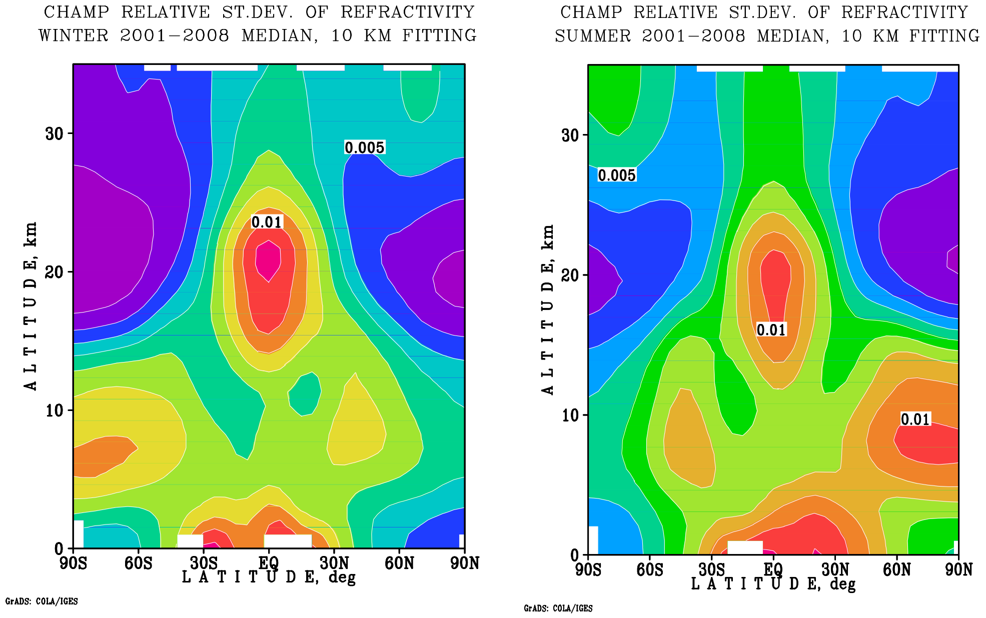

Fig. 1. Mesoscale standard deviation from GPS/CHAMP Data for Northern Winter (left) and Northern Summer (right)

Fig. 2 presents latitudinal-longitudinal distributions of standard deviations of refractivity in different altitude layers averaged for December – February of years 2001 – 2009. Horizontal distributions of standard deviations in Fig. 2 are different in different altitude layers. At low heights standard deviations of refractivity have maxima in middle latitudes, which may reflect convective activity. At the heights of approximately 10 km the maximums of dispersions are concentrated between latitudes 20º and 60º in the northern and southern hemispheres. These maximums correlate with the positions of the tropospheric jet streams, which have maximums at altitudes of 10 - 12 km. At altitudes 15- 25 km in Fig. 2 one can see maximums in the latitudes between -20º and 20º. They may be connected with the deep convection in the equatorial region. At altitudes of 20 - 25 km one can also see the maxima of refractive index at high latitudes of the northern hemisphere.

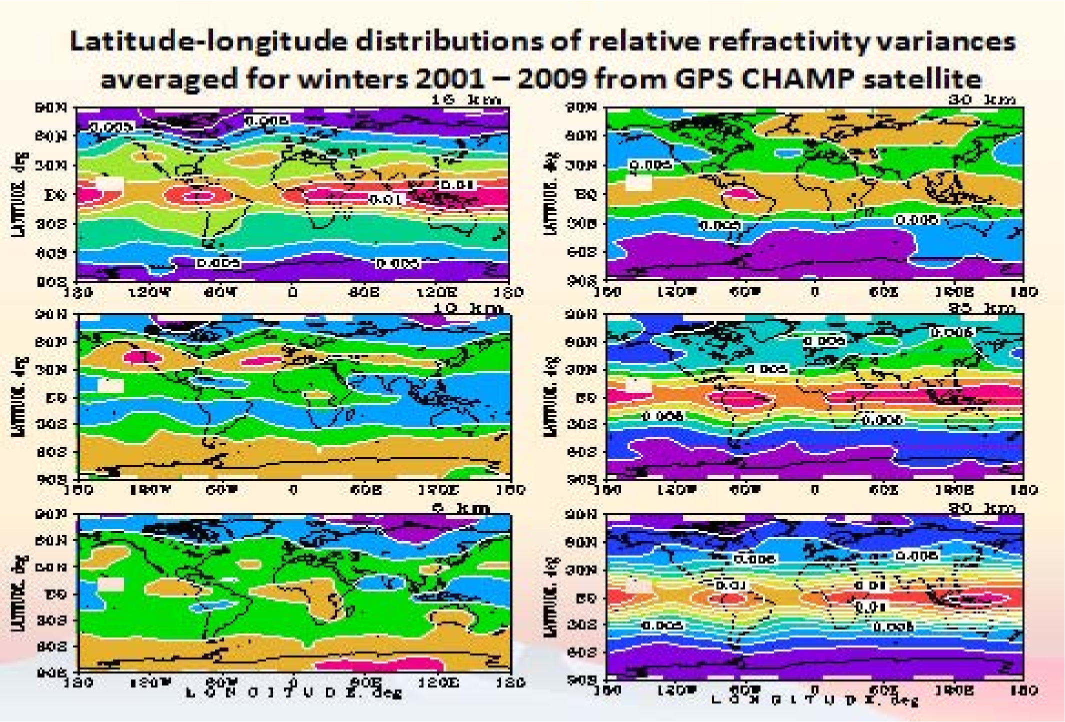

Fig. 2. Longitude-latitude distributions of standard deviations of mesoscale variations of refractivity in 5-km altitude layers centered at heights shown near each plot and averaged over months December – February of years 2001 – 2009..

Fig. 3 is analogous to Fig. 2, but for months June - August. The general distributions of standard deviations in Fig. 3 are similar to Fig.2. The main difference is in large variances in the southern hemisphere at altitudes higher than 20 km in Fig. 3 instead of the northern hemisphere in Fig. 2.

General circulation response

With the use of the version of the three-dimensional COMMA-SPBU numerical model, the structure of the general circulation of the middle atmosphere is calculated in this work for different types of latitudinal inhomogeneities of the IGW intensity in the troposphere and stratosphere. The model equations were integrated from the Earth's surface, and the boundary conditions for the IGW intensity were specified at a height of 30 km (see [Gavrilov et. al., 2005]). One hundred five IGW harmonics modeling the spectrum of stationary waves with zero observed frequency and horizontally propagating IGWs were used in the calculations. The typical latitude distributions of IGW intensity at height of about 30 km, which have maxima at high, middle, and low latitudes, are specified by analytic functions in accordance with the data of ground-based and satellite observations. Axisymmetric and isotropic IGW distributions having equal amplitudes of wave harmonics and propagating in opposite azimuthal directions at the specified level are considered.

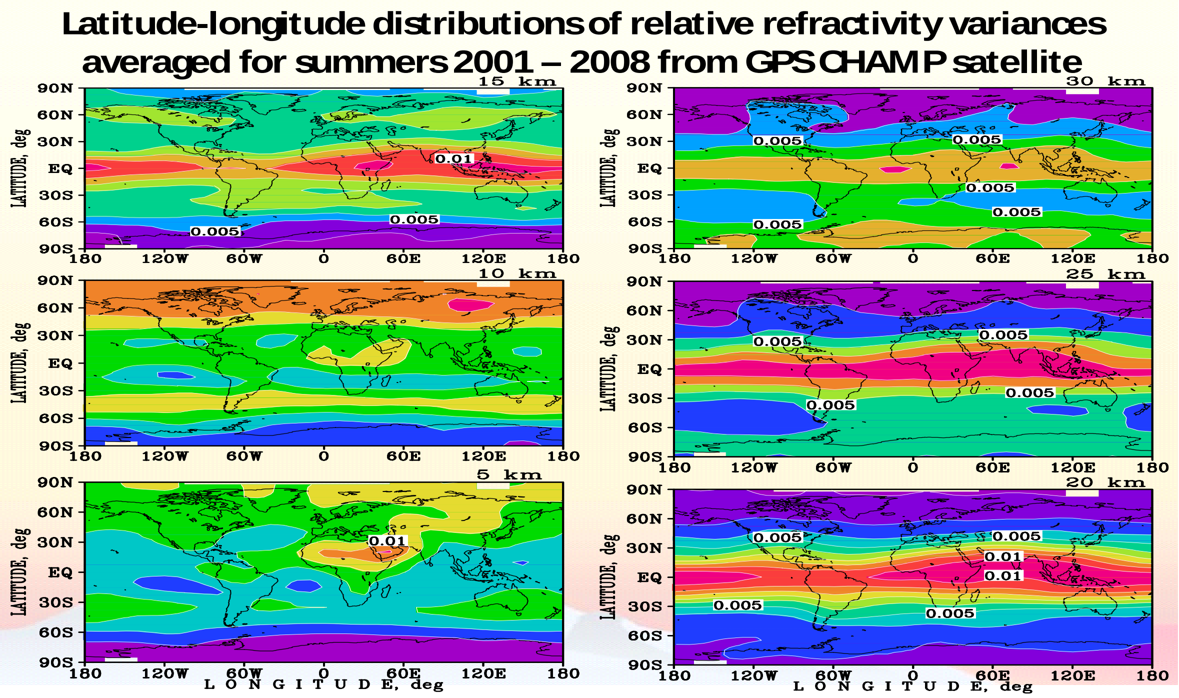

Fig. 3. Same as Fig. 2, but for months June – August.

Calculations showed that accounting for the latitudinal inhomogeneity of IGW sources decelerates the flows of eastward direction and accelerates the flows of westward direction in the stratosphere and mesosphere of the winter and summer hemispheres, respectively. The velocities of flows directed westward and eastward also increase in the lower thermosphere of the winter and summer hemispheres, respectively. Analysis of the results of model calculations for different latitude distributions of the intensity of axisymmetric and isotropic IGWs in the lower atmosphere shows that the general structure of the zonal mean distribution of wind is most sensitive to IGW sources in middle latitudes and to seasonal changes in these sources.

Numerical experiments performed with the COMMA-SPBU model show that the influence of inhomogeneity of latitude distributions of the IGW intensity cannot be compensated by changing the effective mid-latitude values. Therefore, the investigation, parameterization, and taking into account of the latitudinal inhomogeneity of distributions of the IGW intensity and wave sources are important for refining numerical models of the general circulation of the middle atmosphere.

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