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Transport of stratospheric aerosols in the field of averaged vertical wind

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The latitudinal and seasonal dependences of vertical profiles of the averaged vertical wind for different time intervals from 1992 to 2006 based on the data of the UKMO atmosphere general circulation model are analyzed. It is shown that monthly average amplitudes of the vertical wind are approximately ±5 mm/s, while annual average ones are ±1 mm/s. The upward wind can provide the vertical lifting against gravity for sufficiently large (up to 3-5 μm) aerosol particles with a density up to 1.0-1.5 g/cm^3 at stratospheric and mesospheric altitudes. The vertical wind probably is a substantial factor of particle motion up to altitudes of 30-40 km and can change essentially the sedimentation rate and the residence time of stratospheric aerosols. The structure of the averaged fields of vertical wind supposes the opportunity of formation of dynamically stable aerosol layers in the middle stratosphere.

1. Introduction

At the analysis of the field of the average wind in meddle atmosphere usually view its horizontal components - zonal and meridional wind. The vertical component of a wind, as a rule, much less horizontal, is more difficultly spotted instrumentally and more often is estimated theoretically on the basis of methods of dynamic meteorology (Holton, 1992).

There are problems requiring the consideration of the vertical wind in analysis of the stratospheric aerosol transfer. These problems include, first, the phenomenon of migration of soot particles emitted by air transport against gravity to altitudes above flight corridors (Blake et al, 1995; Pueshel et al, 1997) and the growing pollution of the Arctic region with soot aerosol from ground-based burning of hydrocarbon fuel and biomass (Baumgardner et al, 2003; Koch et al, 2005). The action of forces of radiometric photophoresis can partly explain this phenomenon (Beresnev et al, 2003), but the positive (upward) vertical wind may have even greater transport capabilities. Second, the action of the vertical wind on aerosol particles (reducing to the intensification or counteraction to gravitational sedimentation) can help in explanation of not fully clear details of the relative stability and long lifetime of well-known aerosol formations in the stratosphere.

This paper presents a new data array on average vertical wind velocities obtained from satellite measurements, as well as a tentative analysis of the influence of the vertical wind velocity component on the motion of aerosol particles in the stratosphere is performed.

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2. Methods of Analysis

The UKMO (United Kingdom Meteorology Office) unified model is a large meteorological model taking into account atmospheric and ocean transport processes and their coupling. The atmospheric block of this model is assimilation, implied the method, in which the results of regular meteorological observations are included in the computational process to obtain estimates of the atmospheric state maximally close to the actual situation (Swinbank et al, 1994). The data obtained in the stratospheric block – Met Office Stratospheric Data Assimilation System – are of primary interest for analysis (Swinbank et al, 2003).

The regular measurements of required meteorological fields were conducted in 1991–2006 by the NASA UARS (Upper Atmosphere Research Satellite). Invoking the stratospheric block of the UKMO model, the quantitative estimation of the vertical stratospheric wind becomes possible, and this allows the detailed analysis of the vertical wind profiles and their latitudinal and seasonal dependences.

The database used contains a standard set of meteorological parameters (temperature, pressure, zonal, meridional, and vertical winds) for a certain period (days and months). The data are presented for UARS standard pressure levels from 1000 to 0.316 hPa (21 levels). This allows the vertical profiles of meteorological parameters to be obtained roughly up to 55 km with a horizontal resolution of 2.5° in latitude and of 3.75° in longitude. To retrieve the interesting information from this database, we used specially developed program. It should be noted that today it becomes possible to use another database (NCEP/NCAR), allowing the reconstruction of vertical wind fields at different altitudes for the past many-year period (Kalnay et al, 1996).

3. Results And Discussion

Fig. 1 shows the typical vertical wind profiles averaged for one month (Equator, 0°N, 0°E). Analogous data can be also presented for other geographic regions for the period since September, 1992 till February, 2006.

Positive velocity values correspond to the upward wind, while negative ones stand for the downward wind. One can see that monthly average amplitudes of the vertical wind in the troposphere are roughly ±10 mm/s, in the lower and middle stratosphere they are ±5 mm/s, achieving 50 mm/s in the upper stratosphere and mesosphere. Without doubt, the average wind profiles carry rich information about different reasons causing the wind: deep tropic convection, large-scale turbulence, and others.

In the troposphere, the amplitude of the vertical velocity reaches its maximum at altitudes of 3–5 km and, decreasing, vanishes near tropopause. It should be noted that this behavior of the vertical wind is explained in (Matveev, 1984) by the cyclonic and anticyclonic activity. One can see that the seasonal variability is characteristic of the troposphere, and semi-annual oscillations are clearly seen. In the stratosphere, average velocities are much lower, and for the equator at altitudes of 20–30 km a pronounced zone of the positive vertical wind vanishing at altitudes of about 40 km is observed.

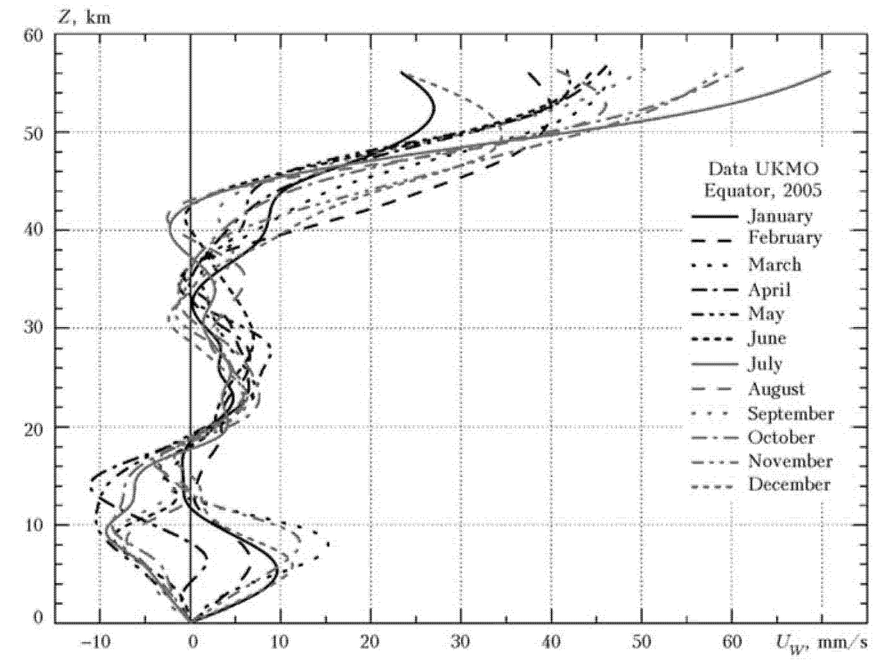

Fig. 1. Monthly average vertical profiles of the vertical wind velocity for the equator in 2005 according to the UARS-UKMO data.

It can be seen also that the positive vertical wind with a very high velocity (up to 50 mm/s) predominates in the mesosphere. The analysis of such monthly average data for other geographic regions suggests the existence of the latitudinal-longitudinal dependence of the vertical wind and the behavior of this dependence may differ qualitatively from that of the equatorial one.

The characteristic time scales of the "residual" stratospheric circulation are known to exceed significantly those of the tropospheric one (up to several years), which assumes the analysis of annual average velocities of the vertical wind. The obtaining of annual average profiles of the vertical wind from the UARS-UKMO data for the equator for the period 1993–2005 (Fig. 2) required the development of a data averaging technique, since the UARS-UKMO database does not contain annual-averaged wind velocities.

At the UARS standard pressure levels, the absolute heights and the corresponding temperature and vertical wind fields were determined for particular geographic regions and time intervals. Then the arithmetic-mean heights and wind velocities were calculated for all months at a fixed pressure. Then the same technique can also be used to average velocities for 13 years of observations (since 1993 to 2005).

It can be seen from Fig. 2 that the annual-average velocities with characteristic values of about ±1 mm/s are an order of magnitude lower than the monthly average ones. It is interesting that for the period 1993–2005 the annual average vertical wind velocity increases in the absolute value, and this increase is characteristic of the entire altitude range and for all geographic regions under study. The rise of zones in which the vertical wind alternates its direction is characteristic as well. The most astonishing fact is that the vertical wind averaged over 13 years has the pronounced height dependence as well.

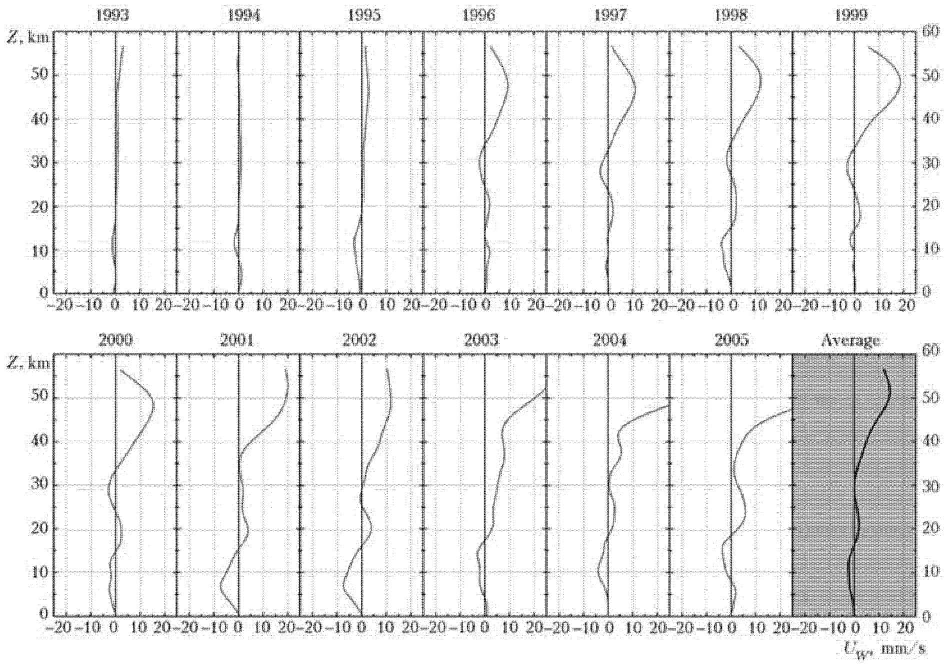

Fig. 2. Annual-average vertical profiles of the vertical wind velocity for the equator according to the UARS-UKMO data.

To use these data in applied calculations, a scheme of height approximation can be proposed. It was found that a seventh-order polynomial is the optimal approximating function for the height range 0–60 km. For sub-polar regions, the deviation of the approximating function from true values of the wind velocity did not exceed 1%, while for the equator it did not exceed 5% for the entire height range.

The comparison of the horizontal and vertical wind components at different heights is shown in Fig. 3, which reflects the well-known regularities for the total atmospheric wind. The zonal (latitudinal) wind with velocities of tens of m/s is most intense, the meridional (longitudinal) wind has velocities of units of m/s, while the vertical wind is nearly invisible against their background.

However, the action of the vertical wind in the stratosphere and mesosphere may be decisive for the vertical transport of aerosol particles. As will be shown below, the vertical wind with velocities of fractions and units of mm/s can efficiently influence the motion of particles having different sizes and densities.

Fig. 4 shows the total velocities of particles at ρ = 1 g/cm^3 and R_p = 1 μm under the action of the gravity and the vertical wind. In the calculations, we used the 13-year averaged data for the vertical wind discussed above. The positive values of velocities correspond to the lifting of particles against the gravity, while negative ones correspond to the sedimentation of particles. One can see that the vertical wind is a decisive factor of the particle motion up to altitudes of about 30–40 km. At altitudes above 40 km, the gravitational sedimentation becomes a decisive factor, while the vertical wind can only accelerate or slow down the sedimentation process.

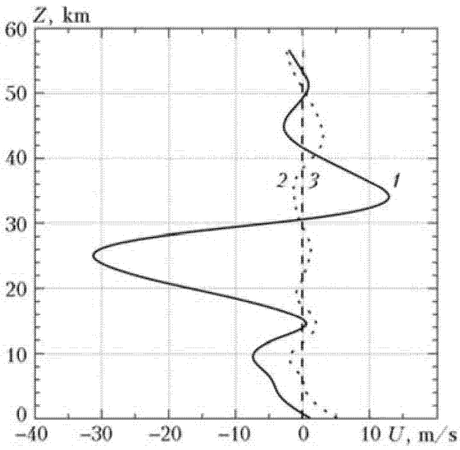

Fig. 3. Monthly average wind velocity components for the equator according to the UARS-UKMO data for October, 2005: zonal (1), meridional (2), and vertical (3) wind component.

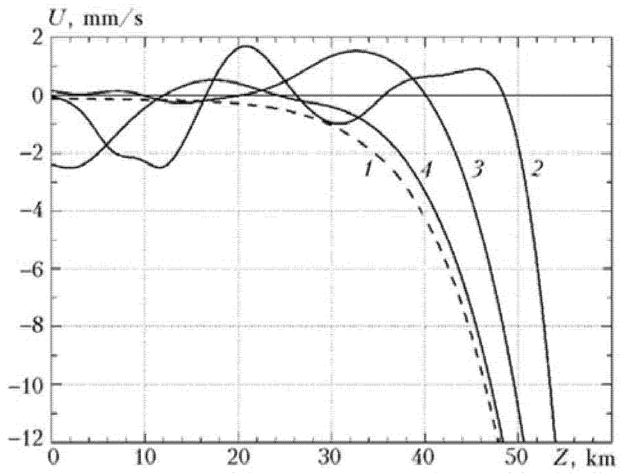

Fig.4. Velocity of particles with ρ = 1 g/sm^3 and R_p = 1 μm. 1 – gravitational sedimentation only; total velocity of particles under action of the annual-averaged vertical wind for: 2 – Equator, 3 – North Pole, 4 – South Pole.

The estimates of the time of lifting and sedimentation of particles from a particular altitude to possible limiting altitudes are of principal significance as well. Fig. 5 shows the time of lifting and sedimentation of particles with ρ = 1 g/cm^3 and R_p = 1 μm under the action of the vertical wind and the gravity for the equator, North and South Poles. It can be seen that the times of lifting and sedimentation of particles with the vertical wind taken into account differ widely from those with only the gravitational sedimentation considered and are equal to one year for the equator and 2.5–3.0 years for the South and North Poles.

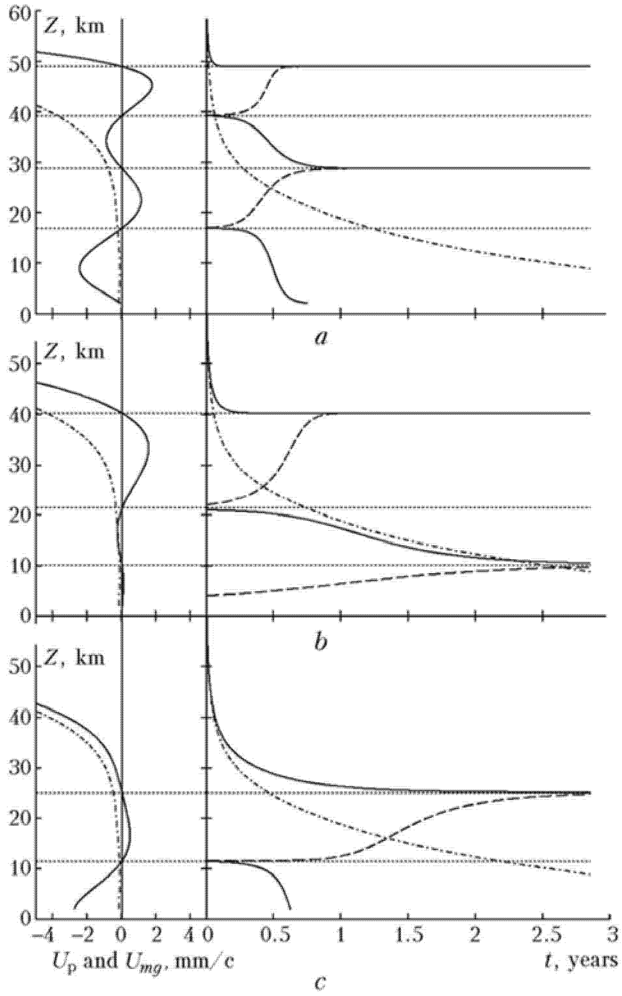

Fig. 5. Times of particle lifting (solid curves) and sedimentation (dashed curves) taking into account the vertical wind: the equator (a), North Pole (b), South Pole (c). Dot-and-dash curves correspond to the action of gravitational sedimentation only.

The vertical wind can be a potential cause for the formation of dynamically stable aerosol layers in the middle atmosphere at altitudes corresponding to the alternation of the vertical wind velocity sign from positive to negative. For example, it can be seen from Fig. 5a that particles starting to move in the altitude range 18–39 km will be entrained by the vertical wind and concentrated at altitudes of about 29 km. The action of gravity cannot move particles out of this zone, and, obviously, we can state the formation of a dynamically stable layer of aerosol particles. This behavior of aerosols will be typical for all altitude ranges with the similar character of alternation of the vertical wind sign.

4. Conclusions

This work undertakes an attempt to estimate the influence of the vertical wind on the transport characteristics of the stratospheric aerosol. The technique of investigation is based on the inclusion of the averaged fields of the vertical wind retrieved from satellite data in the statistical models of the standard atmosphere. In our opinion, the results obtained are the limiting estimates of the effect under study and do not replace the analysis of the characteristics of motion of individual particles under variable atmospheric conditions. Later on the climatological analysis of the results is planned in order to reveal seasonal and latitudinal features of the vertical wind.

The more detailed analysis of the structure of the vertical wind field allowing the long lifetime of stratospheric aerosol layers and the comparison with numerous experimental findings for polar stratospheric clouds is of interest. The estimates also show that the transport capabilities of the vertical wind will especially noticeable for fractal-like particles (for example, particles of soot and volcanic aerosol). The approach proposed possibly will allow the mechanisms of accumulation of soot particles from the air transport and the ground-based biomass burning at altitudes of the lower and middle stratosphere to be revealed.

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5. References

Baumgardner, G., G. Kok, G. Raga et al., 2003, J. Aerosol Sci. 34, Suppl.1, 979.

Beresnev, S.A., L.B. Kochneva and P.E. Suetin, 2003, Thermophys. and Aeromech. 10, 2, 287.

Blake, D.F. and K. Kato, 1995, J. Geophys. Res., 100, D4, 7195.

Holton, J.R., 1992, An introduction to dynamic meteorology. Academic Press, N.Y.

Kalnay, E., M. Kanamitsu, R. Kistler et al., 1996, Bull. Amer. Meteor. Soc., 77, 3, 437.

Koch, D. and J. Hansen J., 2005, J. Geophys. Res., 110, D04204, doi: 10.1029/2004JD005296.

Matveev, L.T., 1984, Course of General Meteorology. Atmospheric Physics. Gidrometeoizdat, Leningrad (in Russian).

Pueshel, R.F., K.A. Boering, S. Verma et al, 1997, J. Geophys. Res., 102, D11, 13,113.

Swinbank, R. and A. O'Neill, 1994, Month. Weather Rev., 122, 4, 686.

Swinbank, R. and D.A. Ortland, 2003, J. Geophys. Res., 108, D19, 4615.