Climatology of a vertical wind in the middle atmosphere

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The paper describes the climatological analysis of a vertical wind in the middle atmosphere on the basis of a global atmospheric circulation model UKMO dataset. The high-altitude, seasonal, and longitudinal dependences of zonal-averaged vertical wind for the period from 1993 to 2005 are discussed. The technique of the approximation of obtained data for the use in the transport aerosol models at the middle atmosphere altitudes is described.

Introduction

When analyzing the field of averaged wind in the middle atmosphere, as a rule, its horizontal components, i.e., latitude (zonal) and meridian winds, are considered. The vertical wind component, as a rule, is much less than horizontal components, it is difficult to determine it instrumentally and it is estimated most often theoretically based on the methods of dynamic meteorology.[1] In the preceding paper[2] the results of analysis were presented of averaged (mean monthly and mean annual) latitude-seasonal dependences of altitude profiles of the vertical wind based on data of an assimilation model of general atmospheric circulation UKMO for some characteristic geographic areas (equator and polar areas). On their basis, in particular, it was shown that the upward wind should ensure the vertical elevation against the force of gravity of large (up to 3–5 μm) aerosol particles at density of 1.0–1.5 g/cm^3 in the stratosphere. A proposal was made about a decisive factor of the wind in the vertical transfer and spatial distribution of aerosols up to the altitudes of 30–40 km; the vertical wind can essentially change the rates of precipitation and lifetime of aerosol particles in the stratosphere, and the field structure of mean wind provides a way for the formation of dynamically stable aerosol layers in the middle stratosphere.

These conclusions call for a more detailed substantiation based on the climatologic analysis, namely, finding and description of regularities in the altitude and seasonal-latitude field structure of the vertical wind when using the standard procedures of zonal and time averaging. If considerable attention has been given traditionally to the climatologic analysis of horizontal components of the wind in the middle atmosphere (see, for example,[3–5]), then in this case, the references in climatology of the vertical wind are absent. The basic reason of this fact is evident: the value of the velocity of the vertical wind (units and even portions mm/s) is much less than the resolution of existing instrumental methods (ground-based or space-borne) of its measurement.

The attempts of analysis by theoretical methods of dynamical meteorology give rise to specific difficulties in the treatment of obtained results: in relation to an approach to the problem solution (different simplifications in the initial equations of the model; the Lagrangian or Eulerian methods of solution) there occur different characteristics of the vertical wind velocity (up to five different versions), but not always identical to its real velocity at a definite altitude U_W (for example, Refs. 1 and 6). Nevertheless, a method exists for determining the velocities of the vertical wind consisting in the use of data of "large" assimilation models of general circulation of the atmosphere (the most familiar of them are the models UKMO [Ref. 7], NCEP/NCAR [Ref. 8], ECMWF [Ref. 9]). In these models the results of regular meteorological observations are included in the calculation process for obtaining the estimations of the atmospheric condition maximum approximated to the real situation. By the terminology used in the analysis of NCEP/NCAR [Ref. 8], the vertical wind field refers to a category of certain characteristics. Both the quality of assimilation meteorological data and the applied OTsA model affect the value of the above characteristics.

The primary goal of this research is a standard climatological analysis of the vertical wind in the stratosphere based on the data base of the model UKMO over a period of a total solar cycle (1993–2005) and also the discussion of a practical use of the obtained results for the approximation of the field of the vertical wind in the aerosol transport models.

1. Description of initial data and the method of analysis

The data necessary for the climatologic analysis were obtained from the stratospheric block of the model UKMO (United Kingdom Meteorology Office) based on the measurement of the required meteorological fields using a research satellite NASA UARS (Upper Atmosphere Research Satellite) over a period from October, 1991 to February, 2006. The

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technique for obtaining this information was analyzed in Ref. 2. The used database (http://badc.nerc.ac.uk) contains a standard set of meteorological parameters (temperature, pressure, zonal, meridian, and vertical winds) during a definite period (days and months). The data are given on the standard pressure levels UARS from 1000 to 0.316 hPa (21 level) that enables one to obtain the altitude profiles of meteorological parameters up to the altitudes of 2.5° at latitude and 3.75° at longitude. The information of interest for us was taken from the above-mentioned database using a specially developed computer program which makes it possible: a) to transform and to structure the initial information of the model UKMO; b) to obtain the altitude profiles and the latitude-longitude distributions of all significant meteorological parameters for any geographic region of interest to us; c) to make zonal and time averaging of necessary characteristics and, first of all, the vertical wind velocity U_W.

At present there is a possibility to use another database NCEP/NCAR, which allows the reconstruction of the vertical wind field at different altitudes over the last many years.[8] A selective comparison of data of two models has shown their good agreement, but the fully identical pattern of the vertical wind field has not been obtained. In our opinion, the reason is connected both with differences in the initial models OTsA and with the instrumental differences in obtaining assimilable meteorological data.

2. Field structure of averaged vertical wind

Figure 1 shows the monthly mean altitude profiles of vertical wind at the equator during 2005, which is taken later as representative. The same data can be obtained for the other (or any) geographic regions over a period from September, 1992 to February, 2006. The positive values of the velocity correspond to the upward wind, the negative values correspond to the fall vertical wind. The monthly mean amplitudes of the vertical wind in the troposphere are about ±10 mm/s, in the lower and middle stratosphere are ±5 mm/s and mesosphere they reach 50 mm/s. Undoubtedly, the averaged wind profiles contain a great body of information about the primary reasons, which cause the wind (for example, for the equator – this is the mechanism of extreme tropical convection, for polar regions – it is the action of circumpolar vortices). It is characteristic that at zonal averaging (Fig. 1*b*) the monthly mean amplitudes of the vertical wind considerably decrease as compared with the geographic – local amplitudes (Fig. 1*a*) and in the middle stratosphere they are ±1 mm/s.

It is evident that the mean during 2005 vertical wind both in the troposphere and in the stratosphere is only the upward wind, and at altitudes from 18 km to 21 km it is very close to zero. As a whole, for the equatorial troposphere the intensive upward wind is typical, which sharply decreases to the tropopause; in the stratosphere its small growth is observed, again alternating by a sharp increase in a direction to the stratopause. The analysis of similar zonal-averaged altitude profiles for the rest years of observations in the main confirms these regularities. The resulting average annual zonal-averaged equatorial profile of the wind is in good agreement with the results of model theoretical calculations.[6]

Of great interest is the comparison of the obtained altitude profiles with the averaged over a period of 0.5–3 years measurements of vertical wind using VHF-radars at three different equatorial stations at altitudes up to 18 km [Ref. 10]. In spite of a great scatter in the data, in the paper[10] a conclusion was drawn about the generality for the equatorial troposphere of the fall vertical wind with an amplitude about 10 mm/s at altitudes of 6–8 km. The data from Fig. 1 do not support such a relationship; both for a local and for a zonal-averaged tropospheric winds we observe practically symmetric, positive for winter and negative for summer season patterns of the vertical wind velocity; in this case, higher than the tropopause such a symmetry is disturbed.

The time scale of data for a period of 2004–2005 is presented in Fig. 2. It makes it possible to expose explicitly in the troposphere the presence of semiannual oscillations developed in the interchange of areas of upward and fall vertical winds at velocities from –2 to +4 mm/s. Further, up to the altitudes of the middle stratosphere, such oscillations are not observed, and in the upper stratosphere again a tendency is discovered for a periodic alternation of a sign of the wind but with another period and amplitude. It is probable that this compound total signal of semi-annual,[11] quasi-two year,[12] and other long-term oscillations[13] in the structure of the vertical wind field.

Figure 3 shows the latitude scanning of annually mean zonal-averaged velocity of the vertical wind for 2005. For the troposphere the practically symmetric for hemispheres alternation of regions of upward and fall winds with mean velocities up to ±2 mm/s are evident. In the stratosphere for altitudes of 20–50 km a given ordering is also noticeable, however, in the northern hemisphere in the circumpolar latitudes the velocities of upward wind (up to 6–7 mm/s) are vastly larger than the corresponding values for the southern hemisphere (up to 2 mm/s) that, probably, is connected with the known asymmetry of hemispheres. Besides, the amplitude of the vertical wind velocity in different hemispheres may also depend on the phase of long-term atmospheric oscillations.[12–13]

Figure 4 shows the polar projections of averaged per month velocity of vertical wind for winter and summer seasons of 2005 for two characteristic pressure levels in the troposphere and stratosphere (the altitudes are about 5 and 45 km). Analysis has shown that up to the altitudes of 15 km (100 hPa) the wind patterns for both seasons are practically identical, in this case in the troposphere the above described areas of tropical upward flux with the velocities up to 10 mm/s are manifested. At altitudes higher than 20 km in the circumpolar regions the vast areas are formed with large values of the upward vertical wind (up to 30–40 mm/s). Semiannual oscillations are clearly defined, which are in the alternation of areas of upward and fall fluxes from winter to summer. The boundaries of regions with extremal high values of velocities of vertical wind coincide practically with geographic seasonal position of Arctic and Antarctic polar vortices.[14–15]

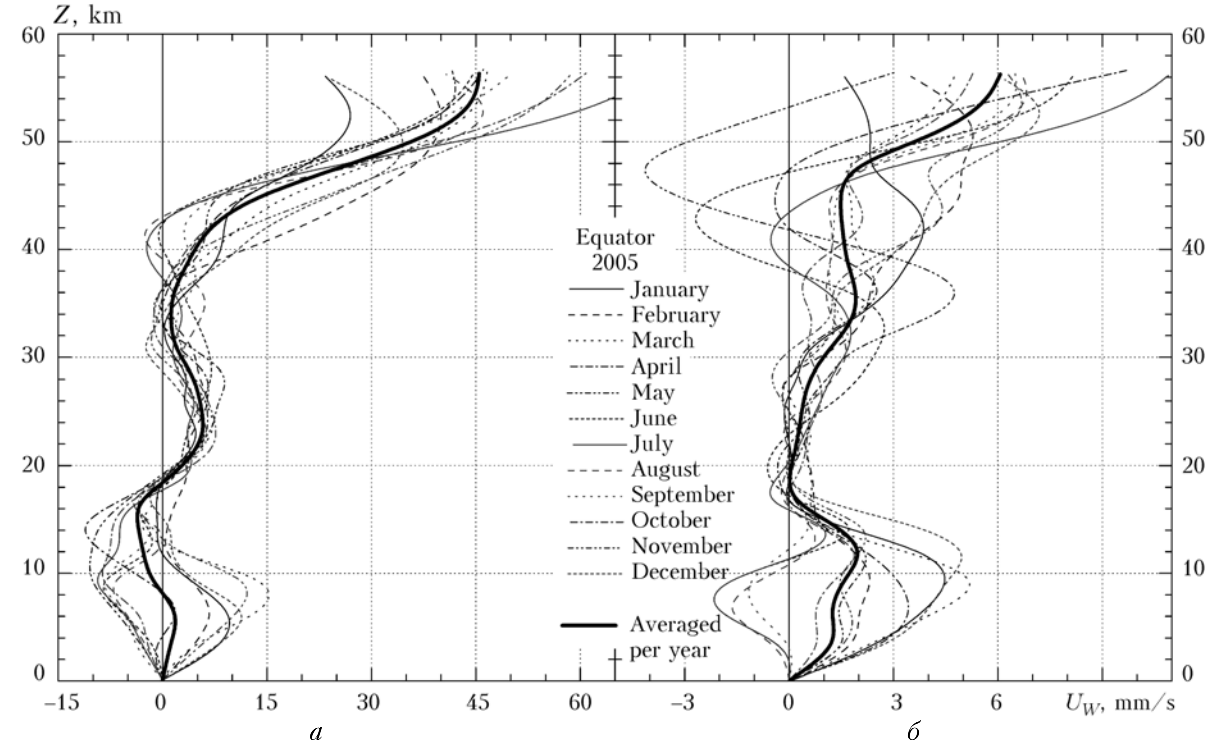

Fig. 1. The altitude profiles of the vertical wind velocity averaged per month: equator, 0°N, 0°E 2005 (*a*); equator, zonal averaging, 2005 (*b*).

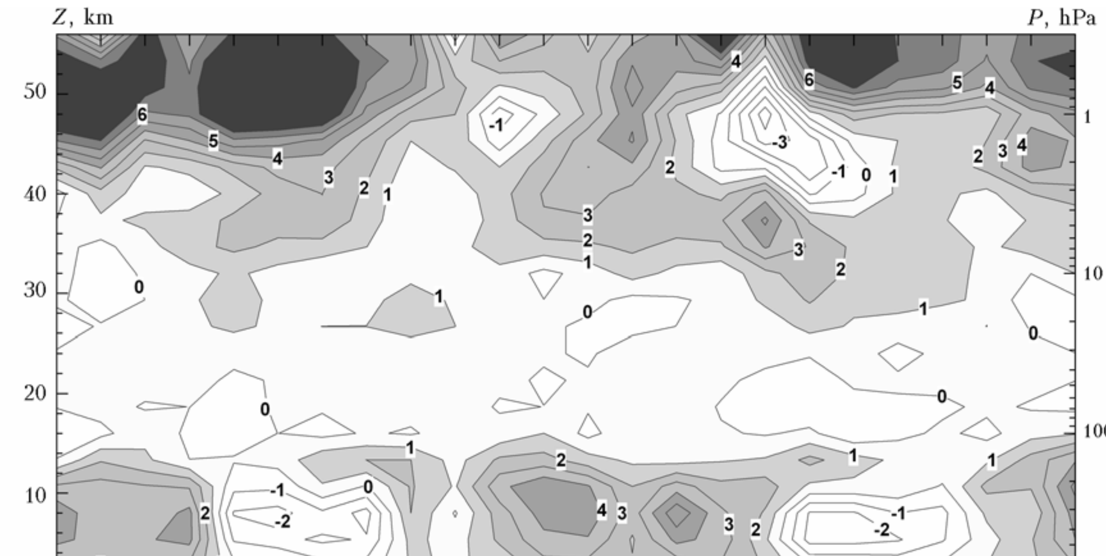

Fig. 2. Zonal-averaged velocities of vertical wind at different altitudes for equator over a period from January, 2004 to December, 2005.

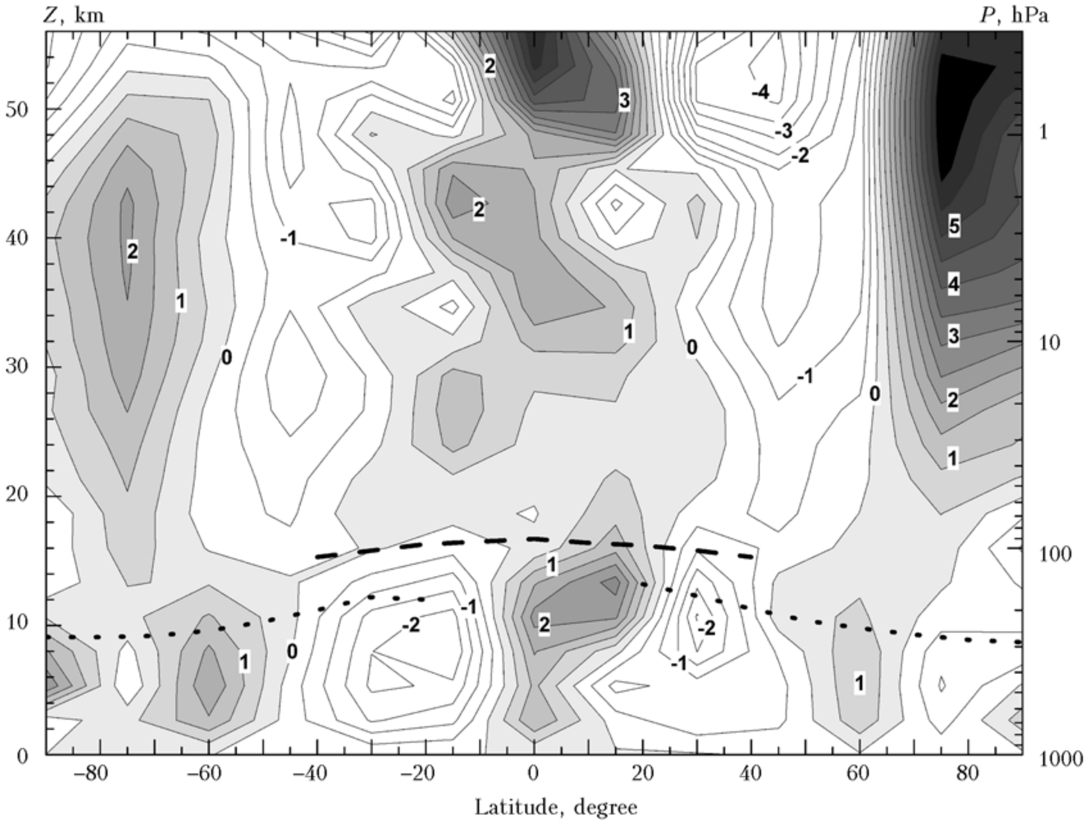

Fig. 3. Average annual zonal-averaged velocities of vertical wind for 2005. Standard average annual values of the altitude of polar tropopause are denoted by dotted line and dot-dashed line is for tropical tropopause.

In our opinion, the discovered qualitative regularities for the field of the stratospheric vertical wind in Fig. 4 are illustrated by a citation from a classical textbook[16]: "The increase of the temperature with height leads to a great stability of the stratosphere: here there are no disordered (convective) vertical motions and active mixing peculiar for the troposphere. However, insignificant in value vertical motions of type of slow lowering or elevation sometimes encompass the layers of the stratosphere occupying vast spaces." Slow vertical motions of air masses of such type can be characterized, evidently, as a vertical advection.[6]

3. Approximation of the vertical wind velocity in aerosol transport models

Climatological analysis of the vertical wind field is of interest not only for a qualitative understanding of regularities of its altitude and seasonal-latitudinal dependences but for a quantitative description of characteristics of vertical transport of aerosols in the middle atmosphere. It is known that the altitude aerosol can tend to the long-term or sporadic stratification (the Yunge layer, polar stratospheric and mesospheric clouds, volcanic clouds, and other aerosol formations).

These aerosol clouds can be transported at long-range distances in the horizontal direction under the action of zonal and meridian wind (see, for example, Refs. 17–18), however, their stability and lifetime must directly depend on the value of the fall or upward vertical winds at proper altitudes. Without taking account of the action of upward vertical wind it is impossible to explain the presence of large and heavy particles in polar stratospheric clouds[19] or large particles of bacteria and fungi in the lower and middle stratosphere.[20]

In the known transport models for stratospheric aerosol the attempts were made to take into account the vertical wind. Thus, for example, the authors of one-dimensional model of the formation and evolution of polar stratospheric clouds[21] believe that the vertical wind can be assumed to be zero because of the absence of any known experimental data. In the model[22] the profile of vertical stratospheric wind is also assumed to be constant in height with the used values of velocities 0 and ± 0.1 mm/s.

In Ref. 23 it is used the piecewise smooth altitude profile of zonal-averaged vertical wind for subtropics (15°S–15°N) set based on the estimates on a theoretical model.[24] The type of this model approximation is qualitatively similar to the curve for annual average zonal-averaged equatorial wind from Fig. 1*b*. The attempts of slight variation of a given profile demonstrated high sensitivity of determined model characteristics to such variations.

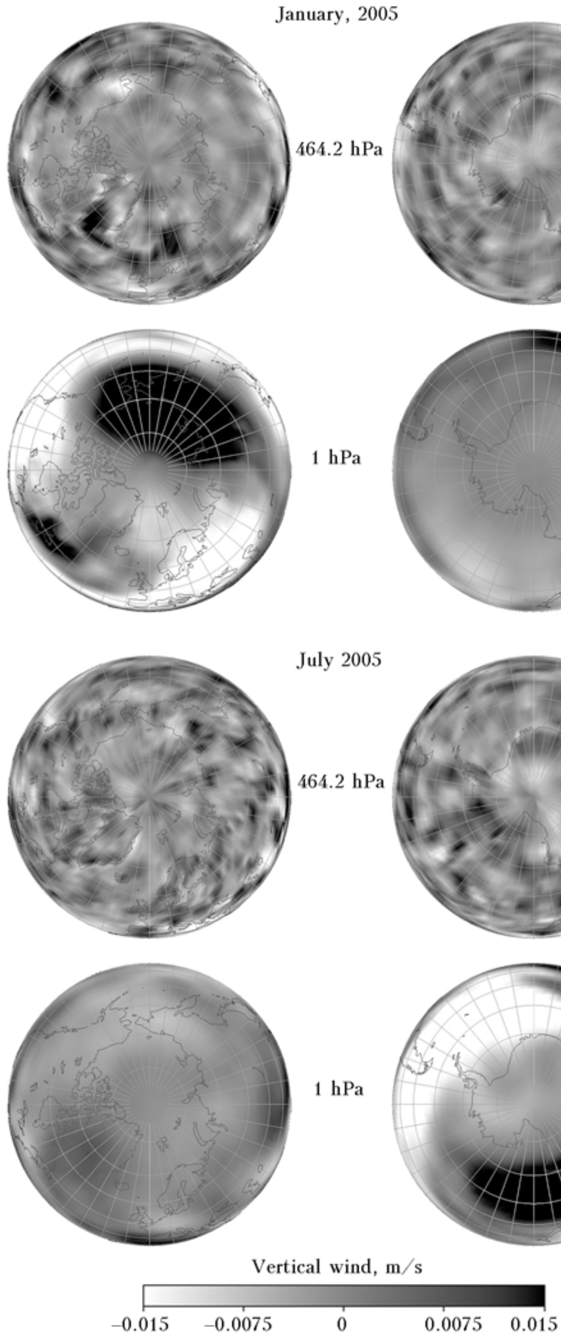

Fig. 4. Geographic distribution of averaged per month velocity of vertical wind at two characteristic altitudes for January and July, 2005.

In the model[25] the vertical wind profile is derived from the experimental data for altitude dependences of aerosol extinction coefficient in the UV and visible range using an algorithm proposed by the authors. A comparison of the resulting profile of vertical wind with the used in model[23] and extracted from data base UKMO shows their considerable difference, especially for the altitudes higher than 35 km. And finally, when developing a new transport model for the stratospheric aerosol MOSTRA [Ref. 26] the authors proposed not to model the necessary profiles of the vertical wind but to assimilate them directly to the model from the known database ECMWF.[9] Such an approach is promising, but however, the concrete results of modeling are unknown as yet.

Thus we can come to the conclusion that the vertical wind in the known aerosol transport models either is not considered generally or its taking account is based on the primitive heuristic or semiempirical approximations of altitude profiles. In the first case we come to the use of a known Casten model for the rate of particle precipitation in the stationary atmosphere[27] and in the second we obtain results *a priori* containing a serious error of the model.

In a given paper we propose the following scheme of the approximation of altitude profiles of vertical wind. After extracting the table of monthly mean vertical wind at standard pressure levels UARS from the database UKMO, its velocity is approximated by a polynomial of the seventh degree for the altitude range z = 0–60 km. As a result, instead of discrete table data we obtain the continuous function of monthly mean or annual average velocity of vertical wind from the argument z either for local geographic region or zonal-averaged one. For circumpolar regions the deviation of the approximating function from the table values of wind velocity did not exceed 1% and for the equator – 5% for the entire altitude range.

At such level of approximation of the wind field it is possible to evaluate properly the vertical velocities of transfer of aerosol particles of different size and densities in the stratosphere using methods described in the previous paper.[2] Figure 5 shows the total velocities of particle motion with $\rho = 0.165$ g/cm^3 and R_p = 1.5 μm under the action of the force of gravity and vertical wind.

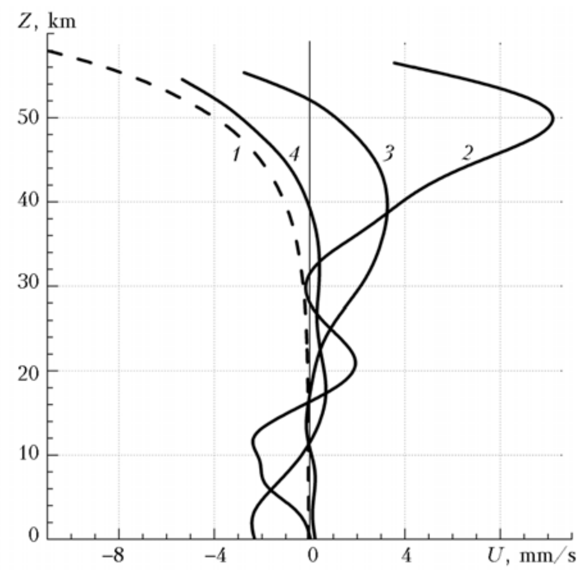

Fig. 5. The velocity of particle motion with p = 0.165 g/cm^3 and R_p = 1.5 μm; the velocity of gravitational sedimentation without taking account of wind (*1*); the total velocity of particle motion with taking account of vertical wind: equator (*2*); the north pole (*3*); the south pole (*4*).

Relatively small values of ρ correspond to the effective density of soot aggregates, which photophoresis motion in the stratosphere was studied in Ref. 28.

In the calculations we used zonal-averaged over the 13 year period data for the vertical wind; the positive values of the velocity correspond to the particle rise opposite the force of gravity, the negative values correspond to the particle precipitation, curve *1* correspond to zero vertical wind, curves *2–4* take into account, beside the force of gravity, the wind effect. This figure shows the necessity of taking account of the vertical wind in aerosol transfer in the stratosphere. The use of the Casten model[27] for estimating the rates of particle precipitation in the stationary atmosphere may result in the incorrect qualitative and quantitative results and conclusions.

The next level of approximation of obtained results can consist in the parameterization of zonal-averaged vertical wind by means of class of functions taking into consideration its time and latitude variability. In this case, clearly, the rough approximation of fine details of real field of the vertical wind should be expected. A given approach may appear to be useful when constructing the aerosol transport models because of the formal independence of the used parameterization from the initial database.

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