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Variations of the outgoing radiation due to the variability of the properties of atmospheric aerosols

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RESUMEN

Con base en un modelo de aerosol atmosférico, cuyas propiedades se definen por medio de la humedad relativa y el rango de visibilidad, se estima la contribución de esta componente a la variación de la radiación emergente. Se toma en cuenta la influencia del albedo de la superficie subyacente. Se demuestra que las variaciones porcentuales de la radiación emergente pueden alcanzar algunas decenas y por lo tanto deben ser tomadas en consideración en la solución de problemas prácticos de percepción remota. En la región infrarroja del espectro los cambios de la radiación térmica emergente pueden ir, desde un pequeño porcentaje hasta del orden de la magnitud del parámetro. La consideración del efecto de las partículas del aerosol puede mejorar la exactitud de la determinación de la temperatura atmosférica en $0.1 \sim 0.2^{\circ}$y de la superficie subyacente en $0.2 \sim 0.3^{\circ}$.

ABSTRACT

The contribution of atmospheric aerosols on the variation of outgoing radiation is estimated on the basis of an aerosol ensemble model, whose optical properties are defined through relative humidity and range of visibility. The influence of the albedo of the underlying surface is also taken into account. It is shown that the variations of outgoing radiation fluxes may reach tens of percent and therefore they must be taken into consideration during the solution of practical problems of remote sensing. In the infrared spectral region, the changes of outgoing thermal radiation may range from some small percentage up to the order of the value. Simple estimates show that more correct accounting for the effect of aerosol particles improves the accuracy of determining the atmospheric temperature by 0.1 to 0.2°and that of the underlying surface by 0.2 to 0.3°.

Introduction

Several methods for remote sounding of the Earth's atmosphere and surface have become widely used during the recent decades. However, their weak points and limitations have become quite obvious in satellite investigations, a method which was once considered very promising. One of the main problems with the improvement of the quality of information obtained from space carriers is the inability to correctly accounting for the influence of the atmosphere, and in particular, of aerosols their variability in composition, structure, and spatial distribution. The contribution of atmospheric aerosols can be taken into account on the basis of some models which make it possible to estimate average optical properties of the aerosols and their main trends and variations with different atmospheric conditions.

Below, are discussed the main features of a model of the aerosol optical characteristics which makes it possible, in the authors' opinion, to describe reliably enough the majority of situations which are observed in the Earth's atmosphere.

Aerosol model

As of now, the problem of proper consideration of the influence of aerosols on the formation of the optical characteristics of the atmosphere, as a whole, is far from a solution. A considerable number of models exist which help estimate the contribution of aerosols to outgoing radiation (McClatchey *et al.*, 1980; Ivlev *et al.*, 1986), but all of these models are far from being complete.

It can probably be agreed upon that the optical–aerosol experiments should be divided into two big groups. In one case, models depicting optical characteristics of aerosols, present the results of statistical processing of experimental data on optical properties of real atmosphere. On this note, definite doubt arises concerning the lack of experimental data, and errors in the determination of the optical characteristics of aerosols are many, because they are not directly measured parameters, but optical characteristics of the whole atmosphere. The procedures for extrapolation of exact aerosols characteristics from measured quantities requires large numbers of arguable and considerably disputable assumptions and tests.

In another case, optical characteristics of aerosols are determined by calculations obtained from a model of aerosol microstructure, which includes the particle concentration, size distribution function, content and basic structure of aerosol particles. Then, the problem of the adequacy of the actual model becomes more complex. While developing forecasting models for these purposes, the problem of prognosis of the optical characteristics of aerosols becomes evident because of the changing conditions of the atmosphere.

The aerosols' optical characteristic estimations were derived while using several different aerosol models. In order to eliminate the above mentioned contradictions and problems, an attempt was undertaken to build a new model of optical characteristics of atmospheric aerosols. The main idea, which was put into effect during this attempt, was the simultaneous usage of optical and microphysical data, the results of experimental measurements, and theoretical calculations.

Throughout recent years, the complex investigations of atmospheric aerosols were completed and optical (the transparency of the atmosphere on horizontal paths in the region 0.5-12 μm) and microphysical observations were also carried out. The aerosol samples obtained during fulfilment of such experiments (Andreev *et al.*, 1972), as well as during the microphysical measurements in other sites (the main results of microphysical investigations were summarized by Ivlev, 1982), were used not only for determination of the concentration and size distribution of particles and their content, but also for the measurements of the effective values of complex refractive index of aerosol matter.

During the fulfilment of this research, the widespread assumption that size distribution may be presented as a composition of three main fraction of particles differing by their concentration and having modal radii of particles $r_{01} = 0.03$, $r_{02} = 0.3$ and $r_{03} = 1$ μm, was confirmed. In Andreev (1989), on the basis of experimental studies, models of optical constants in spectral region 0.3-15 μm are proposed for these fractions. This data is then put into the basis for the calculations of the coefficients of aerosol's extinction, scattering and absorption and their scattering phase function. Model values of particle concentrations of individual fractions have been chosen proceeding from the assumption that at average, most often observed in the real atmospheric conditions (relative humidity $f = 40 - 60$ %, range of visibility S_m = 20-25 km), the particle size distribution is close to the power (or Junge) one at $\nu = 3.6$. Its precise value was found by comparison of the model calculated data and the results of experimental investigations of the atmospheric transmission at horizontal paths (Brounstein, 1976; Andreev *et al*, 1972).

The results of these series of comparison show, similarly to other studies, that it is impossible to construct a single, universal model for a broad spectral region by using a conventional set of such input parameters as f and S_m or aerosol extinction coefficient $\alpha_{ao} = 3.9/S_m$ for $\lambda = 0.55$

μm. The largest discrepancy between the calculational and experimental data is observed in the spectral region $\lambda = 1.5\text{-}4$ μm. In the $\lambda = 8\text{-}12$ μm region, a discrepancy of the order of a factor of 2 or 3 can be found, but the spectral variations of the aerosol extinction coefficients is represented correctly, as well as the trends of its change at air humidity variations.

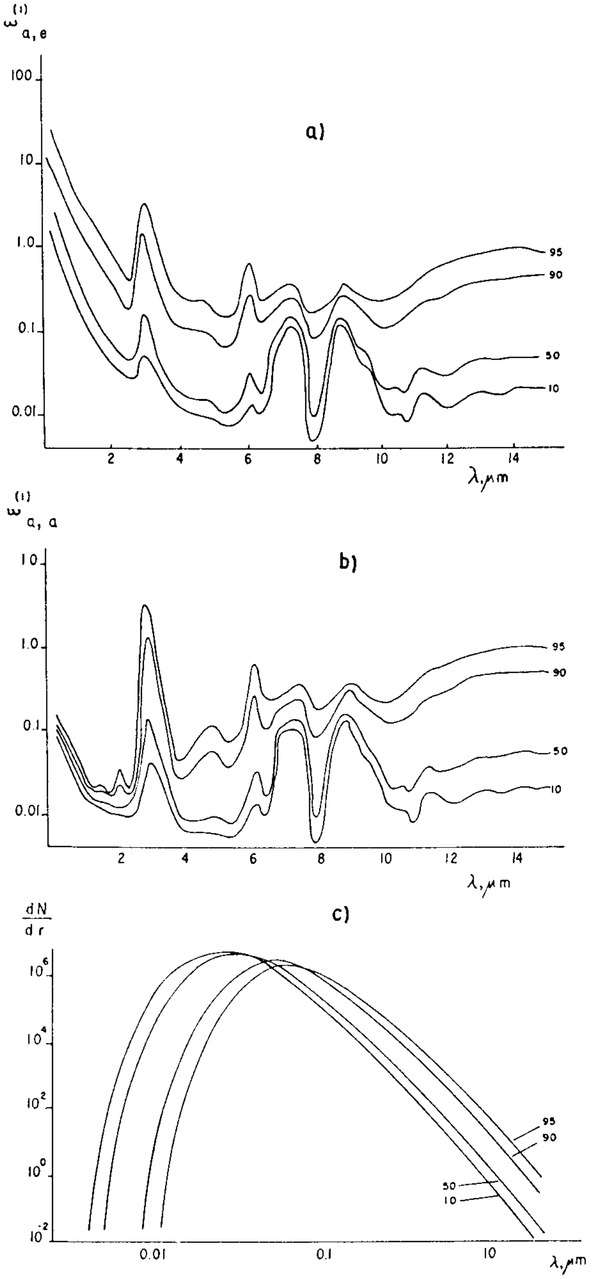

Fig. 1. Spectral dependence (for f = 95, 90, 50 and 10 %) of relative coefficients of aerosol extinction (a), aerosol absorption (b), and size distribution (c) of small particles.

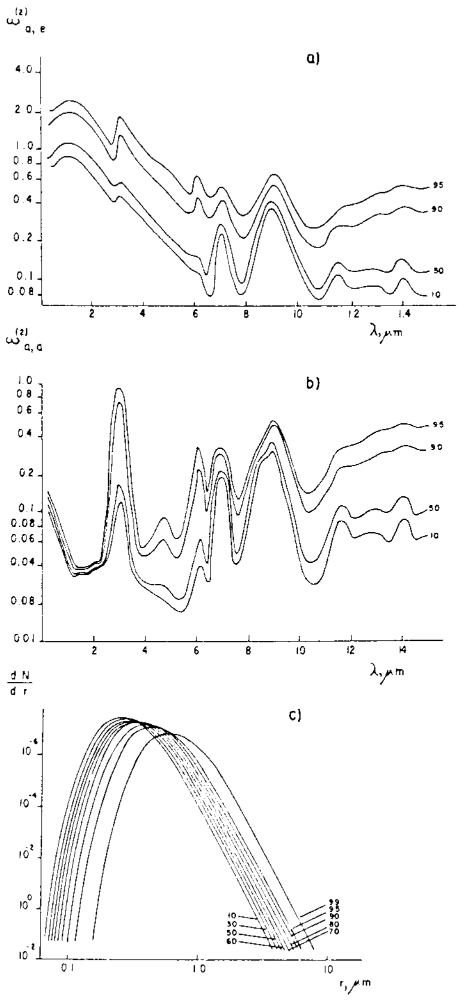

Fig. 2. The same as Fig. 1, but for large particles.

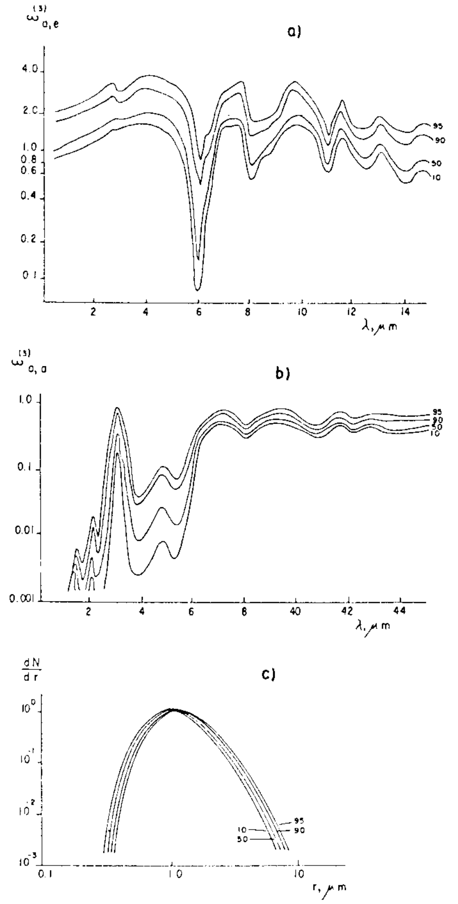

Fig. 3. The same as Fig. 1, but for giant particles.

It should be emphasized that the presence of additional information - the data on the spectral variation of the aerosol extinction coefficient in the visible spectral region (2-3 points in the spectrum), the shape of the scattering function, etc. makes it possible to determine more precisely the relationship between the particle concentrations of different fractions relative to the model one, and to improve sharply the accuracy of prediction of aerosol extinction and scattering coefficients in the entire spectral region $\lambda = 0.3 - 15$ μm. Figs. 1, 2 and 3 present, as examples, the curves of spectral dependence (for diferent values of f) of relative coefficients of aerosol extinction (a) and absorption (b):

$$w_e^i(\lambda,\ f) = \frac{\alpha_e^i(\lambda,\ f)}{\alpha_{eo}^i} \tag{1}$$

$$w_a^i(\lambda,\ f)\frac{\alpha_a^i(\lambda,\ f)}{\alpha_{ao}^i} \tag{1'}$$

The curves of the size distribution $n(r) = dN/dr$ are also shown (c).

This model describes the properties of continental aerosols in the surface atmospheric layer. The presence of data on the vertical profile of the aerosol concentration allows to extend it to the lower tropospherical region, up to heights 5-6 km, since the aerosol particles in this layer do not differ in their composition from the near-ground aerosols. At the same time, the aerosols of this, near-ground layer are responsible for 90-95 % of the aerosol component of the atmospheric optical thickness.

The dependence of the particle size on relative humidity (and hence, the dependence of the complex refractive index on the content of water in the particles) can be presented by the formula (Ivlev, 1982):

$$r(f) = r(f_o)\left(\frac{f_o}{1-f}\right)^{\varepsilon_i}, \quad i = 1,\ 2,\ 3, \tag{2}$$

where $f_o = 50\%$ and $\varepsilon_i = 0.32$, 0.18 and 0.08, for above mentioned three fractions of particles.

It is evident that the sum of the values $w_e^i(\lambda,\ f)$ and $w_a^i(\lambda,\ f)$ with the weighing coefficients, corresponding to the concentration of particles of each fraction, must describe real spectral curves of the coefficients of aerosol's extinction and absorption, respectively. The comparison of experimentally derived coefficients of aerosol extinction according to Andreev *et al.* (1972) and Brounstein (1976) with the results of calculations agree well (up to 30-50 % in all spectral region $\lambda = 0.3 - 15$ μm) and led to the conclusion that the relative amounts of concentrations of particles of different fractions are regularly changing depending on meteorological visibility S_m and air relative humidity f. The existence of such dependence allows us to determine optical properties of aerosols in the wide interval of changes of meteorological conditions.

Figure 4 presents, as an example, the curve of the spectral dependence of the coefficients of aerosol extinction for different conditions in the lower troposphere.

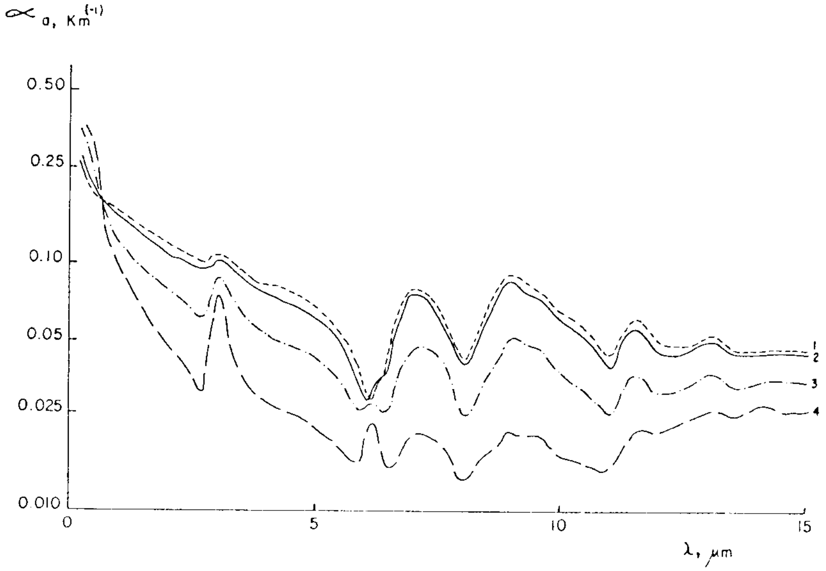

Fig. 4. Spectral distribution of the aerosol extinction coefficient (range of visibility S =20 km and relative humidities f = 20, 50, 80 and 95 % - curves from 1 to 4, accordingly).

Variations of outgoing radiation fluxes

The developed model (which was included with the data (McClatchey *et al.*, 1980) concerning the vertical profiles of aerosol concentration) was used for the estimates of the influence of the changes in the aerosols' properties on the outgoing radiation fluxes $H^{\uparrow}$ - one of the main parameters which is measured when the optical methods of remote sensing of atmosphere and Earth's surface are used.

Let us consider, that the properties of atmospheric aerosols change due to the variations of atmospheric humidity in accordance with formula (2). Then let the humidity in the atmospheric layer 0-6 km have a concrete value of $f_1 = 60\ \%$; in this case one will register the outgoing radiation flux $H^{\uparrow}(\lambda)$. If the humidity in the same atmospheric layer will become $f_2 = 80\ \%$ and at the same time the vertical profile of the concentration of aerosol particles will change in the manner that the vertical profile of the coefficient of extinction α_{eo} would remain constant, one will register the outgoing radiation flux

$$\hat{H}^{\uparrow}(\lambda) = H^{\uparrow}(\lambda) + \Delta H^{\uparrow}(\lambda) \tag{3}$$

On Figure 5a, the curves of the spectral dependencies of $\Delta H^{\uparrow}(\lambda)/H^{\uparrow}(\lambda)$ are drawn for the extreme values of the albedo of the underlying surfaces $A_1 = 0$ and $A_2 = 1$.

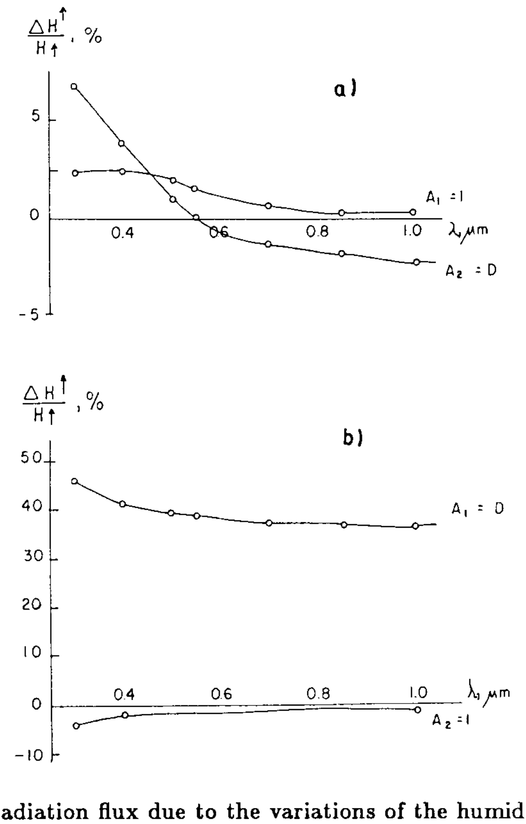

Fig. 5. Change of the outgoing radiation flux due to the variations of the humidity profiles for different values of the albedo A of the Earth's surface (a - in the case of the constant aerosol extinction profile; b - in the case of the constant aerosol concentration profile).

The curves of the Figure 5b illustrate another case, when, while the humidity is changing from 60% to 80%, the vertical profile of the particle concentration remains constant. If, in the first case, the variations of $\Delta H^{\uparrow}(\lambda)/H^{\uparrow}(\lambda)$ do not exceed 5 - 7%, then in the second case they reach 30 - 40%. It seems that these are the values which must be considered while using the methods of remote sensing. Naturally, in realistic conditions, the scene is different from the considered extreme hypothetical cases, and only seldom variations of humidity occur in the layer of smaller thicknesses, and they are accompanied, as a rule, by changes of the dust-loading of the air. I.e., in practice, one has to apparently wait for the variations of the outgoing radiation fluxes of the order of 10 - 20%, or it means that the change of humidity for 1% leads to the variation of outgoing flux also of about the same 0.5-1 % (the same for the change of radii of particles for 1 %). Analogous results were obtained in Vasilyev and Leyva (1986). Still, these are sufficiently significant values.

An even more complicated situation is observed in the IR part of the spectrum at 8-12 μm, where the dependence of optical characteristics of aerosol on air humidity is extremely high. In this spectral region of thermal emission the outgoing radiation is determined primarily, by the temperature of the underlying surface and its transformation while penetrating through the atmosphere - by the presence, first of all, of water vapor. However, aerosol particles, mainly the giant ones, influence the extinction of radiation. In this spectral region, considerably intens aerosols' absorption bands are present and aerosol can give noticeable contribution into formation of the radiation of the atmosphere. Similar estimations of the aerosol's contribution to the formation of outgoing radiation fluxes in this spectral region, as against the visible one, are practically impossible, but appraisal calculations show that, depending on realistic atmospheric profiles of humidity, temperature and concentration of aerosols' particles, the changes of outgoing thermal radiation, caused by the variations of the aerosols's optical properties, may range from some small percentage up to the order of the value.

Conclusions

The variations of outgoing radiation fluxes, caused by the changes in properties of aerosols (depending, for example, on the atmospheric humidity), may reach tens of percent and they must be taken into consideration during the solution of the practical problems of remote sensing. This consideration may be realized in two approaches.

1. The development of one whole global model of aerosols, which gives corrections for the typical conditions in several regions and in case of different stratifications of the atmosphere. Such an approach, apparently, will allow to specify the possible range of the uncertainty of the remote sensed atmospheric and surface parameters.

2. The complex approach to the problem of the determination of the influence of aerosols, differing in their concentration, sizes, content, etc., has well defined peculiarities in their spectral optical characteristics. The particles of various fractions differing much in their sizes give diverse contributions into the typical characteristics of the atmosphere in several spectral regions. Thus, the aerosols' extinction coefficients, in case of realized size distribution functions in the atmosphere, in the visible spectral region are practically determined in more or less equal parts by the presence of all three fractions, while in the IR-region the definite role (up to 90 %) is played by the fraction of large particles. Results which confirm this statement were obtained in Vasilyev and Leyva (1986). This gives us the possibility to obtain, directly on the basis of the measurements of outgoing radiation, the information about the current state of aerosols in the atmosphere, approximately in the same manner, as in the case of the solution at the present time of similar problems for ozone or water vapor. The satellite instrumentation already used (devices such as MSU, used on Soviet sputniks, or close to them by their characteristics such as MODIS used in the USA) allows us to solve the analogous problem.

It must be mentioned also that the complex approach to the solution of the problems of remote sensing -in the considered case of the estimation of the aerosol's properties and their further usage for the specification of other characteristics of the atmosphere - leads not simply to the broadening of the amount of the problems which may be solved, but to a qualitative change of the obtained characteristics.

The authors suppose that simultaneous determination of the water vapor concentration, temperature and estimation of the distribution function and aerosol particle concentration from the data of measurements of the thermal radiation, will make it possible to substantially improve the accuracy of determining the temperature and humidity profiles. Comparatively simple estimates (regrettably far from being comprehensive) show that more correct accounting for the effect of aerosols improves the accuracy of determining the atmospheric temperature by 0.1 - 0.2°, and the underlying surface temperature by 0.2 - 0.3°.

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