Range of application of the scattering theory within the multicomponent turbid media of the cloud atmosphere is the reason for anomalous absorption and incorrectness of climate prediction

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Contemporary climatic models predicting different scenarios of climate formation are examined and educated on examples of known parameters of the climatic system of the last century. The atmospheric aerosols’ impact is taken into account as adjusting factor. The cloud influence on increasing absorption of the solar radiation in the atmosphere (‘anomalous absorption’ in the short wavelength ranges) is not considered in the climatic simulations. Observations of the shortwave solar radiation in the Earth’s atmosphere demonstrate increasing radiation absorption under cloudy conditions compared with the clear atmosphere. The difference between the spectral dependence of the cloud optical thickness together with the value of the single scattering albedo, retrieved from airborne, satellite and ground-based radiation observations, and results of model calculations with applying scattering theory is revealed. A possible physical explanation is proposed in this paper. An incorrect account of the absorption of solar radiation in the cloudy atmosphere during the process of refining a climatic model attaches too much weight of the greenhouse gases yield on atmospheric energy balance in simulation. As a result, the influence of greenhouse gases on formation of the temperature field appears overestimated.

1. Introduction

Spectral dependencies of cloud optical parameters (optical thickness, single scattering albedo, scattering, and absorption coefficients) obtained in the case of stratus cloudiness from airborne, satellite and ground-based spectral observations of the shortwave solar radiation (spectral ranges 0.33–0.95 μm) are presented in papers by Kondratyev (1972), Kondratyev et al. (1977, 1997), Kondratyev and Binenko (1984), Melnikova (1989, 1992), Melnikova and Mikhailov (1994), Melnikova et al. (2000), and Melnikova and Nakajima (2000). Airborne radiative experiments were accomplished over two decades (from 1965 to 1986) under the guidance of the academician Kirill Kondratyev. Descriptions of the observational conditions have been referred to elsewhere, e.g. tables 3.2–3.4 in the book by Melnikova and Vasilyev (2004). The optical parameters retrieved from airborne observations are shown in figure 1(a, b) in terms of the volume scattering and absorption coefficients \( \alpha \) and \( k \).

Results of processing airborne observational data demonstrate significant absorption: the absorption coefficient is \( k \sim 0.05–0.15 \text{ km}^{-1} \) and the single scattering
Albedo is $\omega_0 = 0.985 - 0.999$ (Melnikova 1989, 1992, Kondratyev et al. 1997, Melnikova and Mikhailov 1994). Values of the single scattering albedo obtained from satellite and ground based data have appeared very close to the values obtained from airborne data (Melnikova et al. 2000, Melnikova and Nakajima, 2000). Values of the single scattering albedo only for dozens of pixels were equal to unity and for several thousand of pixels were about 0.999. But the model calculations on the basis of the scattering theory lead to values $\omega_0 \approx 0.9999999$.

Figure 1. Spectral dependence of volume coefficients (a) scattering and (b) absorption of cloud layers retrieved from airborne observations of the solar radiation. Experiment numbers are taken from Melnikova and Vasilyev (2004).
corresponds much more weak absorption than values $\omega_0 \sim 0.985–0.999$ revealed from observations.

The optical thickness $\tau_0$ and scattering coefficient $\alpha(\lambda)$, determined from airborne and ground observations demonstrate the apparent spectral dependence. The result of processing seven satellite images each containing about 600 pixels has also shown the spectral variations of $\tau_0$.

In addition to the above considered results retrieved from data of radiation observation, it is important to consider data obtained by Asano (1994): namely the cloud optical thickness at IR wavelengths appeared less than twice compared with the optical thickness at visual wavelengths. Mayer et al. (1998) obtained cloud optical thickness from data from ground UV radiation measurements by selecting values. Unbelievably high values have been obtained, around 300–500, which accord with our results for visual wavelengths and optical thickness increasing with decreasing wavelength. However, from the scattering theory, the volume scattering coefficient $\alpha$ (and the optical thickness $\tau_0$) for cloud droplets (particles of size around 5–10 $\mu$m) must not depend on wavelength within the spectral ranges considered.

Dianov-Klokov et al. (1973), Pfeilsticker et al. (1998), and Pfeilsticker (1999) have observed solar radiation with high spectral resolution in clouds, and the oxygen band 0.762 $\mu$m has been analysed. A significant deformation of the band curve, compared with the clear atmosphere, has been revealed.

All these facts have been explained by multiple scattering influence within clouds in papers by Dianov-Klokov et al. (1973), Melnikova (1989), Kondratyev et al. (1997), Pfeilsticker et al. (1998), Wagner et al. (1998), Pfeilsticker (1999), and Melnikova and Nakajima (2000), but the explanation has not been proved from a strict physical point.

### 2. Scattering theory for multicomponent turbid media

Possible explanation of obtained properties of optical parameters within cloud (the spectral dependence of the scattering coefficient and the high value of the absorption coefficient) is multiple scattering of the solar radiation together with averaging optical parameters of the media arising from different components. The yield of molecular scattering within clouds is usually accounted for on the basis of summarizing rules of scattering theory. This yield turned out to be negligible because the molecular scattering coefficient is three orders of magnitude less than the scattering coefficient of cloud droplets. Certain authors consider a cloud additively placed on the molecular atmosphere, others account for the influence of optical parameters of molecular atmosphere is accounted within molecular absorption bands only (e.g. in the paper by Kurosu et al. 1997). However, the standard approach does not take into consideration the fact that dimensions of particles of cloud components differ greatly, and consequently the axiomatic relations between linear characteristics of turbid media are not valid.

The rules of summarizing have been derived, with the assumption that the particles are interacting with radiation independently (e.g. in books by Shifrin 1951 and Hulst 1957). Here the following question is pertinent: is this assumption correct? From the view of geometrical optics, which we have appealed to, when introducing the cross-sections of the interaction, their areas (sections) must not intersect within the elementary volume, i.e. the total area of its projection to the side $dS$ must be equal to the sum of the areas of all particles. It would be accomplished rather exactly if
1. The distances between particles were much larger than the linear sizes of the cross-sections of the interaction or, roughly speaking, much larger than the particle sizes. Dividing the elementary volume into small cubes with side $d$, where $d$ is the distinctive size of the particle, we conclude that for this condition the particle number in the volume $dV$ has to be much less than the number of cubes—$ndV \ll dV/d^3$, i.e. $n \ll 1/d^3$, where $n$ is the particle number concentration.

2. The second condition of independency of the interaction between the particles and radiation follows from the points of wave optics, according to which the independence of the interaction occurs if the distances between the particles are much larger than the radiation wavelength $\lambda$ leading to the inequality $n \ll 1/\lambda^3$.

Using the values of the real molecules and aerosol particle concentrations in the atmosphere, it is easy to test that the condition $n \ll 1/d^3$ is always correct, the condition $n \ll 1/\lambda^3$ is correct in the short-wave range for aerosol particles, and it is broken for molecules of the atmospheric gases. Nevertheless, it is assumed in books by Einstein (1966), Volkenstein (1951), and Levich et al. (1971) that light scatters not on molecules but on the air density fluctuations (thus, the air is considered as a continuous medium), and it is possible to ignore this violation. For the calculation of the radiation field, the elementary volume is chosen so that only one interaction may happen within the elementary volume. Such a volume is different for the particles of different sizes (cloud droplet size is close to 10–20 $\mu$m; for atmospheric gas molecules (more exactly density fluctuations), this is about $0.5 \times 10^{-3}$ $\mu$m). Thus, the diffusive medium is found to be non-continuous. The violation of both conditions could occur when there are large particles in the air (for example cloud droplets). Taking into account the large size of the droplets (tens and hundreds of microns), there are many gas molecules (density fluctuations) and small aerosol particles around these droplets, and both conditions are violated for them. Therefore, the question of applicability of the summarizing rules in the cases mentioned above needs special analysis.

In accordance with the initial conditions chosen by Hulst (1957), the distance between particles must be more than $3d$ for electromagnetic waves reflected from different particles not to interfere—the approximation of independent particles. The approximation of the single scattering is adopted so that the same initial flux may illuminate every particle in the elementary volume (only one act of scattering occurs). This volume differs for particles of different sizes: for cloud droplets ($d \sim 10–20 \mu$m) it is around $1000–8000 \mu$m$^3$; for density fluctuation ($d \sim 10^{-2} \mu$m) it is $10^{-6} \mu$m$^3$, and for aerosol particles ($d \sim 1–10 \mu$m), it is $10^{-3}$ to $1.0 \mu$m$^3$. Thus, sizes of elementary volumes, corresponding to different particles within cloud, vary within 6–10 orders of magnitude!

Shifrin (1951) began the consideration in his book from introducing relations between linear characteristics within turbid media. The wavelength of initial flux is the definitive size, with which all other sizes are compared. The value $\lambda = 0.5 \mu$m is taken in the visual spectral range. The following linear characteristics are introduced:

1. the distance between molecules $\delta$ within the density fluctuation of the molecular atmosphere (or between molecules within the droplet) satisfies the inequality $\delta \ll \lambda$;
2. the size of scatterers: density fluctuations of the molecular atmosphere $d \sim 10^{-3}$ to $10^{-2} \mu m$; aerosol particles $d \sim 0.1$–$1.0 \mu m$ and cloud droplets $d \sim 10$–$20 \mu m$;
3. the distance between scatterers (density fluctuations, aerosol particle and cloud droplets) $l$;
4. the size of macro volume of the media (the cloud size in our case) $Z \approx 5.0 \times 10^{-7} \mu m \gg \lambda$. Shifrin (1951) has introduced four dimensionless parameters:

- $x_1 = \delta / \lambda$—describes the inner structure of the particle (density fluctuations, aerosol particle and cloud droplets);
- $x_2 = d / \lambda$—describes scattering properties of the particle;
- $x_3 = l / \lambda$—describes the structure of the turbid media;
- $x_4 = Z / \lambda$—describes scattering properties of the whole media.

While derivation of relation of the scattering theory for the turbid media consisting of the particles of the one kind the following inequalities are supposed:

$$x_1 < x_2 < x_3 < x_4,$$
and also $x_1 \ll 1$; $x_4 \gg 1$.  

The dimensionless parameter $x_2$ is equal to following for density fluctuations, aerosol particle, and cloud droplets: $x_2 \sim 0.02$, $0.2$–$2.0$, and $20$–$200$ respectively for every component.

Distances between particles can be estimated as the following: $0.5$–$1.0 \mu m$ for density fluctuations (Volkenstein 1951, Einstein 1966), $100$–$500 \mu m$ for aerosol particle (Kondratyev 1969), and $10000 \mu m$ for cloud droplets (Mazin and Khrgian 1989) leading to values of the parameter $x_3 \sim 1.0$–$10$, $200$–$1000$, and $20000$ respectively.

Hence, it is evident that the relations (1) are not fulfilled in the cloud media for linear characteristics $x_3 \sim 1.0$ for density fluctuations and $x_2 \sim 20$–$200$ for droplets: the parameter $x_3$ for droplets is much higher than the parameter $x_2$ for density fluctuation of the molecular atmosphere and the same order of magnitude as the parameter $x_3$ for aerosol particles. In accordance with results of the book by Shifrin (1951), reducing the problem to scattering on one particle is incorrect under condition $x_2 = x_3$. In such a case, multiple scattering must be accounted for, and the linear size of the whole medium $Z$ must be included in the resulting formulas.

Shifrin (1951) presented the relations between optical thickness of the whole media and linear characteristics:

$$\tau \approx \frac{d^2 Z}{\lambda^3} = \frac{x_2^2 x_4}{x_3^3}.$$

Substituting the above-mentioned estimations for linear characteristics in equation (2), the value of the optical thickness $\tau \sim 20$–$50$ is obtained, which is highly typical for stratified clouds (Mazin and Khrgian 1989), and this indirectly points to our correct choice of magnitudes of linear characteristics.

In this way, it is clear that the basic relations between linear characteristics for scatterers of different kinds, which are the foundation of the scattering theory, are broken in cloud turbid media. Thus, direct application of results of calculating optical parameters according to the scattering theory and especially summing optical parameters of different components is incorrect and leads to an erroneous result.
3. Radiation transfer in multicomponent turbid media

Consider the problem in ranges of radiation transfer theory applied to multicomponent turbid media. It is known that the average number of collisions of transmitted photons in the optically thick cloud layer with conservative scattering is proportional to $\tau^2$ (Minin 1981, 1988), and for reflected photons the average number of collisions is proportional to $\tau$ (Yanovitskij 1997). The photon’s route within a cloud becomes much longer compared with the route in a clear atmosphere, and the number of collisions with molecules and aerosol particles increases. This intensifies the yield of molecular and aerosol scattering and absorption in forming the radiation field. Radiation absorption removes photons from the process and partly decreases the effect of multiple scattering. The increase of the molecular absorption, which occurs as a result of a lengthening a photon’s path within a cloud by reason of multiple scattering, has been considered in papers by Dianov-Klokov et al. (1973), Pfeilsticker et al. (1998), and Pfeilsticker (1999). The same reasons are valid for scattering and absorption of the radiation by atmospheric aerosols, whose particles are between cloud droplets. It is clear that the transfer theory and transfer equation adequately describe all scattering processes only if they are correctly accounted for in the optical model of turbid media. Commonly averaged values of initial parameters of an elementary volume, obtained according to summarizing rules, are chosen as an optical model, and then the transfer equation is solved using a certain method as in books by Hulst (1980), Minin (1981), and Yanovitskij (1997), for example. However, in many physical problems, an averaging of values on the initial stage of solution, especially scales of averaging, is different for different components of the media. The integral term in the transfer equation, accounting for the yield to the radiation in the considered direction from other points of the media, supposes a continuity of the turbid medium (i.e. elementary volume considered during the phenomenological derivation of the transfer equation). Otherwise the integrand would have discontinuities, and the question about integral term existence would arise. However, because the elementary volume is different for different components, the turbid media appeared discontinuous.

In our previous studies, the solution of the inverse problem, i.e. revealing the optical thickness and single scattering albedo from measured radiative characteristics (irradiance or radiance), has been accomplished using inverse asymptotic formulas with substituting measured real values into formulas. As a result, values of real cloud optical parameters have been obtained in studies by Melnikova (1989, 1992), Melnikova and Mikhailov (1994), Kondratyev et al. (1997), Melnikova et al. (2000), and Melnikova and Nakajima (2000), which do not coincide with values calculated using scattering theory and summarized according to summarizing rules. Here we do not consider mathematical aspects of multiple scattering in multicomponent media but point out that the phenomenological equation for one component media is not adequate for processes in multicomponent media. Thus, in the next section, the empirical approach is proposed for transition from values of the scattering and absorption coefficients $\alpha$ and $k$, calculated with scattering theory without accounting for the break of relations between linear characteristics, to real values scattering and absorption coefficients obtained from observational data $\alpha$ and $k$. 
4. Empirical formulas for estimating transformation of the volume coefficients of scattering and absorption under conditions of multiple scattering within a cloud layer

Usually, the scattering coefficient $\alpha$ (or absorption coefficient $k$) of multicomponent media is presented as the sum of scattering (or absorption) coefficients $\alpha$ of corresponding components (e.g. Minin 1981). Note the optical parameters relating to molecular component by the letter M, aerosol by letter A and droplet D. Then, the following relations are valid for the short-wavelength spectral ranges in a standard consideration:

$$
\alpha = \alpha_M + \alpha_A + \alpha_D
$$

$$
k = k_M + k_A
$$

$$
\omega_0 = \frac{\alpha}{\alpha + k}.
$$

Taking into account the mutual influence of multiple scattering and absorption of different components, empirical formulas are proposed in the papers by Melnikova (1989, 1992) and Kondratyev et al. (1997):

$$
\tilde{\alpha} = (\alpha_R + \alpha_A) \tilde{\omega}_0^{\tau_D^p} + \alpha_D
$$

$$
\tilde{k} = (k_M + k_A) \tilde{\omega}_0^{\tau_D^p}
$$

$$
\tilde{\omega}_0 = \frac{\tilde{\alpha}}{\tilde{\alpha} + \tilde{k}}.
$$

where $\omega_0$ is the single scattering albedo, $\tau_D$ and $\alpha_D$ are the optical thickness and volume scattering coefficient, caused by scattering only on droplets (they correspond to values of $\tau$ and $\alpha$ at $\lambda>0.8\mu m$ in figure 1), $\alpha_R$, $\alpha_A$, $k_M$ and $k_A$ are the values of volume scattering and absorption coefficients on molecules and aerosol particles outside droplets, known from calculations with scattering theory. The exponent $q$ accounts for a decrease in photon collisions caused by absorption. The scattering coefficient on droplets $\alpha_D$ does not have a multiplier because the transfer equation is written for one component—droplets, and the influence of the multiple scattering by droplets on the value $\alpha_D$ is accounted in the transfer equation. Call values $\tilde{\alpha}$ and $\tilde{k}$ real coefficients of scattering and absorption, and the value $\tilde{\omega}_0$ real single scattering albedo. The term $k_M \tau_D^p$ in the second relation from equation (4) does not equal zero only within molecular absorption bands; the value $\alpha_R$ is the coefficient of Rayleigh scattering at the corresponding wavelength and altitude in the atmosphere. Remember that our consideration is valid for a large optical thickness of the cloud $\tau_0\gg1$. The author has obtained earlier (Melnikova 1989, 1992) the estimation of the exponent $p=2.1$ considering numerical values of scattering coefficient and optical thickness at wavelengths, where the absorption coefficient is equal to zero (conservative scattering). This is in agreement with the above-mentioned fact: the mean number of photon collisions in the cloud for transmitted radiation is proportional to $\tau^2$ in the conservative case. Estimating the value $\tilde{\omega}_0^q$ in equations (4) from experimental data leads to the magnitude in the range from 1.0 (conservative scattering) to 0.02 (data for experiment 5 under strong radiation absorption). Also, it was revealed in studies by Melnikova (1989, 1992) that the exponent $q=\tau^2$. It is necessary to recall, that the single scattering
albedo has an evident physical meaning: the probability of survival of a photon and probabilities of independent events (acts of scattering) are multiplied for calculating the resulting probability, and the number of events is proportional to $t^2$.

Figure 2. Volume coefficients of molecular (a) scattering and (b) absorption, transformed using equations (4). Every curve presents the spectral parameter retrieved from data from airborne experiments with the corresponding number. The curve marked letter R corresponds to Rayleigh scattering at the altitude 1 km.
5. Multiple scattering of the solar radiation as a reason of the shortwave radiation absorption within clouds

Let the molecular scattering coefficient be small (∼10⁻³ km⁻¹) at wavelength λ≈0.8 so that the increase with the process of multiple scattering would be negligible. It can be thought that the difference between the value of the scattering coefficient at wavelengths λ<0.8 and its value at wavelength λ=0.8 is caused by molecular scattering together with the multiple scattering within cloud. Transformation of equation (4) for transition from real values of scattering and absorption coefficients to theoretical ones, calculated with scattering theory methods is accomplished in the following manner:

\[ \alpha_R + \alpha_A = \frac{\tilde{x} - \tilde{x}_D}{\tau_D^2 \omega_0} \]

\[ k_M + k_A = \frac{\tilde{k}}{\tau_D^2 \omega_0^5} \]

Values of [\(\alpha(\lambda)-\alpha_D\)]=[\(\alpha(\lambda)-\alpha(0.8)\)] and \(k(\lambda)\), retrieved from observed irradiance and radiance in cloudy atmosphere, have been transformed to values usually attributed to the elementary volume of turbid media (e.g. Grassl 1975, Stephens 1979) using equations (5). The spectral dependence of the volume absorption coefficient \(k(\lambda)\) and scattering coefficients \(\alpha_R + \alpha_A\), transformed using equations (5) are shown in figure 2(a, b). It can be seen that the sums of scattering coefficients of molecular atmosphere and atmospheric aerosol \(\alpha_R + \alpha_A\) in figure 2a are very similar to the spectral dependence of the Rayleigh scattering coefficient, and values of the absorption coefficient, presented in figure 2b coincide with model values calculated using scattering theory (e.g. Grassl 1975, Stephens 1979). These magnitudes correspond to single scattering albedo values, attributed to cloud media in generally accepted cloud optical models: \(\omega_0=0.99998–0.99999\) (e.g. in papers by Grassl 1975, Stephens 1979, King et al. 1995). It should be noted that after transformation, according to equations (5), the absorption bands become significantly more distinctive.
Remember also the experimental results of studies by Mayer et al. (1998), Pfeilsticker et al. (1998), Wagner et al. (1998), Pfeilsticker (1999), and Syachinov and Gorodetskii (2005), where the strong deformation of the oxygen, water vapour, and ice bands in clouds has been revealed compared with the clear atmosphere. Our data of comparison shapes of absorption bands of oxygen at wavelength 0.76 μm and water vapour at 0.82 and 0.86 μm in figures 1(b) and 2(b) approve the results of these experiments.

Values of the absorption coefficient $k$ from the molecular absorption bands in figure 1, obtained from radiative observations in papers by Melnikova (1989, 1992), Melnikova and Mikhailov (1994), Kondratyev et al. (1997), Melnikova et al. (2000), and Melnikova and Nakajima (2000) might be attributed to aerosol absorption. Transformation of these values to model values calculated using scattering theory for unit volume $k_a$ leads to magnitudes presented in table 1. Results of direct measurements in situ by Twohy et al. (1989) and results of radiation absorption measurements from Clarke (1982, 1989) are shown in the same table. From the comparison illustrated in table 1, our data retrieved from radiative experiments and then transformed with equations (5) can be seen to coincide with data from direct measurements by Waggoner et al. (1981), Clarke (1982, 1989), Twohy et al. (1989), and Boers et al. (1996).

Thus, it could be concluded that empirical relations (4) and (5) provide adequate transformation of optical parameters, obtained as a result of solving the inverse problem, from one side and theoretical values, calculated using scattering theory, from the other side.


Numerous observations of solar radiation in the last two decades have revealed that the radiation absorption within clouds reaches 20%. This value greatly exceeds the absorption in clear conditions. This phenomenon was called ‘anomalous’ absorption because it is not predicted by calculation on the basis of scattering together with transfer theories. Excessive absorption within the cloud becomes apparent in terms of radiation characteristics (the radiative divergence) in terms of optical parameters (the single scattering albedo and optical thickness). The attentive and accurate application of the scattering theory with accounting for initial restrictions exposes the reason of the ‘anomaly’. Nevertheless, optical parameters of cloud media can be simulated without accounting for restrictions of the scattering theory (e.g. Grassl 1975, Stephens 1979).

The present consideration concerns the external mixture, i.e. the case when aerosol particles are situated between the cloud droplets. When aerosol particles are situated within the droplets (the internal mixture), the aerosol absorption is correctly accounted for in calculating the formulas for a one-component medium. Based on the results obtained, one could conclude that the anomalous absorption by clouds points to the external mixture of the atmospheric aerosols and cloud droplets because in the opposite case, radiation absorption by clouds coincides with theoretical values.

Aerosols consisting of hydrophobic particles such as sand, soot, etc. could exist within the cloud between droplets with a higher probability than the hydrophilic ones (salt, sulphates); hence, they increase the shortwave absorption of radiation by cloud. Hydrophilic particles, being the nuclei of condensation, increase the droplet number. This obstacle in turn increases the cloud optical thickness and causes cloud cooling. The aerosol absorption by cloud increasing up to 15% has been
approximately estimated based on the proposed mechanism with mean values of aerosol volume absorption coefficient equal to 0.08 km$^{-1}$ and of the volume scattering coefficient equal to 30 km$^{-1}$ with geometrical thickness $\Delta z=1$ km and within the spectral range 0.4–1.0 $\mu$m. The molecular absorption within the ozone Chappuis band increases up to 6–10% for standard ozone content (Kondratyev and Varotsos 1995, 2001, Varotsos et al. 2003). The molecule absorption in oxygen band 0.76 $\mu$m increases up to 10%, which coincides with the results of the study by Dianov-Klokov et al. (1973). This effect turns out stronger for the thicker clouds, and it quantitatively explains the anomalous absorption by clouds.

The molecular absorption of solar radiation in cloudy conditions provides a certain yield, but the strong absorption shortens the photon routes in clouds, and the absorption within molecular bands does not exert a strong influence. It should be borne in mind that hydrophobic absorptive particles between droplets of optically thick clouds are necessary to form anomalous absorption.

Experimental studies by Boers et al. (1996) and Bott (1997) actually indicate the higher content of the carbonaceous and mineral compound in the atmospheric aerosols than has been assumed before, together with a significant yield for forming the radiative regime of the atmosphere. The hydrophobic particles could be injected into the atmosphere as a result of industrial emissions, sand storms, volcanic eruptions, and fires. These sources seem insufficient to explain the anomalous cloud absorption shown on a global scale, but the aerosol flue escapes extend up to 3000 km, keeping their radiation activity in the optical range (Mazin and Khrgian 1989).

### 7. Conclusion

A cloud is a synergic multicomponent turbid media including water droplets, ice crystals, and atmospheric aerosols of different morphologies and density fluctuations in the gas atmosphere. In such media, axiomatic basic relations, accepted in the scattering theory derivation (Hulst 1957, Shifrin 1951) between linear characteristics, are broken. For this reason, the radiation multiple scattering within elementary volume is necessary to account for constructing the adequate optical model and applying the summarizing rules of scattering theory.

The empirical approach proposed here for taking into account the influence of multiple scattering on the interaction between solar radiation, atmospheric aerosols, and density fluctuation provides a one-to-one correspondence between optical parameters calculated theoretically and retrieved from experimental data. Empirical formulas (4) have been derived by analysing the results of two experiments at two wavelengths. Estimations with inverse formulas (5) for whole considered spectral ranges and eight other experiments give results coinciding with data for theoretical calculations, which might be believed as an indirect validation of proposed formulas (4) and (5). It is evident that the above arguments for increasing the aerosol absorption could be applied to the case when aerosol particles are outside water droplets.

It is reasonable that the underestimation of the role of atmospheric aerosols in the process of shortwave radiation absorption within a cloud is just caused by the incorrect accounting of the multiple light scattering by molecules and aerosol particles within the elementary volume. The actively discussed question about the ‘anomalous shortwave absorption in clouds’ is explained completely by the incorrect application of the scattering and transfer theories to the cloudy multicomponent...
turbid media. The proposed empirical formulas are also convenient for correcting the initial optical cloud models in radiation blocks of climate simulations.

The effect of anomalous (or, rather, excessive) absorption significantly changes the old presentation of energy balance of the atmosphere. Academician Kirill Kondratyev has emphasized many times that wrong accounting for the absorption of radiation within a cloud at the stage of refining a climate model cause erroneous forecast of a future temperature regime.

It is reliable to suppose that the absorption of UV-radiation within clouds also adds a significant influence to the radiative regime of the atmosphere (Varotsos et al. 1995, 2001).

Finally, the author would like to point out that Kirill Kondratyev organized spectral solar radiation measurements in the atmosphere from aircraft in the 1970s and 1980s in St. Petersburg University, because as a physicist he understood the decisive role of the interaction atmosphere–solar radiation in the Earth’s radiation regime. The observational data obtained during these airborne observations form an experimental basis for our consideration. Our results show that experiment has a priority in physical problems. If theoretical modelling demonstrates disagreement with experimental data, the theory needs to be very attentively examined.

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