INFLUENCE OF CLOUDS ON THE SHORTWAVE ABSORPTION IN THE ATMOSPHERE. PART 1. ABSORPTION BY BROKEN CLOUDS

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Influence of the effects caused by random cloud geometry on the mean shortwave absorption in a cloud layer and in the entire atmosphere is studied. It is shown that the spectral absorption in broken clouds depends strongly both on the cloud type (cumulus or stratus) and on the cloud layer position in space. In the optically dense cumulus clouds the integrated absorption is a nonmonotonic function of a solar zenith angle $\xi_{\odot}$*, whereas in the stratus clouds it decreases with increasing* $\xi_{\odot}$*. The difference between the absorption by cumulus and stratus clouds is maximum at* $\xi_{\odot} \geq 60°$ *and reaches about 4% for optically dense clouds. The integrated absorption in the atmosphere* $A_{\rm atm}$ *is sensitive to the cloud top height and depends only slightly on cloud layer geometrical thickness. Typically, variations of the absorption* $A_{\rm atm}$ *by different cloud types do not exceed 1%; however, they increase up to 2–3% for intermediate cloud fractions in optically dense low-level clouds (*$\xi_{\odot} = 60°$*) and optically thin middle-level clouds (*$\xi_{\odot} \geq 75°$*).*

1. INTRODUCTION

The shortwave radiation absorbed in the atmosphere and transformed into other forms of energy is one of the main factors determining dynamic processes in the system atmosphere – underlying surface. This parameter is relatively small in magnitude (e.g., in the tropics it averages ≈ 50–60 W/m^2, i.e., ≈ 20% of the total shortwave radiation absorbed by the climatic system[1]), so even its small variations may change significantly the circulation of the atmosphere and ocean. Therefore, to improve the General Circulation Model (GCM) parametrization of physical processes, solar absorption must be known with highest possible accuracy.

Absorption in the layer (z_1, z_2), $z_1 \leq z_2$, is

$$A(z_1, z_2) = F(z_2) - F(z_1),$$

where $F(z)$ is the total flux at height z,

$$F(z) = F^{\downarrow}(z) - F^{\uparrow}(z),$$

and $F^{\downarrow}$ and $F^{\uparrow}$ are the downwelling and upwelling radiative fluxes. The problem is, that the experimental cloud absorption frequently exceeds its model estimates (anomalous absorption in clouds).[1]

Unfortunately, with the present-day understanding of the fundamental processes of cloud –radiation interaction, it is impossible to answer the question whether the absorption anomaly is due to an unknown absorber actually existing in the atmosphere or it is just the consequence of errors intrinsic in radiation measurements and/or errors in determination of the input parameters of radiation models, as well as the model inadequacy. Nonetheless, several possible causes of the cloud absorption anomaly have been formulated and studied in the literature, and the list of them (rather incomplete) is presented here together with the relevant references (but sometimes drawing different conclusions about the same cause).

Among possible reasons for the cloud absorption anomaly are:

– radiation measurement errors[2];

– effect of large cloud particles[,4];

– insufficient account for the atmospheric aerosol in model calculations[2,4];

– influence of an absorbing aerosol in the clouds[1,5];

– inadequate water-vapor parametrization in radiation models[1,6];

– neglect of horizontal inhomogeneity of real cloud fields in GCM radiation codes caused not only by variations of the liquid water content, particle size spectrum, phase composition of clouds, etc., but also by their stochastic geometry.

In 1981 an improved method for experimental data processing was proposed in Ref. 7 to bring experimental data and calculation results into fairly close agreement.[8,9] The absorption estimates were improved by accounting for the horizontal radiative transport

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caused by fluctuations of the cloud optical parameters. For inhomogeneous stratocumulus clouds, the effect of horizontal transport on the accuracy of absorption retrieval was studied by mathematical simulation in Refs. 10 and 11.

The aim of the present paper is to estimate the influence of the effects caused by random cloud geometry on the mean shortwave absorption in the atmosphere. Toward this aim, we compare calculations for cumulus and equivalent stratus clouds, which differ only in the aspect ratio $\gamma = H/D$, where H is the thickness, and D is the mean horizontal cloud size; typically, $0.5 \le \gamma \le 2$ in cumulus and $\gamma \ll 1$ in stratus. To calculate the absorption in the stratus clouds A_{St}, we used the formula

$$A_{St} = N\, A_{pp} + (1 - N)\, A_{\rm clr},$$

where N is the cloud fraction, and A_{pp} and $A_{\rm clr}$ are the values of absorption under overcast and clear-sky conditions, respectively.

The atmospheric model used in calculations was described in Refs. 12 and 13 in detail. We only recall that in the model the atmospheric top height is $H^{\rm t}_{\rm atm} = 16$ km, and the absorption by water vapor and carbon dioxide is also taken into account. Methods of spectral flux calculations in the near–IR spectral range were presented in Ref. 12.

In our previous papers,[14,15] we have already studied the mean spectral and integrated absorption of solar radiation in low-level clouds (with the base height $H^{\rm b}_{\rm cl} = 1$ km and the top height $H^{\rm t}_{\rm cl} = 1.5$ km). However, that was done for rather narrow ranges of variation of input model parameters. More recently, calculations of the mean spectral and integrated fluxes of upwelling and downwelling radiation were carried out for 12 atmospheric levels and 280 set of input model parameters. The latter were varied in the ranges:

– cloud optical depth $5 \le \tau \le 60$;

– cloud fraction $0 \le N \le 1$;

– aspect ratio $0 \le \gamma \le 2$;

– solar zenith angle $0° \le \xi_\odot \le 75°$;

– surface albedo varied from $A_{\rm s} = 0.0$ (ocean) to $A_{\rm s} = 0.8$ (fresh snow).

Based on an analysis of this greater set of calculated results, more detailed description of specific features of formation of the shortwave absorption in the broken clouds can be made.

Analogous calculations of the spectral and integrated radiative fluxes were also made for middle-level clouds with $H^{\rm b}_{\rm cl} = 5.5$ km and $H^{\rm t}_{\rm cl} = 7$ km (the cloud-top height $H^{\rm t}_{\rm cl} = 7$ km is the maximum height typical of the altocumulus and altostratus clouds[16]). We considered the joint effect of the low- and middle-level clouds in order to estimate the range of absorption variations caused by changes of such an important parameter as cloud layer position in the atmosphere.

We assume that a unit solar flux $Q^{\rm t}_{\rm atm}(\lambda) = 1$ is incident on the top of the atmosphere (TOA) in the direction $\omega_\odot = (\xi_\odot, \varphi_\odot)$, where $\xi_\odot$ and $\varphi_\odot$ are the solar zenith and azimuth angles, and λ is the wavelength. By the integrated absorption of solar radiation we mean the parameter

$$A = 100\% \frac{\int\limits_{0.4\ \mu\rm m}^{3.6\ \mu\rm m} \pi S_\lambda \cos\xi_\odot\, A(\lambda)\, {\rm d}\lambda}{\int\limits_{0.4\ \mu\rm m}^{3.6\ \mu\rm m} \pi S_\lambda \cos\xi_\odot\, {\rm d}\lambda},$$

where πS_λ is the spectral solar constant, and $A(\lambda)$ is the spectral absorptance in relative units.

2. ABSORPTION IN CLOUDS

The absorption in a cloud layer (with a fixed position in space) is studied under the following assumptions. The optical depth of beyond-cloud aerosol is, as a rule, much less than that of the clouds; therefore,

– we can neglect the absorption in the above-cloud atmosphere and consider the incident solar radiation at TOA to be independent of the cloud type;

– the difference between the absorptance in cumulus (A_{Cu}) and stratus (A_{St}) clouds is determined by multiple scattering effects in the clouds.[15]

Spectral absorptance. We will consider the dependence of the spectral absorptance $A(\lambda)$ on the solar zenith angle $\xi_\odot$ for different types of low- and middle-level clouds.

As $\xi_\odot$ increases, (1) the fraction of the diffuse radiation increases, while (2) the solar radiation incident at TOA decreases (because the above-cloud aerosol extinction and the atmospheric gaseous absorption increase), and the cloud albedo increases[15]; therefore, the absorption in cumulus depends on two opposite factors.

Let $A_{\rm s} = 0$. As $\xi_\odot$ increases from 0 to $\approx 60°$, in weak absorption bands of water vapor (0.71–0.76, 0.81 μm) and in spectral intervals between H_2O absorption bands, the first factor dominates; so the absorptance $A_{Cu}(\lambda)$ increases irrespective of the cloud position in space (Fig. 1*a*). As $\xi_\odot$ increases further, the second factor becomes more significant, and $A_{Cu}(\lambda)$ decreases.

For moderate to strong water vapor absorption, the influence of the second factor on $\xi_\odot$ dependence of $A(\lambda)$ is largely determined by the top height of the cloud layer. For low-level clouds, absorptance $A^{\rm low}_{Cu}(\lambda)$ in the H_2O absorption bands centered at 1.38, 1.87, and 2.7–3.2 μm, is close to zero for all solar zenith angles. In middle-level clouds, in contrast with the low-level clouds, the solar radiation incident at TOA is attenuated insignificantly, while the fraction of the diffuse radiation increases substantially as $\xi_\odot$ increases from 0 to $\approx 60°$; so $A^{\rm mid}_{Cu}(\lambda)$ increases not only in weak, but also in moderate H_2O absorption bands centered at 0.94, 1.1, 1.38, and 1.87 μm. For $\xi_\odot \ge 60°$, the second factor dominates;

therefore, $A_{Cu}^{\mathrm{mid}}(\lambda)$ decreases. In the 2.7–3.2-μm water vapor absorption band, $A_{Cu}^{\mathrm{mid}}(\lambda)$ is a monotonically decreasing function of $\xi_{\odot}$.

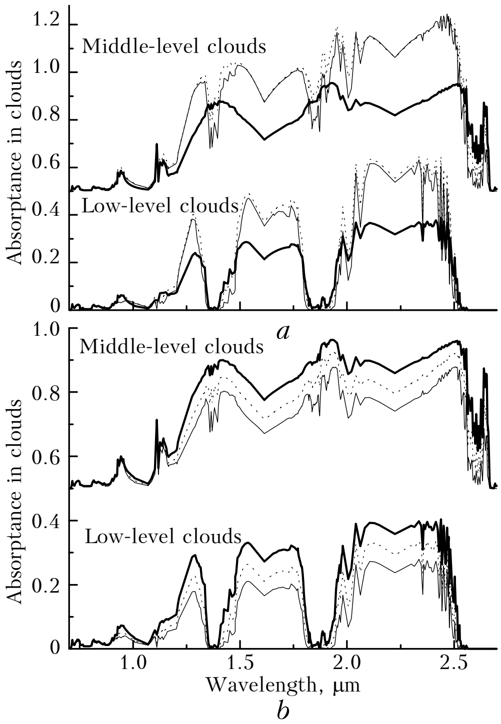

FIG. 1. Spectral absorptance in cumulus (a) and stratus (b) clouds versus the solar zenith angle for $N = 0.5$, $\gamma = 2$, $\tau_{0.71\,\mu m} = 60$, and $A_s = 0.0$: $\xi_{\odot} = 0$ *(bold curve),* 60 *(dashed curve),* and 75° *(solid curve). Absorptance values for middle-level clouds are exaggerated by* 0.5 *for clarity.*

In contrast with cumulus, the fraction of the diffuse radiation in stratus clouds changes insignificantly with increasing $\xi_{\odot}$, provided that the solar zenith angle $\xi_{\odot} < 80°$. Therefore, $A_{St}(\lambda)$ decreases with increasing $\xi_{\odot}$ irrespective of the cloud position in space (Fig. 1*b*). In the H_2O absorption bands for $\lambda > 1$ μm, $A_{Cu}^{\mathrm{mid}}(\lambda)$ substantially exceeds $A_{Cu}^{\mathrm{mid}}(\lambda)$, as in case of cumulus.

Integrated absorptance. It follows from the results of the previous section that the spectral absorptance in clouds depends on the cloud type and position in the atmosphere. How much do these factors influence the integrated cloud absorptance?

Water vapor is the major gaseous absorber of the shortwave radiation; therefore, its concentration influences substantially the value of atmospheric absorptance in this spectral range. For our atmospheric model (midlatitudes in summer[17]), the liquid water content of individual atmospheric layers

$$W(H_1, H_2) = \int_{H_1}^{H_2} \rho(h)\, \mathrm{d}h,$$

where $\rho(h)$ is the water vapor concentration, is distributed in space as follows.

TABLE I. Liquid water content of separate atmospheric layers (midlatitudes in summer), in g/cm².

Cloud position in space	Above-cloud atmosphere $W(H_{\mathrm{cl}}^{\mathrm{t}}, H_{\mathrm{atm}}^{\mathrm{t}})$	Cloud layer $W(H_{\mathrm{cl}}^{\mathrm{b}}, H_{\mathrm{cl}}^{\mathrm{t}})$	Subcloud atmosphere $W(0, H_{\mathrm{cl}}^{\mathrm{b}})$
Low level: $H_{\mathrm{cl}}^{\mathrm{b}} = 1$ km, $H_{\mathrm{cl}}^{\mathrm{t}} = 1.5$ km	1.39	0.339	0.864
Middle level: $H_{\mathrm{cl}}^{\mathrm{b}} = 5.5$ km, $H_{\mathrm{cl}}^{\mathrm{t}} = 7$ km	0.036	0.087	2.47

Let $A_s = 0$. It might be expected that, for fixed optical and geometrical cloud parameters and solar zenith angle, the absorptance in clouds (A_{cl}) increases, when the liquid water content in the above-cloud atmosphere decreases (factor 1) and increases in the cloud layer (factor 2). From Table I it follows that going from low- to middle-level clouds (for indicated cloud top and bottom heights), the liquid water content decreases in above-cloud atmosphere and the cloud layer. This means that the factors 1 and 2 make opposite contributions to A_{cl}, and the relationship between the low- ($A_{\mathrm{cl}}^{\mathrm{low}}$) and middle-level ($A_{\mathrm{cl}}^{\mathrm{mid}}$) cloud absorption depends on dominating factor.

Our calculations show that $A_{\mathrm{cl}}^{\mathrm{mid}} > A_{\mathrm{cl}}^{\mathrm{low}}$ (Fig. 2); this agrees with the results of Ref. 18 and indicates that the decrease of the liquid water content in the above-cloud atmosphere $W(H_{\mathrm{cl}}^{\mathrm{t}}, H_{\mathrm{atm}}^{\mathrm{t}})$ has a stronger effect on A_{cl} than the increase of the liquid water content in the cloud layer $W(H_{\mathrm{cl}}^{\mathrm{b}}, H_{\mathrm{cl}}^{\mathrm{t}})$, possibly because within the cloud layer the water drop absorption dominates over the water vapor absorption.[18]

At the same time, our results (as well as the results of other authors discussed in Ref. 18) differ from findings of Ref. 19 that in clouds the water drops absorb nearly as strong as the water vapor and A_{cl} depends weakly on the cloud top height.

Now we discuss the dependence of cloud absorption on the solar zenith angle. The variations of the integrated cloud absorptance are completely determined by the dependence of spectral absorption on the input model parameters, so in some obvious cases we proceed without giving detailed explanation.

Let $A_s = 0$. As the solar zenith angle increases from $\xi_{\odot} = 0°$ to $\xi_{\odot} = 75°$, A_{St} for optically dense stratus clouds ($\tau = 60$) decreases by a factor of approximately 1.5. When $0 \le \xi_{\odot} \le 75°$, A_{St} in optically thin clouds ($\tau = 5$) varies insignificantly, by no more than 1% for low- and middle-level clouds (see Fig. 2).

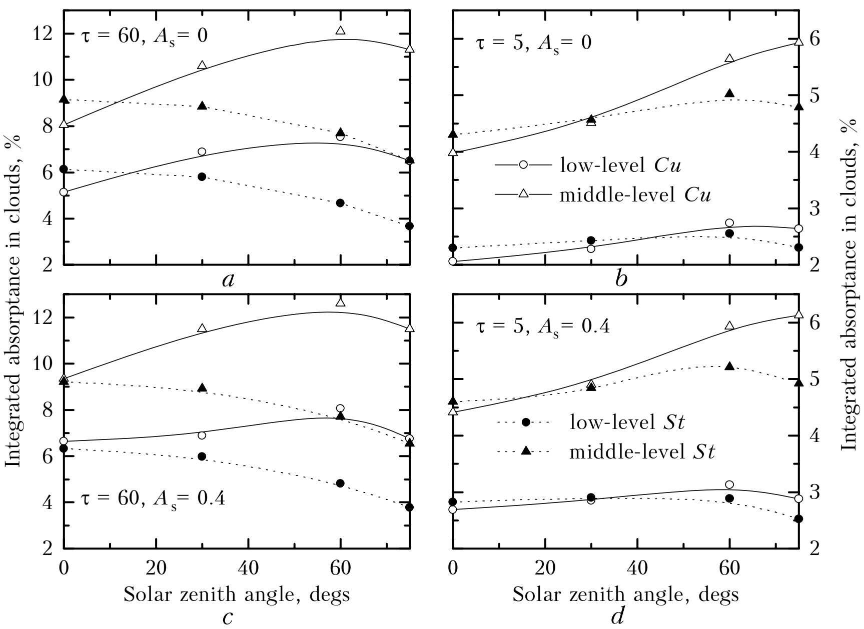

FIG. 2. Influence of the solar zenith angle on the integrated absorptance in low- and middle-level clouds for $N = 0.5$, $\gamma = 2$, *and different values of the surface albedo* A_s *and cloud optical thickness* τ.

In optically dense cumulus, in contrast to the stratus, the absorptance is not a monotonic function of $\xi_\odot$: A_{Cu} increases as $\xi_\odot$ increases up to $\tilde{\xi}_\odot \approx 60°$ and then decreases with increasing albedo of the cloud layer. In optically thin clouds, the albedo is small and hence its increase with $\xi_\odot$ in the range $0 \le \xi_\odot \le 75°$ will have weaker influence on the cloud absorptance. Indeed, at $\tau = 5$, $A^{\rm mid}_{Cu}$ is an increasing function of $\xi_\odot$, while $A^{\rm low}_{Cu}$ changes within 1 % (Figs. 2*a* and *b*).

The dependence of the absorptance on the cloud type for varying $\xi_\odot$ has been discussed elsewhere[15]; so it is not considered here. We only note that the maximum difference between A_{Cu} and A_{St} takes place for optically thick clouds when $\xi_\odot \ge 60°$; its value is ≈ 4% for middle- and ≈ 2% for low-level clouds. For optically thin clouds, the difference between A_{Cu} and A_{St} reduces to ≈ 1–1.5%.

As A_s increases, the absorptance in stratus clouds changes insignificantly, by no more than 1% (Figs. 2*c* and *d*). In optically thick cumulus clouds, the increase of A_s causes the increase of A_{Cu} for $\xi_\odot = 0$ (Ref. 15); noteworthy, the increase of A_{Cu} may be larger in low-level clouds than in middle-level clouds. This is because the higher the cloud bottom boundary, the stronger is the attenuation of radiation reflected from the underlying surface and reaching the cloud layer and hence the smaller is the fraction of radiation absorbed in the cloud.

3. ABSORPTION IN THE CLOUDY ATMOSPHERE

The change of the atmospheric absorptance ($A_{\rm atm}$) due to occurrence of overcast clouds with varying optical depth and position in space for different solar zenith angles was discussed in detail elsewhere.[20] Here, we study these peculiarities for the broken clouds. We calculated an array of upwelling and downwelling radiative fluxes, which allowed us to estimate how much the atmospheric absorptance depends on the cloud type (cumulus $A^{Cu}_{\rm atm}$ and stratus $A^{St}_{\rm atm}$) and what are the input model parameters for which this dependence is the strongest.

In Fig. 3, the difference $(A^{Cu}_{\rm atm} - A^{St}_{\rm atm})$ is plotted versus $A^{St}_{\rm atm}$ for low- and middle-level clouds at $A_s = 0$. From the figure it follows that, independent of the cloud position in space, the cloud type has insignificant influence on the atmospheric absorptance: for a wide range of variations of cloud parameters and illumination conditions, the difference $|A^{Cu}_{\rm atm} - A^{St}_{\rm atm}|$ does not exceed 1% (this agrees with earlier findings[15] for low-level clouds). The largest difference (≈ 2–3%) between $A^{Cu}_{\rm atm}$ and $A^{St}_{\rm atm}$ takes place for intermediate cloud fractions at the highest (among those used in the calculations) aspect ratio $\gamma = 2$ for

– optically thick ($\tau \ge 30$) low-level clouds at $\xi_\odot \approx 60°$;

– optically thin ($\tau = 5$) middle-level clouds at large solar zenith angles $\xi_\odot \ge 75°$. As the surface albedo increases up to $A_s = 0.4$, the difference between $A^{Cu}_{\rm atm}$ and $A^{St}_{\rm atm}$ changes insignificantly.

We now turn to the question of how clear-sky absorption $A^{\rm clr}_{\rm atm}$ changes in response to occurrence of different types of low– ($A^{\rm low}_{\rm atm}$) and middle– ($A^{\rm mid}_{\rm atm}$) level clouds (Fig. 4).

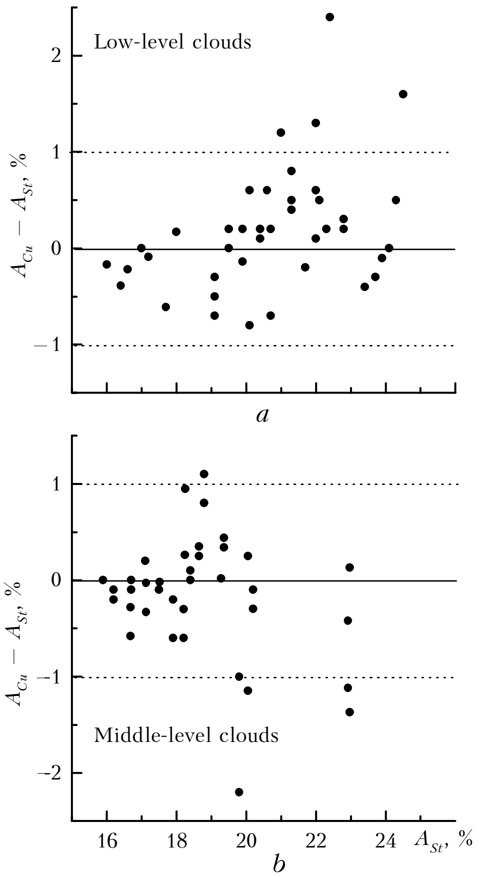

FIG. 3. Difference between the cumulus and stratus cloud absorptance ($A_{Cu} - A_{St}$) versus A_{St} for A_s = 0.0.

In the presence of low-level clouds, $A_{\rm atm}^{\rm low}$ is determined mainly by the absorptance in the above-cloud atmosphere, its relative contribution to $A_{\rm atm}^{\rm low}$ is ≈ 60–90%, depending on the input model parameters. Because the absorptance in the above-cloud atmosphere increases with increasing $\xi_\odot$, so does $A_{\rm atm}^{\rm low}$, irrespective of the cloud type.

At $\xi_\odot = 0°$, the inequality $A_{\rm atm}^{\rm low} > A_{\rm atm}^{\rm clr}$ holds true. As $\xi_\odot$ increases, the absorptance in optically thin clouds remains practically unchanged (see Fig. 2); as a result, the difference between $A_{\rm atm}^{\rm low}$ and $A_{\rm atm}^{\rm clr}$ decreases and hence at certain $\xi_\odot \ge \tilde{\xi}_\odot$, the inequality may reverse: $A_{\rm atm}^{\rm low} \le A_{\rm atm}^{\rm clr}$. For the entire range of variation of $\xi_\odot$ and $0 \le A_s \le 0.4$, the difference between $A_{\rm atm}^{\rm low}$ and $A_{\rm atm}^{\rm clr}$ does not exceed 2%. When optically thick clouds ($\tau = 60$) occur in the atmosphere, the absorptance increases for all solar zenith angles in the range $0 \le \xi_\odot \le 75°$. The maximum difference, between $A_{\rm atm}^{\rm low}$ and $A_{\rm atm}^{\rm clr}$ occurs for $\xi_\odot = 0°$; it equals to ≈ 5% at $N = 0.5$ and increases to ≈ 9–10% at $N = 1$.

The absorption in the atmosphere containing middle-level clouds differs from that in the low-cloud case. Specifically, the fraction of radiation absorbed in the above-cloud atmosphere $A_{\rm atm}^{\rm mid}$ decreases to ≈ 20–30%, whereas the clouds and the subcloud atmosphere accordingly become more absorptive; therefore, they may influence the total atmospheric absorption stronger than low-level clouds.

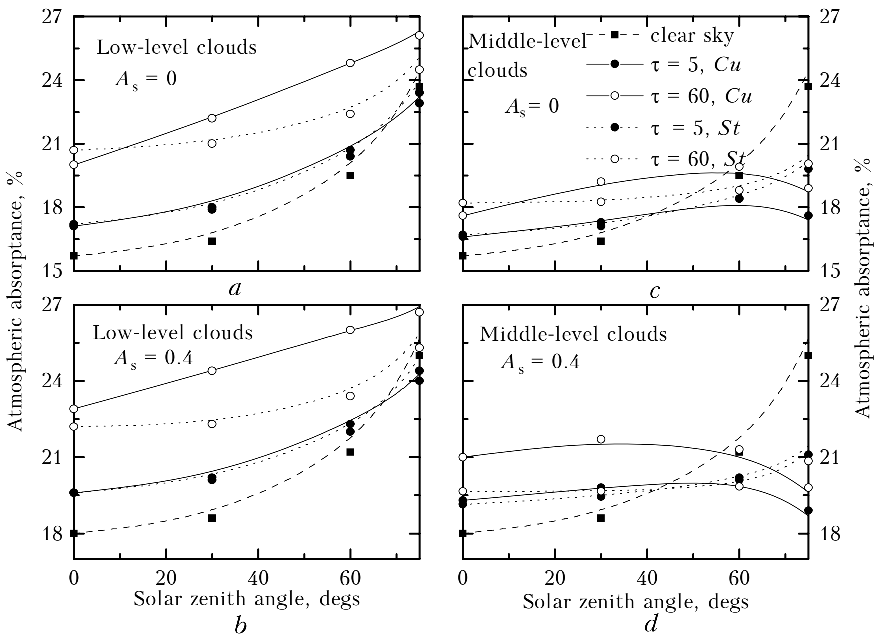

FIG. 4. Integrated atmospheric absorptance by clear sky and low- and middle-level cumulus ($\gamma = 2$) *and stratus clouds for* $N = 0.5$ *and different values of the surface albedo* A_s *and cloud optical thickness* τ.

In the presence of stratus clouds, A_{atm}^{mid}, like A_{atm}^{low}, increases with increasing solar zenith angle, but, by a less amount than for low-level stratus clouds. In cumulus clouds, the downwelling flux at the cloud base level (and hence the absorption in the subcloud atmosphere) substantially decreases with increasing $\xi_\odot$, and the absorption within the cloudy layer depends nonmonotonically on $\xi_\odot$. Together, these factors compensate for the increase of the absorptance in the above-cloud atmosphere with insignificant net change of A_{atm}^{mid}. This is why the inequality $A_{atm}^{mid} > A_{atm}^{clr}$, valid when $\xi_\odot < \tilde{\xi}_\odot$, reverses when $\xi_\odot > \tilde{\xi}_\odot$ (with $\tilde{\xi}_\odot$ value ranging between 40° and 60°, depending on the cloud type and the input model parameters). The largest difference between A_{atm}^{mid} and A_{atm}^{clr} occurs for $\xi_\odot = 75°$ and reaches ≈ 4% for stratus and ≈ 6% for cumulus clouds at intermediate cloud fractions N. Under overcast cloud conditions, this difference increases to 7–8%.

In the above discussion, we have considered the shortwave absorption in clouds and the entire atmosphere for two fixed cloud positions in space. Therefore, the relevant question arises: which of the two factors dominates? To clarify the matter, we additionally performed radiation calculations for the cloud layer with a fixed top height and variable geometrical thickness.

TABLE II. Dependence of the shortwave absorptance on the spatial position of cumulus clouds for $N = 0.5$, $\gamma = 2$, *and* $A_S = 0$. *Nominators give the absorptance in the entire atmosphere, and denominators give the cloud absorption* (%).

Input parameters	H_{cl}^{t} = 1.5 km		H_{cl}^{t} = 7 km		
	H_{cl}^{b}, km				
	0.5	1	3	5.5	6.5
$\tau = 5$, $\xi_\odot = 0°$	16.8/2.8	17.1/2.1	16.8/8.0	16.6/4.0	16.5/2.8
$\tau = 5$, $\xi_\odot = 60°$	20.4/3.6	20.7/2.7	19.2/9.8	18.4/5.6	18.1/4.4
$\tau = 5$, $\xi_\odot = 75°$	22.8/3.3	22.9/2.6	19.0/9.8	17.6/5.9	17.3/4.9
$\tau = 60$, $\xi_\odot = 0°$	20.0/5.9	20.0/5.1	18.2/11.2	17.6/8.1	17.5/7.2
$\tau = 60$, $\xi_\odot = 60°$	24.8/8.0	24.8/7.5	20.9/14.5	19.9/12.1	19.7/11.5
$\tau = 60$, $\xi_\odot = 75°$	26.2/6.9	26.1/6.5	20.1/13.3	18.9/11.3	18.7/10.9

The obtained results are partially presented in Table II; they show that the atmospheric absorptance depends weakly on the cloud geometrical thickness and is primarily determined by the cloud top height: variations of A_{atm} due to changes of the cloud base height usually do not exceed 1%, slightly increasing for large cloud geometrical thickness (4 km) and $\xi_\odot \geq 75°$. The cloud absorptance depends substantially not only on the cloud top, but also on the cloud bottom heights. For instance, as middle-level clouds increase their geometrical thickness from 0.5 to 4 km, A_{cl} may increase by a factor of ≈ 1.5–2, probably because of the increase of water vapor contribution to the cloud layer absorptance. Noteworthy, as cloud geometrical thickness varies, the dependence of A_{cl} on the cloud optical depth and solar zenith angle remains qualitatively the same.

4. CONCLUSION

In this paper, we have studied the absorption by low- and middle-level broken clouds and the entire atmosphere. It has been shown that:

– the spectral absorptance in clouds depends on the cloud type and the cloud position in space;

– integrated absorptance in the optically thick low- and middle-level cumulus is a nonmonotonic function of the solar zenith angle, whereas the absorptance by stratus decreases with increasing $\xi_\odot$. When $\xi_\odot$ varies, the absorptance in optically thin low-level clouds and middle-level stratus clouds changes insignificantly, whereas the absorptance in middle-level cumulus slowly increases as $\xi_\odot$ increases from 0 to 75°;

– absorptance in cumulus and stratus differs most for $\xi_\odot \geq 60°$ and the difference may reach ≈ 4% for optically thick clouds.

The absorption in the atmosphere depends upon the position of the cloud top boundary, and changes insignificantly as the cloud geometrical thickness varies. Also,

– *low-level* clouds mostly increase the atmospheric absorptance relative to its clear-sky value, unless they are optically thin and $\xi_\odot \geq 70°$. In this case, the inequality $A_{atm}^{low} \leq A_{atm}^{clr}$ may hold;

– at $\xi_\odot = 0°$, *middle-level* clouds increase the atmospheric absorptance above its clear-sky value, so that $A_{atm}^{mid} \geq A_{atm}^{clr}$; this inequality reverses to $A_{atm}^{mid} \leq A_{atm}^{clr}$ for $\xi_\odot \geq \tilde{\xi}_\odot$.

The random cloud geometry has insignificant influence on the atmospheric absorptance: difference in A_{atm} caused by the cloud types (cumulus or stratus) normally does not exceed 1%. This difference increases somewhat (to 2–3%) at intermediate cloud fractions and $\gamma=2$ for optically thick low-level clouds ($\xi_\odot \approx 60°$) and optically thin middle-level clouds ($\xi_\odot \geq 75°$). Optically thick low-level cumulus and optically thin altocumulus clouds are fairly typical of midlatitudes; therefore, the neglect of cloud random geometry may result in the underestimate or, correspondingly, overestimate of the atmospheric absorptance by 2–3%. This, in turn, decreases the accuracy of calculation of atmospheric thermal regime and hence the performance of models of cloud formation, climate, and atmospheric general circulation used to simulate cloud formation and dynamics.

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