The Effects of Arctic Stratus Clouds on the Solar Energy Budget in the Atmosphere-Sea Ice-Ocean System

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Radiative Transfer Model

We have developed a comprehensive radiative transfer model pertinent to the atmosphere-sea ice-ocean system (Jin and Stamnes 1994; Jin et al., in press). The main features of the newly-developed radiative transfer model include:

- The atmosphere, sea ice, and ocean each represented by a sufficient number of layers to resolve the change in the optical properties of each stratum.
- An appropriate quadrature structure to take into account the refraction and the total reflection at the air-ice or air-water interface, as well as to solve the radiative transfer equation in the coupled system consistently.
- Provision for a different number of streams (quadrature points) in the atmosphere, ice, and ocean, chosen based on the optical properties in each stratum and the computational accuracy required.

In the atmosphere, the gaseous absorption over a spectral region containing many absorption lines is parameterized and implemented by a suitable band model (Wiscombe and Evans 1977). The optical properties of clouds are parameterized in terms of liquid water content and equivalent radius (Tsay et al. 1989).

In the ice, the processes considered include the pure ice absorption, scattering, and absorption by brine pockets and air bubbles. The volume amounts of the trapped brine and gas in the ice are linked to the temperature, density, and salinity of the ice (Cox and Weeks 1983). The optical properties of the inclusions in the ice are then obtained through Mie computations.

In the ocean, the scattering and absorption by sea water and by particulate material (phytoplankton and their derivative) have been taken into account.

Results and Conclusions

In the following computations, the profiles of air density and absorbing gases were taken from the McClatchey atmosphere model (McClatchey et al. 1972). The base of the stratus clouds is set at a height of 600 m with thickness of 400 m. The sea ice thickness is specified to be 1 m unless otherwise indicated. The ice surface temperature is specified to be -10°C and linearly increased to -2°C at the ice base. In the ocean, we neglect the vertical variation in the properties of sea water and consider it as one homogeneous layer. The solar radiation is integrated over the 24 spectral bands between the wavelength region of 0.25 µm to 4.0 µm and the solar elevation is specified to be 30°.

Figures 1 and 2 show the effects of the equivalent radius and liquid water content of clouds on the outgoing shortwave energy at the top of atmosphere, the incident and reflected solar energy at the ice surface, and the flux transmitted to the ocean. The results indicate that the outgoing flux will decrease as the equivalent radius increases, but increase as the liquid water content increases for the cloud model

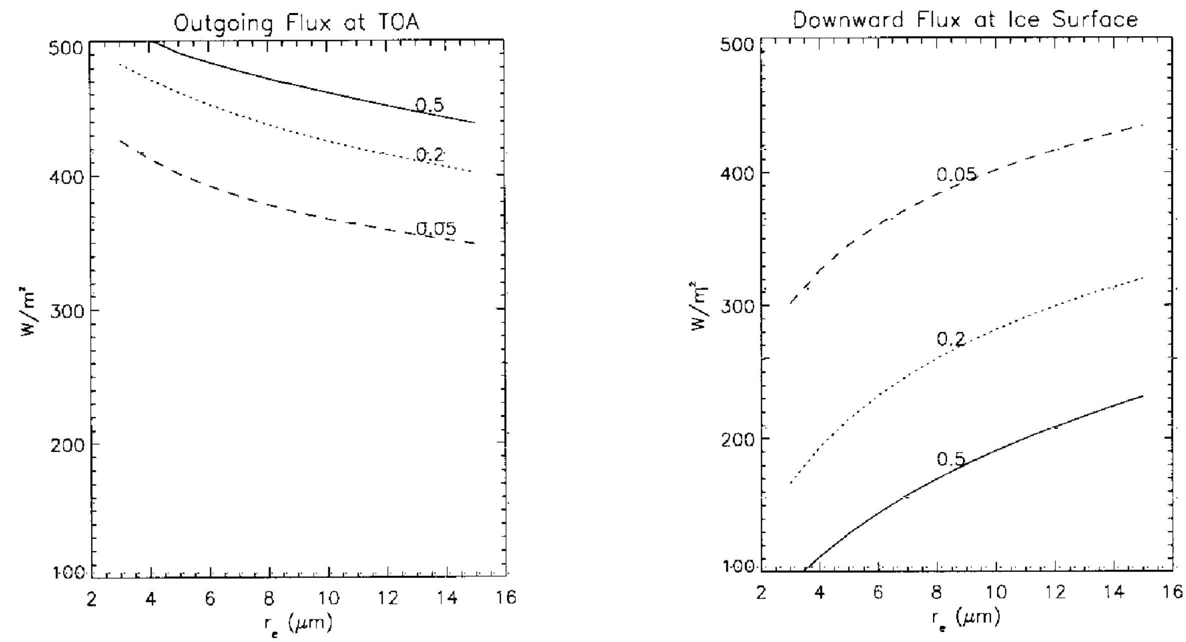

Figure 1. Shortwave flux as a function of the equivalent radius of cloud droplets: a) outgoing flux at the top of atmosphere; b) downward flux at the ice surface. Labels represent the liquid water content of the cloud.

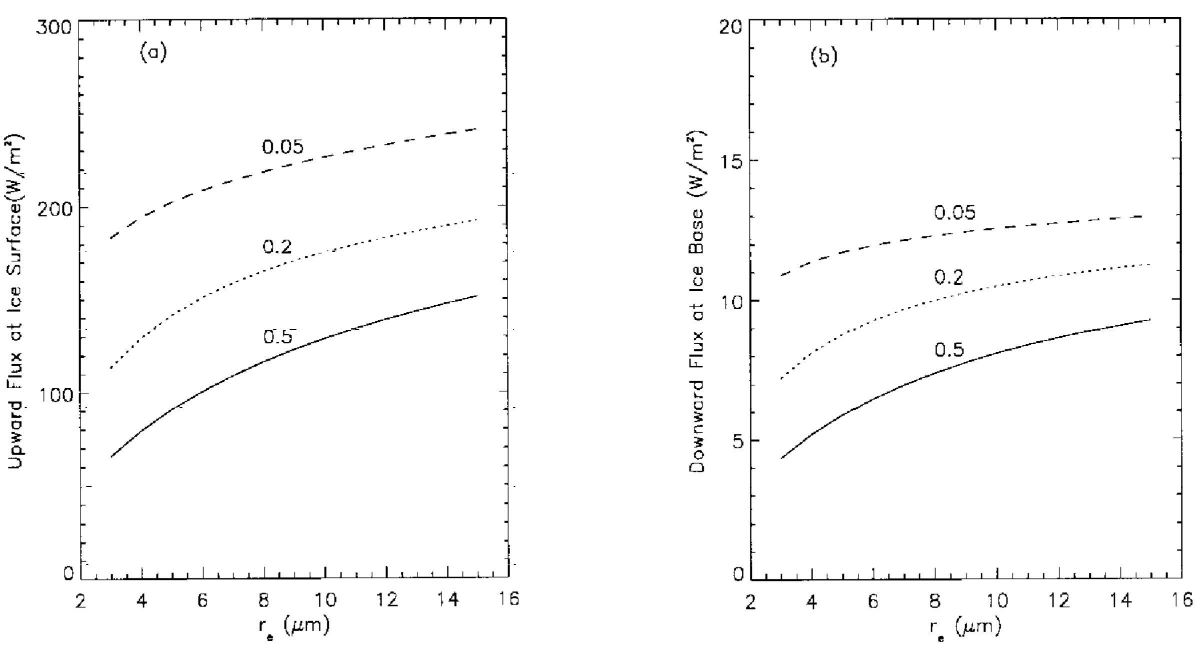

Figure 2. Shortwave flux as a function of the equivalent radius of the cloud droplets: a) upward flux at the ice surface; b) downward flux at the ice bottom (input flux to the ocean). Labels represent the liquid water content of cloud.

used here. Consequently, the downward and upward fluxes at the surface exhibit opposite dependencies on the microphysics of the clouds as compared with the outgoing flux. The flux under the 1-m thick ice is relatively small.

Figure 3 shows the dependence of the solar energy disposition in the atmosphere-sea ice-ocean system on cloud microphysics. It indicates that the absorption in the atmosphere, sea ice, and ocean will increase as the equivalent radius of the cloud increases. On the other hand, absorption in the ice and ocean decreases as the liquid water content increases, but the absorption in the atmosphere exhibits the opposite dependence. The combined effect is that the total absorption in the entire system will decrease as the liquid water content increases. Moreover, the absorption in sea ice shows great sensitivity to both the equivalent radius and the liquid water content of clouds.

Figure 4 shows the effects of clouds on the total system albedo and surface albedo. Both of the albedos, especially the system albedo, demonstrate a high sensitivity to the liquid water path of the clouds, especially when the liquid water path is low.

Figure 5 shows the distribution of the absorbed solar radiation as a function of ice thickness under the clear sky and the cloudy sky conditions, respectively. Comparison of the two panels in this figure shows that not only does the cloud drastically reduce the energy absorption in the ice and the whole system for any thickness and into the ocean for thin ice, it also significantly reduces all sensitivities of the absorbed solar energy to the ice thickness, especially when the ice is thin.

References

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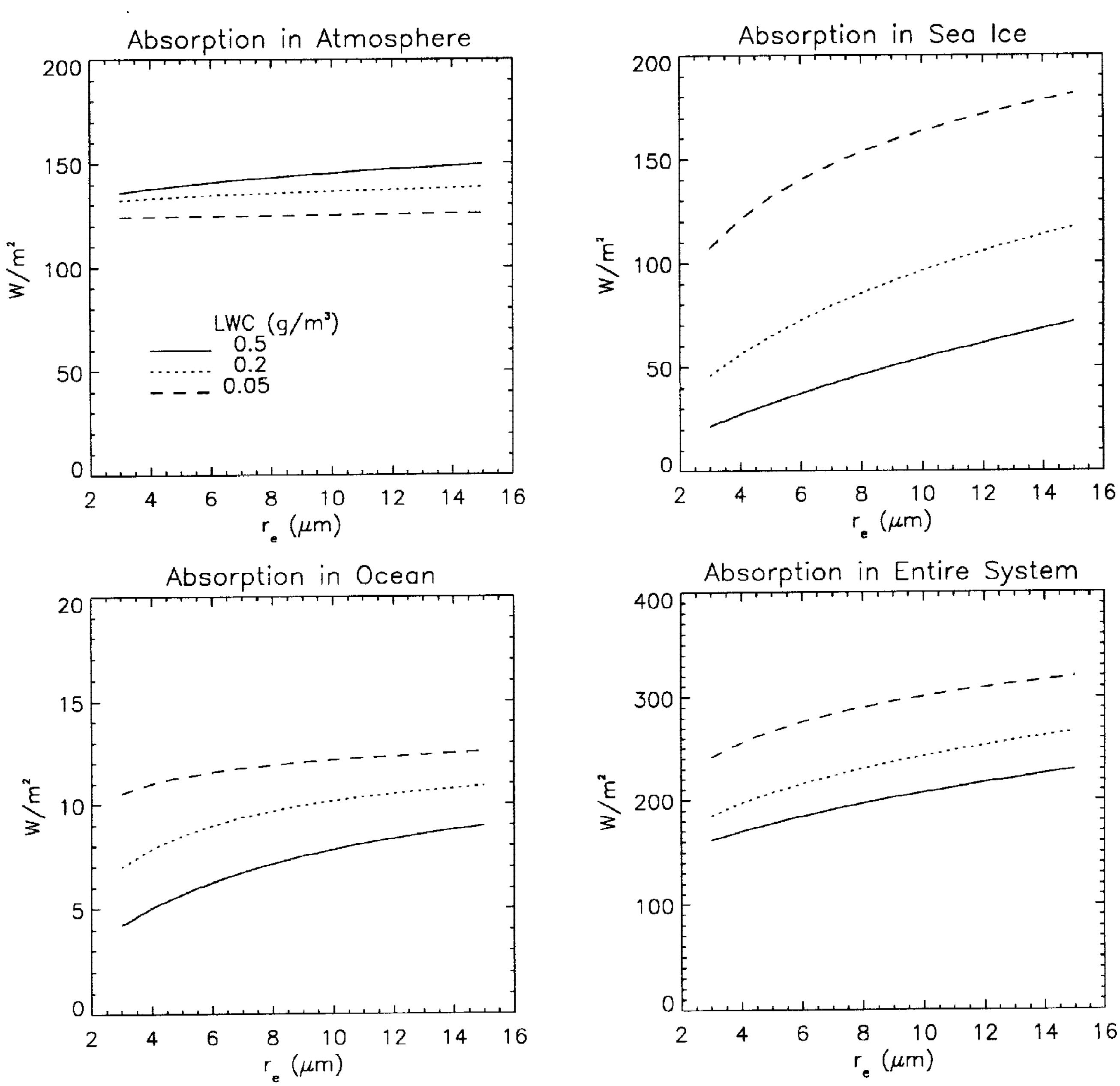

Figure 3. Absorption of solar radiation in various layers as a function of cloud equivalent radius.

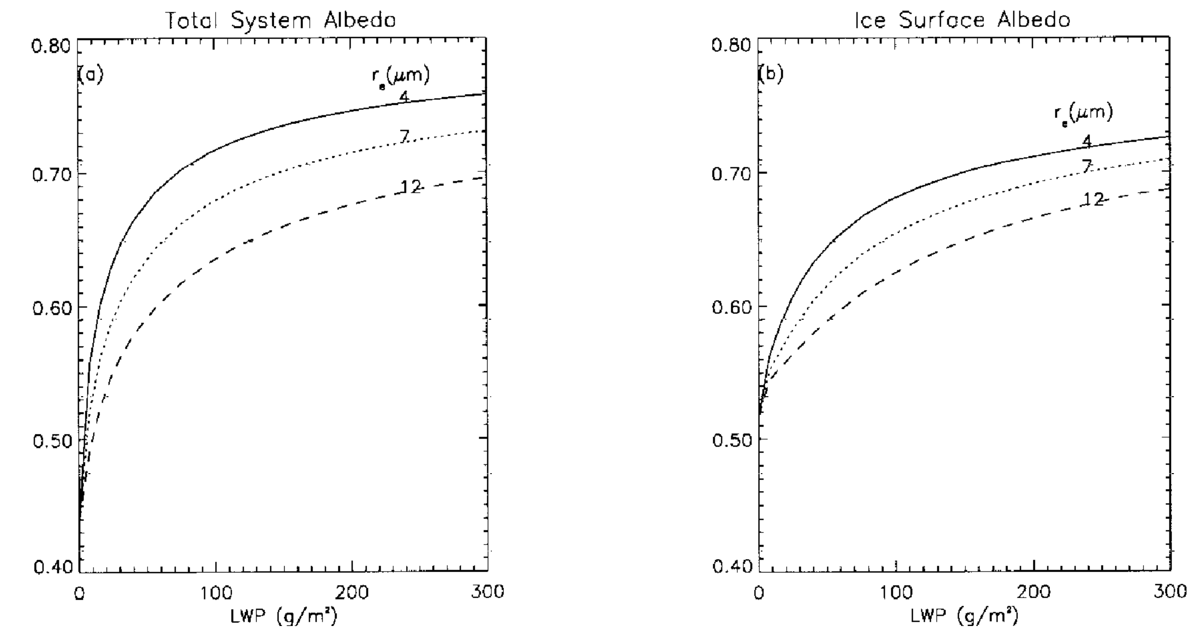

Figure 4. The total system albedo and the ice surface albedo as a function of cloud liquid water path (LWP). Labels represent the equivalent radii of clouds.

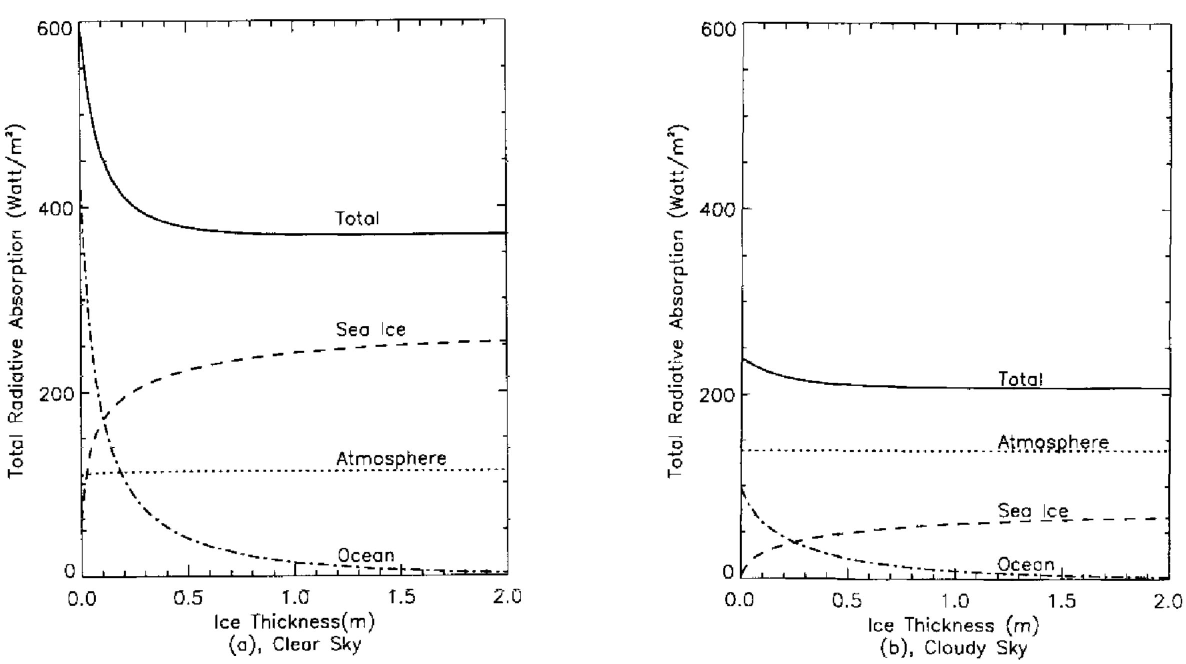

Figure 5. The distribution of total solar radiative absorption in the atmosphere, sea ice, and ocean system as a function of the ice thickness: a) under a clear sky; b) under a cloudy sky.