NOTES AND CORRESPONDENCE

Sensitivity of Surface Solar Fluxes to Cloud Parameterization

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27 April 1987 and 31 August 1987

ABSTRACT

Experiments were performed to examine the sensitivity of computed solar fluxes using a delta-Eddington model to recent parameterizations of cloud albedo of single scattering and asymmetry factor. In particular, the changes in the surface downward solar flux, the planetary albedo and the atmospheric shortwave absorption were investigated as a function of two parameterizations of cloud NIR albedo of single scattering and cloud asymmetry factor. It was shown that the computed downward solar fluxes could differ by as much as 37 W m^{-2} due to changes in cloud parameterization alone.

1. Introduction

Surface radiation budget (SRB) is becoming perceived as an important climate parameter owing to the role it plays in geophysical problems that involve surface–atmosphere interactions and validation of radiation parameterizations used in climate models (Ramanathan, 1985). Pinker and Ewing (1985) formulated a model for computing global solar radiation at the surface from satellite observations. They utilized the cloud parameterization as suggested by Stephens (1978). Stephens' parameterization was subsequently modified by Stephens et al. (1984).

This paper describes results of several experiments intended to test the sensitivity of the model calculated solar fluxes to parameterizations used for cloud NIR albedo of single scattering, ω, and cloud asymmetry factor g. The fluxes were computed at the surface, at the top of the atmosphere and absorbed in the atmosphere. Specifically, the following aspects were investigated: the effect of changing cloud NIR ω from the parameterization of Stephens (1978) to that of Stephens et al. (1984); the effects of changing cloud g from the commonly assumed wavelength independent value of 0.85 (Hansen and Pollack, 1970) to a parameterization based on the values of backscattering coefficients of Stephens et al. (1984). The model atmosphere and the radiative transfer model used are briefly reviewed in section 2. The two versions of the cloud parameterization used are described in section 3. The computational results are discussed in section 4 and the conclusions are summarized in section 5.

2. Model used

The sensitivity studies were performed with a model formulated by Pinker and Ewing (1985) for the computation of global solar radiation at the surface from satellite observations. In the model a three-layer atmosphere was assumed; a radiative transfer model based on the delta-Eddington approximation (Joseph et al., 1976) was used; and the solar spectrum was split into four spectral intervals in the region of ($\lambda < 0.7$ μm), and eight nonspectral intervals in the NIR ($0.7 \leqslant \lambda \leqslant 4.0$ μm). The nonspectral NIR intervals were such that the total water vapor absorption may be represented as a sum of exponentials (Lacis and Hansen, 1974), where each exponential term contains a water vapor optical thickness appropriate for one of the intervals. Rayleigh scattering was taken into account for the four spectral intervals representing the visible and UV parts of the spectrum using the formulations of Margraff and Griggs (1969). The McClatchey et al. (1972) "clear" aerosol model was assumed and the aerosol extinction coefficients, ω, and g were taken from Leighton (1980), who computed these values for each of the four spectral regions and also for the NIR. The precipitable water was kept constant in all experiments and set to be 2.0 cm. The surface albedo was also kept constant at a value of 0.20. Clouds were assumed to be nonabsorbant in the visible and UV regions. Cloud optical thickness τ was specified, and an assumption regarding the cloud NIR ω and cloud g was made as discussed in section 3.

For each layer, the values of τ, ω and g were combined to obtain a composite value. Calculation of surface global flux (direct and diffuse), upward flux at the top of the atmosphere and the atmospheric absorption, for different cloud assumptions were performed.

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3. Stephen's parameterizations

Stephens (1978a) performed calculations of cloud reflection, absorption, and transmission with a detailed radiative transfer model for eight cloud types. These computations give reflection and transmission through absorbing and nonabsorbing media as a function of single scattering albedo, ω, backscatter fraction, B, optical thickness, τ, and cosine of solar zenith angle, μ. They obtained the VIS B, NIR B and NIR ω for eight cloud types for various zenith angles and cloud optical thickness. These values were then averaged for all cloud types to yield tables of the three desired parameters as empirical functions of zenith angle and cloud optical thickness. Cloud g was obtained from cloud B using

$$g = 1 - 2B. \qquad (1)$$

Stephens et al., (1984) revised the work of Stephens (1978) to adjust the cloud absorption, primarily at large zenith angles, and to provide albedos and absorptions which were smooth functions of ω and μ. The changes in the NIR ω were such that the ω were made to be larger on the average. Under most zenith angle/optical thickness conditions, using the new values would produce less absorption. The changes in the backscattering coefficients were minor. The average of all the visible and UV cloud g's from the 1984 VIS B table is 0.869; the corresponding NIR B average is 0.890.

4. Computational results

a. *Effect of changing parameterization of cloud NIR ω*

This section describes results of simulations conducted to assess the effect of changing cloud NIR parameterization of ω from the 1978 to the 1984 values on downward surface and upward top of the atmosphere solar fluxes and on the absorbed solar flux. Calculations were performed for a variety of solar zenith angles and cloud optical thickness, assuming $g = 0.85$ throughout the solar spectrum. The zenith angles ranged from 0 to 80 deg in steps of 20 deg, and the cloud optical thickness assumed the following values: 0.1, 0.5, 1, 5, 10, 50 and 100. The results are shown for the downward and absorbed solar flux only (Figs. 1–2). The 1984 parameterization generally yields an increase in the downward surface flux and upward flux at the top of the atmosphere due to less cloud absorption. The effect of the change is seen to be small for both small solar zenith angles and small optical thickness. The largest effect is seen at zenith angle of 60 deg and cloud optical thickness > 1. The magnitude of the maximum change in the downward flux was 15 W m^{-2} (zenith angle of 60°, optical thickness of 10). The magnitude of the changes of both upward and downward fluxes was about the same for most situations.

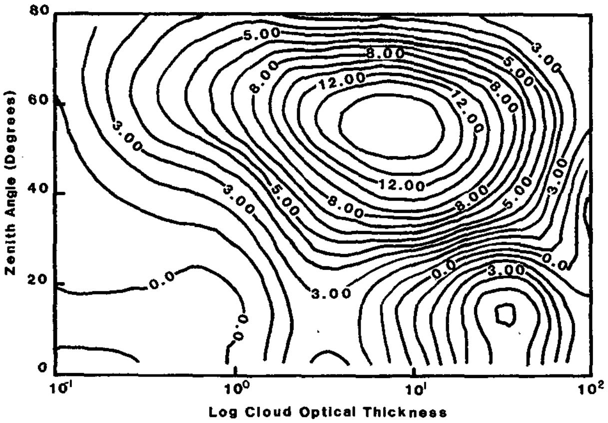

FIG. 1. Changes in surface global solar flux (W m^{-2}) due to changes in cloud NIR ω parameterization [$F\downarrow$ (1978 ω) − $F\downarrow$ (1984 ω)] for different values of cloud optical thickness and solar zenith angle.

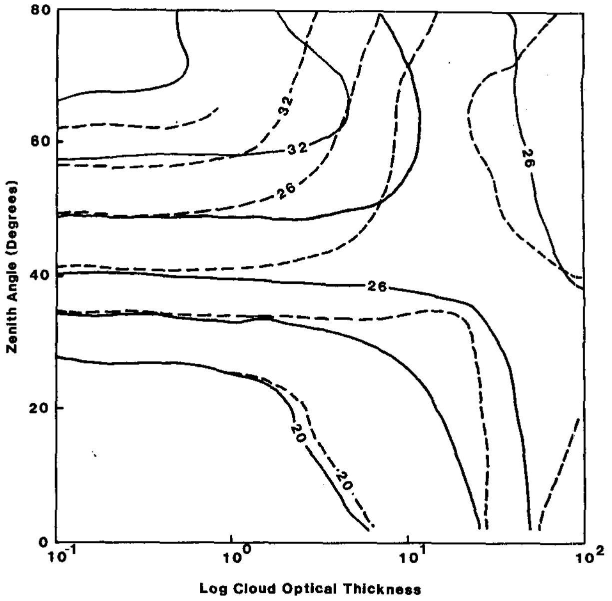

FIG. 2. Changes in total atmospheric shortwave absorption (W m^{-2}) due to changes in cloud NIR ω parameterization. Solid line: 1978 ω. Dashed line: 1984 ω (cloud asymmetry factor $g = 0.85$), for different values of cloud optical thickness and solar zenith angle.

b. *Effects of changing parameterization of cloud g*

Similar calculations to those described in section 4a were performed for the different parameterizations of the cloud g, keeping the NIR ω parameterization constant at the 1984 values. The results are shown in Figs. 3–4 for the downward and absorbed solar flux. Generally, the change of the cloud g parameterization has a stronger effect than the change of cloud ω parameterization. The change from the cloud g parameterization of $g = 0.85$ to the values inferred from the 1984 study increases the surface global flux and decreases the upward flux at the top of the atmosphere. The effect of this change is most pronounced at low solar zenith angles. The change in the upward flux is about the

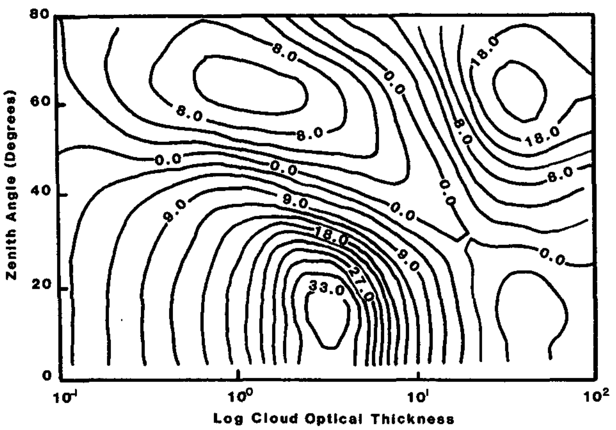

FIG 3. Changes in surface global solar flux (W m^{-2}) due to changes in cloud g parameterization [$F\downarrow$ (g = 0.85) − $F\downarrow$ (1984 g)], for different values of cloud optical thickness and solar zenith angle.

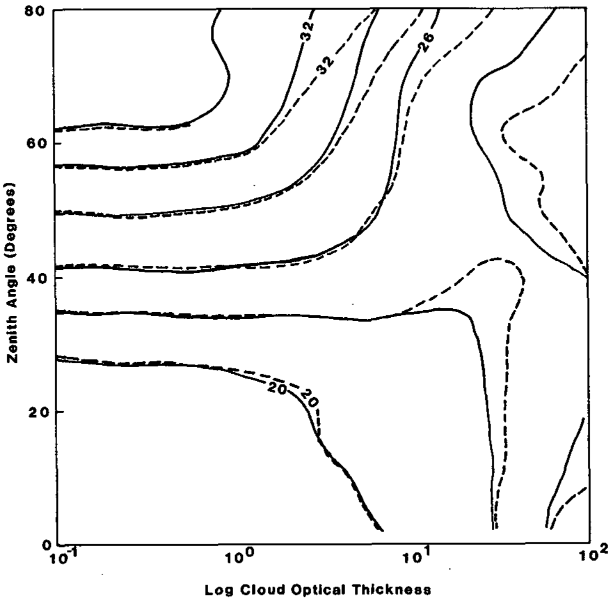

FIG. 4. Changes in total atmospheric shortwave absorption (W m^{-2}) due to changes in cloud g parameterization. Solid line: g = 0.85. Dashed line: 1984 g (cloud ω are from 1984), for different values of cloud optical thickness and solar zenith angle.

same as the change in the downward flux, but of a different sign. The maximum change in the computed downward flux occurs at zenith angle of 0° and optical thickness of 5, when the upward fluxes for the two g parameterizations differ by 37 W m^{-2}.

c. *Effect of changing cloud base height on surface global flux*

The delta-Eddington based model was run for various assumptions of cloud base height, cloud optical thickness, and aerosol extinction coefficient β distribution, to produce estimates of surface global flux. Calculations were performed for two zenith angles: 0° and 60°. For these calculations it was assumed that the surface albedo = 0.2 and precipitable water = 2.0 cm. Cloud g was assumed to be 0.85 for all wavelengths and cloud ω were taken from Stephens et al. (1984). Aerosol scale height was assumed to be 1.5 km (assuming an exponential decrease of β_λ with height). The value of 1.5 is that which would yield aerosol atmospheric τ equivalent to McClatchey's (1971) "clear" atmosphere.

The calculation results are shown in Table 1 for cloud base heights of 0 and 10 km. For constant cloud optical thickness, cloud base height is seen to have essentially a negligible effect on the surface flux calculations. Stephens and Webster (1984) also demonstrated that the reflected solar flux from an ensemble of cloud layers is independent of the vertical distribution of these cloud layers and is only a function of the total water path integrated in the vertical, a property which also determines the solar radiation reaching the surface.

TABLE 1. Surface global solar flux F (W m^{-2}) calculations for solar zenith angle equal to (a) 0° and (b) 60°.

		Cloud base = 0 km			Cloud base = 10 km	
Cloud optical thickness	Number of aerosols	a.s.h. (1.5)	a.s.h. (2.4)	Number of aerosols	a.s.h. (1.5)	a.s.h. (2.4)
		(a) Zenith angle = 0°				
3	939	877	847	937	876	841
10	605	556	534	603	552	524
20	350	315	300	350	316	298
50	138	117		138	123	
		(b) Zenith angle = 60°				
3	351	319	302	356	325	307
10	224	203	193	227	207	196
20	142	127	120	145	131	124
50	63	55		66	60	

5. Conclusions

The calculations performed indicate that changing from Stephens (1978) values of NIR ω to Stephens et al. (1984) values of NIR ω causes a maximal change in computed solar fluxes of 15 W m^{-2}. Both surface global flux and upward flux at the top of the atmosphere increase owing to decreased cloud absorption. Changing from the assumption that cloud $g = 0.85$ to values derived from Stephens' et al. (1984) B values, has a larger effect on calculated fluxes, with a maximal change of 37 W m^{-2}. This change of g parameterization would cause surface flux to increase and upward flux at the top of the atmosphere to decrease. The fact that the calculations were more sensitive to the choice of the cloud g parameterization as opposed to the cloud ω parameterization is due to the fact that the two g parameterizations are quite different, whereas the ω parameterizations are, for many situations, similar.

Acknowledgments. This work was supported by Grant NA84AA-H-00026 from the National Oceanic and Atmospheric Administration (NOAA) to the University of Maryland under the Cooperative Institute for Climate Studies. The Computer Science Center, University of Maryland, provided supplementary computer time.

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