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THE EFFECT OF CLOUDS ON THE EARTH'S RADIATION BALANCE

G. F. Herman, *University of Wisconsin, Madison, Wisconsin,*
M. L. Wu, *National Research Council, Washington, DC, and*
W. T. Johnson, *Sigma Data Services Corporation, c/o Goddard Space Flight Center, Greenbelt, Maryland*

ABSTRACT

The effect of global cloudiness on the radiation balance at the top of the atmosphere is studied in general circulation model experiments. Wintertime simulations were conducted with clouds that had realistic optical properties, and were compared with simulations in which the clouds were transparent to either solar or thermal radiation. Clouds increase the net balance by limiting longwave loss to space, but decrease it by reflecting solar radiation. It is found that the net result of cloudiness is to maintain net radiation which is less than would be realized under clear conditions: Clouds cause the net radiation at the top of the atmosphere to increase due to longwave absorption, but to decrease even more due to cloud reflectance of solar radiation.

1. INTRODUCTION

The role that clouds play in maintaining the global radiation budget is complicated and poorly understood. Clouds affect fluxes and flux divergences by absorbing and scattering solar radiation, and by absorbing, scattering, and emitting thermal radiation. At the same time, the occurrence of clouds depends on surface and atmospheric temperature, both of which are determined in part by the radiation field. Attempts to deduce the role of clouds from observations (e.g., Ellis, 1978), from simplified models (e.g., G. Hunt, 1977), or from global circulation models (e.g., B. Hunt, 1978) have led to conflicting conclusions because of the variety of physical processes that actually were investigated.

We present here a preliminary analysis of the results of GLAS (Laboratory for Atmospheric Sciences) general circulation model experiments that were designed to demonstrate the potential role that clouds play in determining mean monthly climate through their interaction with the radiation field. Attention is focused on the net radiation of earth-atmosphere system (RNEA) as it is affected by cloud interacting with short- and long-wave components, respectively.

2. SUMMARY OF EXPERIMENT

The GLAS General Circulation Model

A version of the model was used that was similar to those described by Somerville et al. (1974), Stone et al. (1977), and Herman and Johnson (1978). It differed in its use of the Wu et al. (1978) longwave radiation code, which was called every 5 hours, sea surface temperatures which varied smoothly during the experiment, Shapiro filtering of wind, temperature, moisture and sea level pressure fields, and fixed snow line. The initial state was defined from the 1 January 1975 0000GMT National Meteorological Center (NMC) global analysis. The integration period was 30 days.

The control was a standard January simulation with fully active short- and long-wave radiation calculations, and fully active cloud formation processes, i.e., convection and supersaturation. In the control, both the cloud and radiation computations are completely consistent with the model's other hydrodynamic and thermodynamic processes.

In one experiment ("solar transparency") all cloud and radiation calculations were carried out as in the control, but the cloud fraction was fixed at zero in the solar radiation calculation (cf. Lacis and Hansen, 1974). Thus, clouds formed, liberated latent heat, and emitted longwave radiation, but were otherwise transparent to the streams of solar radiation. The second experiment ("thermal transparency") specified zero cloud fraction in the Wu longwave calculations, but retained the model-generated cloudiness in all calculations, including solar radiation. We deduce the cloud effect by comparing the control with the "transparent" simulations, and attribute differences in the model climatology to the absence of thermal or solar radiative interactions with global clouds.

3. RESULTS AND DISCUSSION

Cloud affects the terrestrial radiation balance in the solar spectrum by reflecting radiation to space, thus decreasing solar radiation available to the earth-atmosphere system, or by increasing absorption path lengths by multiple scattering, thus increasing solar heating. In longwave regions of the spectrum, clouds absorb radiation emitted from the atmosphere's lower layers ("greenhouse effect") diminishing the total longwave loss to space. Cloud effects are illustrated in Table 1, which shows the effect of solar and thermal cloud transparency on various components. For comparison, the observational results of Raschke et al. (1973) also are included.

When clouds do not interact with thermal radiation (column C) the net longwave loss at the top of the atmosphere increases by

Table 1. Radiation balance for real and transparent cloud conditions (Wm^{-2}).

	(A) Control	(B) Solar transparency	(C) Thermal transparency	(D) Observations
1. Net thermal at top				
N. hemisphere	-207	-215	-236	-232
S. hemisphere	-213	-223	-253	-239
Global	-210	-219	-244	-235
2. Solar absorption (earth-atmosphere)				
N. hemisphere	165	199	159	174
S. hemisphere	332	429	327	330
Global	249	314	243	252
3. Albedo (earth-atmosphere)				
N. hemisphere	.29	.13	.31	.27
S. hemisphere	.31	.13	.33	.29
Global	.30	.13	.33	.28
4. Net radiation (thermal loss minus absorbed solar)				
N. hemisphere	- 42	- 16	- 77	- 56
S. hemisphere	119	206	74	91
Global	39	95	- 1	17

34 Wm^{-2} (16%) globally, and by comparable values in the northern and southern hemispheres. The solar radiation absorbed by the earth-atmosphere system is essentially unaffected, as might be surmised from purely radiative arguments. Similarly, there is no significant change in the planetary albedo, which suggests that the maintenance of global cloudiness is largely independent of cloud longwave radiative processes. The net radiation at the top of the atmosphere in the northern and southern hemisphere, and globally, decreases by 35, 45, and 40 Wm^{-2}, respectively. The effect of clouds on the longwave radiation is therefore comparable to the net radiation itself during the winter.

The role of clouds in the solar radiation balance is shown in column B. When clouds are transparent to solar radiation, thermal radiation at the top of the atmosphere becomes slightly more negative because of warmer surface and atmospheric temperatures. Solar radiation absorbed by the earth-atmosphere system increases by 34 Wm^{-2} (21%) in the northern hemisphere, 97 Wm^{-2} (29%) in the southern hemisphere, and 65 Wm^{-2} (26%) globally.

The predominant effect of cloudiness in the radiation balance is in determining the planetary albedo. In general, clouds maintain the planetary albedo near its observed value of 33% as compared with an albedo of 13% with non-interacting clouds.

The net cloud effect is seen in row 4. During the winter in the northern hemisphere, the difference between the solar and thermal cloud effect is -9 Wm^{-2}, i.e., the balance would become 35 Wm^{-2} more negative due to longwave effects, by only 26 Wm^{-2} more positive due to solar effects. The trend is reversed in the southern hemisphere: Longwave effects would decrease the net radiation by 45 Wm^{-2}, but this would be more than compensated by the solar increase of 87 Wm^{-2}. On a global basis, the solar effect (56 Wm^{-2}) dominates the longwave effect (40 Wm^{-2}).

Evidently, clouds affect the radiation balance mainly through their effect on the planetary albedo. This result is in agreement with the observational analysis of Ellis (1978), where it was concluded that the cloud effect on solar radiation dominated that on longwave radiation at almost all latitudes during all seasons studied. G. Hunt (1978) reached a similar conclusion based on one-dimensional radiative transfer calculations.

It has frequently been argued (cf. Cess, 1976) that the greenhouse effect of clouds would dominate or cancel the cloud effect on solar radiation. While this hypothesis may be valid on a regional basis, such as the Arctic, it is not supported by the results obtained here.

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