# The Quasi-Global Distribution of the Sensitivity of the Earth–Atmosphere Radiation Budget to Clouds

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ABSTRACT

Maps are presented showing the mean annual sensitivities of longwave and net radiation at the top of the atmosphere to changes in cloud amount for the region 60°N to 60°S. The maps are based on an analysis of a 45-month set of monthly mean radiation budget data for the years 1974–78 derived from the NOAA satellite scanning radiometers. The analysis technique is based on the regression method of Ohring and Clapp (1980), with some minor modifications. Both regionally and globally, the maps show that the albedo effect of clouds is greater than their greenhouse effect. The maps also suggest that the longwave sensitivity parameter might serve as a useful measure of the geographical distribution of effective cloud heights.

## 1. Introduction

In a recent paper, Ohring and Clapp (1980) summarized their estimates of the sensitivities of longwave radiation and net radiation at the top of the atmosphere to changes in cloud amount. These estimates were derived for a small sample of geographic/climatic areas of the Earth. In the present extension to that work, these climatically important sensitivity parameters are mapped on a quasi-global basis.

## 2. Methods

The basic data consist of monthly mean values of Earth–atmosphere radiation budget quantities derived from NOAA satellite scanning radiometers, for a 45-month period from June 1974 to February 1978 inclusive, and for a global 2.5° latitude × 2.5° longitude grid (Gruber and Winston, 1978). A 45-month time series of both albedo and longwave radiation was extracted from these data for each 10° latitude–longitude grid point, from 60°N to 60°S. The annual and semiannual cycles were removed from the time series at each grid point by subtracting out these components using harmonic analysis. Long-term trends in albedo and longwave radiation were also removed by the use of least-squares linear fits to the time series at each grid point. These modified values of albedo and longwave radiation are used in the following analysis.

The net radiation passing through each horizontal unit area at the top of the atmosphere is

$$\text{Net} = Q_0(1 - \alpha) - F, \qquad (1)$$

where $Q_0$ is the available solar insolation, $\alpha$ is the albedo of the Earth–atmosphere system, and $F$ is

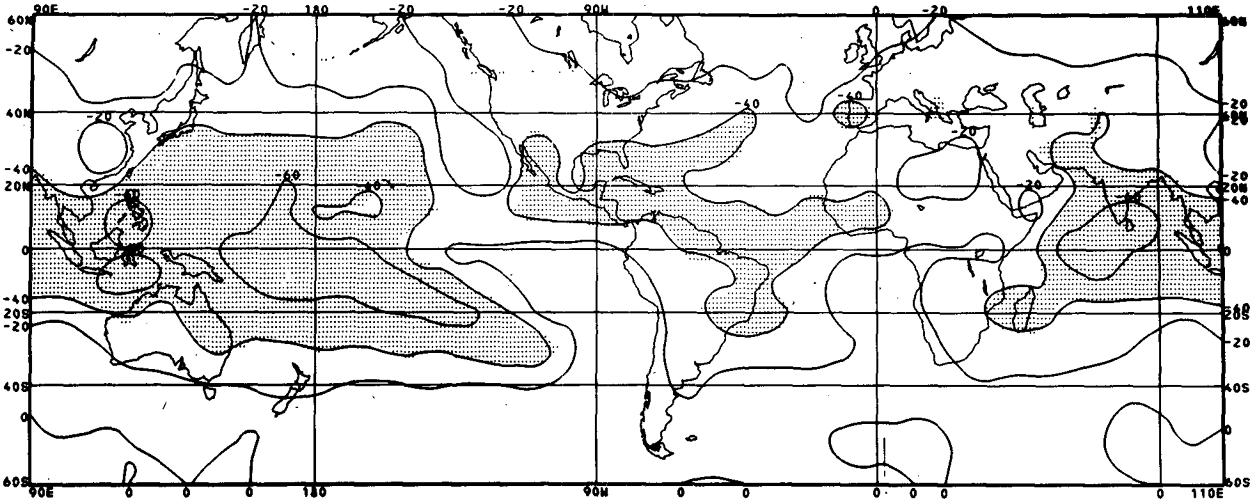

FIG. 1. Global distribution of IR sensitivity parameter, $\partial F/\partial A_c$. The units are the change in outgoing radiation (W m$^{-2}$) as the fractional cloudiness changes from 0 to 1. Sensitivity values less than $-40$ W m$^{-2}$ are stippled.

the longwave radiation emitted to space. Therefore,

$$\partial(\text{Net})/\partial\alpha = -Q_0 - (\partial F/\partial\alpha). \quad (2)$$

As in Ohring and Clapp (1980), the albedo is used as a measure of cloud amount. $\partial F/\partial\alpha$ is obtained from the slope $b$ of the least-squares regression line relating $F$ to $\alpha$ at each grid point

$$F = a + b\alpha. \quad (3)$$

The average annual value of $Q_0$ is a known function of latitude.

The longwave radiation (or IR) sensitivity parameter is defined as $\partial F/\partial A_c$, where $A_c$ is cloud amount. The net sensitivity parameter $\delta$ is defined as $\partial(\text{Net})/\partial A_c$. To obtain estimates of these sensitivity parameters from $\partial F/\partial\alpha$ and $\partial(\text{Net})/\partial\alpha$, the relationship $\partial\alpha/\partial A_c = \alpha_c - \alpha_s$ is used, where $\alpha_c$ and $\alpha_s$ are the cloud and clear-sky albedos, respectively, as seen from space. The global distribution of clear-sky albedo $\alpha_s$ was obtained from processing the data of Posey and Clapp (1964), relating surface albedo to land-use type, together with a correction for atmospheric effects on the radiation (absorption and scattering) as in Ohring and Clapp (1980). The cloud albedo values, $\alpha_c$, are based on the meridional distribution of $\alpha_c$ from Ohring and Adler (1978) as presented in Ohring and Clapp (1980).

Although this method of processing the data is somewhat different from that used in Ohring and Clapp (1980), the results obtained are quite similar.

As a result of a change in the operational data processing system for the NOAA satellite scanning radiometer, the albedo values at high latitudes of the Southern Hemisphere for about half of the year 1976 are in error.[1] Therefore, the values of the sensitivity parameters derived in the present analysis must be considered unreliable south of 40°S.

## 3. Results

Figs. 1 and 2 show the global distributions of IR sensitivity $\partial F/\partial A_c$ and net sensitivity $\partial(\text{Net})/\partial A_c$ from 60°S to 60°N. Fig. 1 shows that the largest (in absolute value) IR sensitivities are generally at low latitudes, associated with the typically high cloud heights in the equatorial region; isopleths of $-60$ W m$^{-2}$ are found in this region. IR sensitivities at latitudes greater than 40° are generally in the 0 to $-40$ W m$^{-2}$ range. However, there are significant deviations from a purely zonal pattern. Of particular interest are the regions of low IR sensitivity, 0 to $-30$ W m$^{-2}$, located in the eastern portions of the tropical and subtropical oceans; these are associated with the extensive regions of low cloudiness typical of these regions. As a result, the horizontal gradients of IR sensitivity can be just as large in the zonal direction as in the meridional direction. The relationship of IR sensitivity to cloud height suggests that global maps of IR sensitivity (perhaps after corrections for typical lapse rate and water vapor conditions) might provide important new climatological information on the global distribution of effective cloud heights.

[1] Winston, J. S., A. Gruber, T. I. Gray, Jr., M. S. Varnadore, C. L. Earnest and L. P. Mannello, 1979: Earth–Atmosphere Radiation Budget Analyses Derived from NOAA Satellite Data, June 1974–February 1978. U.S. Dept. of Commerce, NOAA, NESS, 2 Vols. (see p. 3). (Copies available from National Technical Information Service).

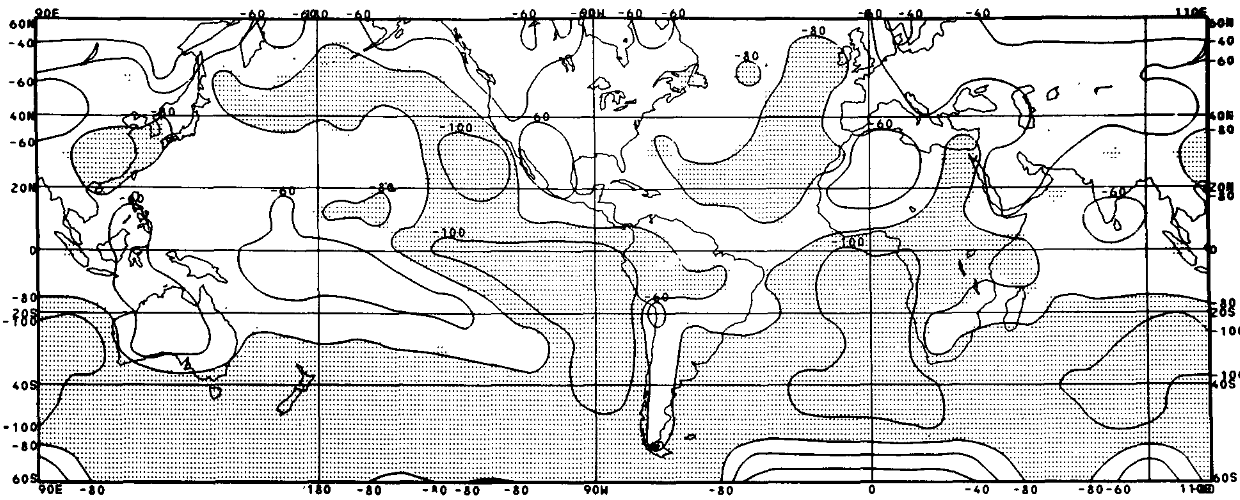

Fig. 2. Global distribution of net sensitivity parameter $\delta \equiv \partial(\text{Net})/\partial A_c$. The units (W m$^{-2}$) are the same as in Fig. 1. Sensitivity values less than $-80$ W m$^{-2}$ are stippled.

Fig. 2 shows that over the entire region $\delta$, the net sensitivity, is negative, indicating that the albedo effect of the clouds dominates over their greenhouse effect. The largest values of $\delta$, values of $-100$ W m$^{-2}$ or greater, are generally found over those low-latitude oceanic regions where the IR sensitivity is low, the available solar radiation is large, and the surface albedo is low. There is a general decrease in the magnitude of $\delta$ with increasing latitude to an average value of about $-50$ W m$^{-2}$ at 60°N. As a result of the large variations of the IR sensitivity at low latitudes, similar large variations in $\delta$ are found at these same latitudes in the zonal direction.

The Northern Hemisphere averages (0–60°N) of $\partial F/\partial A_c$ and $\partial(\text{Net})/\partial A_c$ are $-35$ and $-71$ W m$^{-2}$, respectively. We do not present averages of the Southern Hemisphere sensitivities because of the data processing problem discussed above.

Hartmann and Short (1980) used day-to-day variations of the NOAA scanning radiometer observations to map the quantity ($-\partial$ Net/$\partial F$) (their cloud factor) for a winter season (December 1975–February 1976) and for a summer season (June–August 1975). We have spot-checked the average of their winter and summer values of $-\partial$ Net/$\partial F$ for a number of locations with values of $-\partial$ Net/$\partial F$ that we obtain from the ratios of our $\partial$ Net/$\partial A_c$ values to our $\partial F/\partial A_c$ values, and we find fairly good agreement.

## 4. Conclusions

Analyses of the quasi-global distribution of $\partial F/\partial A_c$, the IR sensitivity parameter and $\delta$ the net sensitivity parameter, which define the sensitivities of outgoing longwave radiation and net radiation at the top of the atmosphere to changes in cloud amount, indicate that 1) $\delta$ is negative over the entire region studied (60°S to 60°N). This suggests that the albedo effect of clouds is greater than the greenhouse effect of clouds on both a regional and global-average basis. 2) Maps of the IR sensitivity parameter, $\partial F/\partial A_c$, might serve as a useful measure of the global distribution of effective cloud heights. 3) Zonal gradients in both $\partial F/\partial A_c$ and $\delta$ can be as large as meridional gradients, especially at low latitudes.

The present analyses suffer from the same limitations as those discussed in Ohring and Clapp (1980), namely, the use of narrow spectral intervals to obtain total planetary albedo and total longwave radiation to space, and the use of albedo variations as a measure of cloud amount variations. We have just begun a study designed to remove the above limitations by using the radiation observations of the Earth Radiation Budget Experiment on Nimbus 7 together with simultaneous cloud amounts derived from processing data of the Temperature Humidity Infrared Radiometer (THIR) instrument on the same satellite.

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