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FINAL REPORT ON

EMPIRICAL DETERMINATION OF THE EFFECTS OF CLOUDS ON THE EARTH'S RADIATION BUDGET OVER THE PACIFIC OCEAN

by

DANIEL ZISKIN

and

DARRELL F. STROBEL

Principal Investigator

Department of Earth and Planetary Sciences

Department of Physics and Astronomy

The Johns Hopkins University

Baltimore, MD 21218

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The main objectives of this research has been to learn how clouds interact with the Earth's Radiation Budget (ERB). This broad goal has been approached in three distinct ways. The first has been to analyze the direct effect cloud amount has on the radiative components of the ERB. The second has been to investigate the indirect effects clouds and water vapor may have on the climate as a feedback mechanism. And finally an attempt has been made to simulate the findings in a simple radiative-convective climate model. This report will summarize these three phases of the research.

The radiative fluxes from ERBE and the cloud properties from ISCCP over Indonesia for the months of June and July of 1985 and 1986 were analyzed to determine the cloud sensitivity coefficients. The method involved a linear least-squares regression between radiative fluxes at the TOP Of the Atmosphere (TOA) and satellite-measured cloud parameters. The calculated slope is identified as the cloud sensitivity. It was found that correlations between the total cloud fraction and radiation parameters were modest, implying that the variability of the radiative effects of clouds are large. Correlations between cloud fraction and IR flux were improved by separating clouds by height. Because of the large temperature difference between high clouds and the surface, we calculated a sensitivity of ~125 W/m2 in the IR. Their presence has nearly twice the radiative effect on the IR flux than mid-level clouds. Likewise, correlations between the visible or Short Wave (SW) flux and cloud fractions were improved by distinguishing clouds based on optical depth. It was calculated that optically thick clouds had a sensitivity of ~200 W/m2, although this sensitivity is an upper limit, since it does not include night observations where the visible sensitivity would be zero. The sensitivity of optically thick clouds is approximately four times larger than clouds classified as moderately thick. Calculating correlations between the net fluxes and either height or optical depth segregated cloud fractions were somewhat improved. When clouds were classified in terms of their height and optical depth, correlations between all the radiation components were improved, especially against the net fluxes. These results showed that high clouds have a positive effect on the net downward flux (~100 W/m2), while mid-level and low optically thick clouds have a strong negative effect (~-320 W/m2) on the net flux. Results were compared to a one-dimensional radiation model with a simple cloud parameterization scheme. There was general agreement, although the model predicted optically thick high clouds to have a negative sensitivity on the net flux.

Satellite data was analyzed in order to determine how changes in cloud properties and water vapor affect the net radiative fluxes at the top of the atmosphere. This effect, combined with an estimate of how the cloud properties and water vapor respond to changes in the sea surface temperature, indicate to what degree they participate as a feedback mechanism. That is, if the temperature changes, will clouds respond in such a way as to increase or decrease net heating at the top of the atmosphere? The conclusion from studying the tropical Pacific is that in response to a rise in sea surface temperature generally clouds increase both their heating and cooling effects through their effect on the IR and SW radiation. However, the dependence of cloud top temperature on sea surface temperature tends to make the warming effect of clouds stronger in the western Pacific. Water vapor is seen to have a strong positive feedback effect, whereas variations in its effect are presumably attributed to its vertical distribution.

A model was constructed to attempt to simulate the physical processes involved in the cloud-radiation-climate interactions. The fundamental assumption of the model is that logarithm of the amount of water vapor is proportional to the Sea Surface Temperature (SST). This assumption is supported by the Clausius-Clapeyron equation (that the saturation pressure of a gas is roughly exponentially related to the temperature) and by observations (see Raval and Ramanathan, 1989, NATURE, vol.342:57-63). Given an initial SST and water vapor amount, the water is vertically distributed in the hydrostatic atmosphere. The amount of water at level determines in grey-body optical depth. The model then calculates the radiative-equilibrium solution (i.e. a temperature is determined for each level, so that the absorbed IR flux is equal to the emitted IR flux). This solution is then tested for convective stability at each layer. If it is convectively unstable then moist convection is simulated. Moist processes generate excess water which condenses out or is re-evaporated by the column. This liquid water becomes clouds or precipitation. The convective process is allowed to alter the temperature profile of the atmosphere, driving it out of radiative equilibrium. The radiation is re-calculated, including interactions with the clouds. The radiative forcing, as well as evaporative cooling and sensible heat exchange, are converted into an effective change in SST. This change is applied to the previous SST and the process is repeated at the next timestep. Although no attempt has been made to include horizontal transport of energy, the SST is seen to respond interactively to radiative cloud forcing and hydrology.