STUDIES OF CONVECTION AND CLOUD PARAMETERIZATIONS IN THE GISS CLIMATE GCM

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1. INTRODUCTION

Several studies of cloud processes in the GISS climate GCM are underway to increase understanding as well as to improve the realism of the model parameterization of these processes. These studies employ a two-pronged approach of data analysis and model experiments. The data analyses use a suite of satellite and conventional datasets, including data from ISCCP, ERBE, and NIMBUS-7, to determine significant patterns of cloud behavior and to diagnose causes for these patterns. The model experiments examine the model output in the same fashion as the data and determine the effects on the model cloud behavior of changes in parameterizations. This presentation briefly outlines three main lines of investigation. In addition to the studies described below, work is beginning on studies of relationships between clouds, relative humidity and meteorology in the upper troposphere using SAGE and ISCCP data, studies of relationships between cloud properties and precipitation variability, using ISCCP and microwave data, and on studies of surface energy (radiative, latent and sensible) exchanges, including effects of vegetation.

2. CONVECTION

2.1 Studies of tropical convection with ISCCP data (Fu, Del Genio, Rossow)

ISCCP observations of tropical clouds are combined with datasets describing the SST, surface winds, and the vertical distribution of temperature and humidity to learn what controls deep convection. A more detailed examination of the distribution of cloud properties than in previous satellite data analyses reveals two distinct high level cloud types, one associated with the convective towers (high reflectivity, high altitude cloud tops, small areal coverage) and one associated with the mesoscale anvil clouds, including cirrus (lower reflectivity, cloud tops lower than the convective towers, large areal coverage). The diurnal variation of these two cloud types have different phases and relative amplitudes: peak mesoscale cloudiness occurs after that of the convective cloudiness. The diurnal phase of the convective clouds coincides with that of surface precipitation variations. When combined with measurements of the relative contribution of the two cloud types to total precipitation, we can infer that the rainfall intensity (amount per unit area) is much higher for convective than anvil clouds. This is qualitative result is no surprise, but the implied quantitative relationships show the complexity of the tropical exchanges of energy between the surface and atmosphere: more latent heating occurs in the convective towers but the mesoscale anvils dominate the radiative heat exchanges.

On-going studies of the variation of convective events show that the processes controlling them are not confined to local thermodynamics. Figure 1 shows the distribution of deep convection and SST and reveals large areas of convection over colder water and large areas of warmer water with no convection. Diagnostic studies are limited by poor meteorological data in the tropical Pacific. Preliminary results suggest that the convection over colder water is apparently stimulated by large scale surface wind convergence in a region that is only conditionally unstable. When SST increases, the atmosphere becomes more unstable and surface wind patterns seem less influential. An explanation for the lack of convection over some areas of warm water is not yet apparent.

2.2 Changes in the GCM (Del Genio, Yao)

The standard version of the GISS climate model parameterizes convection as simple parcel ascent, where the mass flux is prescribed to be 50% of the grid box mass for every convective event. A comparison of the frequency of convection in the model tropics with observations from ISCCP shows that the model convects much less frequently than observed (cf, Figures 2 and 3). Moreover, the location of the ITCZ feature in the model is not correct at all longitudes. An experiment in which the convective mass flux is calculated to be that mass just required to eliminate the instability decreases the convective mass flux and increases the convective frequency (Figure 3). Other experiments, in which the convective mass flux is more directly influenced by surface heat/moisture fluxes, seem to improve the geographical distribution of deep convection in the model.

Arakawa and Schubert proposed a convection scheme based on an assumption of local quasi-equilibrium; their assumption implies that relative humidity and static stability should be correlated. Although available data confirm this, GISS Model II does not behave in this manner. However, changes to the convective parameterization described above and the inclusion of an explicit representation of the effects of convective downdrafts have successfully produced this behavior (Figure 4).

3. CLOUD PHYSICS

3.1 Studies with ISCCP data (Tselioudis, Fu, Del Genio, Rossow, Rind)

Recent discussions of cloud variations have focused on datasets that show that cloud liquid water content increases with temperature and investigations of model cloud parameterizations have begun to include explicitly condensed water budgets. The ISCCP measurements of cloud optical thickness, which is the cloud parameter that controls their effect on the radiation budget, show that total cloud optical thicknesses tend to increase as cloud top height increases. This highlights the fact that the relation between cloud water content and optical thickness involves at least two other cloud properties: cloud vertical extent and cloud particle size.

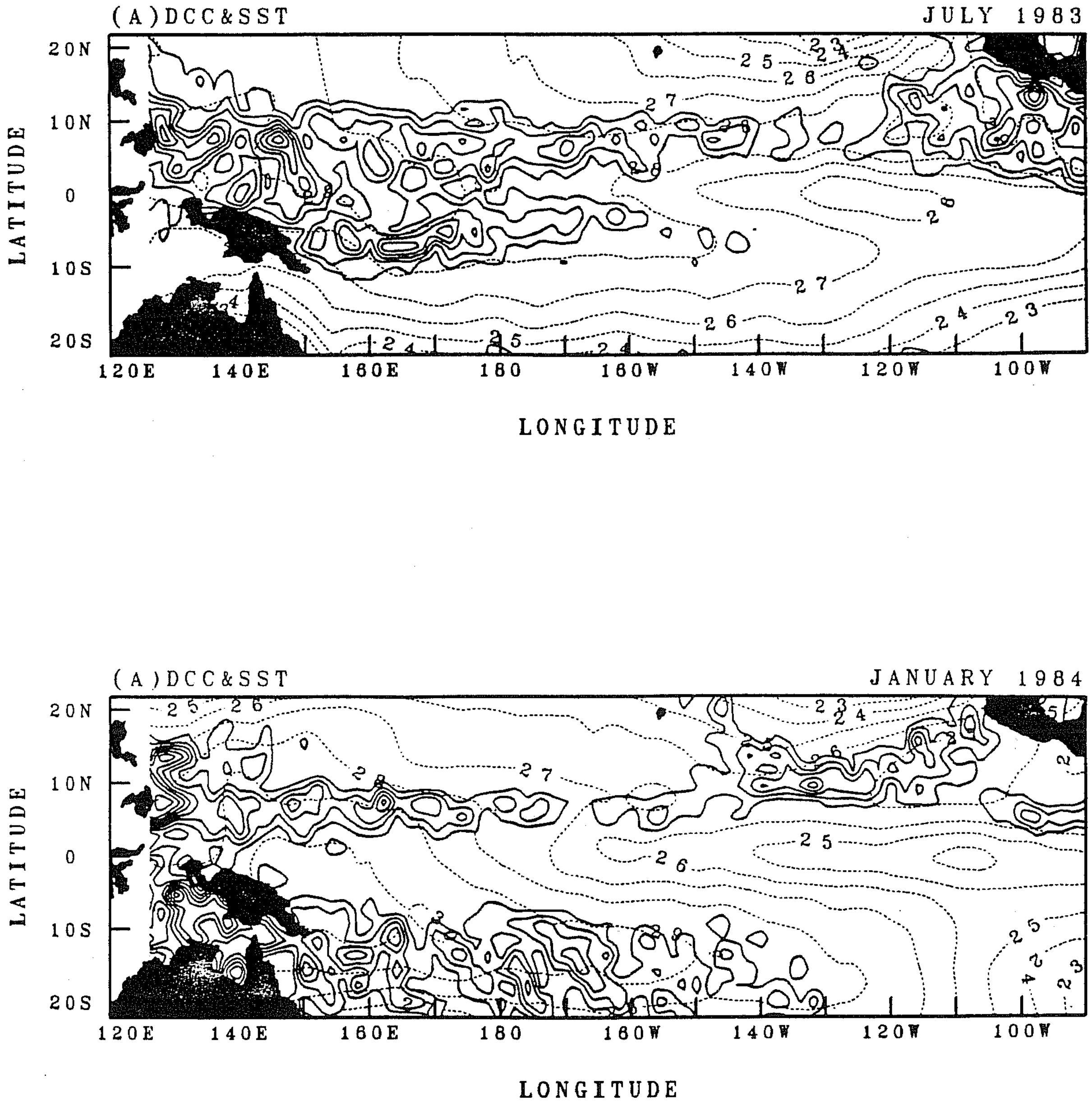

Fig 1. Distribution of deep convective cloud amount (solid contours) and SST (dashed contours) in the tropical Pacific for July 1983 (upper) and January 1984 (lower) (Fu *et al.* 1990).

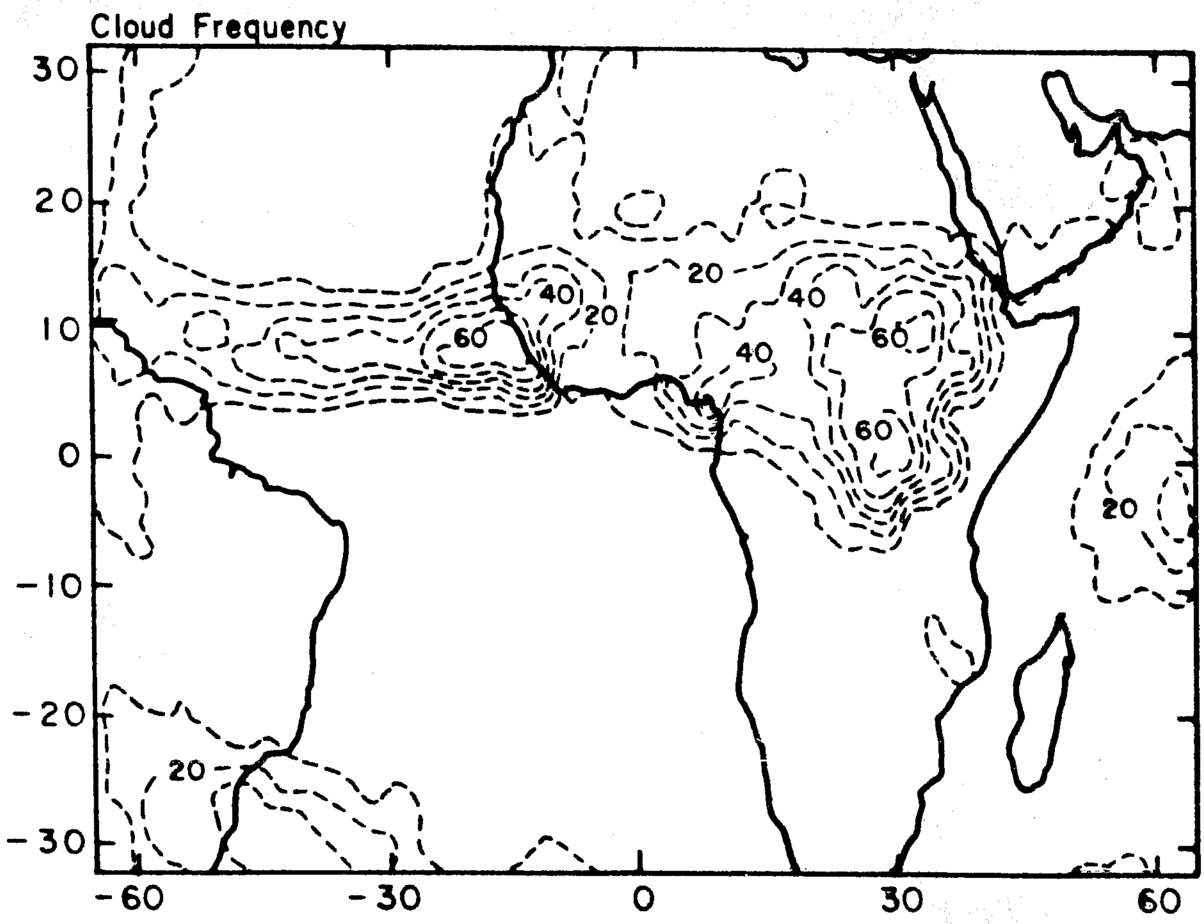

Fig 2. Convective frequency for July 1983 in the tropical Atlantic - Africa sector from ISCCP (Del Genio and Yao 1987).

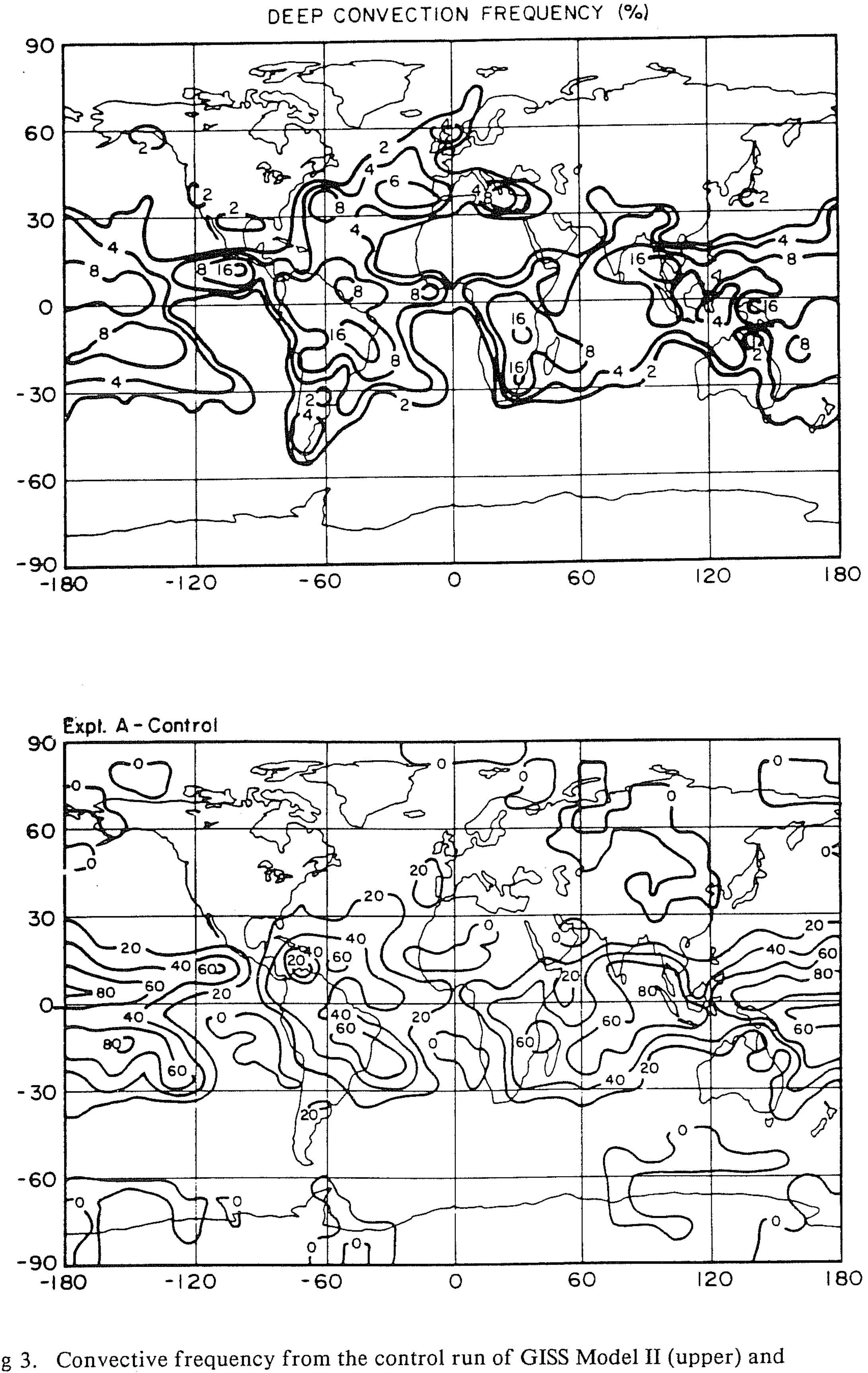

Fig 3. Convective frequency from the control run of GISS Model II (upper) and the differences produced in an experiment with changed convective mass flux prescription (lower) (Del Genio and Yao 1989).

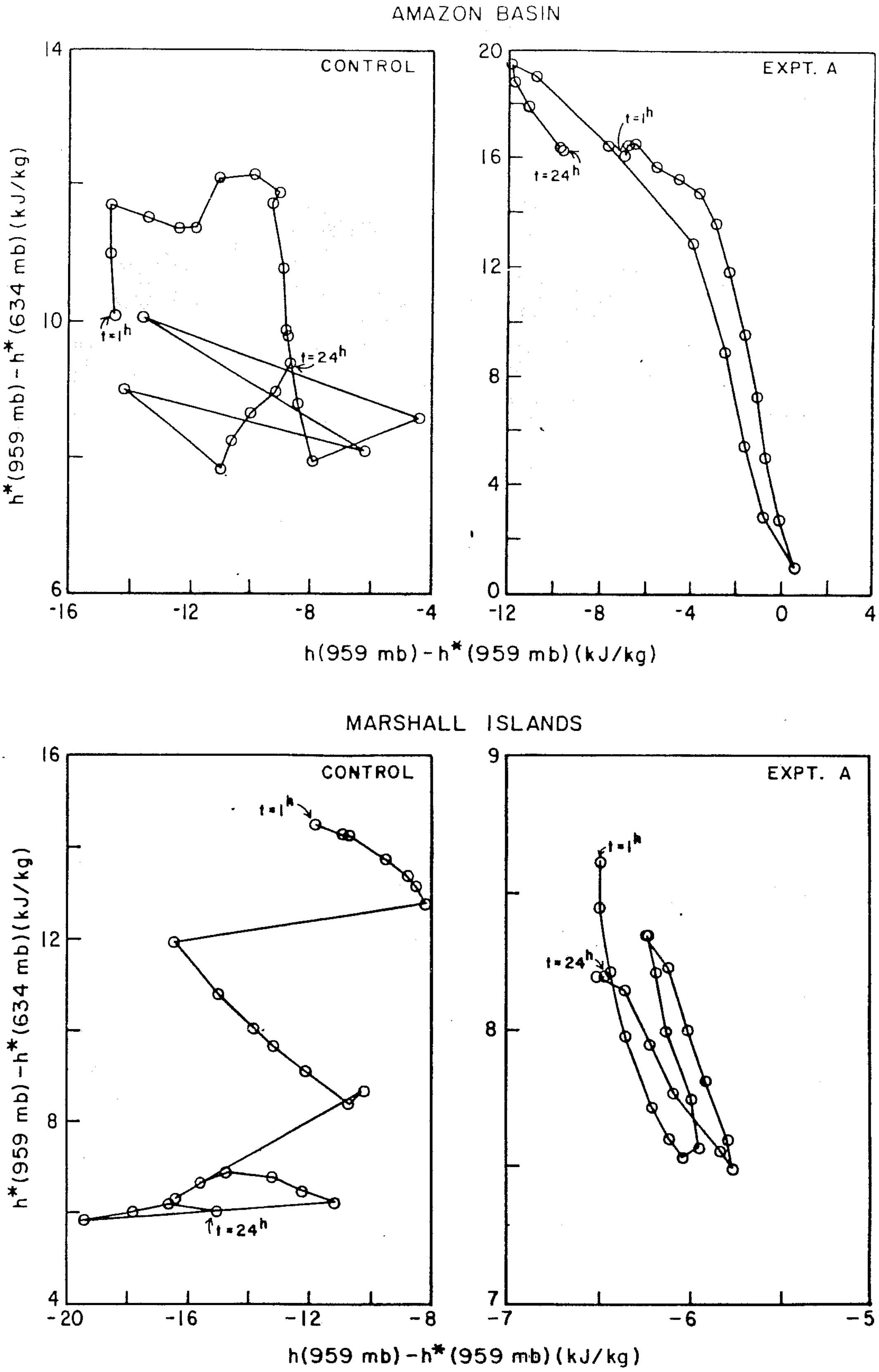

Fig 4. Relationship between variations of relative humidity and static stability in the tropics in GISS Model II (left) and in an experiment with added effects of calculated convective mass fluxes, convective downdrafts, and surface fluxes (right) (Yao and Del Genio 1989).

Studies of the variations of the optical thicknesses of low-level clouds minimize the importance of cloud vertical extent changes; other studies imply that cloud particle sizes do not vary much with changing cloud water contents for low-level clouds. Figure 5 shows the variations of low-level cloud optical thicknesses at middle latitudes over land and ocean determined from ISCCP (the temperatures are cloud top temperatures). This result confirms the previously found correlation of cloud water content and temperature, but only over colder land areas. Note that the datasets that suggested a positive correlation where collected only over land areas. However, at higher temperatures over land and over most ocean areas, the cloud water contents decrease with increasing temperatures, suggesting that something more than the simple thermodynamics controls cloud water contents.

3.2 Changes in the GCM (Del Genio, Yao)

We are currently experimenting with a new cloud physics parameterization that is based on Sundqvist's scheme for an explicit cloud water budget calculation. This version of the model also includes shallow convection and cloud top entrainment instability schemes (Kuo and Schubert) and carries separate ice and water phases so that the Bergeron process can operate. Figure 6 shows the predicted cloud particle sizes from this version of the model; the values shown are in agreement with available qualitative information, but need to be checked quantitatively with satellite measurements. Figure 7 shows the model cloud variations of water content with temperature, which can be compared with the observed behavior shown in Figure 5. Although, the switch in behavior at higher temperatures is not yet modeled, the difference between land and ocean cloud behavior shows some similarities with the observations. The top of the atmosphere radiative fluxes calculated by this version of the model also agree well with the NIMBUS-7 and ERBE radiation measurements.

4. CLOUD RADIATION

4.1 Studies with ISCCP data (Rossow, Zhang, Lacis)

To diagnose the processes that cause changes in radiative fluxes at the top of the atmosphere and surface, we are working on calculations of total radiative fluxes and heating/cooling profiles using ISCCP and some other surface and atmosphere datasets. Table 1 compares calculated with observed global, monthly mean radiative fluxes at the top of the atmosphere; geographic variations of the monthly mean fluxes agree to within 10-15 watts/m^2. Figures 8 and 9 show comparisons of calculated solar and thermal fluxes with surface measurements collected during the FIRE Cirrus experiment in Wisconsin, October 1986. Calculations of the fluxes at the top of the atmosphere for the same sites compare just as well with ERBE data. Although there are still several problems that need work, these results suggest that a diagnosis of the radiative effects of clouds with useful accuracy will be possible.

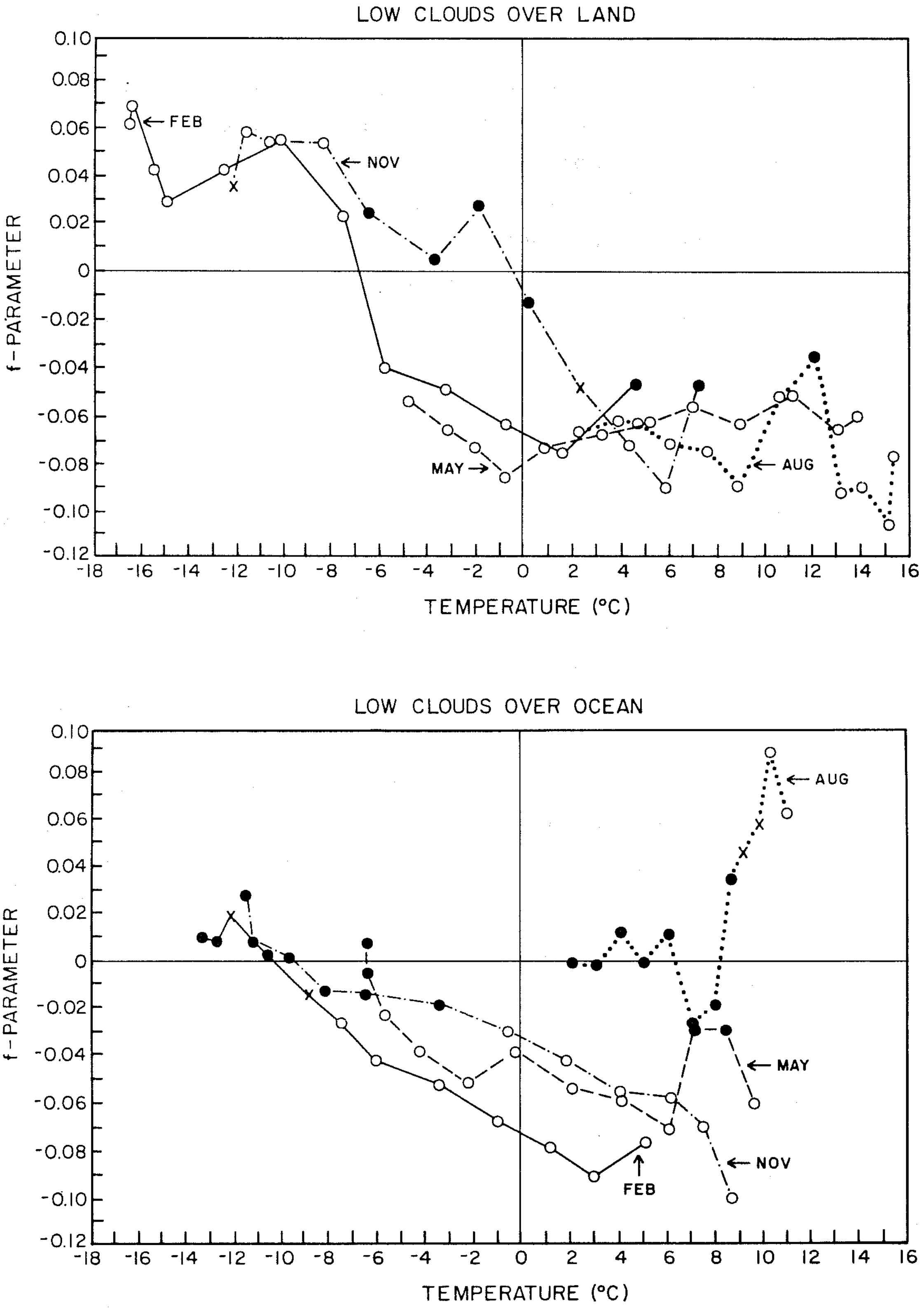

Fig 5. Variations of cloud optical thickness with temperature for midlatitude, low level clouds over land (upper) and oceans (lower). The f-parameter is the normalized first derivative of cloud optical thickness by temperature. (Tselioudis *et al.* 1990).

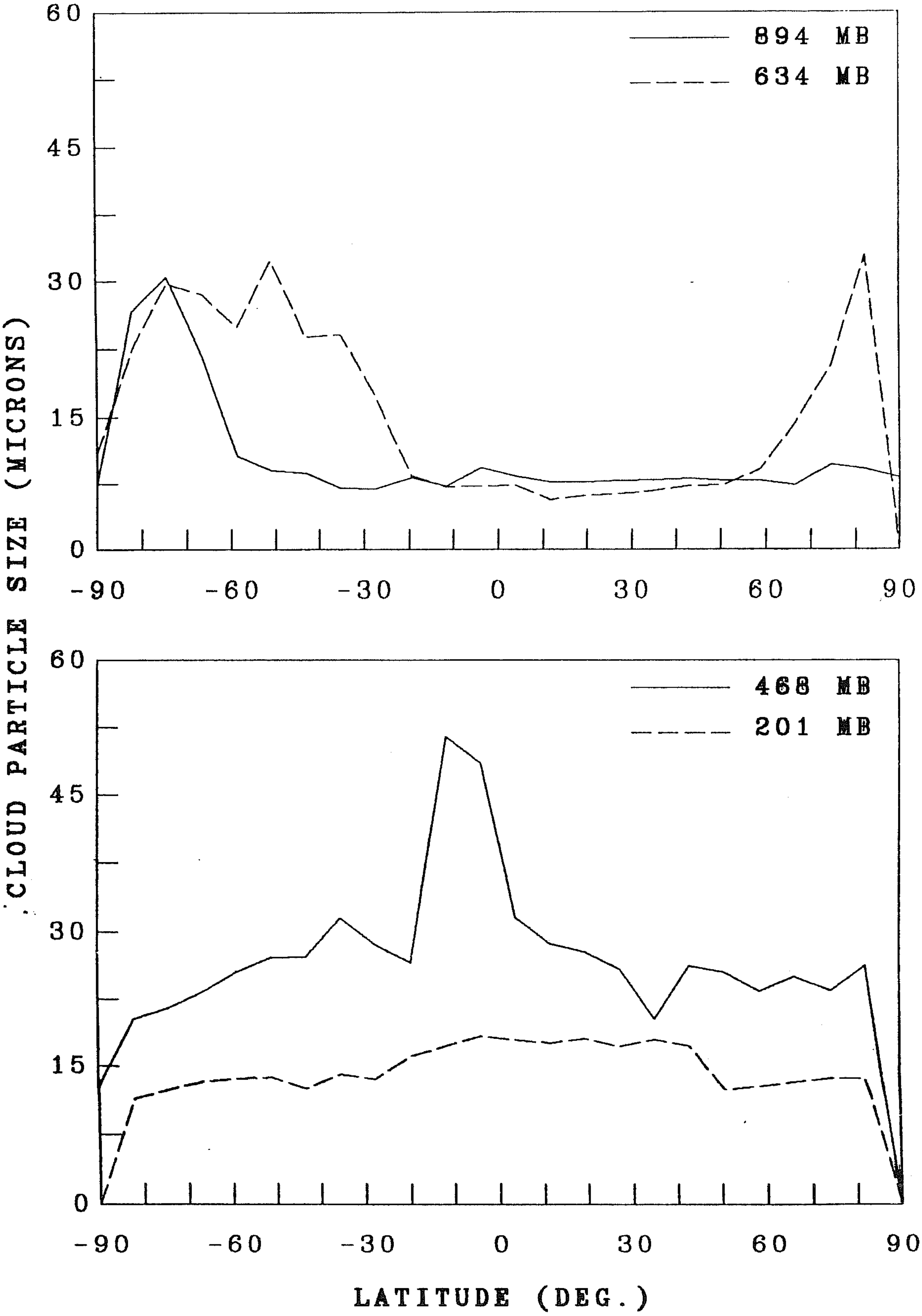

Fig 6. Predicted mean cloud particle sizes at four pressure levels from a version of the GISS GCM with an explicit cloud water budget scheme.

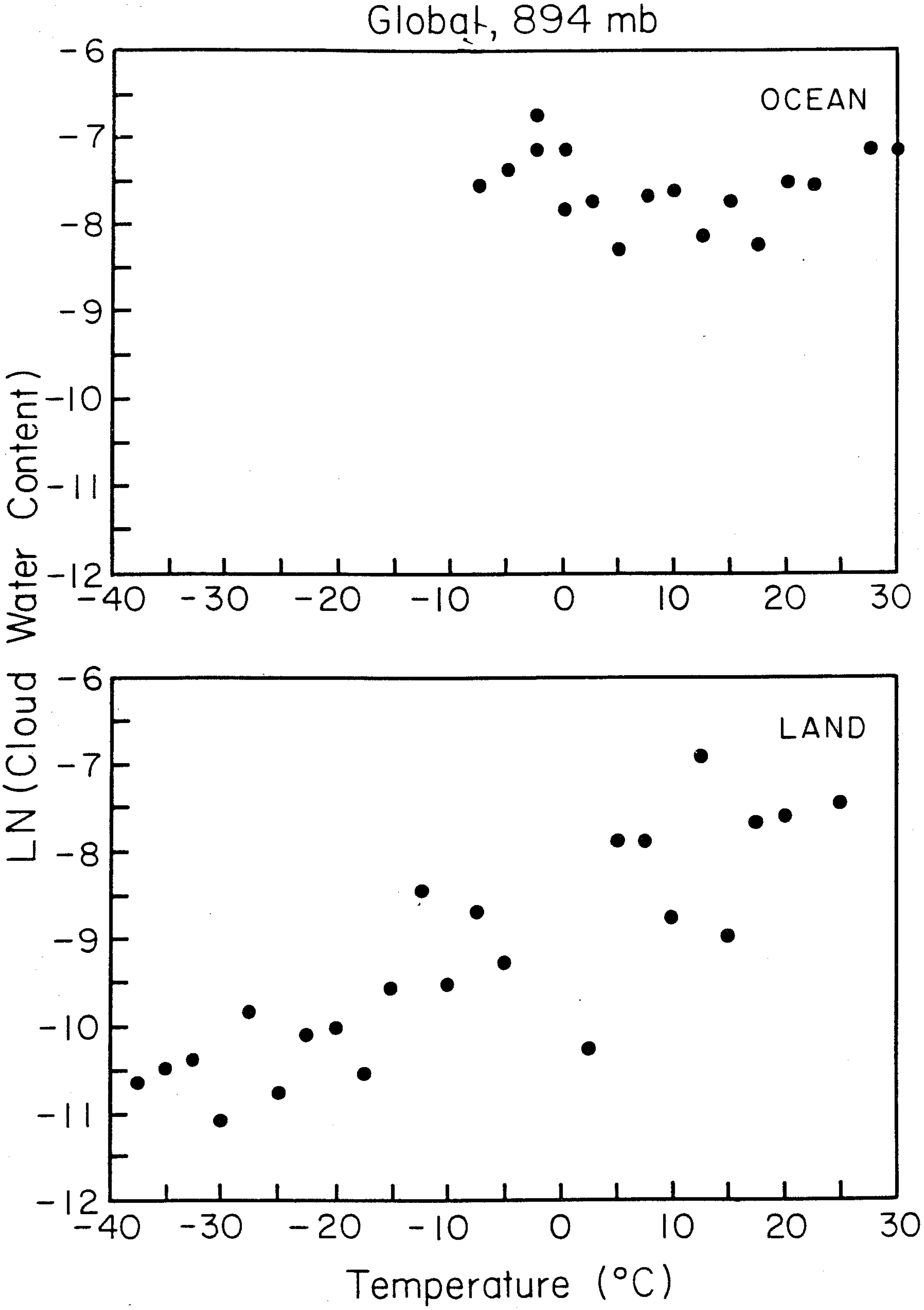

Fig 7. Variations of cloud liquid water content with temperature predicted by the experimental cloud water parameterization in the GISS GCM (Del Genio and Yao 1990).

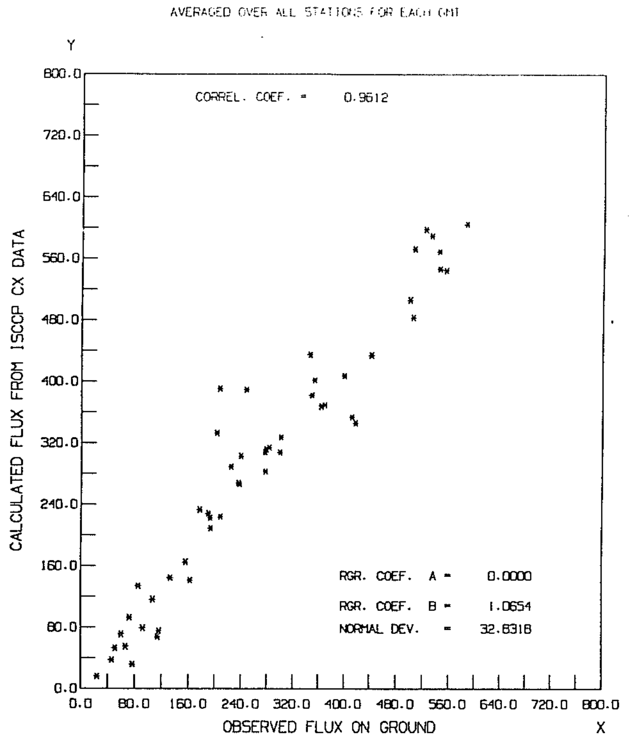

Fig 8. Comparison of downwelling shortwave fluxes over Wisconsin in October 1986 calculated using ISCCP data and the GISS GCM radiation code and measured by surface stations.

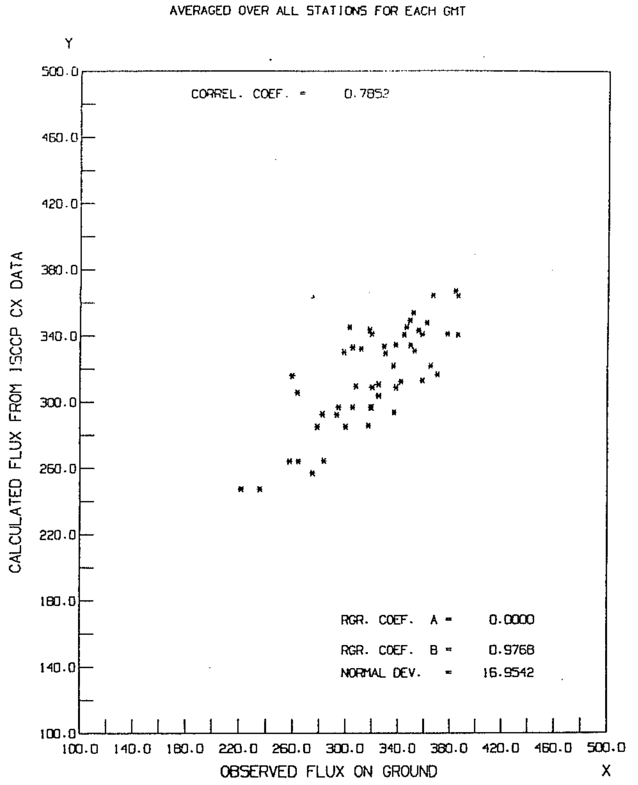

Fig 9. Comparison of downwelling longwave fluxes over Wisconsin in October 1986 calculated using ISCCP data and the GISS GCM radiation code and measured by surface stations.

Table 1. Monthly Mean Radiation Budget for April 1985

Quantity	**ERBE**	**ISCCP**
ALBEDO (AVG)	29.5	30.2
ALBEDO (CLEAR)	16.5	17.3
SW ABSORBED (AVG)	241.1	236.6
SW ABSORBED (CLEAR)	285.6	280.3
LW EMITTED (AVG)	234.5	229.5
LW EMITTED (CLEAR)	265.8	248.9
NET HEATING (AVG)	6.6	7.1
NET HEATING (CLEAR)	19.8	31.4
C_{LW}	31.3	19.4
C_{SW}	−44.5	−43.7
C	−13.2	−24.3

Table 2. Fractional contributions (percent) to annual global radiation from "cloudy" part from NOAA-5 analysis and from the GISS GCM (parentheses). The first line shows actual cloud fraction and net fluxes in watts/m^2.

AREA	ERB	SRB	
52.3 (52.8)	-98 (-7)	39 (32)	
NET SOL TOA	DW SOL TOA	UP SOL TOA	
41 (39)	52.3 (52.8)	77 (77)	
NET SOL SRF	DW SOL SRF	WP SOL SRF	
35 (33)	35 (33)	36 (33)	
NET THERM TOA	NET THERM SRF	UP THERM SRF	DW THERM SURF
49 (43)	22 (36)	52 (53)	56 (56)

4.2 Changes in the GCM (Lacis, Rossow)

The calculations shown in Table 1 and Figures 8 and 9 use the ISCCP dataset and the radiation code from the GISS climate model. Thus, as we examine these results more carefully and compare them with other measurements of radiation, we are providing direct validation of the GCM radiation physics. The comparisons of observed and modeled cloud properties, discussed above, provides validation of the cloud physics. Table 2 shows an earlier comparison of the cloud radiative effects inferred from a preliminary cloud dataset and those in the GISS GCM. These results suggested that the model clouds, on average, have optical thicknesses and top altitudes that are slightly too large and exhibit too little regional and seasonal variability.

If we can eventually improve the model prediction of clouds -- their mean properties, their relationships with other meteorological variables, and their diurnal, synoptic, seasonal, and interannual variations -- to the point that the model cloud effects on planetary and surface radiation budgets are those that can be inferred from new global satellite and conventional datasets, then we may begin to have confidence that these models can predict how clouds will change with climate and how they feedback on climate change.

5. REFERENCES

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