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Use of operational satellite data for study of clouds and radiation in climate

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ABSTRACT

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A brief summary is given of early results from the analysis of operational satellite data for the International Satellite Cloud Climatology Project. These data appear useful for studying the role that clouds play in determining the climate and its variations.

Data flow in ISCCP

The International Satellite Cloud Climatology Project (ISCCP) was established in 1982 by the World Climate Research Program (WCRP) to collect and analyze satellite data to obtain a global, multi-year climatology of cloud properties (Schiffer and Rossow, 1983). The primary objec-

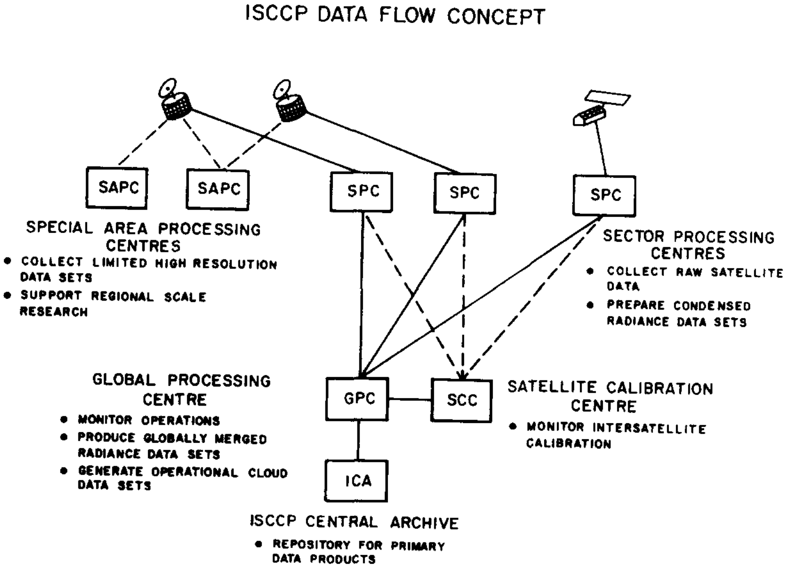

Fig. 1. Data flow in ISCCP.

tive of the data analysis was to characterize the variations of clouds that affect the radiation budget; however, these data can be used to study the behavior of clouds and their role in the hydrological cycle as well. ISCCP was organized to exploit the available satellite datasets being collected by the operational weather satellite system (Schiffer and Rossow, 1985). To obtain data of sufficient quality for climate studies and to reduce the analysis task to manageable proportions, the ISCCP data system is composed of several institutions (Fig. 1). Key functions performed by these institutions are reduction of data volume by a factor of about 1000, normalization of radiometric calibrations to a single standard, quality-checking, and preparation of a global dataset with uniform properties (Rossow et al., 1987).

Measurement of the physical properties of clouds using the satellite radiances requires use of detailed radiative retrieval models and of correlative datasets that describe the properties of the surface and atmosphere that also affect the same measurements. Thus, the ISCCP cloud analysis must merge global information from a number of datasets into a single analysis of the radiance data (Fig. 2). Such a merger needs consistency checks and intercomparisons among the data at several stages of the processing.

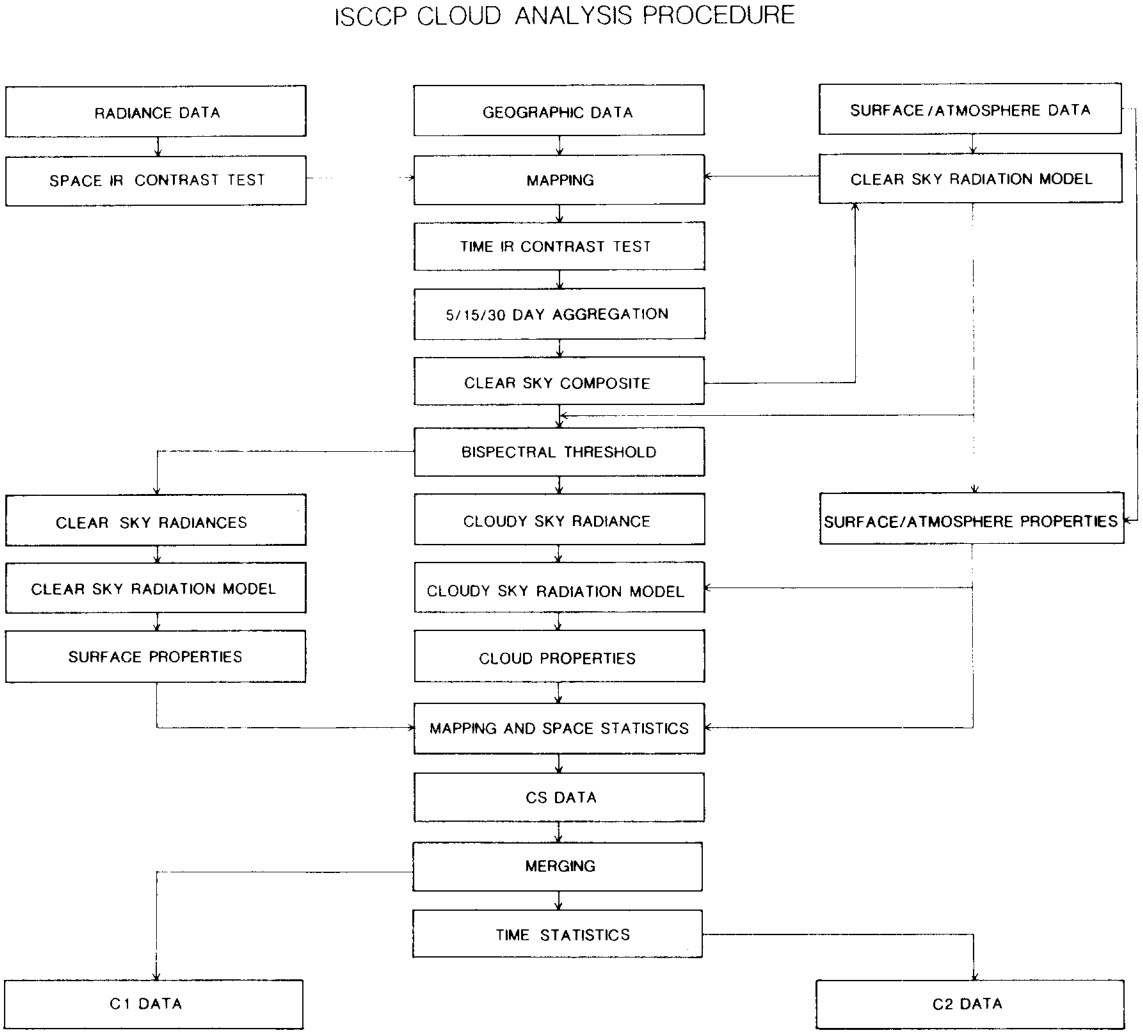

Fig. 2. Data analysis procedure at ISCCP Global Processing Center.

Table 1
ISCCP radiance calibration procedures.

Geostationary satellites	
● Every 3 months	Normalization to afternoon polar orbiter with 4–5 samples of coincident data at same viewing geometry
● Every month	Examine each image for short-term anomalies or spurious diurnal variations
● Every month	Check overlapping measurements for bias
Polar orbiting satellites	
● Every 2 weeks	Produce global maps of surface reflectance, total reflectance and histograms of target radiances Produce global histograms of infrared radiances
● Compare calibrations	to episodic aircraft flights and other satellites.

Quality and calibration monitoring procedures

Currently, the spectral radiance measurements produced as images by operational weather satellites are not well enough calibrated for climate studies. This shortcoming is associated both with inadequate documentation of instrument characteristics and absolute calibrations as well as insufficient routine monitoring and control of calibration stability. Therefore, ISCCP had to undertake a significant effort to obtain adequate calibration information (Table 1). This procedure now combines routine monitoring of the short-term and long-term behavior of every radiometer, intercomparisons of radiometers on satellites operating at the same time as well as between successive satellites in a series, and regular comparisons of reference satellite radiometers to aircraft and site data to obtain absolute calibrations (C.L. Brest, this issue; Brest and Rossow, 1991).

Cloud climatology

Figure 3 shows the global, monthly mean values of the primary cloud and surface properties inferred from the ISCCP analysis (Rossow et al., 1988). What is remarkable about these results is how small the variations are. This is the challenge facing climate studies, that data accuracy and stability must be sufficient to examine changes of this magnitude. The one notable variation shown

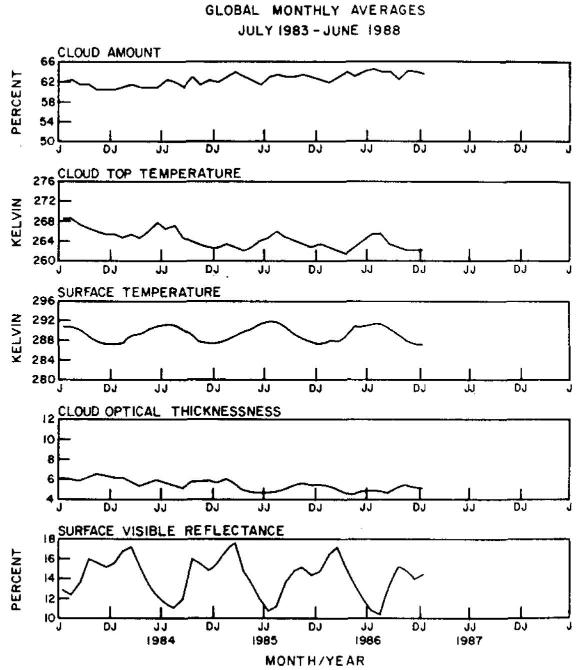

Fig. 3. Cloud climatology shown by long-term global mean values of cloud and surface properties.

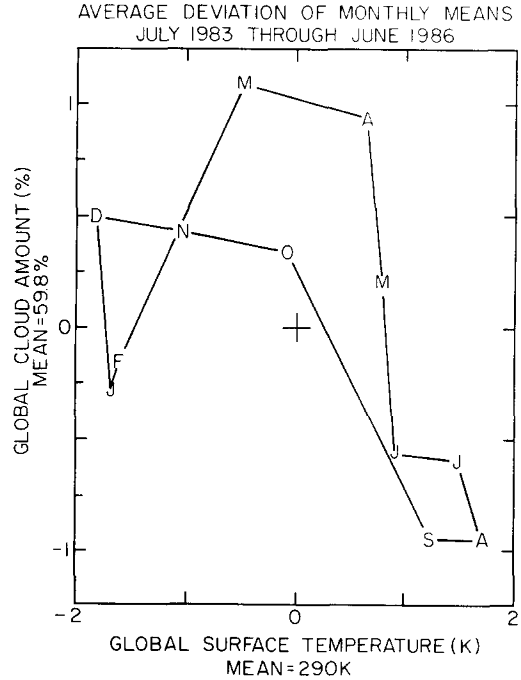

Fig. 4. Mean seasonal cycle of global mean cloud amount.

in the figure is an apparent shift of mean cloud properties in late 1984 at the end of one of the largest El Niño events recorded. Is this real or is it an artifact of calibration changes? This question is difficult to answer because of the calibration uncertainties. However, cloud variations on regional and shorter time scales are much larger than shown in Fig. 3 and can be studied with available data (Rossow and Schiffer, 1991).

Figure 4 illustrates the seasonal variation of the global mean cloud amount. Hemispheric mean cloud amounts actually vary proportionally with surface temperature: cloud amounts are lower in winter. However, differences in the amplitude and

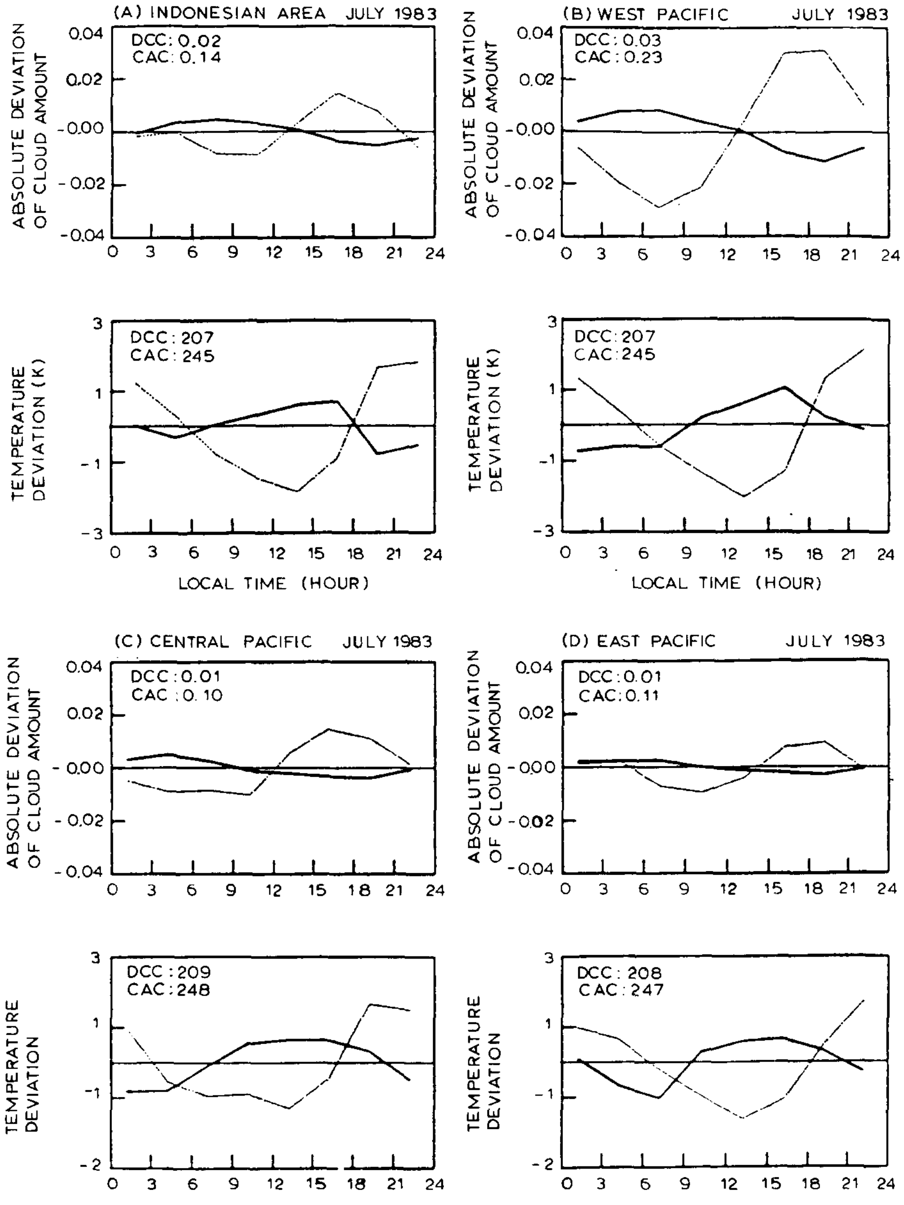

Fig. 5. Monthly mean diurnal cycles of tropical deep convective clouds (DCC) and cirrus-anvil clouds (CAC) for (A) Indonesian area, (B) Western Pacific, (C) Central Pacific and (D) Eastern Pacific for July 1983. Upper panels show absolute deviations of cloud amount from the daily mean and the lower panels show these deviations relative to the mean cloud amount.

phase of the seasonal variations in the two hemispheres produce the semi-annual cycle shown in Fig. 4. Nevertheless, this simple pattern is misleading since the seasonal variation of hemispheric mean cloud amount is dominated by changes at low latitudes while seasonal variation of the surface temperature is dominated by changes at high latitudes (Rossow and Schiffer, 1991). Thus, regional variations must be examined to diagnose the controlling processes.

Diurnal cycles of tropical convection

The major exchange of energy between the surface and atmosphere occurs in the tropics where solar heating is transferred to the atmosphere in the form of thermal radiation and latent heat. These tropical exchanges drive the entire circulation of the atmosphere. The latent heat exchange occurs in convective complexes that produce the bulk of precipitation. Monitoring variations of tropical cloud properties can elucidate the controlling processes. Figure 5 shows that the two types of upper-level cloudiness associated with these convective complexes have different diurnal variation phases: the peak mesoscale anvil cloudiness lags behind that of the convective towers. The correspondence of the diurnal phase of precipitation measured at the surface with that of the deep convective clouds reveals a fundamental separation of the energy exchange into two parts: the small scale convective motions transfer the predominant amount of latent heat (although the contribution of the anvil clouds is significant), but the larger scale clouds influence the radiation exchanges more (Fu et al., 1990).

Detailed comparisons of the distributions of the convective clouds with the pattern of sea surface temperatures (Fig. 6) shows that the correspondence is not simple, implying that something more than the thermodynamics of the local atmosphere controls this process (Fu et al., 1990). Fur-

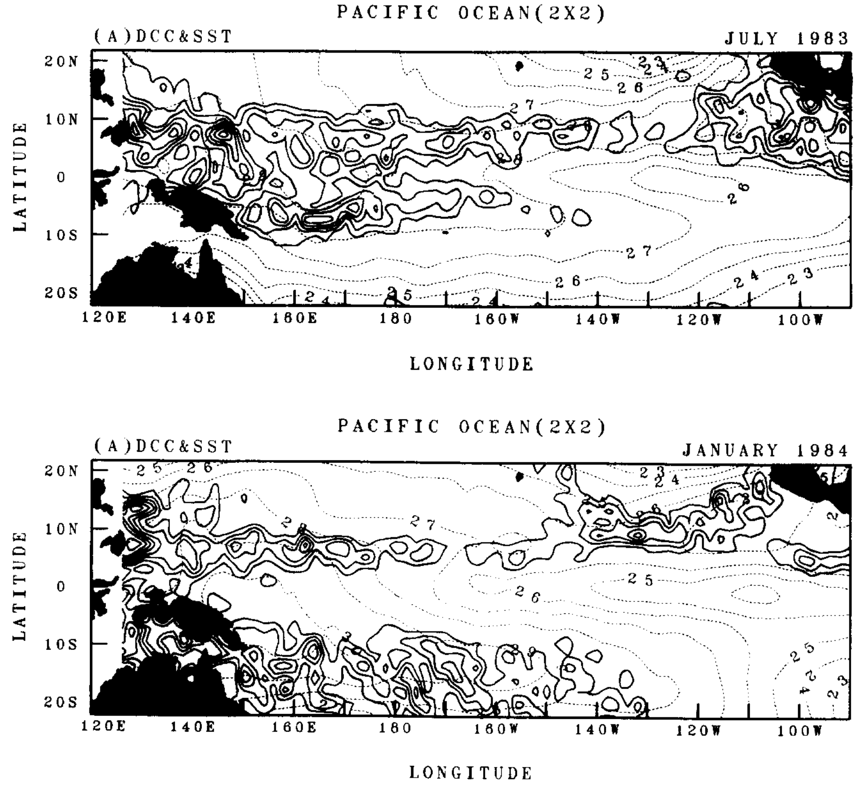

Fig. 6. Maps of monthly mean deep convective cloud (DCC) amount and SST for July 1983 (top) and January 1984 (bottom).

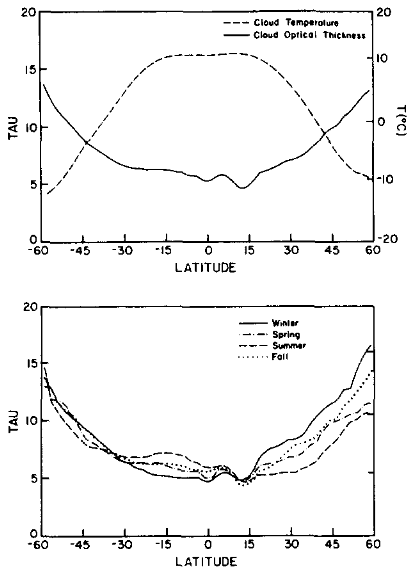

Fig. 7. Variations of annual mean cloud optical thicknesses (O) and temperature (T) with latitude (a) and for each season (b). Seasons are Northern Hemisphere winter (W), spring (A), summer (S) and fall (F).

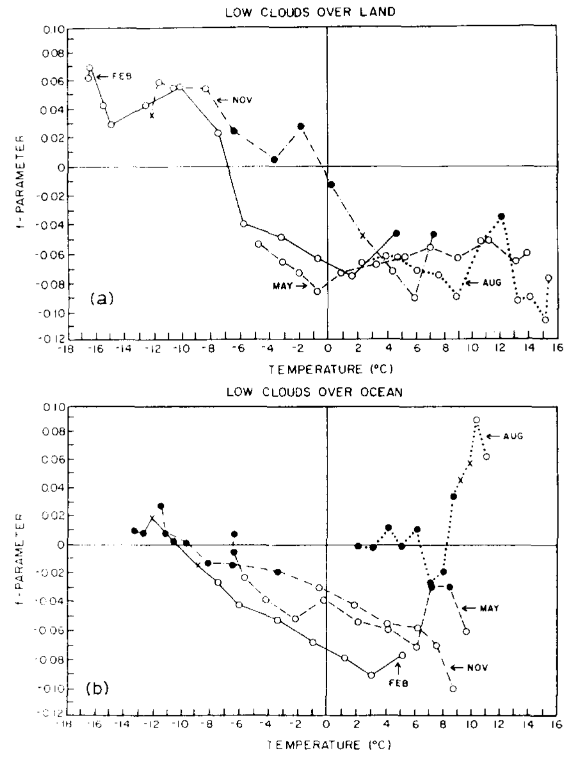

Fig. 8. Variations of f-parameter with temperature and season for low clouds over land (top) and ocean (bottom). The f-parameter is equal to $(1/\tau)\,(\mathrm{d}\tau/\mathrm{d}T)$.

ther study of the variations of the cloud physical properties and their relationships with surface and atmospheric properties will provide a better understanding of the role of tropical convection in the climate.

Variations of cloud optical thickness

Cloud optical thickness determines the interaction of clouds with both the solar and thermal radiative fluxes. The strongest relationship is between cloud optical thickness and the total solar heating of the surface and planet. If thermodynamic processes were the sole influence on cloud properties, such as cloud water content which influences the optical thickness of clouds, then clouds might be expected to increase their optical thicknesses and decrease solar heating in a warmer climate (i.e., act as a negative feedback on climate changes). Figure 7 and 8 show that clouds do not exhibit such simple behavior (Tselioudis et al., 1990). Although temperatures are lower at higher latitudes, cloud optical thicknesses are larger on average. Even within particular latitude zones, cloud optical thickness can either increase or decrease with temperature: at colder temperatures in

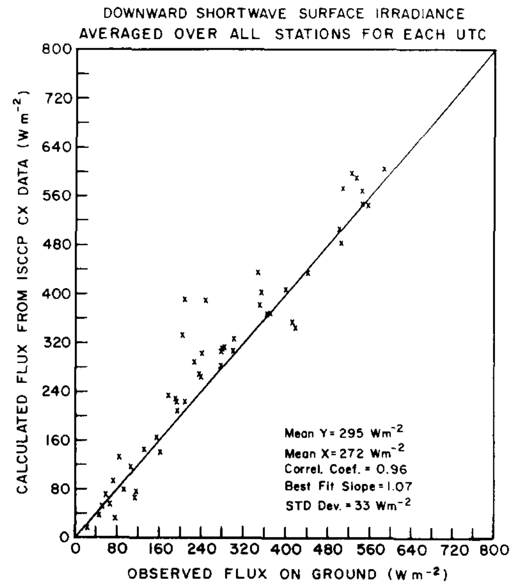

Fig. 9. Comparison of calculated areal mean, downward solar fluxes from ISCCP data with surface measurements collected in Wisconsin.

Table 2
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

winter, cloud optical thicknesses appear to vary with temperature as if only thermodynamic processes were in control; but at higher temperatures in summer, the relationship changes sign. This clearly implies a key role of atmospheric dynamics in determining the properties of clouds.

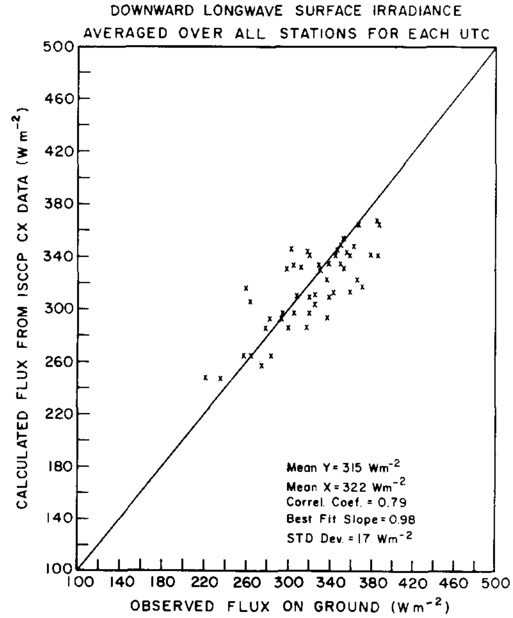

Fig. 10. Comparison of calculated, areal mean thermal fluxes from ISCCP data with surface measurements collected in Wisconsin.

Calculation of radiative effects of clouds

The combination of all of the measured properties of the clouds, surface and atmosphere allows for a diagnosis of the effects of cloud variations on the planetary and surface radiation budgets. Development of methods for performing such calculations is still underway (Rossow et al., 1990), but Table 2, Figure 9 and Figure 10 show that reconstructing the radiation budgets this way may have enough accuracy to determine the detailed effects of clouds in today's climate.

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