Radiative Properties of Nonuniform Clouds

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We report here preliminary results from our first two experiments for the Atmospheric Radiation Monitoring (ARM) Program. The first experiment is mechanistic in character and focuses on testing general circulation models (GCM) parameterizations of cloud radiative properties. In this experiment, Cloud and Radiation Testbed (CART) measurements of solar flux and integrated liquid water content are used to obtain an empirical relationship between the diffuse transmission of stratus clouds and the liquid water path (LWP). Diffuse cloud transmission is defined as

$$T_c = F_{cb}/F_{ct} \quad (1)$$

where F_{cb} is the downwelling shortwave flux at cloud base, and F_{ct} is the downwelling shortwave flux at cloud top. A plot of the experimentally derived cloud transmittance vs liquid water path is shown in Figure 1 for several days of data from the Southern Great Plains CART site in Oklahoma. Each point on this plot consists of a 5-minute average of the relevant data. The solid line is a plot of the empirically derived relationship between LWP and cloud transmittance from Derr et al. (1990).

The shortwave fluxes necessary to compute the cloud transmission in Figure 1 were estimated in the following way. Because no measurements of F_{ct} were made, F_{ct} was estimated from measurements of the downwelling shortwave flux at the surface under clear sky conditions. Clear sky conditions chosen for these estimates were restricted to days adjacent to those when the cloudy sky measurements were made. Since F_{ct} varies with time of day, measurements of F_{ct} were time-matched with radiation measurements made during cloudy periods. F_{cb} was assumed to equal the measured shortwave flux at the surface. Estimates of F_{ct} and F_{cb} made in this way introduce some error; the extent of this error is a subject for future calculations. An alternate procedure would be to calculate F_{ct} and F_{cb} using available field data and a radiative transfer model.

It is apparent from Figure 1 that the data follow the general functional form of the empirical parameterization developed by Derr et al. (1990). However, there is significant scatter about the line that best describes the Derr relationship between LWP and cloud transmittance, and there appears

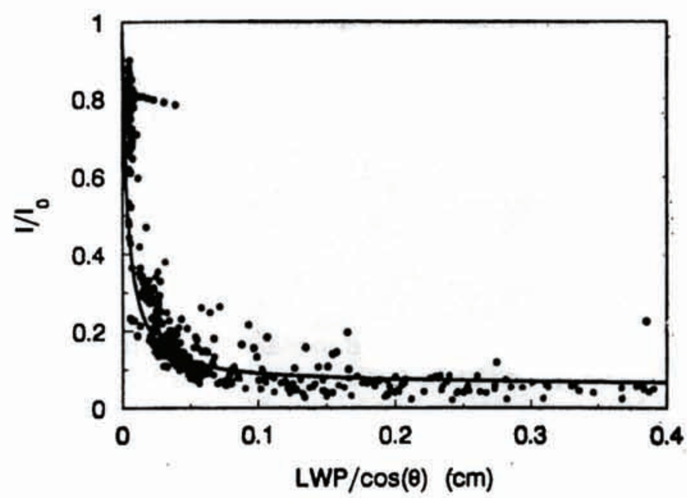

Figure 1. The diffuse solar transmittance as a function of liquid water path derived from CART data. The solid line is the empirical relationship of Derr et al. (1990).

to be some bias in the data. While it is premature to draw conclusions on the basis of such a limited data set, several comments regarding this variability and bias are in order. For a fixed liquid water path, variations in the equivalent radius of the cloud droplets can influence the transmittance. Larger numbers of smaller drops for the same liquid water path lead to decreased cloud transmittance. Thus, knowledge of the droplet size spectrum may be necessary to reduce the scatter and bias in the plot. Small scale variability in the liquid water path may also contribute to the scatter. We also note that measurements of LWP from the microwave radiometer currently used at the CART site is only marginally useful for exploring the LWP-T_c parameterization at low LWPs where T_c is changing most rapidly. Subsequentially, we plan to compare the experimentally derived cloud transmittance to the transmittances calculated using a new parameterization scheme developed in this project and to extend this type of analysis to relationships such as between cloud emissivity and LWP, albedo and LWP.

Our second experiment is a prototype of a set of experiments in which we seek to explore broad climatological relations between radiative properties of the atmosphere and other key atmospheric parameters, both as a general test of parameterizations and as a way of introducing new diagnostic analysis procedures which can be used to test global climate models. In our first effort, we are evaluating a simple graybody relationship (Stephens and Greenwald 1991) between the downwelling longwave flux at the surface, F_g; the outgoing longwave flux at the top of the atmosphere, F_∞ ; and the column integrated water vapor content, ω, *viz.*,

$$F_g = F_\infty(c + d\omega). \qquad (2)$$

Stephens et al. (1993) used an analysis system developed by Slingo and Webb (1992), (Simulation and Analysis of Measurements from Satellites using Operational aNalyses-SAMSON) to establish the constants of the relationship. This model incorporates data from the European Centre for Medium-Range Weather Forecasts (ECMWF) operational analyses into a radiative transfer model to simulate the radiation fields. The results of this simulation gave values for the constants *c* and *d* and suggested that simultaneous satellite observations of ω and clear sky F_∞ may provide a way of predicting downwelling longwave flux at the surface with an accuracy comparable to the best current measurements of these fluxes (15 W/m^2).

Independent evaluation of the flux ratio relationship is difficult since there are few if any concurrent measurements of F_g, F_∞, and ω over the ocean where satellite retrievals of ω using SSM/I measurements are possible (e.g., Greenwald et al. 1993). Our efforts so far use data collected during several oceanographic cruises, the R/V Alliance cruises in the Mediterranean in the summer of 1990 and the fall of 1991, and the USCGC cruise in the polar sea in the summer of 1992. The relevant data from these cruises consist of measurements of the downwelling longwave radiation at the surface, and concurrent soundings of water vapor and temperature. Unfortunately, no satellite measurements of F_∞ are available so, for purposes of this analysis, F_∞ is calculated using a radiative transfer model.

Our evaluation consists of three steps:

1. The F_g calculated from the radiative transfer model using the measured water vapor and temperature profiles is compared with the observed F_g .

2. The flux ratio F_g/F_∞ calculated using the radiative transfer model and the experimental soundings is compared with the relationship derived by Stephens et al.

3. The relationship F_g/F_∞ determined from the measured values of F_g and ω, and F_∞ calculated from the radiative transfer model is compared with the Stephens et al. relationship.

The first two steps in the evaluation are tests of the radiative transfer model's ability to calculate the fluxes correctly. The third step in the evaluation is a direct test of the relationship derived by Stephens et al., albeit with calculated values of F_∞. Figures 2a and 2b show the results of this evaluation.

In Figure 2a, we see that the observed and calculated values of F_g agree quite well, with an average deviation for all of the data on the order of 10 w/m^2. This result gives us confidence that the radiative transfer model is correctly calculating the fluxes. In Figure 2b, we show the results of

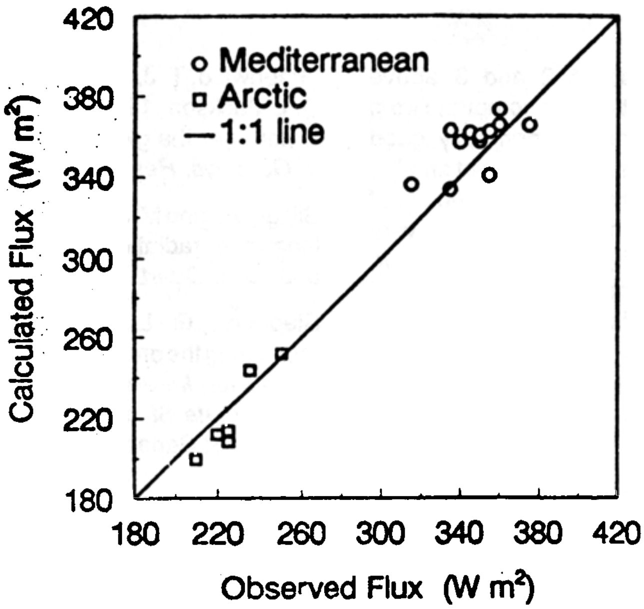

Figure 2a. Comparison of calculated and observed downwelling longwave fluxes.

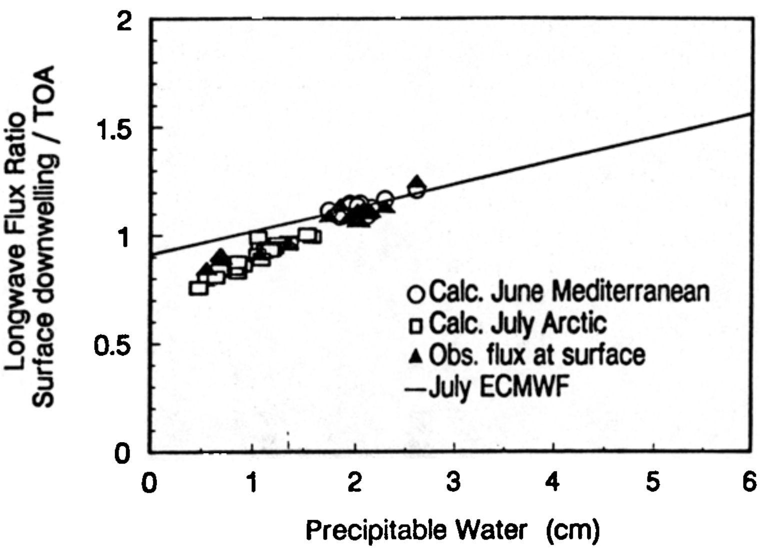

Figure 2b. F_g/F_∞ calculated using the radiative transfer model and the experimental soundings and using the measured values of values of F_g and ω and F_∞ compared to the Stephens et al. relationship.

the calculations described in steps 2 and 3 above superimposed on a plot of the relationship computed from the ECMWF data. Again, we observe generally good agreement including the ratio's curve of growth at smaller values of ω. The cause of this curvature is the subject of current investigation. These preliminary results are very encouraging, and we plan to continue this analysis using CART data. Of particular interest are data from the Tropical Western Pacific locale because of the high values of ω at that location.

References

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