Radiative Effects of Non-Uniform Clouds

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The overall objective of the Atmospheric Radiation Measurement (ARM) Science Project "Radiative Effects of Non-Uniform Clouds" is to improve the treatment of cloud radiation interactions and feedbacks in general circulation models (GCMs) by obtaining a better understanding of the distribution of water in the atmosphere and its relation to the radiation reflected and emitted by clouds. Sub-objectives are to test current model parameterizations of short and long wave cloud radiation interactions and to determine the climatological relations between domain average radiative properties and cloud structure. This abstract summarizes an experimental strategy to achieve these objectives, focusing on the measurements likely to be available from the first Cloud and Radiation Testbed (CART) site.

An organizing concept that is useful in classifying the individual experiments is a distinction between experiments that are primarily *mechanistic* or primarily *climatological*. The emphasis in a mechanistic experiment is to identify morphologically simple cloud systems and assemble sufficient observations to mechanistically link cloud and radiative properties. This category of experiments is primarily directed at the testing of cloud-radiation parameterizations. In the climatological category of experiments, the emphasis is on accumulating a long-term record of radiometric, cloud, and meteorological variables, and thereby determining relations between cloud and radiation climatology.

Model parameterizations that will be tested are for short wave transmittance, absorption and albedo, infrared emittance, and the effects of cloud non-homogeneities on these quantities. Tests of parameterizations necessarily require the measurement of radiative quantities and the measurement of related cloud physical properties that are, or potentially can be, predicted in climate models. Radiative properties of liquid water clouds are typically parameterized in climate models as functions of cloud liquid water path and, in some instances, effective drop size. Radiative properties of cirrus are often given in terms of cloud temperature and depth as prediction and measurement of the ice water path is problematic. Partial cloudiness is usually accounted for by calculating radiative fluxes for clear sky and complete overcast, and then combining fluxes according to fractional cloud cover. A linear weighting scheme is most common, but more complicated weighting schemes taking into account actual cloud geometry have been proposed.

As examples, experimental strategies for testing several parameterizations are briefly described below. Two features should be noted. First, reliance on ground-based instruments means that several tests are indirect. Second, there are sampling difficulties in determining domain averaged values for cloud radiative and physical properties when cloud fields are not homogeneous.

Short wave cloud transmittance is defined in terms of fluxes above and below cloud. In a ground-based measurement system the downward flux measured at the surface has to be corrected for the transmission of the atmosphere between cloud and ground level and also for multiple reflections between surface and cloud base. Flux above cloud is calculated rather than measured. Transmittance is then calculated from the corrected surface flux and the calculated cloud top flux. Observed transmittance is then compared with transmittance from currently used parameterizations, most of which depend upon cloud liquid water path (LWP). This experiment requires a microwave radiometer for LWP, a short wave radiometer for downwelling irradiance at the surface, surface albedo, and clear sky atmospheric transmission. A similar approach has been used by Derr et al. (1990).

The determination of albedo is less direct, as it is inferred from transmission at a non-absorbing wavelength and then corrected for absorption by liquid water. Some parameterizations cannot be evaluated at all from the surface; for example, those dependent upon cloud droplet spectra. Therefore, plans have been made for the use of airborne platforms.

Parameterizations of the effects of cloud non-uniformities on radiative properties will be evaluated by comparing a measured domain averaged radiative property (for example, albedo) with the calculated values given in Equations (1) and (2), below.

Equivalent uniform cloud approach:

$$R^* = R(LWP, r_e) \quad (1)$$

where LWP and r_e are the domain average liquid water path and effective drop radius, assuming a uniform distribution of water.

Weighted average approach:

$$<R> = 1/A \int R(LWP, r_e)\, dA \quad (2)$$

where A represents the area of the domain and LWP and r_e are sub-domain quantities.

Domain averaged quantities (for example, LWP) can be evaluated in several ways. Aircraft platforms can be used to rapidly sample spatially extended regions. Spatial averages can be constructed from time averages obtained from stationary surface instruments. Construction of spatial averages can also involve scanning and combining of data from the CART central and auxiliary sites.

The climatological study of the radiative effects of liquid water distribution is motivated in part by Stephens and Greenwald (1991) who found large difference between the albedo per unit amount of cloud water in the tropics and mid-latitude, which was ascribed to differences in the way in which water is piled up in these regions (i.e., convective clouds versus stratus). CART data will be used to accumulate a long-term record of LWP and albedo (a derived quantity). The entire data set will be analyzed for mean values and frequency distributions, then split into subsets based on stratification variables such as fractional cloud cover, cloud type, and vertical extent, thereby yielding albedo-LWP relations for major cloud categories.

References

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