Additional Confirmation of the Validity of Laboratory Simulation of Cloud Radiances

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ABSTRACT

The results of a laboratory experiment are presented that provide additional verification of the methodology adopted for simulation of the radiances reflected from fields of optically thick clouds using the Cloud Field Optical Simulator (CFOS) at Colorado State University. The comparison of these data with their theoretically derived counterparts indicates that the crucial mechanism of cloud-to-cloud radiance field interaction is accurately simulated in the CFOS experiments and adds confidence to the manner in which the optical depth is scaled.

1. Introduction

The Cloud Field Optical Simulator is a laboratory device designed to simulate the radiative properties of optically thick clouds in the visible portion of the electromagnetic spectrum. A detailed description of the CFOS apparatus and experimental evidence providing the initial verification of the process may be found in Davis et al. (1983). Basically, the initial verification consisted of a comparison between laboratory simulated and theoretically derived radiances reflected by fields of clouds. From these data it was shown that the effects of cloud geometry on the reflected radiance fields that would be observed by medium field-of-view sensors was accurately simulated. These initial patterns were formed from a combination of radiances reflected from the cloud tops and sides with the relative amounts of top versus side radiance depending on the sun-cloud–observer geometry. In particular, the dramatic shift from generally forward-scattered to backward-scattered average cloud radiance patterns was observed at larger solar zenith angles, when cubic clouds were used instead of horizontally infinite clouds. This effect is primarily the result of the exposure of the vertical cloud face to direct solar radiation and its reflection back into that direction, a process that has no analog in the case of the smooth-topped, horizontally infinite cloud case.

Throughout the period during which the original verification was being conducted, the characteristic pattern of radiances exiting the sides of the small cubic clouds used in the experiments was noted. It was this type of observation coupled with some of the original finite cloud modeling efforts that triggered the initial work in the laboratory simulations; see Kuenning et al. (1978). A photograph of an optically thick, cubic cloud made of decorative billet styrofoam that depicts this type of pattern is shown in Fig. 1. The edge effects on the radiance pattern, which have been often noted in the literature, are readily apparent in this photograph. A comparison of this pattern to one derived from theoretical computations is a way of taking the verification process a step further. This comparison is more sensitive to the actual diffusion of the radiation through the cloud and is more analogous to a narrow field-of-view measurement. The next section describes such a comparison, which differs from the original verification experiments in that radiances are measured that exit one of the vertical faces of the cloud from a small area and into a small solid angle of directions.

2. Description of the experimental procedure

In order to measure the radiance patterns exiting the side of the simulated cloud, a separate, smaller laboratory device was arranged. A small cubic cloud identical to those used in the original verification experiments was mounted on a support that could be moved along the main axis of an optical bench. A silicon photodiode of the same type as those used in the CFOS was mounted on another support so that the vertical displacement of the diode and that in a direction perpendicular to the main axis of the optical bench could be measured. The diode was positioned so that it viewed the side face of the cloud from a direction normal to the cloud face. The field of view of the diode was limited to 5 deg. The simulated cloud and the detector assembly were enclosed in a box whose interior was coated with flat black paint in order to minimize stray light contamination. The cloud top was illuminated through a square aperture at a zero degree zenith angle using a lamp identical to those used in the CFOS laboratory. The dimension of the cloud was chosen so that some measure of similarity between the simulated and modeled optical depth could be achieved. The method ar-

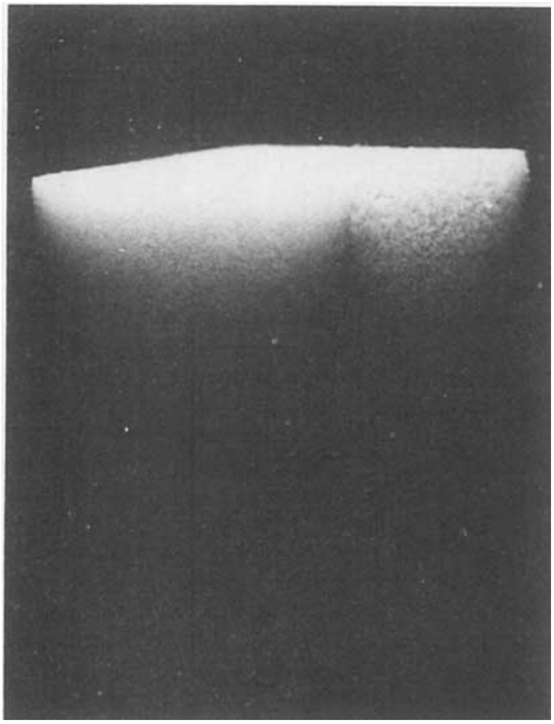

FIG. 1. A photograph of the radiance pattern from an optically thick cubic cloud under normal irradiation as simulated in the CFOS.

rived at was to match the ratio of radiances measured at two points on the face of the cloud to the corresponding value obtained from modeled radiances, which were obtained as described below. The radiances used in forming the ratio were measured along the vertical line passing through the center of the cloud face, one at a distance of $s/10$ as measured down from the top of the cloud, where s is the cloud dimension, and the other at $s/2$, or at the center of the cloud face. This method of scaling resulted in a value of optical depth that agreed with that obtained by another algorithm for scaling the optical depth, which is described in Davis et al. (1983), to within 10 percent.

The radiances were measured at 25 points uniformly distributed across the cloud face. No measurements were taken within a distance of less than $s/10$ from any cloud edge because the cellular nature of the styrofoam coupled with the finite field of view of the detector caused uncertainty that the field of view was completely filled by the cloud. The measurements were found to be symmetrical with respect to the vertical line through the cloud face center to within the rms deviation in the measurement, which was measured to be typically 8 percent of the mean value of the respective radiance. Thus the results were "folded" to provide a symmetric representation of the radiance field. Contours of the relative values of measured radiance are shown in Fig. 2.

3. Calculation of side exiting radiances

In order to evaluate the suitability of the styrofoam as a material for the simulation of cloud radiances the measured values were compared to theoretically derived results. These values were obtained from a backward-walk Monte Carlo model similar to that described in Collins et al. (1972). The model was run for a cubic cloud with an optical thickness of 60 for a solar zenith angle of 0 deg. The value of the optical thickness was chosen in conformance with the ratio criteria described earlier. A C.1 droplet distribution (Deirmendjian, 1968) was used for a wavelength of 0.55 micrometers. The radiances were calculated for points corresponding to those at which the radiances were measured as described above. At each point 1000 photon histories, each with 800 forced-scattering events, were simulated. The standard error resulting from the stochastic model was typically 4% of the respective mean radiance value. The calculated radiances were normalized and contoured in the same manner as were the measured values. The plot of these contours is shown in Fig. 3.

4. Discussion

The similarity between the measured and calculated values is remarkable. A few words of qualification should be added. First, no radiances were measured or calculated close to the cloud edges. Figure 1 indicates that it is likely that the contours of measured radiance should rise steeply near the edges. Second, the reader is reminded that the relative radiances were forced to agree at two points on the cloud face in an attempt to equalize the optical thicknesses of the clouds. Third, the patterns are not identical. The measured radiance values span a slightly greater range than the calculated values. The disagreement between the low end radiances near the bottom of the clouds is less significant than discrepancies of larger values near the cloud top,

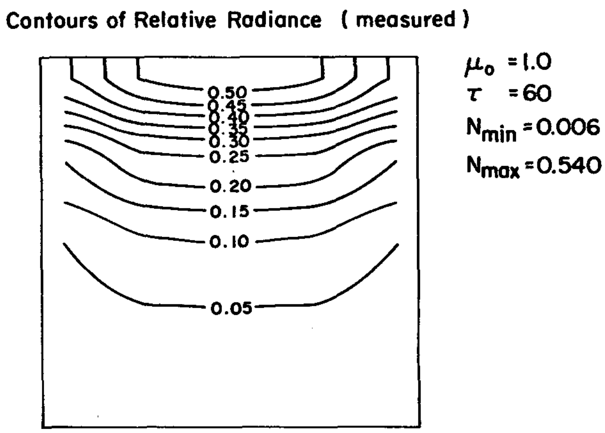

FIG. 2. Contours of relative radiance (measured) exiting the side of a simulated cubic cloud irradiated at normal incidence.

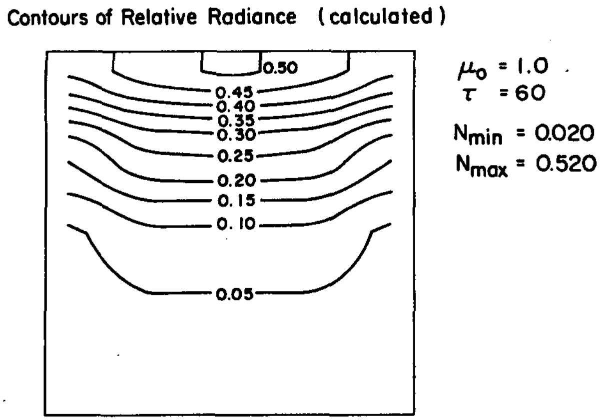

FIG. 3. Contours of relative radiance (calculated) exiting the side of a modeled cubic cloud irradiated at normal incidence.

at least as far as the CFOS simulations are concerned. Fourth, it may be that the measured radiances would have agreed more closely to calculations performed using a different cloud droplet distribution. The C.1 distribution was chosen simply because it is commonly accepted as one that may represent cumulus clouds. The goal of the present research using the CFOS is to examine the reflected radiance fields of simulated, optically thick clouds of a more realistic shape. It is likely that the effects of a more realistic geometry will be at least as important in determining the behavior of the radiance fields as will changing the droplet distribution. Finally, the radiances have been compared only for normal exiting radiances resulting from normally incident radiation. Even with these qualifiers the comparison that has been demonstrated indicates that the CFOS experiments will approximate the real world situation even when cloud coverage is such that cloud to cloud interaction is an important mechanism.

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