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Annual Report

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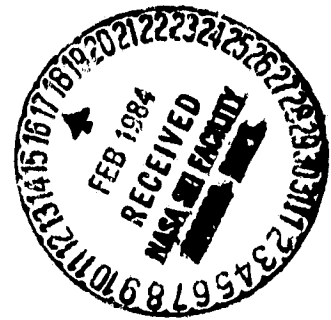
"A Laboratory Investigation of the Reflective Properties
of Simulated, Optically Thick Clouds"

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This report summarizes the progress toward the specific research goals of the cloud field simulation project which has been made since June 1981. Accomplishments prior to this date were reported in our first semi-annual progress report in February 1981 and at the Fourth Conference on Atmospheric Radiation, Toronto.[1]

During the reporting period stated above, progress toward the research goals of CFOS (the Cloud Field Optical Simulator) may be noted in the following areas: (1) improvement in the shape of the desired (visible) spectral response of the measurement, (2) selection of two usable materials for cloud simulation, (3) a means of assigning a "visible" optical depth to the simulated clouds and (4) confirmation that the apparatus is capable of detecting basic finite cloud characteristics. A brief description of the accomplishments in each of these areas follows.

(1) Improved Spectral Bandpass

In order to insure that the measurements were limited to the visible portion of the spectrum an optical filter was placed in front of each detector. Figure 1 shows the relative responses of the system with and without the filter. Although insertion of the filter resulted in a relatively poorer S/N ratio it ensures that the measurements will not include spectrally dependent effects which are visually unobservable.

[1]McKee, T. B., J. M. Davis, and S. K. Cox, 1981: Design and verification of a cloud field optical simulator. Preprints Fourth Conference Atmospheric Radiation, Toronto, Amer. Meteor. Soc., pg. 227.
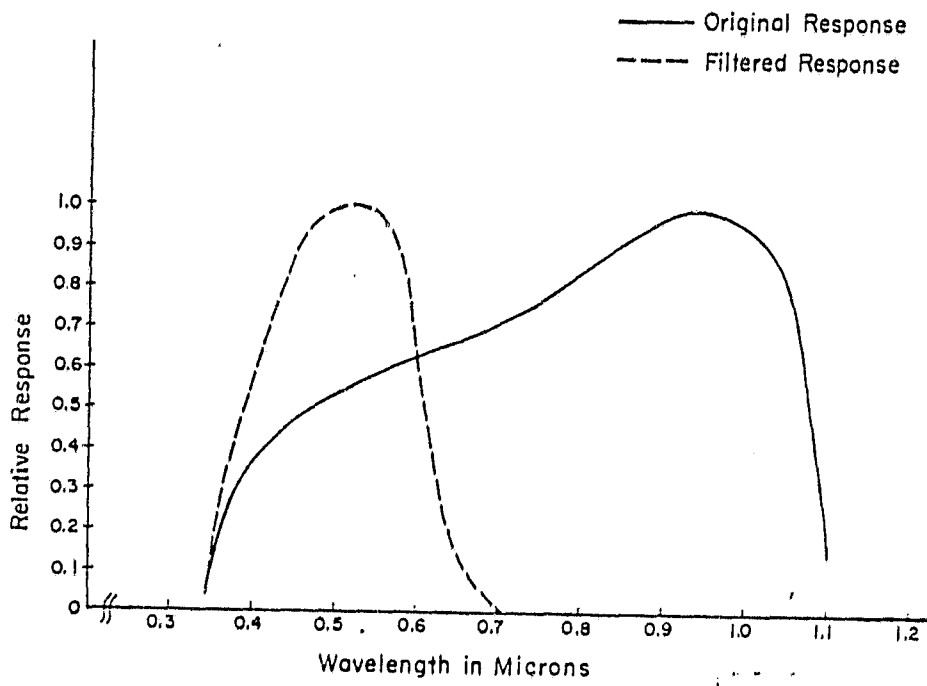
Figure 1. Relative spectral response of the original
and filtered CFOS photodiode.

2. Selection of Suitable Materials for Cloud Simulation

Several materials have been examined in a search for one which adequately simulates the visible reflective properties of optically thick clouds. The criteria which were used to rate the materials were first, the behavior of the radiances reflected into the principal plane by a horizontally semi-infinite cloud, and second, the visual appearance of the clouds simulated from the material. Based on these criteria, two materials were found to be superior to all others tested; they are surgical quality sterilized cotton and decorative billet styrofoam which is marketed by Dow Chemical. Figures 2 and 3 compare measured principal plane reflected radiances of the two materials with theoretical curves for semi-infinite clouds from Monte Carlo radiative transfer calculations. The model was run for two solar zenith angles $\mu_o = 1.0$ and $\mu_o = 0.5$ using the C.1 droplet distribution at a wavelength of 0.7 μm. All radiances have been normalized by the dividing by reflected radiance at the zenith. The materials are almost equivalent in satisfying the first criteria. However, the styrofoam is slightly better in the backscatter direction. The assignment of an equivalent optical depth to the simulation materials is discussed in the next section.

Both materials do well in simulating the visual appearance of clouds. If we add a third criterion, namely the practicality of working with the materials, the styrofoam becomes preferable for a number of reasons. First, the styrofoam material is rigid and will maintain a constant ratio of geometric to optical depth, and the shape of the simulated clouds will not distort due to gravity with rotation of the
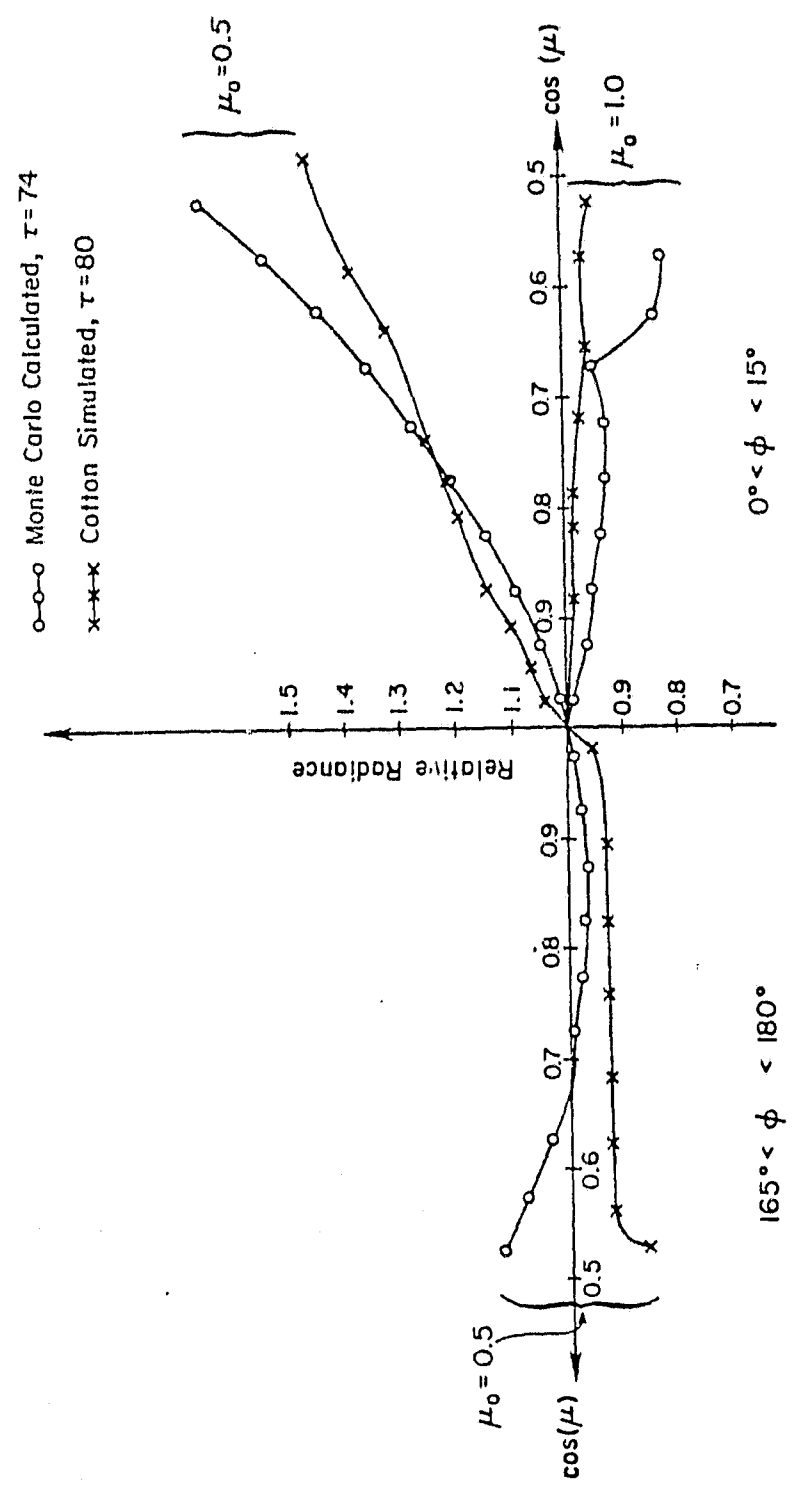
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Figure 2. A comparison between the calculated and simulated reflected radiances from semi-infinite clouds for solar zenith angles of 0° and 60° using cotton as the cloud simulation material.
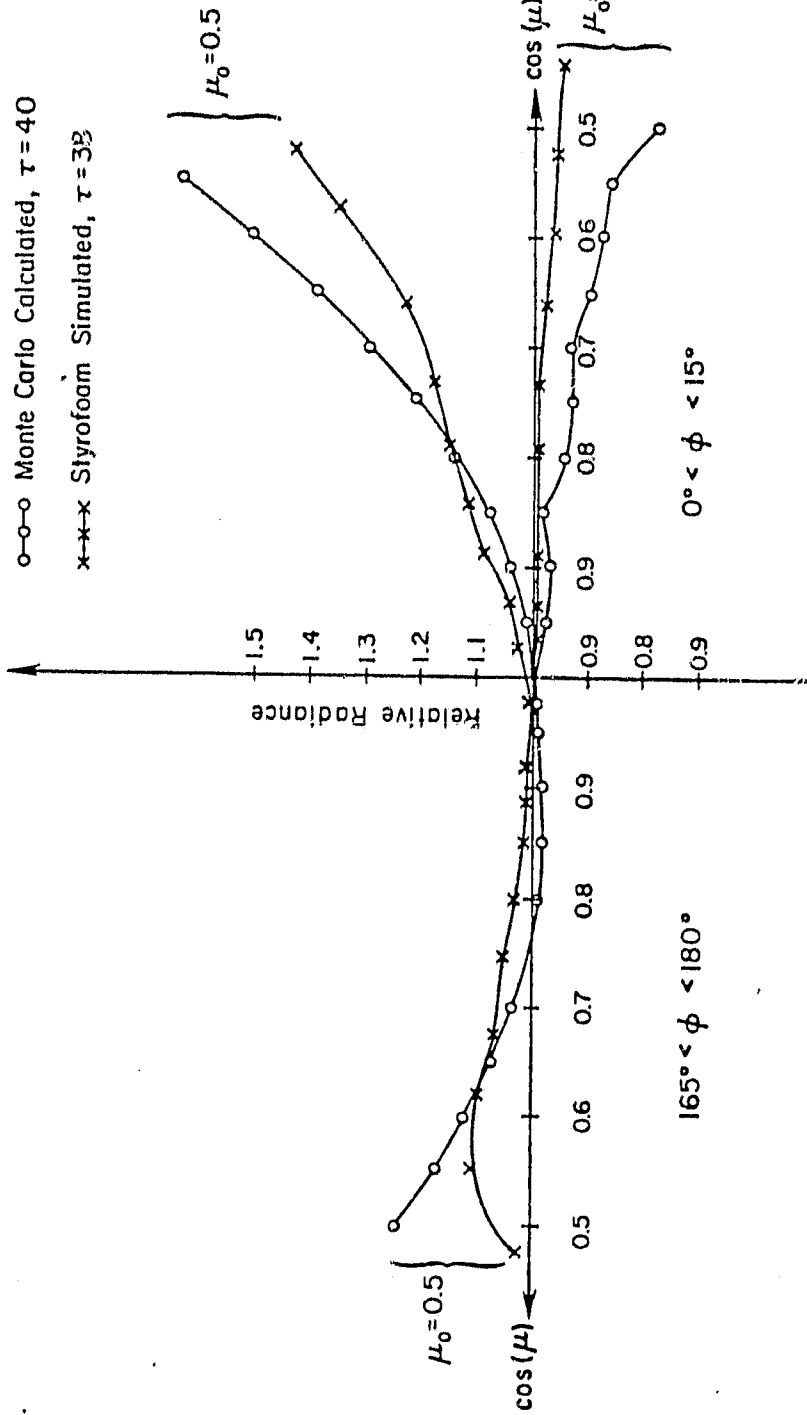
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Figure 3. A comparison between the calculated and simulated reflected radiances from semi-infinite clouds for solar zenith angles of 0° and 60° using styrofoam as the simulation material.

CFOS apparatus about the simulation zenith. Second, simulated styrofoam clouds are easily exchanged from one cloud scene to another or moved about within a cloud scene. Finally the styrofoam simulated clouds are easily made into regular shapes, i.e. cubes, cylinders, inverted paraboloids etc. for comparison with theoretical results for finite clouds.

3. A Method of Assigning a Visible Optical Depth to the Simulated Clouds

In order to relate the reflective properties of simulated clouds to real water clouds it is necessary to have an accurate estimate of the optical depth of the simulated clouds. One means of doing so is based on the bulk radiative properties of a 'semi-infinite' sheet of the cloud material at 0° zenith. Specifically theory predicts that the ratio of spectral reflectance R_λ to spectral transmittances T_λ of a semi infinite cloud over a non reflecting surface is nearly a linear function of optical depth, see for example Coakley and Chy'lek (1975) and Stephens (1978). Figure 4 shows a plot of the ratio of R/T generated from the parameterization of Stephens (1978) for water clouds in the visible portion of the spectrum. Also shown is the same ratio from a simple Eddington-model which employed the Henyey-Greenstein approximation for various cases and also a few results of the R/T ratio from Monte Carlo calculations. The linear dependance between R/T and τ the visible optical depth is apparent.

An equivalent visible optical depth (τ_e) may be assigned to the CFOS cloud simulation material by measurement of the ratio of R/T for a sheet of the material with a large ratio of
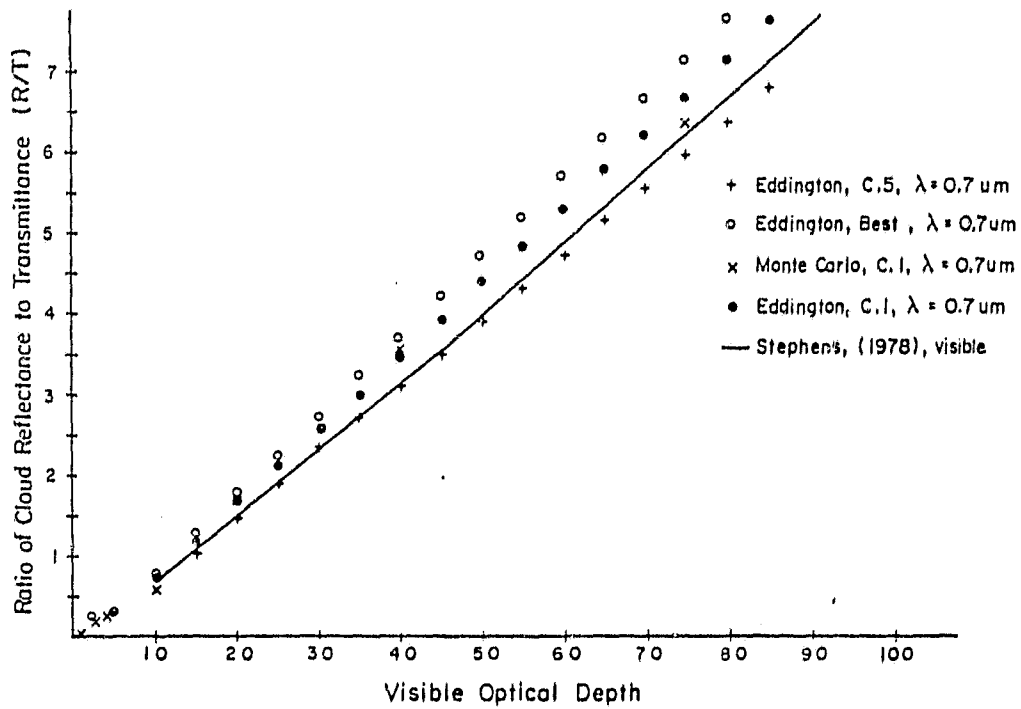
Figure 4. A plot of the ratio of reflectance to
transmittance derived from various
calculations as a function of optical
depth.

horizontal to vertical dimension. Once τ_e is

established for a large slab of styrofoam several clouds may be

'sculptured' from the slab while maintaining in each the vertical

dimension of the original slab. The procedure requires an additional

step in the case of cotton since the vertical structure of the original

'slab' (surgical cotton is available in 12" by 60" sheets) can not be

maintained while forming clouds of a realistic shape. However, it was

found that the mass of the material in a vertical column of unit cross

section is also related to the ratio of the R/T in a nearly linear

manner; see figure 5. Thus, for a cloud simulated from surgical cotton

an approximate visible optical depth may be assigned by weighing the

cloud and measuring the cross sectional area to determine the area mass

density then using the R/T line as a transfer function to

τ_e. The additional measurement is yet another

limitation to the suitability of using cotton as the cloud simulation

material.

4. Retrieval of Basic Finite Cloud Features

The most recent accomplishment with the CFOS concerns the ability

to measure the reflected radiances of finite clouds. Figures 6 and 7

are comparisons between radiances reflected into the principal plane by

finite clouds as measured on CFOS and the same quantities predicted by

the theoretical Monte Carlo model as described in McKee and Cox (1974).

The radiances in each case have been normalized by the radiance measured

or calculated at the zenith. The CFOS profiles have been retrieved from

measurements over a field of simulated (styrofoam) cubic clouds cut from

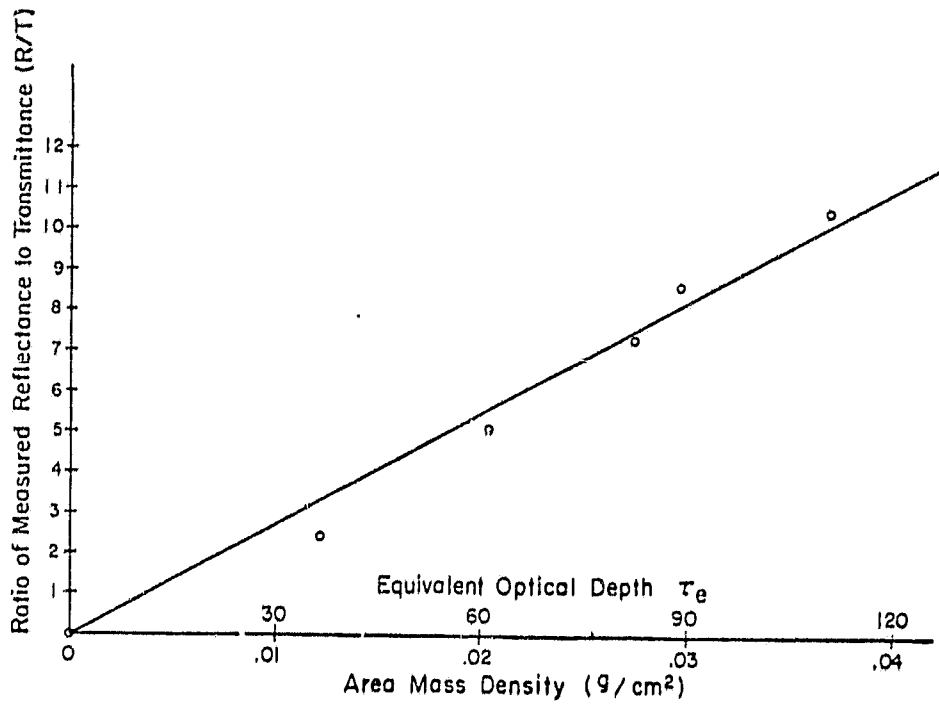a slab of material whose R/T ratio corresponds to an equivalent optical

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Figure 5. A plot of the ratio of reflectance to
transmittances measured by CFOS for a
'semi-infinite' cotton simulated cloud
plotted as a function of area mass density
and equivalent visible optical depth (T_e).

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Figure 6. A comparison between calculated and simulated reflected radiances from finite cubic clouds for a solar zenith angle of 0° using styrofoam for the simulation material.
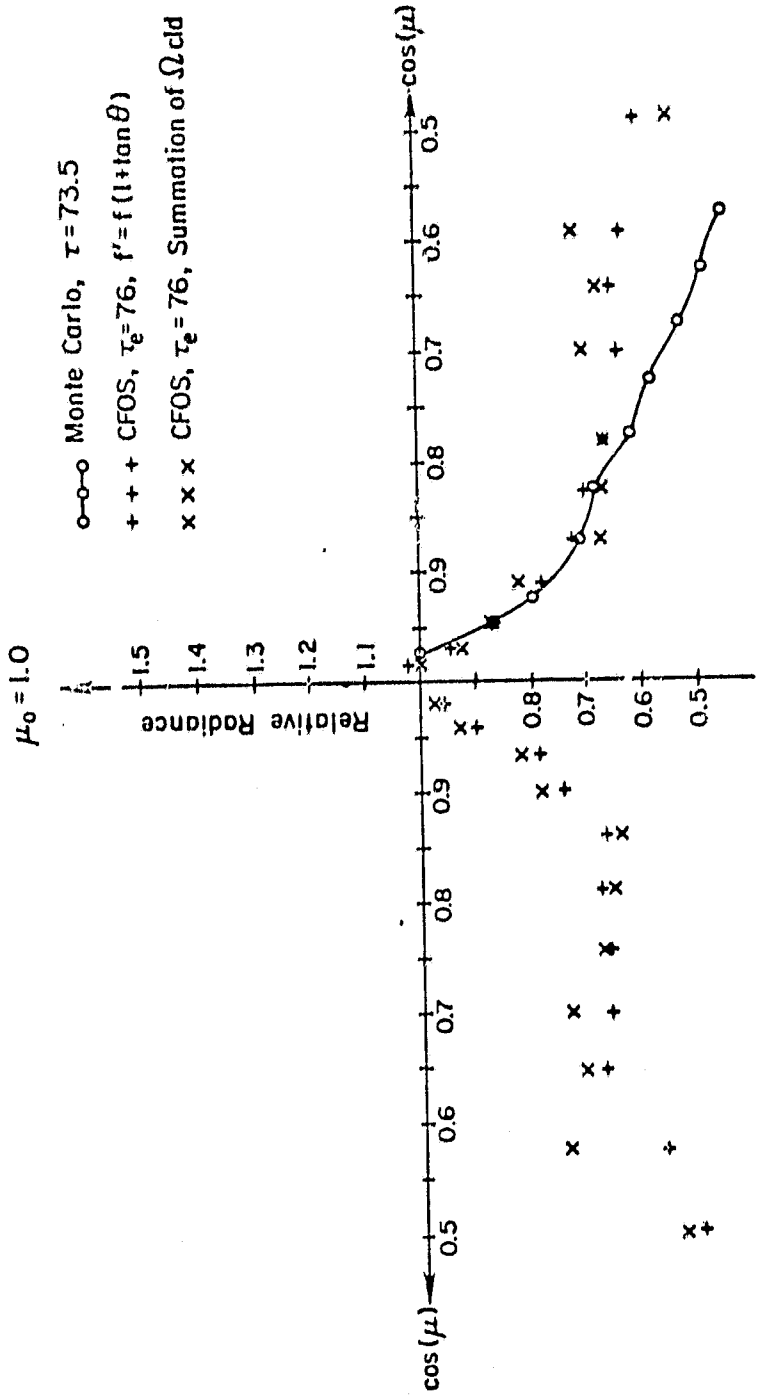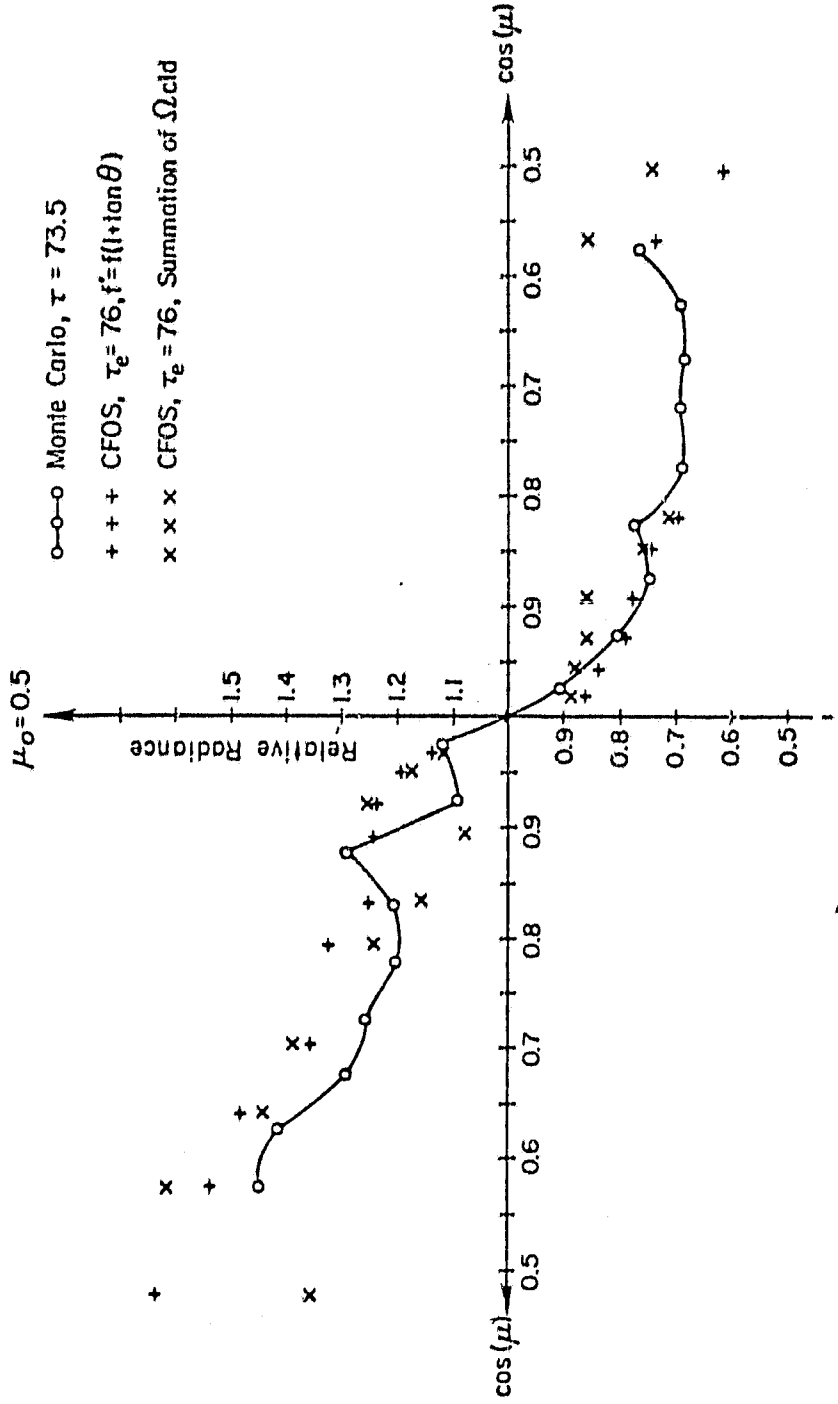
Figure 7. A comparison between calculated and simulated reflected radiances from finite cubic clouds for a solar zenith angle of 60° using styrofoam for the simulation material.

depth $\tau_e = 76$. The clouds were evenly spaced on a
horizontal grid such that the true fraction cloud cover (f) was 0.04.
Figures 6 and 7 each show two measured profile retrievals. One assumes
that as the nadir angle (θ) increases, the solid angle of cloud
field relative to the underlying surface increases as $(1 + \tan \theta)$
resulting in a modified fractional cloud cover $f' = f (1 + \tan \theta)$;
see Davis, Cox, and McKee (1979). The second treatment utilizes the
exact geometry of the cloud field and the CFOS detectors, counts the
clouds in the field of view and calculates the total solid angle
subtended by the clouds and their shadows. The radiance measurement (N)
is given as

$$N = N_{cld} \Omega_{cld} + N_{clr} \Omega_{clr} + 0 \Omega_{sdw}$$

In the above formula the subscripts cld, clr and sdw stand for
cloud, clear and shadow, respectively, and Ω represents solid angle.
It is assumed that there is no radiance contribution from the shadow
regions. The N_{clr} measurements were made over the surface
on which the clouds were mounted. The albedo of the surface was 0.02.
The second treatment results in a 'noisier' curve because the cloud is
either considered completely within or exterior to the field of view.
Nevertheless, smoothed versions of the curves are in good agreement.
The apparent disagreement between measured and calculated radiances at
large nadir in the 0° solar zenith angle case is believed to be due
primarily to the basic scattering properties of the material. Similar
disagreement is seen in the radiance comparisons for infinite clouds at
0° zenith.

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It should be noted that retrieval of the finite cloud reflected radiances, as described above, represents a rigorous test of the CFOS concept. The low surface albedo combined with the extremely small fractional cloud cover result in reflected radiances at the lowest bound of the domain for which CFOS was originally intended. Larger clouds, smaller cloud spacing and more realistic simulated surfaces will all tend to increase the radiance signal. In addition, the above experiment represents the retrieval radiances reflected from only part of the scene. Measurement of total scene radiances are of a more stable nature. Thus, it appears that the CFOS concept is indeed a valid means of exploring the effects of realistic cloud geometries on the radiances reflected by optically thick clouds and cloud fields.

References

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