N90-28237

Observed Cloud Reflectivities and Liquid Water Paths--An Update

J.A. Coakley, Jr.
Department of Atmospheric Sciences
Oregon State University
Corvallis, OR 97331-2209

J. B. Snider
NOAA/ERL Wave Propagation Laboratory
Boulder, CO 80303

We have used the FIRE microwave radiometer observations of liquid water path from San Nicolas Island and simultaneous NOAA AVHRR observations of cloud reflectivity to test a relationship between cloud liquid water path and cloud reflectivity that is often used in general circulation climate models (Stephens, 1978). Here we report on the results of attempts to improve the data analysis which was described at the previous FIRE Science Team Workshop and elsewhere (Coakley and Snider, 1989). The improvements included the analysis of additional satellite passes over San Nicolas and sensitivity studies to estimate the effects on the observed reflectivities due to 1) nonzero surface reflectivities beneath the clouds, 2) the anisotropy of the reflected radiances observed by the AVHRR, 3) small scale spatial structure in the liquid water path and 4) adjustments to the calibration of AVHRR.

NOAA-9 and NOAA-10 AVHRR data and San Nicolas Island microwave radiometer data were analyzed for all satellite passes for which San Nicolas Island and neighboring 60 km regions were overcast and there was no precipitation detected by the surface observers. The 1 minute liquid water path measurements obtained from the microwave radiometer were averaged for the hour containing the satellite overpass to obtain a value resentative of overcast conditions. The average 0.63 µm reflectivity for 1 km AVHRR fields of view that were within 60 km of San Nicolas Island and which were identified as being overcast was taken to represent the reflectivity of overcast conditions. The standard deviation of the reflectivity for these fields of view was taken to represent the typical variability in the reflectivity.

Figure 1 shows the observed 0.63 µm reflectivities and the parameterized cloud albedo for the liquid water paths observed with the microwave radiometer. The parameterized albedo is that developed by Stephens (1978) for nonabsorbing clouds. To obtain the agreement shown, we multiplied the reflectivities observed with NOAA-9 by 1.25 and those observed with NOAA-10 by 1.35. These factors gave the best linear least-squares fit with zero offset between the observed reflectivity and parameterized cloud albedo. As discussed below, we take these factors to represent adjustments to the calibration of the AVHRR instruments.

Because the parameterization is for cloud albedo while the observations are of the bidirectional reflectivity for clouds over a reflecting surface, we considered making corrections to the observations to allow for the reflectivity of the underlying surface, the anisotropy of the reflected radiation

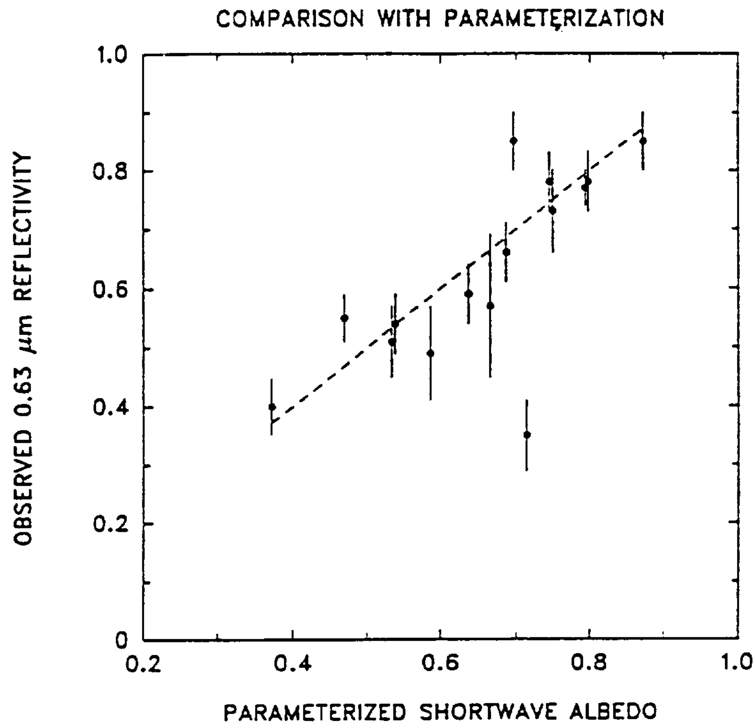

Figure 1. Observed 0.63 μm reflectivities and albedos calculated using the microwave liquid water paths in the parameterization developed by Stephens (1978). The line indicates perfect agreement. The observations for NOAA-9 were multiplied by a factor of 1.25 and the observations for NOAA-10 were multiplied by 1.35. The error bars indicate the typical variability in the reflectivities as deduced from the observations.

and the small scale spatial structure in the liquid water path which is not resolved by the AVHRR observations.

To first order in surface albedo, the reflectivity as observed by the AVHRR is given by

$$R' = R_c + \alpha_s (1 - R_c)^2 \qquad (1)$$

where R_c is the cloud reflectivity and α_s is the surface reflectivity for the particular viewing geometry. α_s is deduced from reflectivities observed under cloud-free conditions. The desired quantity is the cloud reflectivity, R_c, which is deduced by solving (1). We find that for the current set of observations $R' - R_c$ is generally less than 0.02 and as a result is a fraction of the typical variability in R' which is 0.05.

Concerning the anisotropy of the reflected radiances, the observations for NOAA-9 indicate that the reflectivities are nearly isotropic (after effects due to surface reflectivities have been removed). Consequently, for the

NOAA-9 observations no adjustments are made (Coakley and Briegleb, 1989). For NOAA-10, the observations indicate that the reflected radiation is slightly anisotropic. We allow for the anisotropy by assuming that for the forward scattering direction the observations are representative of all azimuths $0 < \varphi < \pi/2$ and for the backward scattering direction the observations are representative of all azimuths $\pi/2 < \varphi < \pi$. These assumptions give rise to the definition of a bidirectional reflectivity which can be used to convert the observed reflectivities to albedos. Allowing for the anisotropy of the reflected radiances for NOAA-10, we find that the absolute difference between the cloud albedo and the cloud reflectivity, $| \alpha_c - r_c |$ is generally less than 0.04, which is comparable to the variability of the observed reflectivities.

Because the 1 km AVHRR data is unable to resolve the spatial structure which is evident in cloud reflectivities, and because the relationship between liquid water path and cloud reflectivity saturates for large values of the liquid water path, we suspect that the values of the reflectivities reported here fall below those that would be expected from the parameterized relationship using the mean of the liquid water path derived from the microwave radiometer observations. To estimate the degree to which the small scale variability in liquid water path affects the observed reflectivity, we assume that the parameterized relationship holds, and we evaluate the mean reflectivity which is taken to be given by

$$\langle r_c \rangle = \int r_c(L)P(L)dL \qquad (2)$$

where P(L)dL is the probability of the liquid water path lying between L and L+dL. We assume the probability distribution to be given by

$$P(L) = AL^N \exp(-\Gamma L) \qquad (3)$$

with N and Γ are adjusted to give the mean and standard deviations in the liquid water paths observed with the microwave radiometer and A is a normalization constant.

We find that the effect of small scale variability on the reflectivity is small when $L/\sigma_L << 1$ where σ_L is the standard deviation of the liquid water path, i.e. when the variability is indeed small, when L is small so that the reflectivity becomes a linear function of L, and when L is sufficiently large that the reflectivity has, for practical purposes, reached saturation. Saturation appears to be reached for L > .05 mm. At most, the difference between the observed and expected values of cloud reflectivity are, $r_c(\langle L \rangle) - \langle r_c \rangle = 0.03$. Again the correction to the reflectivity is small compared to the variability in the observed reflectivities.

If the factors used to obtain the results in Figure 1 are due to calibration adjustments, then by far the largest corrections to the observed data will be corrections for calibration. Corrections for the factors considered above result in changes to the observations which are generally less than 5% and only in one instance do the corrections amount to 22%. For the case of the comparison for NOAA-9, we note that the correction, 1.25, is similar to that obtained from experiments performed to determine the calibration, 1.20

(Whitlock *et al* 1988). Similar calibration experiments have been performed for NOAA-10 but the results are as yet unavailable.

In conclusion, the results shown in Figure 1 indicate that at least the functional form of the parameterization developed by Stephens (1978) is correct. Furthermore, for the NOAA-9 observations, once corrections are made for the instrument's calibration, the parameterized albedo is typically within 5% of the observed reflectivities.

References

Coakley, J.A., Jr. and B.P. Briegleb, 1989: Reflectivities of uniform and broken stratiform clouds--an update. Extended Abstracts, FIRE Science Team Workshop, 11-14 July, Monterey, (this volume).

Coakley, J.A., Jr. and J.B. Snider, 1989: Observed Reflectivities and Liquid Water Content for Marine Stratocumulus. Extended Abstracts, AMS Symposium on the Role of Clouds in Atmospheric Chemistry and Global Climate, pp. 175-177.

Stephens, G.L. 1978: Radiation profiles in extended water clouds. II: Parameterization schemes. *J. Atmos. Sci.*, **35**, 2123-2132.

Whitlock C.H. W.F. Staylor, G. Smith, R. Levin, R. Frouin, C. Gautier, P.M. Teillet, P.N. Slater, Y.J. Kaufman, B.N. Holben and S.R. Lecroy, 1988: AVHRR and VISSR satellite instrument calibration results for both cirrus and marine stratocumulus IFO periods. Presentation, FIRE Science Team Workshop, July 11-15, Vail, Colorado.