N91-10524

Dependence of Marine Stratocumulus Reflectivities on Liquid Water Paths

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1. Introduction

Simple parameterizations that relate cloud liquid water content to cloud reflectivity are often used in general circulation climate models to calculate the effect of clouds on the earth's energy budget. Such parameterizations have been developed by Stephens (1978) and by Slingo and Schrecker (1982) and others. Here we seek to verify the parametric relationship through the use of simultaneous observations of cloud liquid water content and cloud reflectivity. The column amount of cloud liquid water was measured using a microwave radiometer on San Nicolas Island following techniques described by Hogg et al. (1983). Cloud reflectivity was obtained through spatial coherence analysis of AVHRR imagery data (Coakley and Beckner, 1988). We present the dependence of the observed reflectivity on the observed liquid water path. We also compare this empirical relationship with that proposed by Stephens (1978).

2. Data Analysis

Estimates of the column amount of cloud liquid water or the cloud liquid water path were obtained from microwave radiometry data taken continuously on San Nicolas Island July 3-18, 1987. The data was averaged and recorded at one minute intervals. The cloud liquid water path generally shows considerable fluctuation as is shown in Fig. 1 for July 3. To allow for this variability in comparing liquid water path to satellite observed reflectivity we have used the average of the liquid water path in the hour bin associated with the satellite overpass. On most of the days for which results are reported the satellite observations indicate mostly overcast conditions for San Nicolas Island and thus the average of the near simultaneous liquid water path observations is taken to be typical of overcast conditions at the time of the overpass.

The reflectivities obtained from the 0.63 μm channels of the AVHRRs on NOAA-9 and NOAA-10 were used to derive reflectivities representative of overcast conditions. The spatial coherence method was used to identify fields of view that were completely cloud covered by the marine stratus. Average reflectivities were calculated for overcast fields of view extracted from the $(60\ km)^2$ subframes surrounding and including the island. These averages were taken to be representative of the clouds in the vicinity of the liquid path observations. Like the cloud liquid water path obtained from the microwave radiometer, the cloud reflectivity derived from the satellite radiances also exhibited considerable fluctuation at the $(1\ km)^2$ resolution of the AVHRR.

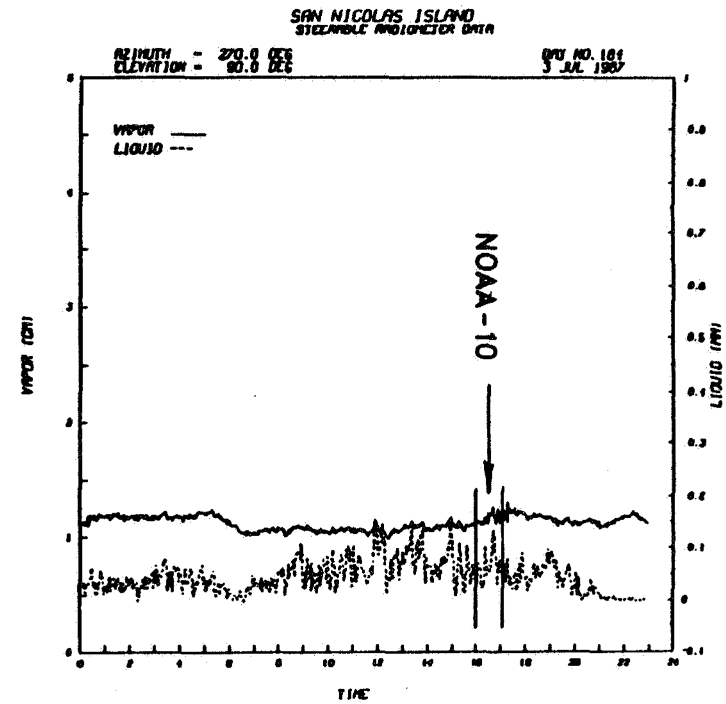

Figure 1. Column amounts of cloud liquid water and water vapor as obtained from a microwave radiometer on San Nicolas Island, July 3, 1987. Time is UTC.

3. Results

Simple two-stream and Eddington approximations to the transfer of radiation in a conservatively scattering medium show that the reflectivity, R, is given by

$$R = \frac{\beta(\tau, \mu_0)\tau/\mu_0}{1 + \beta(\tau, \mu_0)\tau/\mu_0} \tag{1}$$

where, for clouds having moderate optical depths, $\beta(\tau, \mu_0)$ is a slowly varying function of τ and μ_0 (Stephens, 1978); τ is the optical depth and μ_0 is the cosine of the solar zenith angle. Comparisons of the reflectivities given by (1) with those obtained through accurate numerical methods indicate that (1) provides a rather good approximation. Neglecting for the time being the dependence of optical depth on droplet size, we take the optical depth, τ, to be linearly proportional to the cloud liquid water path, W. Thus, from the observations we expect to find the reflectivities and liquid water paths to be given by

$$1/R = A + B\mu_0/W \tag{2}$$

Fig. 2 shows $1/R$ as a function of μ_0/W for the times of the satellite overpasses when clouds were present over San Nicolas. The observations follow the expected linear relationship reasonably well. A least squares fit gives $A = 1.69$ and $B = 0.019$ with W given in precipitable millimeters.

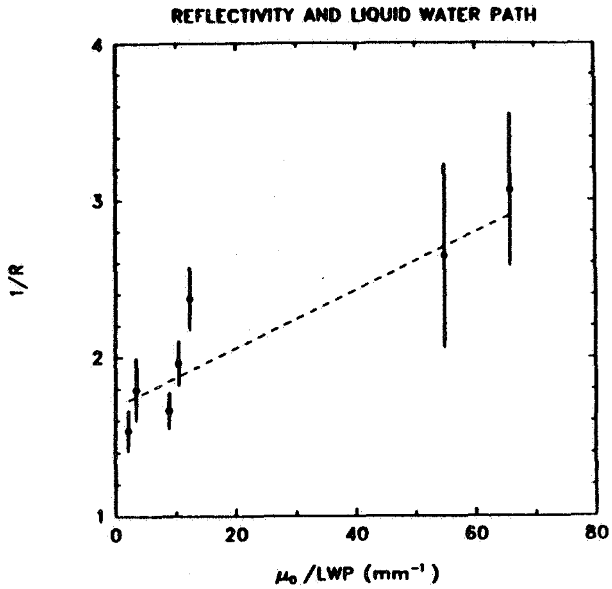

Figure 2. Reflectivities and cloud liquid water paths. The error bars on the reflectivities indicate the standard deviation of the reflectivities for overcast fields of view in the vicinity of San Nicolas Island. The dashed curve is a least squares fit to (2).

Theory also indicates that the reflectivities observed from satellites should depend strongly on the sun-cloud-satellite geometry at the time of the observations. Attempts to correct for the anisotropy of the radiance field using the results of radiative transfer calculations for plane-parallel cloud models (Coakley and Kobayashi, 1988) produced considerable scatter about the linear relationship given by (2). As a result, the AVHRR data itself was used to determine the anisotropy of the reflected radiances. The observed anisotropy showed little if any distinct trends, and as a result corrections for the viewing geometry were deemed unnecessary for the current study. Finally, theory indicates that when the cloud is thin, reflection by the underlying surface can significantly alter the reflectivities measured above the cloud. In the cases reported here, these corrections are small and thus also neglected.

Fig. 3 shows a comparison of the observed reflectivities and those predicted by Stephens (1978) for the observed liquid water paths and the solar zenith angles at the time of the observations. While the reflectivities obtained from the parameterization correlate well with those observed, the paucity of points and the uncertainty in the calibration of the AVHRR prevent a critical assessment of the parameterization.

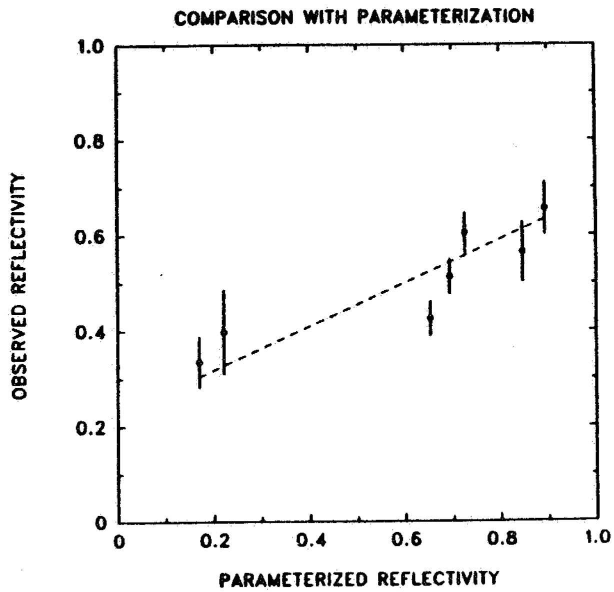

Figure 3. Observed and parameterized reflectivities. The parameterization is by Stephens (1978). The dashed curve is a least squares fit.

4. Summary and Conclusions

We have found that by taking clouds to be isotropic reflectors, the observed reflectivities and observed column amounts of cloud liquid water are related in a manner that is consistent with simple parameterizations often used in general circulation climate models to determine the effect of clouds on the earth's radiation budget. Attempts to use the results of radiative transfer calculations to correct for the anisotropy of the AVHRR derived reflectivities resulted in a greater scatter of the points about the relationship expected between liquid water path and reflectivity. The anisotropy of the observed reflectivities proved to be small, much smaller than indicated by theory.

To critically assess parameterizations, more simultaneous observations of cloud liquid water and cloud reflectivities and better calibration of the AVHRR sensors are needed. More points for comparison will be obtained when data from PCDS for days not included in this study are analyzed. Better calibration of the AVHRR sensor might be afforded through simultaneous observations with the ERBE scanner on NOAA-10 when the ERBE data become available.

Acknowledgment

This work was supported in part by AFGL and AFOSR through transfer of funds to NASA, GLH6-6031, by NASA Grant L-79877B and by ONR.

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