N91-10510

Estimating Integrated Cloud Liquid Water from Extended Time Observations of Solar Irradiance

C.W. Fairall and Raja El-Salem Rabadi
Department of Meteorology
Pennsylvania State University
University Park, PA 16802

and

J. Snider
NOAA/ERL/WPL
325 Broadway
Boulder, CO 80303

INTRODUCTION

Extended time observations (ETO) were made at San Nicolas Island (SNI) from March to October, 1987. A small ground station was installed at the NRL trailer (Site B). Hourly averages of air temperature, relative humidity, wind speed and direction, solar irradiance, and downward longwave irradiance were recorded. The radiation sensors were standard Eppley pyranometers (shortwave) and pyrgeometers (longwave). Data records of SNI rawinsonde launches for this period have been requested from the Pacific Missile Test Center (PMTC).

This data will be processed in a variety of was to deduce properties of the stratocumulus covered marine boundary layer (MBL). From the temperature and humidity the lifting condensation level, which is an estimate of the height of the cloud bottom, can be computed. Combinations of shortwave and longwave irradiance statistics can be used to estimate fractional cloud cover parameters.

This paper describes an analysis technique used to estimate the integrated liquid water content (W) from the measured solar irradiance. The cloud transmittance is computed by dividing the irradiance measured at some time by a clear sky value obtained at the same time on a cloudless day. From the transmittance and the zenith angle, the cloud LWC is computed using the radiative transfer parameterizations of Stephens et al. (1984). The results are compared with 17 days of mm-wave (20.6 and 31.65 GHz) radiometer measurements made during the FIRE IFO in July of 1987.

CLOUD RADIATIVE TRANSFER COMPUTATIONS

Stephens (1978) has developed a simple parameterization of cloud albedo (Re), transmittance (Tr), and absorption (Ab) in terms of the cloud optical thickness (T) and the zenith angle (θ). The parameterization is based on the two-stream approximation of Coakley and Chylek (1975). A look-up table of values for single scattering albedo (ω) and backscatter fraction (β) is given as a function of T and $\mu=\cos(\theta)$. The values are based on results of sophisticated 10-layer, 15-band radiative transfer computations. The revised look-up table (Stephens et al., 1984) was used for the work presented here. Non absorbing ($\lambda<0.7$ μm) and absorbing ($\lambda>0.7$ μm) wavelength regions are considered. The two-stream model is as follows:

(i) Non absorbing, ω=1

$$Re = \beta T/\lambda/(1 + \beta T/\lambda) \qquad (1a)$$

$$Tr = 1 - Re \quad (1b)$$

(ii) Absorbing, $\omega < 1$

$$Re = (u^2 - 1)[\exp(Tef) - \exp(-Tef)]/R \quad (2a)$$

$$Tr = 4u/R \quad (2b)$$

$$Ab = 1 - Re - Tr \quad (2c)$$

where

$$u^2 = (1 - \omega + 2\beta\omega)/(1 - \omega) \quad (3a)$$

$$Tef = SQRT[(1 - \omega)*(1 - \omega + 2\beta\omega)]T/\mu \quad (3b)$$

$$R = (u + 1)^2 \exp(Tef) - (u - 1)^2 \exp(-Tef) \quad (3c)$$

The optical thickness is calculated from the cloud W using a parameterization obtained from a number of measured cloud properties.

$$\log_{10}(T) = 0.2633 + 1.7095 \log_e[\log_{10}(W)], \quad \lambda < 0.7 \quad (4a)$$

$$\log_{10}(T) = 0.3492 + 1.6518 \log_e[\log_{10}(W)], \quad \lambda > 0.7 \quad (4b)$$

Since the Stephens parameterization was developed to apply to some 15 cloud types, we decided to compare it to a model with microphysics specific to the marine stratocumulus, which we shall refer to as the DFBS (Davidson et al., 1984) model. The DFBS model is a 15-band, delta-Eddington radiative transfer model that assumes a linear liquid water profile in the cloud with a log-radius gaussian cloud droplet distribution where the mode radius is determined from the liquid water assuming a constant number of cloud droplets (100/cc). Figure 1 shows a comparison of transmittances for the two models at three different zenith angles for a generic California stratocumulus with cloudtop at 600 m and total water (liquid plus vapor) mixing ratio of 8 g/kg. Optical thickness was varied by varying the cloud thickness from 50 m to 450 m. The comparison is very good but the Stephens parameterizations (Eqs. 4) appear to underestimate the optical thickness at low values of W, which are at the lower limit of his fit. Since marine stratocumulus often have low values of W, we used the parameterization given below for W<100 g/m^2 (see Fig. 2), which is obtained from the DFBS model:

$$\log_{10}(T) = -0.35 + 0.91 \log_{10}(W) \quad (5)$$

Using this slightly modified form of the Stephens model, a nomogram can be constructed in terms of contours of transmittance versus zenith angle and integrated liquid water path (Fig. 3).

RESULTS

Using the clear sky irradiance, the cloud transmittance was computed for each day from July 1 to July 18 for the times 1600 to 0100 GMT. Low incidence angles ($\mu < .4$) were not used because of the potential for large errors. For the same reason, transmittances greater than 0.9 were not considered. For a given value of Tr and μ, the value of W was iterated until the Stephens model gave the measured transmittance. This computed value of W is compared with the values from the NOAA radiometer (Fig. 4).

The mm-wave radiometer values of W are on average about 50% greater than the values estimated from the transmittance. The rms scatter is about 35%. The NOAA radiometer is believed to be accurate to 20%, but a 50% fractional bias is not out of the question. Some of the rms scatter is due to differences in sampling geometry, since the pyranometer has a hemispherical field of view and the radiometer has a narrow field of view. These differences in field of view are somewhat moderated by averaging for one hour. Another source of error is the use of a single clear sky irradiance for the entire 17 day period, which ignores variability in the meteorological conditions above the mixed-layer. Once these issues are sorted out, we expect to use this method to analyze the entire data base.

REFERENCES

Coakley, J.A. and P. Chylek, 1975: The two stream approximation in radiative transfer: Including the angle of the incident radiation. J. Atmos. Sci., 32, 409-418.

Davidson, K.L., C.W. Fairall, P. Jones Boyle and G.E. Schacher, 1984: Verification of an atmospheric mixed-layer model for a coastal region. J. Clim. Appl. Met., 23, 617-636.

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

Stephens, G.L., S. Ackerman, and E.A Smith, 1984: A shortwave parameterization revised to improve cloud absorption. J. Atmos. Sci., 41, 687-690.

Acknowledgements. This work is supported by NASA grant NAG 1-652. Part of this work was performed while CWF was a visiting scientist at the Naval Environmental Prediction and Research Facility. The authors wish to express special thanks to Richard Dixon and Carl Otten of PMTC for aiding and abetting the installation and maintainence of the ETO system at SNI and to Dick Thompson of the Department of Meteorology, PSU, who put the system together and kept the data flowing.

Fig. 1 Comparison of transmittance versus integrated cloud LWC at zenith angles of 0, 60, and 80 degrees for the Stephens (circles) and DFBS (line) models.

Fig. 2 Optical thickness versus integrated cloud LWC for the Stephens parameterization of Eq. 4a (solid line), the DFBS calculations (circles), and Eq. 5 (dotted line).

Fig. 3 Contours of transmittance as a function of solar zenith angle and integrated cloud LWC from the modified Stephens parameterization.

Fig. 4 Integrated cloud LWC: the vertical axis is computed from solar irradiance versus W from the NOAA radiometer measurements.

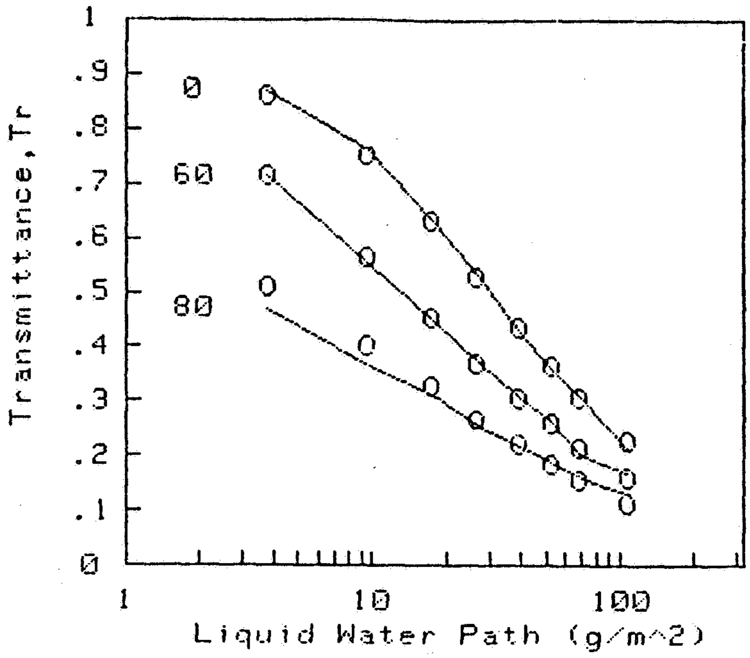

Fig. 1 Comparison of transmittance versus integrated cloud LWC at zenith angles of 0, 60, and 80 degrees for the Stephens (circles) and DFBS (line) models.

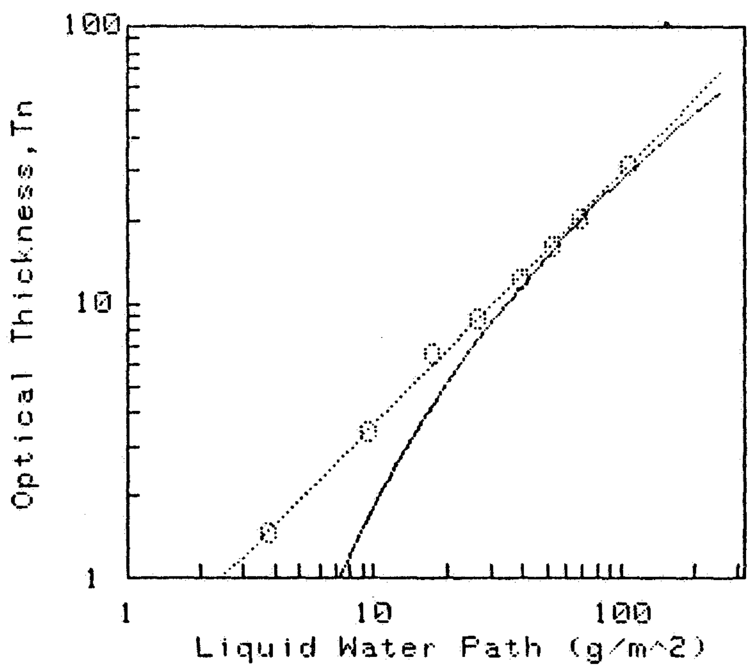

Fig. 2 Optical thickness versus integrated cloud LWC for the Stephens parameterization of Eq. 4a (solid line), the DFBS calculations (circles), anc Eq. 5 (dotted line).

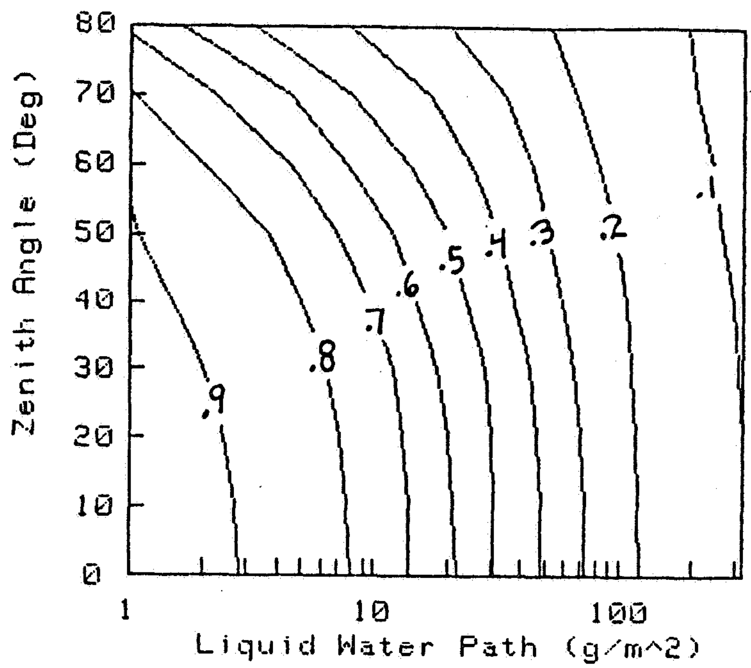

Fig. 3 Contours of transmittance as a function of solar zenith angle and integrated cloud LWC from the modified Stephens parameterization.

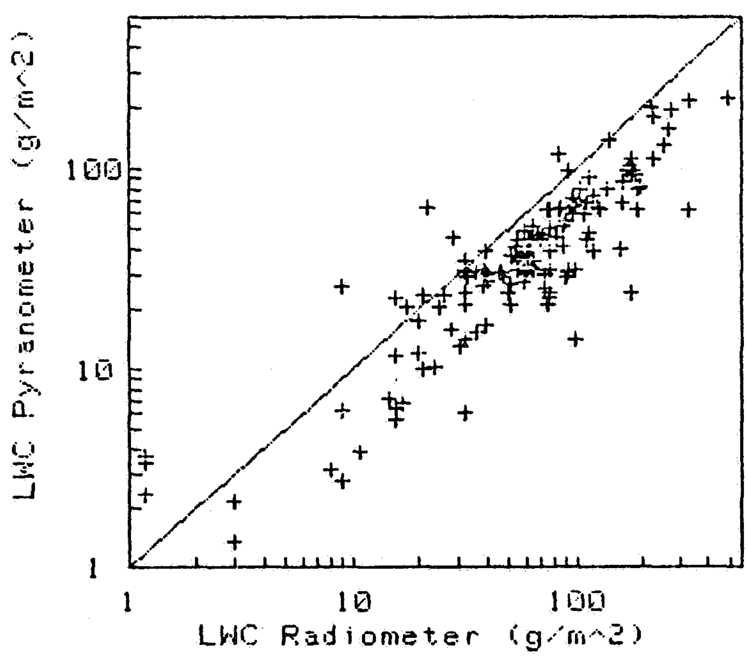

Fig. 4 Integrated cloud LWC: the vertical axis is computed from solar irradiance versus W from the NOAA radiometer measurements.