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## RELATION BETWEEN ISCCP C1 CLOUD OPTICAL THICKNESS AND SSM/I DERIVED CLOUD LIQUID WATER PATH

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### 1. INTRODUCTION

The optical thickness ( $\delta$ ) is the most important variable governing the effects of clouds on the radiation budget of the earth - atmosphere system. Thus the parameterization of  $\delta$  as a function of dynamical variables is of eminent importance in Global Circulation Models (GCM). The parameterization frequently used in this context was introduced by Stephens (1978). His relationship assumes a non - linear dependency between effective radius ( $r_e$ ) and the cloud Liquid Water Path (LWP) and predicts  $\delta$  as a logarithmic function of LWP, which is available from most GCMs. Other parameterizations use linear relationships based on constant effective radii (Fowler and Ramanathan 1993).

Both parameterizations are tested by comparing the optical thickness from the International Satellite Cloud Climatology Project (ISCCP) C1 data set with LWP measurements from the Special Sensor Microwave/Imager (SSM/I).

### 2. ISCCP C1 DATA SET

The ISCCP data set is based on radiance measurements in the IR and VIS spectral range from operational meteorological satellites. The final C1 product contains the global distribution of cloud parameters on a  $2.5^\circ \times 2.5^\circ$  grid with a temporal resolution of three hours. Clouds are associated with one of 35 cloud classes based on the division of the optical thickness range into five classes (available only during daytime) and

the cloud top pressure into seven classes (Rossow and Garder 1988). These 35 classes can be associated qualitatively with nine cloud types (Poetzsch - Heffter et al. 1994). For the comparison with the microwave measurements the mean optical thickness of the clouds within each grid area is computed by averaging the center values ( $\bar{\delta}_i$ ) of each optical thickness class weighted with the coverage of that cloud class. We did not use the mean optical thickness  $\bar{\delta}$  provided by the C1 data set. This value has been provided to represent the whole cloud ensemble within one grid box by one single cloud type in radiative transfer calculations, i.e.  $\bar{\delta}$  is calculated from the mean cloud albedo ( $\alpha$ ). Due to the nonlinear relation between  $\alpha$  and  $\delta$  the use of  $\bar{\delta}$  would lead to an underestimation of true mean optical thickness.

### 3. SSM/I DATA

We used the algorithm by Hargens et al. (1994) to determine LWP from the SSM/I brightness temperatures :

$$LWP = 0.399635 \cdot \ln(280 - TB_{22V}) - 1.40692 \cdot \ln(280 - TB_{37V}) + 4.299 \quad (1)$$

From the LWP values the optical thickness is computed using either the parameterization by Stephens (1978) :

$$\log_{10}(\delta) = 0.2633 + 1.7095 \log_e[\log_{10}(LWP)] \quad (2)$$

or a linear relationship :

$$\delta = \frac{3}{2} \frac{LWP}{r_e} \quad (3)$$

For the comparison with the ISCCP data the derived optical thickness for each microwave pixel is

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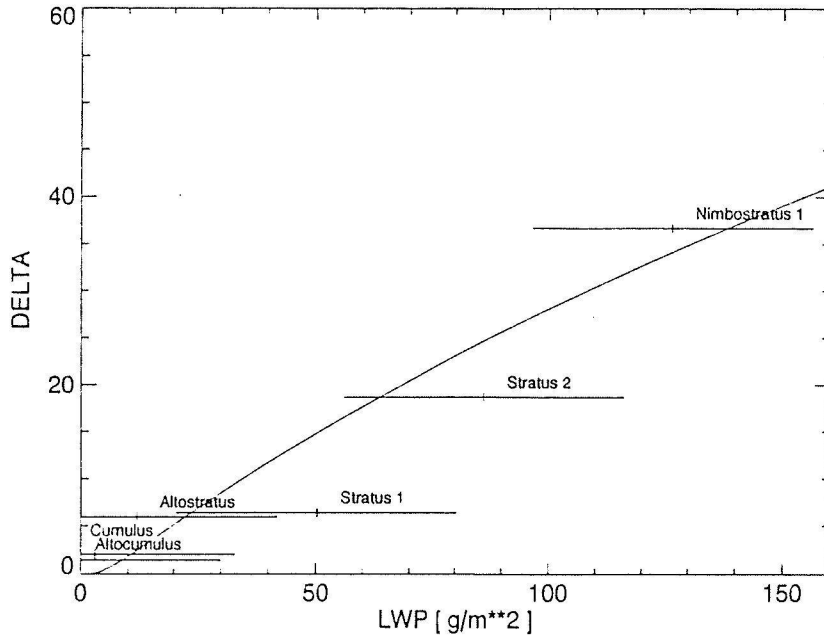


Figure 3: Single gridbox averages compared with Stephens parameterization

for subtropics and tropics with Stephens parameterization for the midlatitudes the correlation coefficient is largely increased from 0.53 to 0.74 and the systematic difference is reduced from a factor of 1.4 to 1.09. To confirm our results we compared single box averages of optical thickness (no monthly mean) consisting of homogeneous cloud layers of one cloud type. We can assume that in this cases the effective radius is constant. To assure that both systems measure the same cloud layer in spite of the different observation times, the comparison is restricted to stationary and fully cloud covered areas. Stationarity was assured by the restriction to those data pairs which show 100% cloudiness in the C1 dataset prior and after the SSM/I observation time. For these cases  $\bar{\delta}$  (see introduction) is more appropriate than the class center value  $\bar{\delta}_i$ . The results (Fig. 3) support the conclusions drawn from the comparison of monthly means and are in qualitative agreement with results from measurements presented by Nakajima et al. (1991) (Fig. 4).

## 5. ERROR DISCUSSION AND CONCLUSIONS

The analysis of simulated box averages show that

due to the error introduced by using  $\bar{\delta}_i$  instead of the real optical thickness restricts the correlation coefficient already to 0.88. This value does not include the sampling error caused by the low number of SSM/I and ISCCP observations. Statistical tests indicate that the systematic differences found using Stephens parameterization can not be explained by sampling errors.

Of course there are other sources of error. The ISCCP cloud analysis can lead to errors for cases of low contrast either in IR or VIS measurements. In these cases the ISCCP cloud analysis scheme will characterize the pixels as 'clear sky'. A regional negative bias up to 10 % is possible (Rossow et al. 1992).

The LWP algorithm has a rms error of  $30 \text{ gm}^{-2}$  Hargens et al. (1994). For low LWPs systematic errors in the same range can be expected over regions with low or high windspeeds. The errors of both SSM/I and ISCCP can not explain the observed systematic differences.

We conclude that the Stephens parameterization underestimates the optical thickness for LWPs between 30 and  $110 \text{ gm}^{-2}$  and that a choice of a constant effective radius of  $10 \mu\text{m}$  is more appropriate for subtropical cloud types, and an even higher value for tropical cloud types. A final decision, however, can only be drawn with collocated data

linearly averaged over the same  $2.5^\circ \times 2.5^\circ$  grid areas. Only boxes with more than 50 measurements were taken into account, representing a coverage of roughly 50%.

Both parameterizations are based on Mie - Theory. Equation (2) is obtained from (3) by a least square fit to  $\delta$  - LWP pairs calculated for eight water cloud types characterized by different effective radii, liquid water density and a limited range of vertical extents. So this parameterization is expected to lead to good results when a wide range of cloud types is considered. Larger errors can occur however for individual cloud types (Fig. 1).

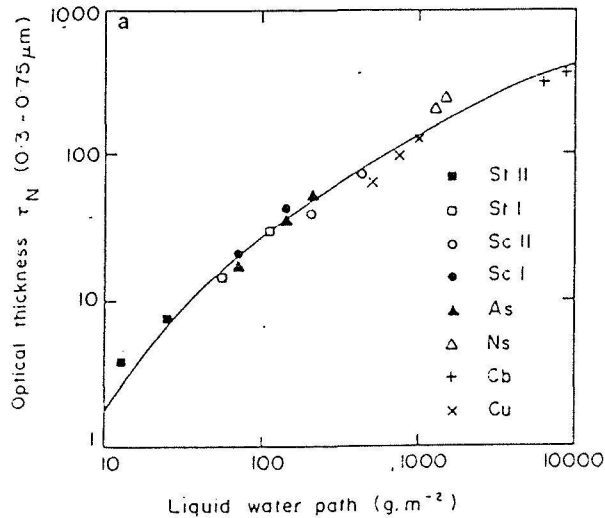


Figure 1: Optical thickness for the 0.3 - 0.75  $\mu\text{m}$  region as a function of liquid water path (from Stephens 1978)

#### 4. RESULTS

Since SSM/I and ISCCP measurements were obtained at different daytimes (SSM/I at roughly 6:00 and 18:00 local time; C1 optical thickness data between 9:00 and 15:00 local time), monthly means were computed from each data set for each  $2.5^\circ \times 2.5^\circ$  grid area. Only boxes with at least 10 measurements from SSM/I and 30 from ISCCP were considered for the comparison, to assure representativeness.

For October 1987 both data sets (Fig. 2) show a correlation coefficient of only 0.53 and the optical thicknesses derived from SSM/I measurements are larger than the ISCCP values by a factor of 1.4. When we restrict the comparison to different latitudinal zones ( $60^\circ\text{lat.} - 40^\circ\text{lat.}$ : midlatitudes;

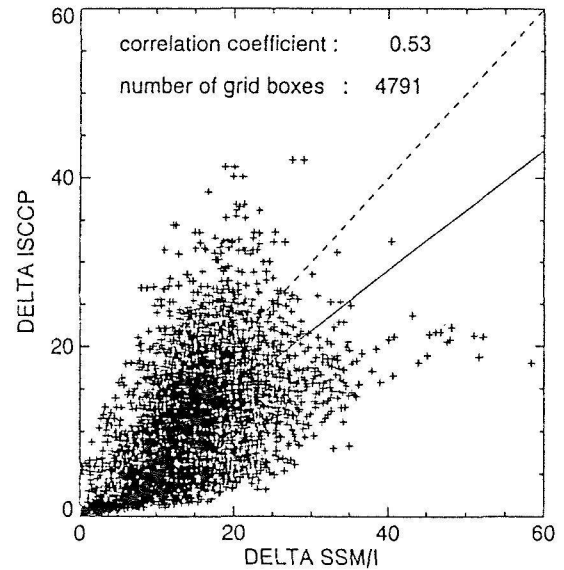


Figure 2: Comparison between optical thickness derived from SSM/I and ISCCP

$39^\circ\text{lat.} - 20^\circ\text{lat.}$ : subtropics;  $19^\circ\text{lat.} - 0^\circ\text{lat.}$ : tropics), we obtain the following results: For the midlatitudes the optical thickness is between 10 and 20 and the correlation of both data sets is lower than the correlation of the global data. The systematic difference, however, is largely reduced. We attribute this to the fact that cloudiness here is related mainly to cyclonic activity leading to optical thicknesses which cover the whole possible range. This gives rise to the large scatter and also explains the small systematic difference, the latter because Stephens parameterization is based on averages of the observed optical thickness range. The subtropics and tropics are dominated by only a few cloud types. Thus the observed monthly mean optical thickness relates to the mean LWP of only these few cloud types. The scatter is reduced leading to higher correlation coefficients (subtropics: 0.65; tropics: 0.74). The systematic differences are very large, however, indicating that Stephens parameterization overestimates  $\delta$  for cloud types in this region. Better results can be obtained using the linear relationship (3) with a constant effective radius of  $10\mu\text{m}$  (Fowler and Ramanathan 1993). The correlation coefficients do not change significantly, but the systematic difference for the subtropics is reduced to a factor of 0.95, for the tropics to a factor of 1.46. If we combine the linear parameterization

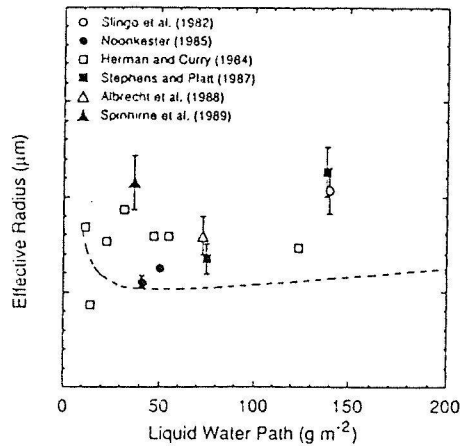


Figure 4:  $LWP$  and  $r_e$  measured by previous investigators in comparison to the empirical relationship used by Stephens (dashed line) (from Nakajima et al. 1991)

sets in area and time of VIS, IR and microwave measurements.

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