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P5.17 THE USE OF THE ISCCP DATA TO STUDY CLOUD EFFECTS ON THE EARTH RADIATION BUDGET

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1. INTRODUCTION

Cloud-radiation interaction is one of the most important problems in climate research. The process is, however, not yet fully understood. A large number of diagnostic studies were carried out during the last 20 years (e.g., Cess 1976, Ohring and Clapp 1980, Hartmann and Short 1980, Arking, 1991) with the aim to understand the changes of radiation budget at the top of the atmosphere (TOA) due to changes in cloudiness. The derived cloud effects, however, differ by magnitude and even by sign. It is the lack of adequate observational data which hampers such studies. Measured global-scale cloud distribution together with the corresponding measured radiation fields are not available.

A difficulty in understanding the influence of clouds on the earth radiation budget (ERB) arises because there exist two competing effects: the albedo effect (increase of reflected solar radiation) and the greenhouse effect (decrease of emitted longwave radiation). Both effects depend not only on the amount of clouds but also on their geometrical (e.g., top height, thickness, and structure) and microphysical properties (e. g., optical thickness, droplet distribution, phase, and shape of ice particles), which are very difficult to monitor.

In the 1980's two projects, based on satellite observations, were initiated to solve a few of the problems discussed above: Earth Radiation Budget Experiment (ERBE) (Barkstrom 1984) and International Satellite Cloud Climatology Project (ISCCP) (Schiffer and Rossow 1983). Both experiments complement each other. ERBE provides radiation fluxes and ISCCP global cloud distribution. We use the ISCCP cloud information as input in radiation transfer models to calculate the outgoing longwave radiation and the reflected solar radiation. Thus both the radiation budget components and the corresponding cloud distribution are available. The ERBE results are used for a verification of the calculated radiation fluxes. Diagnostic studies are performed with this data set.

2. FLUX CALCULATION AND TREATMENT OF CLOUDS

In order to calculate the outgoing short wave and outgoing longwave radiation, radiative transfer models based on the Two-Stream-Approximation have been used. Details of the models see in Poetzsch-Heffter (1994) and Poetzsch-Heffter et al. (1994). Input for the models are the parameters given in the ISCCP C1 data set as optical thickness δ in 5 bins, top

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height h_c in 7 pressure bins, and the coverage of each of the 35 cloud types defined by δ and h_c in a 2.5° x 2.5° (longitude, latitude) area. Clouds are treated in the models as

- horizontally homogeneous,
- consisting of water droplets (in the IR) and of water and ice spheres (in the solar model), thus absorption and extinction coefficients, single scattering albedo, and phase function can be calculated by Mie theory,
- a 1-km-thick layer (in the solar model) and an infinitesimal thin layer (in the IR model).

In the ISCCP C1 data set optical thickness δ is given for $\lambda = 0.6\ \mu m$. For the other wavelengths δ is determined by Mie theory applied to the cloud types and their droplet distribution given by Stephens (1978).

The calculated radiation fluxes are subject to two tests. With the internal test the radiation model and the correct application of the ISCCP C1 data are checked. The fluxes are converted to IR brightness temperatures corresponding to those of channel 4 of NOAA-7 AVHRR and to reflectances corresponding to those of channel 1 of NOAA-7 AVHRR. In this form the simulated data can be compared against the values given in the C1 data set. For the longwave part the test gives good agreement (bias less than 1 K, RMS - difference better than 1.9 K (2.9 K) for clear sky (cloudy) situations). The clear sky reflectances show also sufficient results (bias 0.2 %, RMS-difference 0.9 %). Larger RMS-differences are found in cloudy cases (3.2 %), in particular for optically thick clouds. The calculated reflectances can be too low up to 20 %. Non-isotropy accounts for large part of these differences, a further contribution can arise from the reduced accuracy of the Two-Stream-Approximation when applied to optically thick clouds.

In a second test the fluxes are compared against ERBE-results. For the longwave fluxes in cloudy cases both results agree with almost no bias (0.9 W/m^2) and RMS - difference of 13.9 W/m^2. Part of this scatter is due to natural cloud variability because actual values for each 2.5° x 2.5° area went into this comparison. Since there exist only very few simultaneous ISCCP and ERBE observations, we allowed a time difference of ± 1 hour between these two data sets.

The striking feature of clear sky comparison is the overestimation of ERBE outgoing longwave radiation over tropical oceans. Our results agree in this sense with those of Kiehl and Briegleb (1992), who concluded that the ERBE fluxes are too small. The planetary albedos show no systematic difference for all cases (bias less than 1 %, RMS-difference 7.2 %), explanation for the latter number is the same as for the longwave radiation in cloudy case.

After these successful verification tests the calculated shortwave and longwave fluxes can be used together with the cloud information from the ISCCP C1 data set to carry out diagnostic studies about the effects of clouds on the earth radiation budget.

3. CLOUD - RADIATION INTERACTION DIAGNOSTICS

In order to quantify the two cloud effects (albedo and greenhouse), cloud forcing is introduced:

shortwave cloud forcing:

$$C_{SW} = Q - Q_0 = SA_c(\alpha_0 - \alpha_c)$$

longwave cloud forcing:

$$C_{LW} = F_0 - F = A_C(F_0 - F_C)$$

Q, Q_0 are the total, clear sky absorbed solar radiation of the earth atmosphere system, S is the incoming solar radiation, A_C cloud coverage, α_c, α_0 cloud, clear sky planetary albedo, F, F_0, F_C total, clear sky, cloudy outgoing longwave radiation.

In general, C_{SW} is negative, since $\alpha_0 < \alpha_c$. Only for clouds over very bright surfaces (e.g. fresh ice and snow) the sign can change. Such situations were found in the C1 data set of July 1985 and January 1986, but the coverage of these clouds was less than 0.02 %. C_{LW} is in general positive. Negative values can occur with clouds at the top of the surface inversion. For the same period as above, we found such clouds with a coverage of 2 %.

Cloud forcing is calculated for four months (April, July, October 1985, January 1986), one for each season (W/m^2):

Month	C_{SW}	C_{LW}	C_{Net}
April 1985	-43.9	25.1	-18.8
July 1985	-44.3	24.2	-20.1
October 1985	-48.9	22.5	-26.4
January 1986	-52.9	23.1	-29.8
annual mean	-47.5	23.7	-23.8

The annual mean is an average of the four months.

It is obvious that the cooling effect of the clouds is always larger than the warming or greenhouse effect. In the present day cloud distribution the albedo effect is about two times larger than the greenhouse effect.

A change in cloud cover alone cannot change the tendency of the cloudy effects from cooling towards warming. This is possible only by changing other cloud properties like optical thickness or top height. How the different cloud types work are shown at Fig. 1. Here the annual mean of cloud coverage (%), longwave cloud forcing (W/m^2), and shortwave cloud forcing (W/m^2) are given for nine cloud types. The 35 original ISCCP cloud types are summarized in three pressure bins (surface pressure -680 hPa, 680-440, 440-tropopause) and three optical thickness bins (0-3.6, 3.6-9.4, 9.4-12.5).

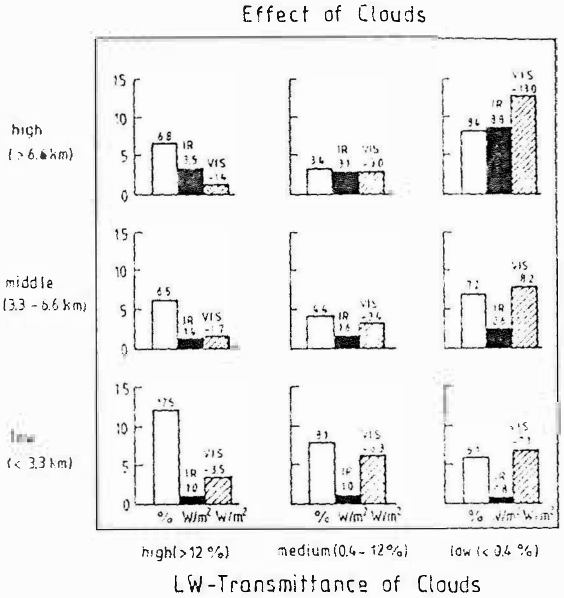

Fig. 1: Global annual mean values (1985/86) of albedo- (VIS) and greenhouse effect (IR) of the 9 cloud types (unit Wm^{-1}), open column cloud cover in %.

Only the high thin cirrus clouds have a warming effect, thicker cirrus and thin altostratus are radiatively neutral and for all other types the albedo effect dominates. The most effective coolers are the low thick clouds. Their greenhouse effect is almost negligible, but their albedo effect is very large. The deep convective clouds produce the largest single effect for both longwave (8.8 W/m^2) and shortwave (-13.0 W/m^2) forcing but their net effect is smaller than the one for the low-level clouds.

4. CONCLUSION

In order to assess the effects of clouds for a climate change and within a different climate correctly, climate models have to treat clouds much more accurately than it is done now. All cloud properties which influence albedo (e.g. hydrometeor distribution) must be calculated. Only cloud top height and coverage is not enough. Our results make it very clear that in particular the thin cirrus and the thick clouds at the top of the boundary layer are of great importance for the earth radiation budget.

Global distribution of the shortwave and longwave forcing (not shown here) showed large regional differences in particular between continent and ocean. Thus, change in regional circulation patterns can be the consequence of different cloud regimes in other climates.

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