STATISTICAL APPROACH FOR A CONSISTENT TREATMENT OF CLOUD VARIABILITY IN GCM SOLAR RADIATIVE TRANSFER COMPUTATION

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ABSTRACT

The atmospheric general circulation model (AGCM) *ECHAM* [1] in its latest version 5 (not yet officially released) uses a new cloud cover scheme [3], which prognoses the probability distribution function (PDF) of the total water mixing ratio, i.e. water vapor, ice and liquid water. From the latter the PDF for cloud condensate can be retrieved and such the PDF of optical thickness of clouds. Solar radiative transfer through a cloudy layer is then computed using a two-stream approximation, which accounts for non constant optical thickness. First results with a single column model version are presented.

INTRODUCTION

Currently most general circulation models (GCM) use the plane parallel homogeneous approximation (PPH) for treating the influence of clouds on the transfer of solar radiation, i.e. clouds are taken as homogeneous boxes of air with internally constant mass mixing ratio of liquid water q_l, spreading over the whole layer height and covering the fraction A_c of the grid cell. No information about the internal variability of q_l, nor about the horizontal or vertical structure is available. For the latter some kind of assumption has to be made, ranging from random to maximum overlap, while the former is usually neglected.

Reflectivity and transmissivity of a cloudy layer are nonlinear functions of the optical depth τ, which in turn is a linear function of the liquid water path and therefore the mass mixing ration q_l. Computing these radiative characteristics from mean values of mixing ratio of liquid water and weighting it by the fractional cloud cover, both supplied by the cloud scheme, leads to a systematic error. Since reflectivity is a convex function of τ the albedo of a cloud using PPH is always overestimated while its transmissivity is analogously underestimated. This problem is usually called *PPH albedo bias*.

CLOUD SCHEME

The cloud cover scheme assumes that the probability distribution $G(r_t)$ of the total water mixing ratio r_t within each model layer can be described by a Beta distribution function of the form

$$G(r_t) = \frac{1}{B(p,q)} \frac{(r_t - a)^{p-1}(b - r_t)^{q-1}}{(b-a)^{p+q-1}} \tag{1}$$

where $a \leq r_t \leq b$. The function is determined by its limits a and b and the two shape parameters p and q. With the saturation mixing ratio r_s one can compute the vapor r_v and condensate amount r_c as

$$r_v = \int_a^{r_s} G(r_t) r_t \, dr_t + \int_{r_s}^b G(r_t) r_s \, dr_t, \qquad r_c = \int_{r_s}^b G(r_t)(r_t - r_s) \, dr_t, \tag{2}$$

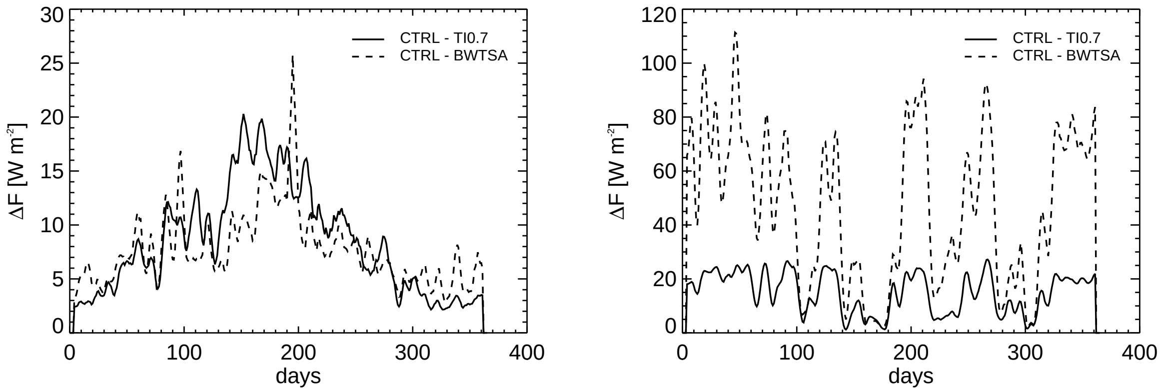

Figure 1: Differences of shortwave upward fluxes at TOA at point C (left) and F (right)

the fractional cloud cover A_c is

$$A_c = \int_{r_s}^{b} G(r_t)\, dr_t. \tag{3}$$

Currently the shape factor p is held constant, while q is prognosed from cloud processes like detrainment and horizontal mixing, while the limits a and b are calculated from r_v and r_c using (2). In case of overcast ($A_c = 1$) and clear sky conditions ($A_c = 1$) an additional prognostic equation for the width $(b - a)$ has to be introduced.

BETA WEIGHTED TWO STREAM APPROXIMATION

Principle

Since optical thickness τ of a layer is a linear function of liquid water path and therefore the mixing ratio of cloud condensate $\tau(r_c)$ one gets from (1) the PDF for the optical thickness $G(\tau(r_c))$. The reflectivity $R(\tau)$ and transmissivity $T(\tau)$ of a layer with optical thickness τ is computed using a standard two-stream approximation (Eddington approach). Knowing $G(\tau)$ the reflectivity and transmissivity can be written as

$$R_{BWTSA} = \int_{\tau_{min}}^{\tau_{max}} R(\tau) G(\tau)\, d\tau, \tag{4}$$

$$T_{BWTSA} = \int_{\tau_{min}}^{\tau_{max}} T(\tau) G(\tau)\, d\tau, \tag{5}$$

where τ_{min} and τ_{max} are the minimum and maximum optical thickness, respectively, deduced from a, b and r_s.

Single Column Mode Experiments

In order to test the approach described above, the Beta Weighted Two Stream Approximation (BWTSA) was implemented in the ECHAM GCM and several single column experiments have been performed. They are driven by a full 3D integration of the model. The positions are listed in Tab. 1. A second approach to correct for the albedo bias due to cloud inhomogeneity as proposed by Tiedtke [2] is to use a scaled optical thickness $\tau_{eff} = \lambda\tau$, where $\lambda = 0.7$ is used. This approach was also tested in the

	A	B	C	D
longitude	-150	-130	-40	150
latitude	18	40	45	46

Table 1: Position of SCM experiments

	A	B	C	D
TI	7.8	6.2	8.3	15.2
BWTSA	8.8	5.8	7.7	48.0

Table 2: Annual means of differences of shortwave upward fluxes at TOA

ECHAM model. Fig. 1 shows the differences in shortwave upward radiation at the top of atmosphere (TOA) between the control run and the scaling approach (TI) and the BWTSA approach, respectively, for two columns. In Tab. 2 the annual mean values of the flux differences are summarized. Except for the column D in the tropical warm pool, the means are quite similar, but there are seasonal differences, as can be seen from Fig. 1, where the BWTSA is lower in winter time, but higher in summer time. For the tropics the BWTSA reduces albedo dramatically. Since convective clouds are more inhomogeneous than stratiform clouds a larger correction compared to the scaling approach is to be expected. From cloud resolving models one found scaling factors of approximately $\lambda = 0.5$ [2], which gives annual flux differences of app. $25\,\mathrm{Wm}^{-2}$. The large difference found here may be due to an overestimation of cloud variability by the cloud scheme, but further investigations have to be done.

CONCLUSIONS

The PPH approximation for radiative transfer in cloudy layers leads to a systematic overestimation of the albedo, because horizontal inhomogeneities are neglected. A consistent approach to correct for this error is to use PDF for cloud condensate as prognosed by the cloud cover scheme in the two-stream radiation computation. Comparison of SCM experiments using the BWTSA and the scaling approach show good agreement with respect to annual means except for the tropical warm pool region. Nevertheless there are seasonal differences.

References

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