The Cloud Radiative Forcing simulated by the CPTEC GCM with the UK Met Office's radiation scheme

Henrique M. J. Barbosa[*,†] and J. C. S. Chagas[*]

[*]*CPTEC/INPE, Rod. Presidente Dutra km40, 12630-000 Cachoeira Paulista - SP, Brazil*
[†]*IF/USP, R. Matao, Travessa R, 187, 05508-090 Cidade Universitaria, Sao Paulo - SP, Brazil*

Abstract. The UK Met Office's radiation code was recently incorporated on CPTEC's climate model. To provide its necessary input the Community Climate Model micro physics parameterization was introduced as well. We show that while atmospheric absorption is much better represented with the new implementations, large differences from observed Cloud Radiative Forcing and all-sky surface fluxes remain. A detailed analysis of both SW and LW CRF over three regions indicates that at least part of these come from model's deficiencies in reproducing the observed cloud structure and in simulating cloud radiative parameters such as droplets and ice crystals effective radii.

Keywords: cloud radiative forcing, general circulation model, cloud micro physics
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INTRODUCTION

Cloud-radiation interactions are amongst the most important sources of climate feedbacks and the greatest uncertainties in modeling the climate system. As emphasized by [1] the ability of climate models to reproduce the observed distribution of clouds and the radiative fluxes in cloudy atmospheres is a necessary though not sufficient condition to allow credibility in climate change predictions. Different studies [1, 2, 3, 4] have presented ways of testing such interactions within models, mostly based on analysis of the cloud-radiative forcing (CRF) at the top of the atmosphere (TOA). [4] investigated the impact of clouds on the radiation budgets of several GCMs over the tropical Pacific through an analysis of anomalies in shortwave (SW) and longwave (LW) CRF. They found that most models in the Atmospheric Model Intercomparison Project (AMIP) II produced unusually large biases in net CRF (-10$\pm$12 W/m^2).

The "Centro de Previsão do Tempo e Estudos Climáticos" (CPTEC) GCM is a Global Spectral model developed at the "Instituto Nacional de Pesquisas Espacias" (INPE), used operationally for weather and climate forecasting since 1994. It has been shown that the model simulates reasonably well the main features of global climate and the seasonal variability of the main atmospheric variables[5]. However, [6] pointed out a systematic overestimation of surface solar fluxes if compared to satellite-derived estimates due to deficiencies in the currently operational (OPER) shortwave scheme which is based on [7]. Since then different radiation schemes have been implemented in the CPTEC GCM [8, 9] and the model CRF has been analyzed in a previous study [10] in which the OPER shortwave scheme was substituted by a modern code [11, 12]. Significant improvements in the surface fluxes were found but not in the simulated CRF because fixed values for microphysical parameters were used.

The present study uses the methodology of [4] and [10] to analyze cloud-radiation interactions in the CPTEC GCM with the introduction of the UK Met Office (UKMO) radiation scheme [13] for treating SW radiation and microphysics parameterized as in [14]. The CPTEC GCM with these modifications will be hereafter called NEW. The main differences between NEW and OPER are the introduction of atmospheric extinction due to O_2, CO_2, background aerosols and water vapor continuum, updated absorption lines of H_20 and O_3 and the introduction of parameterized microphysical quantities based on temperature, pressure and water content. With these modifications an improvement on the simulated CRF is to be expected.

CLOUD-RADIATION INTERACTIONS

For evaluating fluxes and heating rates, UKMO's code requires four cloud micro-physics parameters: condensed water mixing ratio, ice fraction of condensed water and effective radius of droplets and ice-crystals. Previously not available in CPTEC's GCM, these are now calculated as in [14]. In this parameterization the vertical profile of cloud-water is given an exponential decay where the scale height is a function of column precipitable water. Mixed-phase clouds exist in layers with temperatures between -30^{o}C (100% ice) and -10^{o}C (100% water) and the variation of ice fraction in between is linear. The effective radii of droplets are kept constant over the ocean (10μm) and dependant on temperature over land (typically 5-15μm). For ice crystals, the radius is diagnosed from the ratio between level pressure and surface pressure (range is 10-30μm). Details on the implementation of [14] can be found in [15]. As a result, four types of clouds are provided as input to the UKMO radiation code: convective and stratiform clouds, each formed of water or ice. In calculating the optical properties of one of these cloud types, the scattering properties of a single particle are needed. These depend on the spectral band and are based on [16].

EXPERIMENT AND DATA USED FOR VALIDATION

Integrations of NEW and OPER models were performed at T62L28 ($\sim$200km and 28 vertical levels) resolution, with time-steps of 20min, from 13 Nov 1984 to 31 Dec 1989. NOAA's optimum interpolation (OI.v2) sea surface temperature (SST) was used as a boundary condition. For validation of the new radiation scheme data from the World Climate Research Programme/Global Energy and Water-Cycle Experiment (WCRP/GEWEX) Surface Radiation Budget (SRB) Project were used: monthly shortwave and longwave radiative fields from releases 2.81 and 2.5 respectively. Quality control was done by comparisons with sites of the Baseline Surface Radiation Network (BSRN), which has measurement uncertainties around $\pm 5 \pm 15$ W/m^2. Estimate - observation differences are around -8.2$\pm$23.8 W/m^2 for SW and -2.0$\pm$13.3 W/m^2 for LW. Data from the Global Precipitation Climatology Project (GPCP v2) were also used.

RESULTS

Table 1 shows the annual global mean solar radiation absorbed in the atmosphere for OPER and NEW simulations and for SRB. Here and in the following, bias is defined as the difference between model and SRB. For clear-sky atmospheric absorption, bias was reduced from -21 W/m^2 to +1.6 W/m^2 over land and from -4.9 W/m^2 to +2.4 W/m^2 over the oceans, bringing the model's result in agreement with observations. [10] has shown that the reduction of the CPTEC GCM's systematic error in atmospheric absorption is mainly due to the introduction of background aerosols. However, for the time period of our simulations, climatological aerosol loading over the oceans seems to be slightly overestimated. In addition, the +2.3 W/m^2 clouds' contribution to atmospheric absorption in NEW is closer to the +4.6 W/m^2 derived from SRB dataset than the +0.3 W/m^2 simulated by OPER. However, there are still large errors in the all-sky SW flux at the surface, as shown in Fig.1a. These are partially due to errors in cloud cover, as suggested by the high spatial correlation with Fig.1b, but might also stem from unrealistic cloud optical depth, cloud vertical structure or/and cloud albedo. To further investigate this issue, we analyzed the cloud radiative forcing.

TABLE 1. Atmospheric absorption, SWCRF and LWCRF simulated by OPER and NEW models and derived from satellite observations (SRB), averaged between Jan85 and Dec89. Values in W/m^2.

	Global			Ocean			Land		
	OPER	NEW	SRB	OPER	NEW	SRB	OPER	NEW	SRB
SW ATM ABS	62	75	75	64	74	74	58	79	77
SW ATM ABS clear	62	74	72	64	71	69	57	80	78
SW cloud forcing	-54	-47	-47	-61	-49	-52	-38	-42	-35
LW cloud forcing	33	31	28	36	35	29	25	22	26

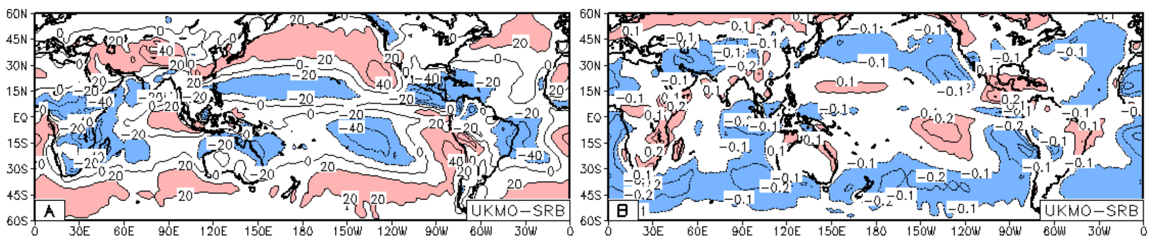

FIGURE 1. Differences between NEW model and satellite-derived (SRB) estimations of (a) all-sky shortwave flux at the surface (W m^{-2}) and (b) total cloud cover, averaged between Jan85 and Dec89. Spatial correlation coefficient between (a) and (b) is -0.74.

The SW and LW CRF [17, 18] are defined as the difference between clear-sky and all-sky outgoing fluxes at TOA. Typically SW CRF is negative (cooling) and LW CRF positive (heating). The net CRF is $netCRF = SWCRF + LWCRF$. Despite the deficiencies of the model's cloud parameterization, table 1 shows that SW CRF is improved over the oceans, with the bias reduced from -9.3 W/m^2 to +3.1 W/m^2. Over land this bias was increased from -2.4 W/m^2 to -6.9 W/m^2, due to an overestimation of the all-sky outgoing SW flux, which could stem from errors in cloud albedo and cover. The LW CRF bias is also increased over land, from -1.9 W/m^2 to -4.7 W/m^2.

Fig.2 shows the zonal averaged SW and LW CRF as simulated by OPER and NEW and from SRB. The left panel shows significant differences in the SW CRF as simulated by NEW and OPER, particularly over the tropics. It is worth noting that the agreement between NEW and SRB shown in table 1 reflects a compensation of large positive and negative biases in the subtropical and tropical regions respectively. For the LW CRF there is no significant changes.

For a detailed analysis of the radiative forcing, the three regions marked in Fig.1 were chosen and studied as in [4]. The regions in the tropical western Pacific (10°N-5°S 135°E-170°E) and in the Amazon (15S-0S 48W-70W) are dominated by deep convection and, according to [19], net CRF$\sim$0 and N$= -SWCRF/LWCRF \sim 1$. The Pacific southeastern region (15°S-27°S 92°W-120°W) is characterized by trade cumulus which are shallower than the deep cumulus of western region, having warmer cloud-tops. Hence LW CRF is smaller compared to the western region and net CRF<0. Fig.3a presents a scatter plot of N$\times$netCRF for the western region built from the mean DJF field between Jan85 and Dec89. Points on the plot corresponds to $1.8^o \times 1.8^o$ grid boxes and represent time averages of and not specific cloud systems. SW and LW CRF, and so netCRF, are linearly dependent on cloud cover (CC) [14]. Hence N is invariant. For a fixed cloud optical depth a reduction in CC would produce a horizontal scatter as netCRF changes. A vertical scatter means a change in cloud top altitude (CT) as it would change LW CRF and hence N.

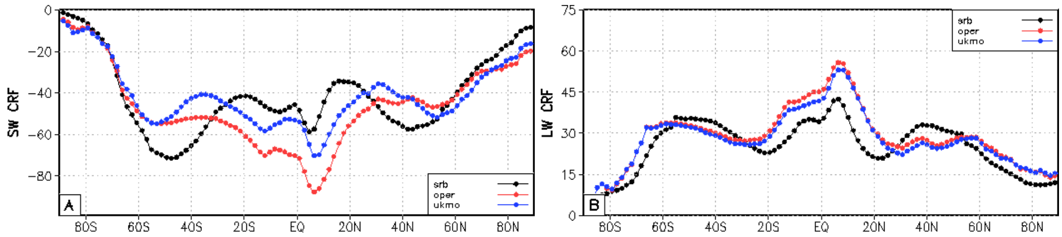

FIGURE 2. Zonal average of (a) SW and (b) LW cloud radiative forcing averaged between Jan85 and Dec89. Values in W/m^2. OPER results are shown in red, NEW in blue and SRB in black.

SRB data shows low scatter in the western region, meaning that both CC and CT are spatially uniform. OPER results however present large variations in CC and CT and fail to reproduce the deepest convective clouds (there are no points near N=1 netCRF=0). NEW results are in much better agreement but underestimate cloud albedo and hence LWCRF dominates. The area averaged netCRF are: SRB = -4.6 W/m^2, OPER = -22 W/m^2 and NEW = +2.5 W/m^2. In the Amazon region both simulations fail to reproduce SRB, generating overly bright clouds with highly variable CC and CT. The resulting differences between modeled and observed SWCRF range between -60 W/m^2 and +70 W/m^2 for both OPER and NEW. In the southeastern region (Fig.3c) SRB shows a more pronounced variation in both CC and CT compared to the western region. Both OPER and NEW fail to reproduce SRB, showing too much variation in CC. OPER performs worst with the optically thinnest trade cumulus in the lower right while NEW performs worst with the thickest ones. The average netCRF are: SRB = -22 W/m^2, OPER = -35 W/m^2 and NEW = -23 W/m^2.

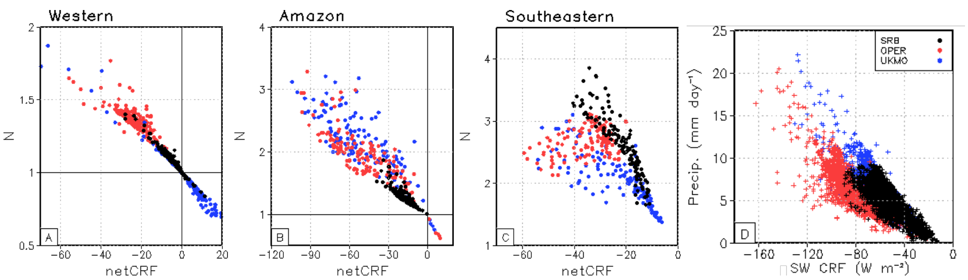

FIGURE 3. Scatter plots of $N \times netCRF$ and of convective precipitation versus SWCRF over tropical oceans (20^{o}S–20^{o}N, mean SST>27^{o}C) from SRB/GPCP (black), OPER (red) and NEW (blue), for the mean DJF between Jan85 and Dec89

Fig.3d shows a scatter plot of precipitation versus SWCRF over the deep convective regions in the tropical oceans (annual mean SST>27^{o}C and 20^{o}S–20^{o}N). OPER seems to be offset in relation to SRB while NEW shows a good match. A closer look reveals that both simulations fail to produce low precipitation rates (<2 mm day^{-1}) and overestimate the high rates (>10 mm day^{-1}).

DISCUSSION AND CONCLUSIONS

Using the UKMO SW scheme the CPTEC GCM simulates radiative fluxes, atmospheric absorption and SW CRF that globally agree with observations within measurement precision. Improvements in atmospheric absorption are mostly due to the absorption by background aerosols [10]. However, specific regions still show large errors in the all-sky surface flux (± 40 W/m^2) which are spatially correlated to errors in cloud cover with a coefficient of -0.71. Large regional discrepancies are also present for CRF. For instance, although averaged net CRF is reproduced in the Pacific southeastern region (bias is -1 W/m^2), cloud-radiation interactions are not (see Fig.3c). In the western region, the bias in netCRF was significantly reduced, but cloud albedo is still underestimated, possibly due to an overestimation of effective radii of ice crystals and water droplets. Clouds produced over the Amazon, show a larger range of optical depths than that inferred from SRB and the bias in netCRF is -35 W/m^2. A comparison of modelled summer precipitation and cloud cover over the Amazon with observations (analysis not shown) indicated this to be a deficiency of the convection scheme, known to underestimates deep convection in this region [5].

It has been shown that the failure in simulating the observed CRF and all-sky shortwave at the surface is a combination of errors in the vertical and horizontal distributions of cloud cover and optical depth. These may compensate each other, confirming [4] who note that spatially averaged CRF may be misleading for judging a model's ability to represent clouds and their interaction with the radiation field. This study showed that a new shortwave radiation parameterization improved the CPTEC GCM's ability to represent cloud-radiation interactions and pointed out some of its remaining deficiencies.

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