Incorporation of UK Met Office's radiation scheme into CPTEC's global model

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

*CPTEC/INPE, Rod. Presidente Dutra km 40, 12630-000 Cachoeira Paulista - SP, Brazil
†IF/USP, R. Matão, Travessa R, 187, 05508-090 Cidade Universitária, São Paulo - SP, Brazil

Abstract. Current parameterization of radiation in the CPTEC's (Center for Weather Forecast and Climate Studies, Cachoeira Paulista, SP, Brazil) operational AGCM has its origins in the work of Harshvardhan et al. (1987) and uses the formulation of Ramaswamy and Freidenreich (1992) for the short-wave absorption by water vapor. The UK Met Office's radiation code (Edwards and Slingo, 1996) was incorporated into CPTEC's global model, initially for short-wave only, and some impacts of that were shown by Chagas and Barbosa (2006). Current paper presents some impacts of the complete incorporation (both short-wave and long-wave) of UK Met Office's scheme. Selected results from off-line comparisons with line-by-line benchmark calculations are shown. Impacts on the AGCM's climate are assessed by comparing output of climate runs of current and modified AGCM with products from GEWEX/SRB (Surface Radiation Budget) project.

Keywords: atmospheric radiation, solar radiation, general circulation model, radiation parametrization, radiative schemes
PACS: 92.70.Np, 92.60.Vb

INTRODUCTION

The parameterization of radiative transfer in the Atmospheric General Circulation Model (AGCM) run at CPTEC/INPE (Center for Weather Forecast and Climate Studies/National Institute for Space Research, Brazil, hereafter CPTEC code or scheme) since early nineties is based on [1] for long-wave and on [2] for short-wave. The characteristics of CPTEC's AGCM climate were analyzed by [3], who confirmed its deficiencies in simulating the observed radiative fluxes and highlighted the need for improvement on the radiation and cloud parameterizations. Moreover, [4] showed that the model systematically overestimates surface solar fluxes if compared to satellite-derived estimates. Overestimation of solar radiation reaching the surface has been a problem for most GCMs worldwide and improvement is being gradually achieved during recent decades [5]. At CPTEC, an improvement was achieved in 2004 when the formulation of [6] for water vapor short-wave absorption became operational. In parallel, efforts are being made to implement and test modern radiative transfer schemes inside CPTEC's AGCM [7, 8]. This paper describes some impacts of the implementation of the UK Met Office's radiation scheme [9], hereafter UKMO code, on the climate characteristics of CPTEC's AGCM.

OFF-LINE COMPARISONS

Before being incorporated into CPTEC's AGCM, both short-wave and long-wave UKMO schemes were compared in off-line mode with current CPTEC codes using line-by-line results as reference. Selected short-wave results of these comparisons are shown on Table 1.

TABLE 1. Partition of incident short-wave radiation (among **reflected at top-of-atmosphere**, **absorbed by atmosphere** and **absorbed by surface**, appearing in this order in the table cells). LBL are line-by-line LBLRTM+CHARTS [10, 11] results; figures for broad-band codes current-CPTEC (CPT) and UKMO (UKM) are differences from line-by-line results. Table headings: TRO: tropical atmosphere; 00, 75: solar zenith angle in degrees; HIGH, LOW; high and low cloud cases as described by [12].

	Clear-sky cases		Cloudy-sky cases			
	TRO 00	TRO 75	HIGH 00	HIGH 75	LOW 00	LOW 75
LBL	.170 .207 .622	.216 .292 .492	.188 .210 .602	.425 .212 .362	.387 .225 .388	.567 .242 .191
CPT	.003 –.024 .021	.007 –.035 .028	–.010 –.027 .037	–.091 .006 .084	–.176 –.033 .209	–.139 –.023 .162
UKM	–.001 –.006 .007	–.005 –.013 .017	.001 –.006 .005	–.048 .004 .044	–.009 –.005 .014	–.009 –.016 .025

It is possible to see that UKMO performs better than CPTEC for all cases, specially when clouds are included (note the very big errors made by CPTEC when the thick low cloud is present, which are strongly reduced by UKMO). The main reason for the much better performance of UKMO when clouds are present is that CPTEC uses only cloud cover and temperature to estimate cloud optical thickness, while when implementing UKMO the cloud microphysics scheme of [13] was also incorporated to provide the particle effective radius, the condensate mixing ratio, and the ice-water ratio needed as input to UKMO. Some clear-sky long-wave results appear on Table 2. It can be seen that UKMO sistematically brings the long-wave fluxes closer to the reference values as compared to current CPTEC code, specially for the upward long-wave fluxes at the top of atmosphere. Such results of the first step (off-line assessment) of the incorporation of UKMO scheme into CPTEC's AGCM were encouraging.

TABLE 2. Long-wave fluxes (Wm^{-2}; **upward flux at top-of-atmosphere** and **net flux at surface**, appearing in this order in the appropriate table cells) obtained with line-by-line model LBLRTM [10] and differences from line-by-line of fluxes obtained with current CPTEC and UKMO codes. Table headings: numbers are for cases of [14]; TRO: tropical, MLS: mid-latitude summer, MLW: mid-latitude winter, SAS: sub-arctic summer, and SAW: sub-arctic winter standard atmospheres; 300, 600: CO_2 concentration in ppmv.

	25 TRO 300	27 MLS 300	28 MLS 600	29 MLW 300	31 SAS 300	33 SAW 300
LBLRTM	293.2 63.5	284.4 76.3	281.4 74.5	233.3 90.3	265.9 87.0	200.5 77.1
CPTEC–LBL	+12.4 +16.3	+10.2 +14.2	+10.4 +15.0	+5.7 +12.4	+9.1 +12.1	+3.4 +9.3
UKMO–LBL	+6.8 +6.0	+5.5 +6.8	+6.0 +7.5	+2.8 +3.8	+4.9 +5.0	+1.4 +1.2

IMPACTS ON AGCM CLIMATE

The main gaseous short-wave absorption differences between UKMO and CPTEC are updated line parameters of H_2O and O_3, extinction by O_2 and CO_2, and water vapor continuum. Along with the implementation of a simple cloud microphysics scheme, a simplified aerosol climatology was implemented as input for the UKMO code following [15]. Although simplified, it allows the introduction of first order effects of aerosols on the radiation balance and achieves reasonable agreement with observations. For present analysis two versions of the AGCM, one with CPTEC and other with UKMO for both short-wave and long-wave, were integrated for a 13-month period starting in November 1st 2002. Results are displayed as one-year-averaged fields (December/2002—November/2003) and compared with release 2.5 of the dataset produced by the NASA/GEWEX Surface Radiative Budget Project (SRB). The grand means of some surface short-wave and top-of-atmosphere and surface long-wave terms displayed on Table 3 lead us to conclude that the AGCM represents radiative fluxes much better with UKMO than with current CPTEC codes.

TABLE 3. Global mean of short-wave and long-wave fluxes (in Wm^{-2}) at top-of-atmosphere (TOA) and at surface (SFC) averaged over a twelve-month (Dec/2002–Nov/2003) period for clear sky (CLR) and all-sky (ALL) conditions. SRB are reference fields taken form GEWEX/SRB Project.

	Short-wave			Long-wave	
	SFC down CLR	SFC down ALL	SFC net ALL	TOA up ALL	SFC net ALL
SRB	242.5	182.9	160.3	241.2	54.8
CPTEC-SRB	20.2	20.4	20.8	–5.4	1.9
UKMO-SRB	–2.1	–2.2	0.7	–1.2	0.9

Comparison of zonally-averaged annual means of the differences of incident short wave at surface, depicted on Figure 1, reveals some details which were hidden by global averaging. For clear-sky and all latitudes the incident short wave at surface is clearly better represented with UKMO than with CPTEC even though the sign of the errors, always positive for CPTEC, changes to negative over large latitude extents for UKMO. In this case, everything is in accordance with the global means of Table 3. For all-sky, however, although the grand mean (Table 3) shows big improvement when unsing UKMO instead of CPTEC, zonal averages (Figure 1) reveal that CPTEC performs better between 25^{o}S and 25^{o}N. The large errors in UKMO short-wave fluxes in this region are partially due to errors in cloud cover and also to errors in cloud optical depth, vertical structure and albedo (see comments and Figure 1 of [16]). Figures 2 and 3 show global fields of annual means and differences of respectively clear-sky and all-sky incident short-wave at surface. For clear-sky, as its gaseous absorption is low and no aerosol effect is included, CPTEC overestimates surface incident short-wave almost everywhere and the biggest errors are in regions with high aerosol loading. Gaseous absorption is higher in UKMO and a simple aerosol climatology (just two distributions, one over land and other over ocean) is included. Things are much better but there are still big errors in regions with high aerosol concentration. When the effects of clouds are added, global averages are of the same magnitude as for clear skies but the spatial distribution of errors changes from CPTEC to UKMO. Figure 3 shows that, with UKMO, surface incident short wave is improved at high latitudes but worsens at low latitudes in accordance with the zonal means of Figure 1.

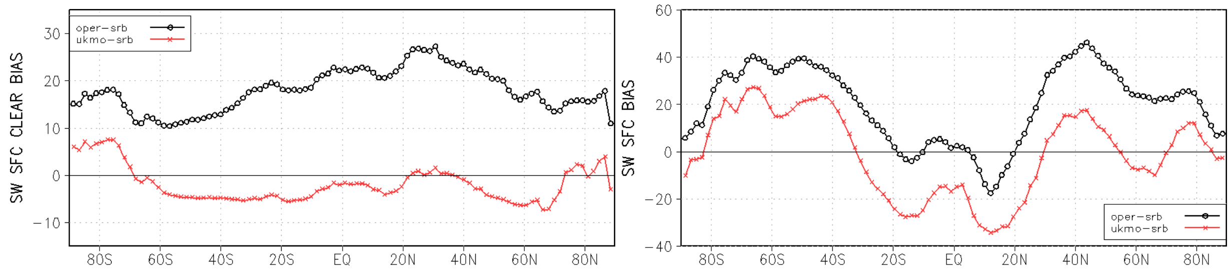

FIGURE 1. Zonally-averaged annual mean of the differences from SRB of incident short wave at surface (Wm^{-2}) as calculated by current CPTEC AGCM (oper-srb) and by the AGCM with UKMO radiation code (ukmo-srb). Left: clear-sky; right: all-sky.

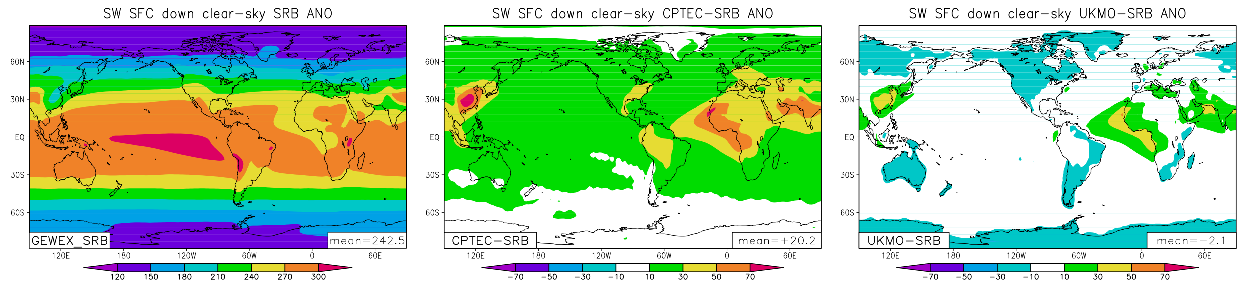

FIGURE 2. Annual mean of the clear-sky incident short wave at surface (Wm^{-2}). Left: generated by SRB project; middle: difference from SRB of current CPTEC AGCM; right: difference from SRB of CPTEC AGCM with UKMO code.

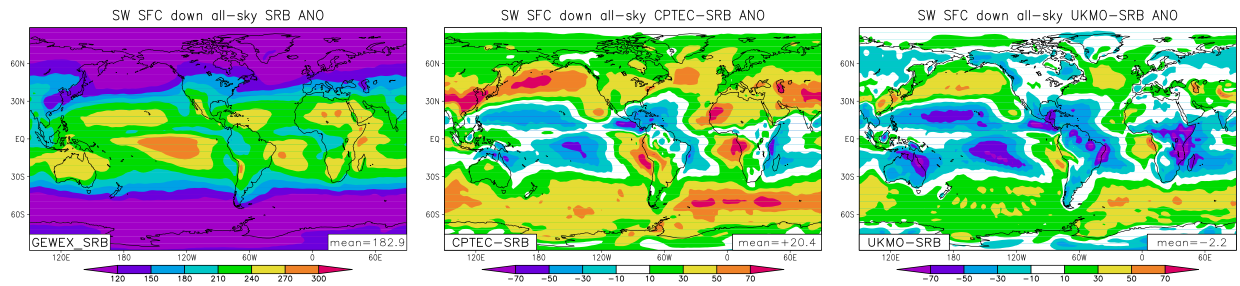

FIGURE 3. Annual mean of the all-sky incident short wave at surface (Wm^{-2}). Left: generated by SRB project; middle: difference from SRB of current CPTEC AGCM; right: difference from SRB of CPTEC AGCM with UKMO code.

As for long-wave global averages, Table 3 shows that the outgoing radiation at top-of-atmosphere is underestimated by CPTEC and that this underestimation is reduced with UKMO. Inspection of Figure 4 reveals that this global difference results from the improvement of big regions with negative differences but associated with worsening in some small regions with positive differences. CPTEC overestimates the long-wave balance at surface by a small amount and UKMO brings a slight reduction of that amount. Figure 5 however shows no noticeable difference between the two fields. For long-wave results differences are generally small. One of the main advantadges of UKMO long-wave scheme if compared to CPTEC is the reduction in computing time. A more detailed analysis is still needed.

CONCLUSIONS

This work discusses some results of the incorporation of UK Met Office's radiation scheme into CPTEC's AGCM. Among others the main deficiencies of current CPTEC radiation scheme can be listed as: low short-wave atmospheric

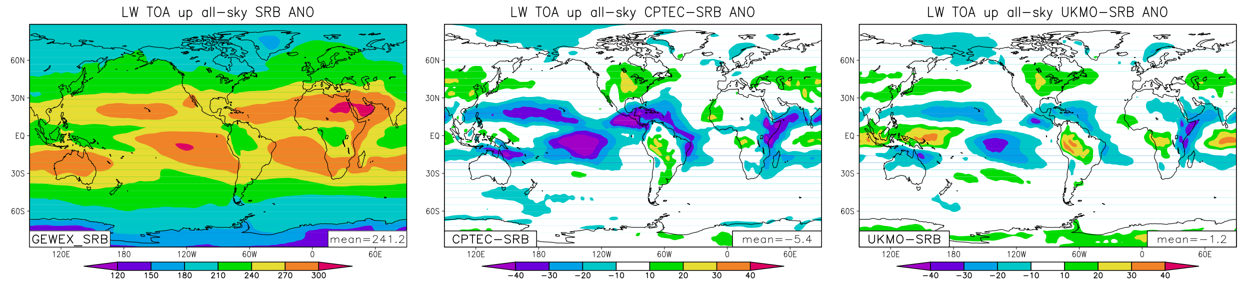

FIGURE 4. Annual mean of the all-sky outgoing long wave at top-of-atmosphere (Wm^{-2}). Left: generated by SRB project; middle: difference from SRB of current CPTEC AGCM; right: difference from SRB of CPTEC AGCM with UKMO code.

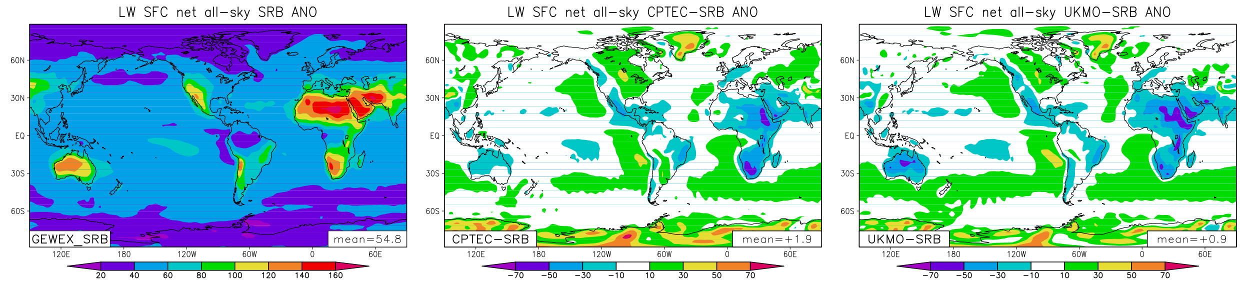

FIGURE 5. Annual mean of the all-sky net long wave at surface (Wm^{-2}). Left: generated by SRB project; middle: difference from SRB of current CPTEC AGCM; right: difference from SRB of CPTEC AGCM with UKMO code.

absorption due to errors in modeling gaseous and cloud absorption and to the lack of aerosol effects, and very expensive long-wave scheme. Substituting current CPTEC's code with UK Met Office's code along with introducing a simplified aerosol climatology and a more detailed representation of cloud properties resulted in substantial reduction of errors in atmospheric short-wave absorption except at low latitudes. For long-wave, a more detailed analysis is due to be made, but a preliminary inspection shows that errors in long-wave balance, which were already small with CPTEC, were slightly reduced with UKMO.

REFERENCES

1. Harshvardhan, R. Davis, D. A. Randal, and T. G. Corsetti, *J. Geophys. Res.* **92**, 1009–1016 (1987).
2. A. A. Lacis, and J. E. Hansen, *J. Atmos. Sci.* **31**, 118–133 (1974).
3. I. F. A. Cavalcanti, et al., *J. Climate* **15**, 2965–2988 (2002).
4. T. A. Tarasova, and I. F. Cavalcanti, *J. Appl. Meteorol.* **41**, 863–871 (2002).
5. M. Wild, C. N. Long, and A. Ohmura, *J.Geophys.Res.* **111** (2006), D01104.
6. V. Ramaswamy, and S. M. Freidenreich, *J. Geophys. Res.* **97**, 11487–11512 (1992).
7. J. C. S. Chagas, and H. M. J. Barbosa, "Impact of UKMO's shortwave scheme on CPTEC's global model," in *The 12th Conference on Atmospheric Radiation*, American Meteorological Society, Madison, Wisconsin, USA, 2006.
8. H. M. J. Barbosa, and T. A. Tarasova, "New solar radiation parameterization in CPTEC/COLA GCM," in *Proceedings of 8 ICSHMO*, edited by INPE, 2006, pp. 493–494, Foz do Iguaçu, Brazil.
9. J. M. Edwards, and A. Slingo, *Q. J. Roy. Meteorol. Soc.* **122**, 689–719 (1996).
10. S. A. Clough, M. J. Iacono, and J.-L. Moncet, *J.Geophys.Res.* **97**, 15761–15785 (1992).
11. J.-L. Moncet, and S. A. Clough, *J.Geophys.Res.* **102**, 21853–21866 (1997).
12. H. W. Barker, et al., *J.Climate* **16**, 2676–2699 (2003).
13. J. T. Kiehl, *J. Geophys. Res* **99**, 23107–23115 (1994).
14. R. G. Ellingson, J. Ellis, and S. Fels, *J. Geophys. Res.* **96**, 8929–8953 (1991).
15. S. Cusack, A. Slingo, J. M. Edwards, and M. Wild, *Q. J. Roy. Meteorol. Soc.* **124**, 2517–2526 (1998).
16. H. M. J. Barbosa, and J. C. S. Chagas, "The Cloud Radiative Forcing simulated by the CPTEC GCM with the UK Met Office's radiation scheme," in *Proceedings of the IRS 2008*, edited by IRC, 2008, Foz do Iguaçu, Brazil.