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Interactive comment on "Impact of an improved radiation scheme in the MAECHAM5 General Circulation Model" *by* C. Cagnazzo et al.

Y. Balkanski (Editor)

yves.balkanski@cea.fr

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This comment was written by the authors of the manuscript: C. Cagnazzo, E. Manzini, M. A. Giorgetta, P. M. De F. Forster and J.J. Morcrette

Comments on Nissen et al., (SRef-ID: 1680-7375/acpd/2007-7-45)

The paper presents results from stand alone tests of the FUBrad code compared to a reference code and the standard shortwave scheme of the generic ECHAM5 GCM. Further it compares simulations using the standard MAECHAM5 GCM to simulations based on the modified MAECHAM5 GCM that includes the FUBrad scheme for the UV and visible range in the middle atmosphere, coupled by the MESSy interface system to ECHAM5. The main conclusions are that the heating rates of the standard scheme and the combined standard+FUBrad scheme are comparable up to about 0.1 hPa in the selected tropical test case (Figure 1), and that the high spectral resolution and broader spectral range of FUBrad, compared to the single UV/visible band of the standard shortwave scheme, is able to capture the signal of the 11-year cycle in the heating rate profiles (Figures 2-4).

The second finding is sensible and it is clear from the very beginning that the single UV/visible band used in the 4 band shortwave scheme of ECHAM5 cannot account properly for the spectral irradiance changes of the solar spectrum changes. If it is necessary to have more than 40 bands, as available in the FUBrad scheme, to simulate solar cycle heating effects remains open.

The first conclusion is, however, disturbing because the UV/visible band of the standard shortwave code does not account for the absorption by O3 in the Hartley bands at wavelengths shorter than 250 nm and it neglects absorption by O2 in the Herzberg continuum or the Schumann-Runge bands, which are part of the FUBrad scheme. Hence one should expect significant differences down to the stratopause region. The shortcoming in SW heating produced by the 4 band SW code that is implemented in MAECHAM4 and MAECHAM5 has been addressed before for example in Iacono et al. (2002) and Egorova et al. (2005), and recently in Cagnazzo et al. (2006). This apparent contradiction between the new paper and the older ones was pointed out to me by a co-author of the Nissen et al. paper and by other people using ECHAM5/MESSy, and I found it important to contribute to the understanding of the problem. This led to a number of questions outlined below and some possibly useful hints from the analysis of a version of the ECHAM5-MESSy code (package “MESS1 1.3.1”), which probably corresponds in the FUBrad implementation to the one used for the simulations in the paper dicussed here.

1. How exactly is the FUBrad scheme coupled to the standard 4 and SW code in the MAECHAM5 GCM?

The ECHAM5 SW4 scheme has a single broad band in 250-690 nm for the UV and visible. SW4 considers Rayleigh scattering as well as scattering by aerosol and cloud particles, which modifies the optical path used for gas absorption. Radiative transfer through the absorbing gas is parameterized by Pade coefficient. The downward or upward gas transmission at a particular level is computed by functions (Pade coefficients) of the total absorber path length from TAO to the level of interest including effects of scatterig on the path length. The FUBrad scheme covers the spectral ranges 206-363 nm (43 bands for Herzberg continuum of O2 and Hartley and Huggins bands of O3) and 408-682 (1 band for Chappuis bands). These ranges overlap with the single broad band of SW4.

Additionally the FUBscheme includes the Schumann-Runge continuum and bands (125-205nm) and Lyman-alpha heating. This scheme neglects Rayleigh scattering as well as scattering by any particulates, allowing to use Lambert's law for the computation of the transmission within each band.

The interesting problem is now to how to couple both schemes in a physically sensible way; the SW4 scheme operating on the whole vertical domain from the surface to the top of the atmosphere (TOA) and the FUBrad scheme being limited by construction to the stratosphere and higher layers . The authors explain that they merge both schemes as a model level next to 70 hPa, but do not give details.

Specific questions I have are:

1. Is the SW4 scheme integrated over the whole atmospheric column of the GCM or only over the atmosphere below 70 hPa?

2. How does the upward flux in the FUBrad scheme between 206 and 682 nm depend on the radiative properties of the atmosphere below 70 hPa and the surface?

3. How is the upward optical path computed? Does the scheme use a constant magnifying factor, or does it depend on the zenith angle? (The downward calculation probably

uses the standard magnification factor of the direct beam.)

4. How does the radiative transfer in the atmosphere below 70 hPa depend on the radiative transfer above 70 hPa?

5. Specifically how does the absorption between the surface and 70 hPa depend on ozone absorption above 70 hPa?

6. Is radiant energy conserved in the sense that the net flux at TOA is in balance with the energy used for SW heating?

7. Is absorbing matter used exactly once for extinction of radiation from the direct beam?

8. The SW4 scheme makes separate transfer calculations for the cloudy and non-cloudy sub-columns. Is there a need to couple these sub-columns separately?

9. The FUBrad scheme neglects Rayleigh scattering. Consequently the (ozone) absorber paths are underestimated for small zenith angles, when the main ozone heating is centered at relatively low levels, and underestimated when the zenith angle is large and the heating is centered at relatively higher levels. What is the effect of neglecting Rayleigh scattering on the heating profile?

10. What is the effect of the modified SW radiation scheme on the SW fluxes at the surface and the top of the atmosphere compared to the standard SW scheme, for example for the single column test of figure 1?

11. How do the schemes compare for other standard cases like mid-latitude summer or mi latitude winter?

2. Assessment of the model code As I have the model code available (ECHAM5-MESSy1.3.1) I tried to find some answers to the questions listed above, and the results may help the authors to improve the implementation of the FUBrad code in MAECHAM5.

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(A) Optical path above 70 hPa In the downward flux each layer adds to the ozone optical path as follows: dtau(downward)=dx*M(Theta0), where dx represents the (vertical) optical depth and M(Theta0) is the common magnification factor of Rodgers (1967). This is ok, since scattering is neglected.

In the upward flux each layer adds to the ozone optical path as follows: dtau(upward)=dx*m/M(Theta0),

where m=1.9 is the “diffuse flux approximation” factor of Lacis and Hansen (1974). Here it is unclear why the amount is divided by the magnification factor M of the direct beam. The effect is that dx is decreasing with increasing zenith angle. Most likely this is an error in the coding of the FUBrad scheme.

Location:

- messy_1.3.1/echam5.3.01_messy_1.3.1/messy/src/messy_rad4all_fubrad.f90

- SUBROUTINE o3fluxes

- Line in file: 695

(B) Coupling of FUBrad code and SW4 code The MAECHAM5 GCM computes the radiative transfer in 2-hourly intervals and the heating rates at every time step use a correction for the changing solar zenith angle. FUBrad computes fluxes and heating rates at every timestep. In the following I describe only the coupling of the schemes as it happens at the 2-hourly intervals, when the SW4 and the FUBrad scheme compute fluxes. Following my understanding this is working as follows:

1. FUBrad computes downward fluxes between the surface and 70 hPa considering:

- Herzberg continuum 206-244 nm (*)

- Hartley bands in 206-244 nm (*)

- Hartley bands in 244-278 nm

- Huggins bands in 278-363 nm (*)
- Chappuis bands in 408-683 nm (*)

and computes the downward transmissivity from TOA to 70 hPa averaged over the bands marked with (*), i.e. for the range of 206-683 nm excluding the strong Hartley bands in 244-278 nm.

Here it would be necessary to explain why the transmissivity is computed this way, remembering that the SW4 scheme has the spectral range 250-690 nm for the UV and visible. Maybe the intention was to exclude the 206-244 interval from the computation of the transmissivity in order to obtain a broad band average fitting to the single UV and visible band of SW4.

Location:

- messy_1.3.1/echam5.3.01_messy_1.3.1/messy/src/messy_rad4all_fubrad.f90
- SUBROUTINE middle_atmosphere_downward_flux
- Line in file: 217

2. SW4 computes the transmissivity of the scattering non-cloudy atmosphere. The transmissivity is computed at each level of the atmospheric column, between TOA and surface, considering Rayleigh scattering and aerosol scattering. In the standard SW4 code of MAECHAM5 this starts formally with a downward transmissivity of 1 at TOA. In the modified scheme this is replaced by the TOA-to-70hPa transmissivity calculated in step 1.

standard: t[TOA,down,no clouds,SW4,250-690nm]=1

with FUBrad: t[TOA,down,no clouds,SW4,250-690nm]=t[70hPa,down,FUBrad]

Location:

- messy_1.3.1/echam5.3.01_messy_1.3.1/messy/src/messy_rad4all_short.f90

- SUBROUTINE rad_sw_swclr

- Line in file: 1694

3. SW4 computes the transmissivity of the scattering cloudy atmosphere. This is done without any modifications:

standard: t[TOA,down,with clouds,SW4,250-690nm]=1

with FUBrad: t[TOA,down,with clouds,SW4,250-690nm]=1

4. SW4 computes downward and upward fluxes resulting from the bandwise defined solar spectrum at TOA, the equivalent solar zenith angles computed in steps 2 and 3 for non-cloudy and cloudy downward paths, a diffusivity factor of 1.66 for the upward path, the surface albedo and the gas transmission functions, parameterized by Pade coefficients. Fluxes are computed for all levels between TOA and surface. The reduced TOA transmissivity of step 2 is applied in the non-cloudy part of the column, while the cloudy part uses the standard transmissivity t(TOA)=1 at the top of the model atmosphere. This has the effect that the fluxes of the non-cloudy part of the column are computed with a reduced solar irradiation, while the cloudy part of the column uses the standard solar irradiation. SW4 computes it own ozone absorption by Hartley (beyond 250nm), Huggins and Chappuis band as approximated by the broad band Pade coefficients for the range 250-690 nm. To my understanding this means that fluxes in the non-cloudy column as computed at this stage have been reduced first by the imposed reduction in solar irradiation, and then also by the ozone absorption of the SW4 scheme:

Reduced irradiation due to due to absorption in FUBrad scheme:

- Herzberg continuum

- Hartley bands in 206-244 nm

- Huggins bands

- Chappuis bands

Absorbed in SW4 scheme:

- Hartley bands for wavelengths larger than 250 nm
- Huggins bands
- Chappuis bands

Hence it looks like Huggins and Chappuis bands are taken into account twice. The Hartley bands are effective once below 250 nm in FUBrad and once above 250 nm in SW4, maybe accidentally, see point 1. The Herzberg continuum is used once; it is neglected in the SW4 scheme.

Further, the fluxes in the non-cloudy part of the column depend on the fluxes computed in the FUBrad scheme above 70 hPa, but the fluxes in the cloudy columns are independent of the FUBrad computations. Non-cloudy and cloudy fluxes are then merged using the total cloudiness of the column. It seems like the coupling is efficient only in non-cloudy atmospheres, and the way it is implemented needs reconsideration to avoid double absorption by ozone.

5. The downward and upward fluxes of step 4 are used to define a broad band reflectivity at 70 hPa of the atmosphere below 70 hPa and the surface.

6. New upward fluxes are computed in the FUBrad scheme based on the downward flux at 70 hPa from step 1, the reflectivity at 70 hPa of step 5 and the magnification factors pointed out in section (A).

7. Fluxes in the near infrared bands are calculated without modifications.

8. Later heating rates are calculated from the divergence of the net flux profiles.

This quick analysis may help the authors to find answers to the questions above. Of course it may be that I missed some details, but I think it shows the main characteristics.

Summary The coupling of the SW4 scheme and the FUBrad scheme is not trivial. In its current implementation I see some serious problems that must be resolved to avoid erroneous conclusions in scientific applications of this model. Though the effects might not be large, they might be large enough to produce artefacts, especially if the aim is to identify weak signals in the general circulation, as it is the case for the 11-year solar cycle forcing, which is the major motivation for the implementation of a better spectrally resolved radiation scheme. The need for an extension of the radiation scheme to shorter wavelengths and a better representation of the absorbers for solar cycle studies is however clear.

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Interactive comment on Atmos. Chem. Phys. Discuss., 6, 11067, 2006.

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