**Atmospheric
Chemistry
and Physics
Discussions**

Interactive
Comment

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

C. Cagnazzo et al.

Received and published: 1 March 2007

We would like to thank the Referees for their detailed and useful reviews that have made us set the basis for a more thorough report of the differences between SW6 and SW4 as well as carry out a number of more minor improvements. Furthermore, the questions of the Referees have made us improve the focus of our work and the interpretation of our results.

The major change in the manuscript concerns Section 3, which has been completely rewritten to accommodate the additional computation with the offline schemes and the LBL model. In addition, Figure 1 has now been subdivided into two.

Changes in the Abstract and in the Introduction have been made in order to avoid the misunderstanding that we think had led Referee 1 to conclude that we had developed

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

EGU

the SW6 parameterization and to clarify the aims of our work.

We have added "shortwave" in the title, to make it more specific.

Jean-Jacques Morcrette has joined the co-authorship of the manuscript, given his valuable contribution to the revised version of the manuscript.

The scientific results of our work are unchanged, and we think are now put on a stronger basis thanks to the requested additional computation.

Reply to Referee 1

We regret that our work has been partly misunderstood: We did not develop a new shortwave radiation scheme, but implemented a scheme (already in use at ECMWF since April 2002) into the MAECHAM5 general circulation model, thus replacing the one used in the standard version of the MAECHAM5 model. As stated in the original manuscript in ACPD, page 11070, lines 11-13:

"we follow the upgrade from 4 to 6 bands of the solar radiation parameterization in the ECMWF model (Morcrette et al 2001; Iacono et al 2002)".

What is new in our work is the evaluation of the response of the simulated stratospheric temperature and circulation of the MAECHAM5 GCM to the improvements in the parameterization of the radiative heating (better resolved ozone absorption), and the demonstration that this parameterization improvement indeed reduces the temperature bias of the GCM at the stratopause.

We acknowledge that our original wordings in the manuscript as well as the existence of Section 3 had clearly led to the mentioned misunderstanding. Concerning the existence of Section 3, given that the "new" scheme we implemented is actually not new, one may wonder why then we have this Section at all. Our motivation for Section 3 comes from the request within the scientific modeling community to document the parameterizations used in the global models, against common benchmarks (the GRIPS and CCMVal efforts mentioned in the Introduction, second paragraph). Therefore, we

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

EGU

though useful to compare the SW4 and SW6 schemes with the LBL results, although for the full validation of both schemes we refer (and do not need to redo) to the work of Morcrette and Collaborators. Indeed, our comparisons with the LBL reproduce and confirm the earlier work of Morcrette and Collaborators, adding more information to the robustness of models in the stratosphere.

We agree, however, with the Referee that we should have performed a more thorough validation in Section 3. Therefore, we have acted following the Referee's remarks. We have performed the requested additional tests, using the same spectral interval for SW6 and the LBL and modified the text in various places, as detailed below. The new results have been included in Figure 1 and a new Figure 2. Text has also been modified to answer the specific points.

Response to points in general comment:

1. Daily averaged heating rates and O3 profiles: The discussion and the revised Figure 1 are now based on daily averaged heating rates for three different cases: Mid-Latitude Summer, Mid-Latitude Winter and Tropics. Section 3 rewritten.

2. Spectral ranges: The spectral range of the LBL model has been adapted to the spectral range of the SW6 scheme. The heating rates are now computed from the LBL fluxes for the SW6 range spectral interval (185-4000 nm). The original choice of the spectral range used in SW4 and SW6, which is used as given in this study, reflects a compromise between computational efficiency in the major applications: numerical weather prediction (e.g. at ECMWF) and climate research, and accuracy with respect to other error sources.

3. Heating by O2: Including the 185-200 nm range in the LBL has changed the difference in the heating rate between SW6 and LBL above 0.3 hPa confirming the role of O2 heating in the mesosphere. The SW6 scheme neglects the Schumann-Runge bands and continuum. The main improvement of the SW6 scheme compared to SW4 is the full representation of the heating by the ozone Hartley bands, the main heating

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

source in the stratosphere. The SW4 scheme covers the Hartley bands only for wavelengths larger than 250 nm. Hence the compromises accepted in the design of the SW6 scheme fit to the general design of the MAECHAM5 GCM, which is constructed for troposphere-stratosphere applications. The revised Figure 1 shows indeed a tendency towards an underestimation of the heating rates in SW6 compared to LBL above 0.3 hPa.

Of course we agree that O2 heating is essential for the representation of the mesosphere. However, a proper treatment of the mesosphere would need a model with a top well above 0.01 hPa, as for instance the HAMMONIA model, which includes also chemistry as a prerequisite to model realistically the mesosphere and mesopause region. Other non-LTE considerations also come into play, which this paper does not assess. (See also answer to 1st specific point of Referee 2)

Response to specific comments:

p. 11072, L22-23:

We have changed the spectral range of the LBL to replicate the range of the SW6 scheme. See also response 2 above. Note also that it is not our interest to validate the SW4, which is shown only to demonstrate the effects of the change to SW6. The comparison between the SW4 and SW6 is of interest because they are both used in general circulation models, and because the coarse representation of UV/visible heating in SW4 is the "suspect" for temperature biases in existing MAECHAM simulations. In this way, it is possible to make the connection between the difference in the offline diagnosed heating rates and their impact on the mean temperature field when the schemes are used online.

p. 11073, L1:

The radiation parameterizations are approximations of the radiative transfer and are commonly much coarser than LBLs. Therefore, in the SW6 parameterization the range

185-4000 nm does represent the limits of the total solar irradiance. Respectively, 250-4000 nm represents the limits of the total solar irradiance for the SW4 parameterization. In the general circulation model, the solar constant is set to 1370 Wm-2: This means that both the CTRL and EXP simulation use the same solar constant also if the spectral ranges of the respective shortwave radiation parameterizations are different. Of course the total solar irradiation and its spectral distribution depend on the phase of the solar cycle, and have uncertainties associated with them.

In the offline comparison of the radiation schemes, the solar "constant" is set to the integral of the spectral solar extraterrestrial irradiance over the 185-4000 nm wavelength domain of the LBL and SW6 models. Assuming a total integral of 1370 W/m2, the integral over 185-4000 nm amounts to 1357 W/m2. Each radiation model therefore employs 1357 W/m2 over its employed wavelength range. Text is added to explain this.

The flux at the model top is divided between the different spectral bands in the following way:

SW4: 250-690nm(45.976 %), 690-1190nm(32.6158 %), 1190-2380nm(18.0608 %), 2380-4000nm(33.474 %).

SW6: 185-250nm(0.1917 %), 250-440nm(13.5708 %), 440-690nm(32.2135 %), 690-1190nm(32.6158 %), 1190-2380nm(18.0608 %), 2380-4000nm(33.474 %).

p. 11074, L5-6: Text describing figure 2 has been rewritten:

p. 11074, L12-13: The text has been modified.

p. 11074, L10-19:

Yes, the top of the model is at 0.01 hPa. However, it is not the scope of the MAECHAM5 model to simulate the mesosphere. The purpose of the MAECHAM5 model is to simulate the troposphere - stratosphere system, namely the part of the atmosphere from the surface to 1 hPa. The mesosphere is a buffer zone for the model. To properly resolve the mesosphere, it would be necessary to resolve the model atmosphere to much

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

lower pressure values. Such an extension based on the MAECHAM5 model already exists, the HAMMONIA model of Schmidt et al. (2006). Its computational costs are, however, much higher due to the detailed parameterization of physical (for instance, radiation down to 105 nm) and chemical processes necessary for the mesosphere and lower thermosphere, so that the MAECHAM5 model is more appropriate for many applications. Note that the need for computational efficiency is also the reasons why we have undertaken a relatively modest modification of the radiation parameterization. In addition, the mesosphere is a region, where the temperature distribution is dominated by gravity wave processes; see for instance Manzini and McFarlane (1998) for such variations in the precursor of the current model.

The model temperature bias is shown in Figure 5 (former 4), because the aim of our work being to improve the summer temperature bias close to the stratopause. Note also that analysis data do have differences between themselves in the stratosphere (Randel et al 2004). We have chosen the NCEPCPC data for consistency with Manzini and McFarlane (1998), where the model temperature bias at 1 hPa in the summer polar latitude was found to be insensitive to changes in the gravity wave parameterization.

p. 11074, L20:

The upper boundary of NCEPCPC is 0.4 hPa. Also, the NCEPCPC data in the stratosphere are objective analysis (Randel et al 2004). Therefore they can be trusted up to 1 hPa.

p. 11074, L20-21: Corrected, thank you.

p. 11075, L5-6: Corrected, thank you.

p. 11075, L7: Text removed, not essential.

p. 11076, L7-8: Removed, thank you.

p. 11076, L21-22:

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

EGU

"to facilitate" means "to make easy", or, more technically in the current context "to enhance".

Yes, the zonal mean zonal wind differences indicate stronger jets in the middle atmosphere: the direct radiative response. The secondary response we are discussing now does not necessarily have to dominate in the wind difference (indeed, it does not), but it is consistent with the decrease in the difference in the zonal mean zonal winds in the mesosphere (all seasons, Figure 6 and 7, former 5 and 6, respectively).

p. 11078, L4: Text removed, thank you.

p. 11078, L7: Corrected, thank you.

p. 11078, L9: Corrected, thank you.

p. 11078, L21:

Clarified and rewritten because of the new results reported in Section 3. The main conclusion is unchanged.

P. 11080, L7-9:

The set of experiments used in this paper has specified sea surface and sea ice distributions. Therefore the lower troposphere temperature is by and large defined by the lower boundary conditions. This restriction, however, does not exist in a coupled atmosphere ocean system. Changing the radiative balance necessarily leads to a response also in the lower troposphere and in the sea surface temperatures. Coupled atmosphere ocean models, as for example ECHAM5/MPIOM (Jungclaus et al 2006), show indeed a clear sensitivity to changes in the radiative balance. Text slightly modified to improve clarity.

19) p. 11084, Table 1:

This table summarizes the bands and absorbers represented in SW4 and SW6. As outlined above, the O_2 heating by Schumann-Runge bands and continuum is neglected

in these schemes.

Response to technical and typographical correction:

We thank the referee for detecting misspelling and typos: all corrections done and spell-checker run.

Concerning the labels, our original figures do have a large size of the labels: The figures were reduced for fitting into the portrait ACPD format. For the manuscript version for ACP, we ask the production please not to unrealistically reduce our figures.

Concerning some misspelling, for instance "he" instead of "the", we would like to point out to the Editor that these have been created by the ACPD automatic checking, given that we submitted a correct spelling.

p. 11068, L12: Corrected

p. 11069, L20: Re-phrased.

p. 11069, L25: Corrected.

p. 11070, L11: Corrected.

p. 11071, L13: Corrected

p. 11069, L20: Corrected

p. 11071, L21: Corrected.

Note, however, that the MAECHAM5 model includes the entire mass of the atmosphere. The upper boundary of the uppermost layer is defined by p =0 hPa. Hence, concerning mass, the top of the atmosphere is also the top of the model, though the model cannot represent vertical structures above 0.01 hPa, which is the pressure center of the uppermost layer. The revised manuscript makes now use of TOM instead of TOA.

p. 11071, L24: Corrected

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

EGU

p. 11072, L11: Text modified.

p. 11073, L10: Text modified (Section rewritten).

p. 11073, L22-24: Removed

p. 11075, L3: Text modified.

p. 11075, L20: Corrected.

p. 11075, L22: Corrected.

p. 11076, L17: Fig. 5: Corrected

p. 11077, L1-2: Corrected.

p. 11078, L3: Corrected.

p. 11079, L2: Corrected.

p. 11079, L27: Corrected.

p. 11080, L6: Corrected.

p. 11088, Fig. 2: Corrected.

p. 11088, Fig. 3: Corrected

p. 11089-1092, Corrected.

p. 11090, Fig. 5 caption: No. corrected.

p. 11090, Fig 5 caption: Removed.

p. 11091, Fig 6: Corrected

p. 11091, Fig 7: Corrected

References:

Jungclaus, J., and Coauthors, 2006: Ocean circulation and tropical variability in the

coupled model ECHAM5/MPI-OM. J. Climate, 19, 3952-3972.

Randel, W., and Coauthors, 2004: The SPARC intercomparison of middle atmosphere climatologies. J. Climate, 17, 986-1003.

Schmidt, H., and Coauthors, 2006: The HAMMONIA chemistry climate model: Sensitivity of the mesopause region to the 11- year solar cycle and CO2 doubling. J. Climate, 19, 3903-3931.

Reply to Referee 2

Concerning the offline validation, please see the answers to the general comments of referee 1. In summary: we have performed all the calculation requested and rewritten Section 3. The conclusions of our work are unchanged.

Response to specific comments:

More bands and issue talked:

Obviously it is desirable to represent the radiative heating in atmospheric GCMs as accurately as possible. Higher spectral resolution and/or extension of the spectral range are ways to achieve this aim, though other factors must also be considered:

- The success of efficient radiative transfer schemes depends not only on the spectral resolution, but also on the method applied in the scheme to approximate the extinction within a band. - Heating in the stratosphere depends also on the treatment of scattering. Scattering by variable clouds and aerosols in the troposphere, or Rayleigh scattering or episodic volcanic aerosol layers in the lower stratosphere are important for the O3 radiative effects. - Heating depends on the distribution of the absorbers. While the use of climatologies for O3 is a reasonable choice for many studies focusing on the troposphere and stratosphere, it is important to introduce coupled atmospheric chemistry for investigations of the mesosphere or higher layers, including also chemical heating, or for investigations where the ozone variations are important within the stratosphere as for example in studies of the effects of the ozone hole on the dynamics

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

EGU

and vice versa.

Introducing more accurate schemes increases computational costs - sometimes drastically. Therefore the construction of a GCM is always a compromise between accuracy in representation of the dynamics and the driving processes, and the necessity to apply the model with given resources. Furthermore it is important to realize that the overall model performance depends on the combined forcing of all processes included in the model. Hence, a scheme should be as cheap as possible in relation to its contribution to the overall model biases, in order to maximize the use of the model.

The SW6 scheme is an improvement over the SW4 scheme for MAECHAM5 applications for the investigation of the stratosphere troposphere system, as for instance the evolution of the ozone layer and the dynamical coupling between the troposphere and the stratosphere. But there are topics for which neither the SW6 scheme nor this GCM are appropriate. An example is the investigation of solar cycle effects. In this case it is indeed important to include a wider and better resolved spectrum, as it is important to consider atmospheric chemistry. An example of a model developed for this purpose is the HAMMONIA whole atmosphere model (Schmidt et al., 2006), which is based on MAECHAM5 and resolves the atmosphere up to the lower thermosphere.

In conclusion, it is very desirable, over time, to improve the radiation schemes as well as other parameterizations. For the radiation scheme the historical development generally shows an increase in the number of bands as computing power is increasing.

Physical explanation:

The SW6 scheme (3 bands in 185-690 nm) includes the heating by the complete Hartley and Huggins bands and the Chappuis bands. The strong Hartley bands were only partly covered by the SW4 scheme, which ends at 250 nm near the maximum of the absorption cross section of the Hartley bands. Therefore the SW6 scheme is better suited to represent ozone absorption leading to increased heating rates in the ozone layer. Furthermore, the resolution of the UV and visible into three bands allows a better

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

EGU

representation of the very different absorption cross sections of O3 across the Hartley to Chappuis bands, which is difficult within the single UV-visible band of the SW4 scheme.

Response to technical comments

The number acronyms have been reduced and spelling corrected.

Reference

Schmidt, H., and Coauthors, 2006: The HAMMONIA chemistry climate model: Sensitivity of the mesopause region to the 11- year solar cycle and CO2 doubling. J. Climate, 19, 3903-3931.

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

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

EGU