**Atmospheric
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Discussions

Interactive comment on "Analysis of the ozone profile specifications in the WRF-ARW model and their impact on the simulation of direct solar radiation" *by* A. Montornès et al.

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Response to "Referee Comment for ACP Manuscript acp-2014-143", Anonymous Referee #2

We are thankful to Anonymous Referee #2 for his suggestions, comments and ideas. Without any doubt whatsoever, all of them are valuable to improve the quality of our work. In the current document, we will answer each one with more emphasis to those considerations that deal with technical or scientific considerations than those related to the language aspects.

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The paper entitled *Analysis of the ozone profile specifications in the WRF-ARW model and their impact on the simulation of direct solar radiation* was published in the Atmospheric Chemistry and Physics Discussion in 6th August 2014. During the Open Discussion period, the paper was reviewed by two anonymous referees.

The first review was received in 29th August 2014 by the Anonymous Referee #2 while the second one was published in 3rd August 2014 by the Anonymous Referee #1. We have decided to give a personalized response to each referee. However, some points are common for both or they have a full impact to the entire paper. For this reason, we will present firstly a common block and then we will discuss each review point by point. Hereinafter, we will use R#1 and R#2 such as Referee #1 and #2, respectively.

In order to contextualize the response, the referee's commentary appears before our answer. Each review is quoted in gray. Our response appears with **A:** (from Authors) at the beginning and in black color. Each one is identified with a label composed with a number and a tag: GC (General Comments) and SC (Specific Comments). For example, SC4 refers to the 4th specific comment. During the discussion, the reader can find some cross-references between responses for R#1 and R#2. For example, **SC7 R#1** means the 7th specific comment of R#1.

Some of the answers are also aimed to the Editor. These responses are: **GC4 R#1**, **SC4 R#1**, **SC8 R#1**, **GC4 R#2**, **SC10 R#2** and **SC67 R#2**.

Regarding the submission of revised manuscript, we wait to the final Editor's decision. At that moment, we will finish the last modifications and updates and we will submit the new version.

Common comments

By our understanding, both referees agree that the first part is interesting but they have doubts regarding if the second one was addressed correctly. Nevertheless, they

diverge on the reasons and the solutions about that. In short, R#1's opinion is that we are analyzing the absorption instead of the direct flux whereas R#2's perspective is that a full WRF simulation (at the least for one time step) could address better the discussion.

A further discussion about these considerations is presented in the following points: **GC1 R#1**, **SC7 R#1**, **SC8 R#1**, **GC1 R#2** and **SC35 R#2**.

Introduction

We have concluded that we can improve the introduction in two aspects: i) a better contextualization of the interest of the paper and ii) a better explanation of the presented ideas.

Further information is presented in **SC4 R#2** and **GC1 R#1**.

Methodology

Based on the ideas from both referees, we propose a set of updates in the methodology in order to increase the scientific significance of the results. Two of them have an important impact in the paper structure and the others introduce small improvements or clarifications in the current text. Through the following paragraphs, we will present a small overview of these modifications. You can find further details in the full text at the particular responses (referred in the following explanation).

In his review, R#2 suggested that excluding the GFDL scheme from the analysis deprives the readers from the opportunity to understand its accuracy relative to the other methods (see **SC12 R#2**). We agree about this consideration and we have decided to add this parameterization to the discussion, thus giving a global vision of WRF. As a consequence, we propose to add some changes on section 2 (providing further details

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about this parameterization), on sections 3 and 4 (adding this scheme to the discussion) and on the figures (adding the respective maps).

On the other hand, from the commentaries of R#1 (see **GC1 R#1** and **GC2 R#1**), we have concluded that we could show and discuss the vertical profiles provided by each scheme. Moreover, this discussion could be linked with the current results and conclusions. As we understand it, this small study could be interesting to the scientific community as well as for the WRF users because it is missing in the state-of-the-art.

Results

After reading the review from R#1, we have concluded that the used metrics are useless for a good paper understanding (see **GC4 R#1** and **SC8 R#1**). We would like to improve this point.

In the first part (sections 2.2 and 3.1), our discussion was based on the relative error (equation 5 in the paper) without including any figure as a baseline (e.g. monthly maps for the MSR data-sets). We concluded that this way of showing the results is useless if the reader does not have a background about the ozone spatial and seasonal distributions. In order to correct this point, without adding new figures, we propose to replace the relative error by the bias (in Dobsons). As a consequence, equation 5 in the paper, section 3.1, Conclusions and Figures 1 and 2 must be updated accordingly.

In the second part (sections 2.3 and 3.2), we computed the bias in the ozone absorption (equation 22 in the paper) normalized with respect to the radiation at the top of the atmosphere. As a result, we compared two percentages and we lost the physical sense of the results. To improve this point, we propose to show the results as W m^{-2} multiplying the previous results by the incoming radiation at the top of the atmosphere. Sections 2.3 and 3.2, Conclusions and Figure 3 must be updated accordingly.

Figures

Both referees noted that the quality of the images could be improved. We agree about these considerations. The original figures were created using the R language. We have been testing the NCAR Command Language and it clearly improves the quality of the results. We would like to improve all figures (map size, mosaic distribution, color palette and labels).

In order to avoid a larger document, we save the new figures until the final revision of the paper. Please, contact with us if you need further details, and we will provide them.

Response to general comments

GC1 R#2: This paper describes the specification of ozone profiles used within most of the WRF-ARW radiation options, compares these to the MSR total ozone dataset, and reviews the impact of the differing ozone amounts on the calculation of the direct solar radiation in two of the WRF radiation options. The first part of the analysis, which compares the various WRF ozone specifications to the MSR data, is a very useful demonstration of the degree to which the ozone concentrations vary spatially and temporally among the radiation codes. While the worthwhile goal of the second part of the analysis is to illustrate the isolated impact of the ozone differences using a consistent, if simplified, radiative transfer method, this result does not relate directly to how the ozone variations contribute to actual radiation calculations within WRF. The paper would be more useful to the WRF user community if the authors added an analysis using one or more of the WRF radiation codes so that the full complexity of the radiative processes involved were represented. For example, the two models applied in the second part could be run within WRF for a single time step for some region or globally. In different experiments, each radiation code could be run with its own ozone specifi-

cation and then run again with the ozone concentration from the other radiation code. This might be an insightful way to demonstrate the impact of the ozone changes within the context of actual WRF calculations.

A: As we understand it, full WRF simulations are not necessary in the second part of the paper (this answer links with point **SC35 R#2**). We will argue this idea through the following lines.

The general approach in all the radiative codes is to assume independent columns at each grid-point. In brief, the upward and downward solar fluxes are solved at each column considering the vertical profile information provided by the model (e.g. air density, water vapor or hydrometeors) and a set of auxiliary information that is not explicitly solved by the NWP model such as the ozone or the other trace gases (e.g. oxygen, carbon dioxide). Forgetting Dudhia's parameterization that is a special case, the downward component is split in two contributions: direct and diffuse. The first component is solved by using the Beer-Lambert law, while the diffuse contribution requires solving the radiative transfer equation (RTE) assuming different approximations.

Given one wavelength interval, two variables are necessary to solve the Beer-Lambert law: the optical thickness and the cosine of the solar zenith angle. The first one is a function of the absorption/extinction coefficient (intrinsic magnitude of the material) and the mass amount traversed by the solar beam. The second one is a result of positional astronomy.

The RTE is solved in terms of the same variables, the single scattering albedo and the asymmetry factor. Both last describe how the light is scattered.

In the atmosphere, there are many elements that contribute to the absorption and the scattering processes (e.g. ozone and water vapor absorption or the molecular scattering among others). Thus, the total optical thickness, τ_t, the total single scattering albedo, ω_{0t}, and the total asymmetry factor, g_t, are a function of those contributions.

As a first order approximation (widely used in the radiative codes), we can assume that all these contributions are independent one another. Following this assumption, the radiative variables may be split as the sum of contributions as

$$\tau_t = \sum^N \tau_i,\tag{1}$$

$$\omega_{0t} = \sum^N \omega_{0i},\tag{2}$$

$$g_t = \sum^N g_i,\tag{3}$$

where N is the number of elements (e.g. ozone, aerosols, ice crystals, molecular scattering, water vapor, etc).

In virtue of the exponential form of the Beer-Lambert law, the total transmission of the direct beam through a layer is the product of each contribution. Thus, each one of them can be analyzed independently and we can consider the ozone impact without the other elements.

Regarding the diffuse component in the ozone's case, the radiative parameterizations do not consider explicitly this gas as an scatter element (i.e. ω_{O3} = 0 and g_{O3}=1). The molecular scattering of ozone molecules is parameterized in the Rayleigh scattering term without any differentiation of the gas species. Therefore, the ozone profile is useless in that computation and it can be omitted for the purposes of this paper.

The idea of this reviewer related on real WRF simulations is interesting but the analysis of the problem becomes more complex. In a real simulation, new sources of error are overlapped due to the number of vertical levels, the distribution of the ETA levels and

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the top of the model. Vertical ozone profiles are interpolated to the domain's ETA levels, thus the ozone information can be smoothed of even lost. Moreover, the radiative codes approximate the atmosphere composition between the top of the model and the top of the atmosphere (TOA) losing the details in those layers.

Moreover, real simulations add a part of particularism (region, domain settings, etc) that was not desired in our work.

Although the regional particularism could be solved using global simulations (see **SC35 R#2**), this part of the code is not commonly-used and it must be used with caution as it is indicated in the User's Guide:

> Note: since this is not a commonly-used configuration in the model, use it with caution. Not all physics and diffusion options have been tested with it, and some options may not work well with polar filters. Also, positive-definite and monotonic advection options do not work with polar filters in a global run because polar filters can generate negative values of scalars. This implies, too, that WRF-Chem cannot be run with positive-definite and monotonic options in a global WRF setup.

Therefore, we think that the derived conclusions could be useless for the scientific community because we could not be sure about the output reliability.

Concluding, we believe that the proposed methodology is valid because

- We reduce a complex problem in a simpler one based on well supported physics.

- The ozone absorption is independent of the other physical processes.

- We are rigorous and transparent in the derivation of the equations.

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- The results are useful as a baseline to quantify the impact of the ozone profile simplifications on the direct flux computation.

- The results and conclusions are general.

However, as a self-criticism this part of the paper should be better explained and contextualized.

GC2 R#2: Furthermore, from this reviewer's perspective, the differing specification of trace gas amounts within each radiation option is a fundamental flaw in the design of WRF-ARW itself rather than the radiation codes. These quantities should be provided to each radiation option in a consistent and sufficiently detailed manner from the host model, rather than be defined haphazardly as presently done. In some cases the radiation codes were extracted from other global models, which define their own ozone specification, while in other cases the radiation codes were provided for WRF independently of any existing dynamical model and without a pre-defined ozone specification. The authors are encouraged to consider addressing this perspective by using this paper not simply to compare the various ozone approaches but to provide guidance to the community on a better way forward; that is, to provide evidence for the advantages of improving WRF by adopting a unified and accurate approach to atmospheric specification for all of the radiation options.

A: We agree about these ideas. When somebody start to work with the source code, the first difficulties appear. The most relevant is in the nomenclature. In general, each scheme uses a different nomenclature to refer to the same physical magnitudes (e.g. temperature, pressure, height, ozone, absorption coefficient, etc). As a consequence, the time to work with the codes increases because each one requires starting from zero.

Linked with this, another incoherence is in the physical constants. All these magnitudes are defined in the module share/module_model_constants.F. Nevertheless, these vari-

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ables are redefined with other names in each code.

Moreover, some processes are similar for all the schemes (e.g. prepare the vertical profiles). All of the common processes could be shared using new subroutines or they could be run in the module_radiation_driver.F and shared as input arguments.

Furthermore, there are more physical differences similar to the ozone profile. For example, the carbon dioxide concentration.

In our opinion, this makes more difficult read the source code and it increases the sources of bugs. However, we understand that it is difficult to deal with the code structure and with the outside contributions.

We will put an emphasis on these issues.

GC3 R#2: From a technical writing standpoint, the manuscript contains numerous grammatical difficulties and unclear sentences that are specified in the detailed comments along with suggested improvements.

A: We have improved all those issues.

GC4 R#2: It is also suggested that the current three figures be separated into five figures. It is recommended that publication of the paper be reconsidered after major revisions to the manuscript are completed.

A: We agree with the point of view of this referee. However, we will wait for the Editor's decision. This response is linked to points **SC67 R#2**, **SC68 R#2** and **SC9 R#1**.

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Response to specific comments

Abstract

SC1 R#2: Page 20232, Line 12: The phrase "ozone modeling" suggests a more so-phisticated approach than what is described in the paper; the phrase "ozone profile" is recommended.

A: We agree that "ozone modeling" is not correct in this context. However, we prefer to use "ozone profile specifications" in this case.

Introduction

SC2 R#2: Page 20232, Line 23: The first sentence of the Introduction uses a some-what awkward analogy. The shortwave absorption is more the "fuel" than the "engine". A better start may be "The absorption of shortwave radiation by the surface and atmo-sphere is the primary source of energy that drives the atmospheric system."

A: We agree that the analogy is not suitable and the language was misused. Never-theless, we do not fully agree with this proposal because it seems that the "absorption of shortwave radiation" is the unique source of energy. This is not really true because both terrestrial and solar radiation have this role.

This sentence has been updated as:

The radiative transfer is the primary physical process that drives the atmospheric cir-culation.

SC3 R#2: Page 20233, Line 2: Specify the peak level of ozone heating in the strato-sphere. The authors might also specify here the top pressure level required to simulate the stratospheric ozone heating effectively.

SC4 R#2: Page 20233, Line 24: The phrase "defining a region denoted by ozone layer" is unclear and should be reworded.

A: We agree about these considerations and we have concluded that some parts of the introduction are shallow. For this reason, we propose rewording this part.

We add a draft version:

Water vapor is an atmospheric gas mainly found in the troposphere which concentration decreases with altitude because water sources are found on the surface. The water vapor absorption in the shortwave region occurs in spectral bands of the near-infrared (near-IR) from 700 to 4000 nm. Below 10 km, the solar energy absorbed by water vapor produces a heating rate ranging from 0.5 to 2 K day^{-1}.

In contrast, ozone is located in two atmospheric regions with a different impact on the radiative transfer. Most ozone ($\sim$90%) is located in the stratosphere. The region with the highest ozone concentration is commonly denoted as ozone layer and it is found between about 10 and 50 km above the surface. The remaining ozone ($\sim$10%) is found in the troposphere. The highest values in this layer are located near the surface as a consequence of human activities.

The absorption of ozone in the solar spectral region occurs in three spectral bands: Hartley, Huggins and Chappuis. The Hartley bands are the strongest covering the ultraviolet (UV) from 200 to 300 nm. This absorption of solar flux is located primarily in the upper stratosphere and in the mesosphere. The other two bands are weaker. The Huggins bands appear in a UV region from 300 to 360 nm. Energy absorption in this spectral range occurs in the lower stratosphere and in the troposphere. Finally, the Chappius bands cover the photosynthetic active region (PAR) and the near-IR from

400 to 850 nm. The absorption by the Chappius bands is mainly located in the troposphere.

The absorption of solar flux produced by ozone yields to a heating rate ranging from 10 to 30 K day^{-1} in the stratosphere. This absorbed energy is an important physical process in maintaining stratospheric thermal structure.

Stratospheric ozone is continuously created and destroyed by photochemical processes associated with solar UV radiation. Due to the annual solar variation as well as the Earth's sphericity, significant latitudinal and seasonal variations on the ozone distribution are observed. Since the tropics receive more insolation than the poles, those processes result in an ozone source in the tropics and a net poleward transport due to the large-scale air circulation in the stratosphere referred to the Brewer–Dobson circulation. Consequently, the ozone layer in the tropics is thinner than at middle and higher latitudes where ozone is accumulated, increasing the thickness and, thus, total ozone amount.

Seasonally, the total ozone in the tropics shows smaller variations than in the polar regions. The total ozone is maximum at high latitudes after the polar night because the ozone transport due to the Brewer–Dobson circulation is maximum during late fall and winter. In contrast, this circulation is weaker during the summer and early fall, more in the Southern Hemisphere than in the Northern. In polar summer, when daylight is continuous, total ozone decreases gradually reaching the lowest value in early fall. This process is known as ozone depletion. Nevertheless, in the Antarctica, an important minimum is observed during the spring (September - October) as a result of the ozone hole described by the chemical ozone destruction by other substances.

SC5 R#2: Page 20234, Line 1: Replace "These results. . ." with "This results. . ."

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A: We apologize for this grammatical error. It has been replaced.

SC6 R#2: Page 20234, Line 6: If the intended meaning of this phrase is ". . .an analysis of the uncertainties associated with the computation of the direct solar radiation" then reword accordingly, otherwise clarify.

A: We agree about this consideration. We have reworded accordingly.

SC7 R#2: Page 20234, Line 14: Replace "error over the direct" with "error on the direct"

A: We have corrected this error.

SC8 R#2: Page 20234, Line 15: Replace "composed only by ozone" with "composed only of ozone"

A: We have replaced it.

SC9 R#2: Page 20234, Line 16: Replace "is centered in" with "focuses on"

A: The proposed word is better than our. The paper has been updated.

SC10 R#2: Page 20234, Line 20: The footnote on this page might be more appropriately added to the acknowledgments, but this is a point to take up with the editor.

A: We agree with you. However, we will wait to the Editor's decision.

Methodology

SC11 R#2: Page 20235, Line 15: It might be clearer to reword this sentences as ". . .neglect the pressure and temperature (i.e. height) dependence of the ozone absorption. . ."

A: This sentence has been reworded accordingly.

SC12 R#2: Page 20236, Line 8-9: Excluding the GFDL shortwave code from the

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A: We agree about this reviewer's suggestion and we have been working to include this parameterization in the discussion.

As a consequence, we need to update some parts of the paper:

- After reading in depth the source code, we have improved our knowledge about the ozone treatment in this radiation scheme. Therefore, we can improve the description of section 2.1.

- Following the same procedure that was described in section 2.2, we can include the analysis of the errors in the total ozone column.

- Finally, this scheme can be added in the analysis presented in section 2.3. However, this scheme does not consider the Beer-Lambert law and it computes the ozone absorption following an empirical relationship proposed by Lacis and Hansen (1974). We include a draft version of this part here:

The aforementioned procedure can not be applied to GFDL because this scheme does not considers the Beer's Law. Following the expressions proposed by Lacis and Hansen (1974), the ozone absorption is computed as

$$A_{o3}^{uv}(x) = \frac{1.082x}{(1 + 138.6x)^{0.805}} + \frac{0.0658x}{1 + (103.6x)^3} \qquad (4)$$

in the UV spectral region, and

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$$A_{o3}^{vis}(x) = \frac{0.02118x}{1 + 0.042x + 0.000323x^2} \tag{5}$$

in the PAR region.

In equations 4 and 5, x is defined as the ozone amount u_{O3} traversed by the solar beam in a defined layer as

$$x = u_{O3}M, \tag{6}$$

where M is denoted as the magnification factor proposed by Rodgers (1979) as

$$M = \frac{135}{(1224\mu_0^2 + 1)(1/2)}. \tag{7}$$

Therefore, considering the UV and PAR bands as a single one, the total absorption is

$$A(x) = A_{o3}^{uv}(x) + A_{o3}^{par}(x). \tag{8}$$

Note that if we consider the entire atmosphere, u_{O3} it is directly $TO3$ as in the aforesaid schemes.

In order to avoid a large document, we keep the analysis, the discussion and the conclusions related to this parameterization to the revised version.

Lacis, A. A. and Hansen, J.: A parameterization for the absorption of solar radiation in the Earth's atmosphere, J. Atmos. Sci., 31, 118–133, 1974.

Rodgers, C. and Dickinson, R. E.: The radiative heat budget of the troposphere and lower stratosphere, Planetary Circulation Project, Rep, A2, 1967.

SC13 R#2: Page 20236, Line 10: The WRF-ARW user's guide lists the reference for the original Goddard scheme as Chou and Suarez (NASA, 1994), for the GFDL SW model as Fels and Schwarzkopf (JGR, 1981), and for RRTMG_SW as Iacono et al. (JGR, 2008).

A: We chose these references because we considered that they were representative of the approximations used in each scheme. However, we agree that it is better to use the references listed in the WRF-ARW User's Guide. They have been updated.

This review is linked with **SC3 R#1**.

SC14 R#2: Page 20236, Line 12: This reviewer's understanding of the RRTMG_SW code is that the number of sub-intervals (i.e. quadrature points) used to integrate the k-distributions in each spectral band is variable among the fourteen bands, not fixed at 16, and totals 112. This is a time saving feature of that code relative to the RRTM_SW model, which does use a fixed set of 16 quadrature points in each spectral band for a total of 224.

A: We agree about this consideration. We tried to give a simple description of the scheme but the result was a simplistic and inaccurate view. This part will be improved.

SC15 R#2: Page 20237, Line 4: Replace "81th" with "81st"

A: It has been updated.

SC16 R#2: Page 20237, Line 6: The phrase "In the first part" is vague. Please clarify.

A: We agree with you that it is not clear. It has been replaced as "In section 3.1,"

SC17 R#2: Page 20237, Line 10: Replace "composed by 37 levels" with "defined at 37 levels"

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A: It has been replaced.

SC18 R#2: Page 20237, Line 20: Replace "cover" with "covers"

A: It has been replaced.

SC19 R#2: Page 20237, Line 25: A better word than "assigned" in this sentence would be "distributed"

A: It has been updated accordingly.

SC20 R#2: Page 20238, Line 3: Add "with" before "respect"

A: It has been updated.

SC21 R#2: Page 20238, Line 12: This sentence has to be reworded. The phrase ". . .individual gas species loss progressively the hydrostatic equilibrium. . ." doesn't communicate the intended meaning.

A: This sentence has been reworded.

SC22 R#2: Page 20238, Line 16: Reword the end of this sentence to read ". . .and are monotonically decreasing"

A: It has been updated.

SC23 R#2: Page 20238, Line 19: Reword "Because of available ozone profiles. . ." as "Because the available ozone profiles. . ."

A: It has been reworded.

SC24 R#2: Page 20239, Line 6: Change "pressure at surface" to "surface pressure"
SC25 R#2: Page 20239, Line 7: Change "pressure at surface" to "surface pressure"

A: Both have been replaced.

SC26 R#2: Page 20239, Line 8: Suggest rewording ". . .shows a dependence on the location and the season" as "varies by location and season"

A: Your suggestion sounds better than our sentence. We have reworded following your idea.

SC27 R#2: Page 20239, Line 10: Change "since" to 'from", and change "has been consistent" to "is consistent"

A: They have been updated.

SC28 R#2: Page 20239, Line 15: Suggest rewording "To discuss about the geographical. . ." to "To quantify the geographical. . ."

A: It has been updated.

SC29 R#2: Page 20239, Line 17: Suggest rewording "For the discussion about the seasonal. . ." to "In order to examine the seasonal. . ."

A: We have updated this sentence.

SC30 R#2: Page 20239, Line 20: Replace "situations" with "situation"

A: We have update this grammatical error.

SC31 R#2: Page 20239, Line 20: Suggest replacing "summarized" with "identified"

A: We agree with your suggestion.

SC32 R#2: Page 20240, Line 16: The phrase "leading a quantification about the error" is unclear and should be rewritten.

A: This part has been rewritten.

SC33 R#2: Page 20240, Line 18: Equation (5) suggests that the resulting error term on the left hand side is a function of ozone method in addition to the spatial dimensions.

A: Your are right, the nomenclature was not well defined. Equation 5 in the paper has been updated.

SC34 R#2: Page 20240, Line 23: Replace "previous" with "previously"

A: It has been updated.

SC35 R#2: Page 20240, Line 25: While it's insightful to examine the ozone method of each radiation model using a similar, simplified radiative method as described in Section 2.3, it isn't clear how this result relates to the effectiveness of each model to simulate the radiative effects of ozone within WRF. For example, are the differences in the ozone absorption related to the radiative transfer method used by each model larger, smaller or comparable to the differences caused by the ozone specification? Perhaps global calculations for a single time step with each radiation model (or at least New-Goddard and CAM) using its own ozone specification and the ozone specification of the other model would also be insightful.

A: In virtue of the Beer-Lambert law, we can analyze the ozone contribution independently of the others (see **GC1 R#2**). Moreover, real model simulations introduce other sources of error and some particularisms that were not desired for the purposes of our study.

We understand your concern when you say that it is unclear how the presented results relate to the effectiveness of each scheme to simulate the radiative effects of ozone within WRF. Nevertheless, note that, given one scheme (e.g. New Goddard), we compare two scheme outcomes (equation 22 in the paper). Variables $A_{sch,ij}(m)$ and $A_{MSR,ij}(m)$ are computed using equation 21 where $W(\lambda)$ and k_λ are provided by the scheme and TO_3 is the total ozone using the scheme ozone data and the MSR dataset, respectively.

Therefore, we intrinsically did your proposal but using the MSR as a baseline instead of permuting all the ozone datasets.

From our perspective, this is a valid procedure because the MSR dataset has been accepted by the scientific community whereas the ozone profiles in WRF do not appear

in the literature and they have not been validated until our work.

In our opinion, we can include a discussion about the effectiveness of each model to simulate the radiative effects of ozone within WRF using the MSR outcomes as a baseline (i.e. $A_{MSR,ij}(m)$ from New Goddard and $A_{MSR,ij}(m)$ for CAM). This new discussion could be valuable for the readers and it is in the line of your suggestion. These considerations link with **GC2 R#1**.

SC36 R#2: Page 20241, Line 3: Replace "we" with "be"

A: It is a typing error. It has been updated.

SC37 R#2: Page 20241, Line 6: Reword the phrase "discussed by many literature such as"

A: The sentence has been reworded.

SC38 R#2: Page 20242, Line 3: The provided definition of W(λ) is unclear. Is this the ratio of the energy in a band dλ to the total integrated energy?

A: Yes, it is. We have tried to clarify the definition of W(λ) writing the equation explicitly in the paper.

SC39 R#2: Page 20242, Line 9: Suggest replacing "with the wavelength throughout the interval" with "on wavelength in the interval"

A: This sentence has been replaced.

SC40 R#2: Page 20244, Line 17: Reword the phrase "the minimum slant respect the normal. . ."

A: This phrase has been rewritten.

SC41 R#2: Page 20244, Line 22: Suggest rewording "using as TO3, the original and MSR datasets" as "using TO3 from the model and the MSR datasets"

A: We have updated this sentence.

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SC42 R#2: Page 20245, Line 4: Clarify and reword the phrase "due to total absorptions are normalized respect. . ."

A: We agree about the inaccuracy of this sentence. In equation 11 (in the paper), we normalized the fluxes with respect to the solar radiation at the top of the atmosphere. Thus, the results from equation 21 range from 0 to 1. In equation 22, we compared two outcomes from equation 21 and, as a consequence, the bias is dimensionless. With this sentence, we tried to clarify this point to avoid any misunderstanding related to the relative error. As we detail in **SC8 R#1**, we propose to use physical units (i.e. W m^{-2}) instead of dimensionless values.

Results

SC43 R#2: Page 20245, Line 12: Move the first comma so that the sentence reads "In the RRTMG scheme, shown in Fig. 1, the lowest. . .)

A: The comma has been shifted.

SC44 R#2: Page 20246, Line 2: Replace ". . .due to the ozone profiles are limited to winter. . ." with ". . .due to the ozone profiles being limited to winter. . ."

A: It has been updated.

SC45 R#2: Page 20246, Line 4: Suggest replacing ". . .larger in the Southern during the Southern Hemisphere fall. . ." with "larger in the Southern Hemisphere from March to May. . ."

SC46 R#2: Page 20246, Line 5: Suggest replacing ". . .lower in the Northern Hemisphere during the Northern Hemisphere winter. . ." with "lower in the Northern Hemisphere from December to February. . ."

A: Your suggestions make the sentence simpler. They have been replaced.

SC47 R#2: Page 20246, Line 7: Remove "the" after "around

A: It has been replaced.

SC48 R#2: Page 20246, Line 9: Does this sentence refer to boreal spring and summer?

A: The sentence refers to the spring and summer of each Hemisphere.

In Figure 1 (G-NG-FLG), you can see negative departures in NH mid-latitude regions during April, May and June. These values drift to positive in July and August.

In contrast, you can note the reversed pattern in the SH. In October, November and December, we have negative deviations while in January and February they drift to positive values.

We have clarified the sentence to avoid any confusion.

SC49 R#2: Page 20246, Line 20: Suggest replacing "emulated" with "simulated"

A: We agree that "emulated" is not the most suitable word here, but neither "simulated" because the context is not a simulation. We propose "represented".

SC50 R#2: Page 20246, Line 27: Replace ". . .around the Greenwich's meridian. . ." with ". . .around 0deg E. . ."

A: In our opinion, we preferred using the geographical nomenclature. However, this sentence has been updated to avoid any confusion.

SC51 R#2: Page 20247, Line 5: Regarding the statement ". . .while the largest errors are observed in the RRTMG", are the authors referring to a globally weighted RMS error, or to the extreme errors? The prior text refers to larger extreme biases in the G-NG-FGL ozone method. In addition, it is recommended that this sentence be revised to refer to the biases of the ozone method used with RRTMG rather than the model itself, since the ozone specification defined in the interfacing is not strictly part of the

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RRTMG code itself.

A: In that paragraph we referred globally while in the G-NG-FLG we considered the extreme errors. After your review, we agree that this part must be reworded to avoid any misunderstanding.

SC52 R#2: Page 20247, Line 9: Clarify the phrase ". . .during the ending Southern Hemisphere winter and the near Southern Hemisphere spring due to the ozone hole is smoothed. . ."

A: This sentence has been clarified.

SC53 R#2: Page 20247, Line 14: Replace ". . .it is observed an underestimated region. . ." with ". . .an underestimated region is observed. . ."

A: It has been replaced.

SC54 R#2: Page 20247, Line 24: Suggest replacing "determination" with "specification"

A: We have improved this sentence.

SC55 R#2: Page 20248, Line 6: Replace "Mid-latitudes" with "Mid-latitude"

A: This error has been updated.

SC56 R#2: Page 20248, Line 10: Add "a" before "bias"

A: It has been added.

SC57 R#2: Page 20248, Line 22: Remove "the" after "around", and replace "maximum" with "maxima"

A: Both have been updated.

SC58 R#2: Page 20248, Line 27: Clarify the phrase ". . .seasonal ozone depletion occurred since winter until near spring. . ."

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A: This sentence has been reworded to be more clear.

Conclusions

SC59 R#2: Page 20250, Line 5: Figures 1 and 2 suggest that this sentence should refer to the Northern Hemisphere winter.

A: Your are right, it was a typing error. We have corrected this sentence.

SC60 R#2: Page 20250, Line 9: Replace ". . .in front of the climatology" with ". . .relative to the climatology"

A: It has been replaced.

SC61 R#2: Page 20250, Line 10: The sentence that beings "Only the northern. . ." is unclear and should be reworded

A: This sentence has been rewritten.

SC62 R#2: Page 20250, Line 26: Replace "composed by" with "composed of"

A: It has been updated.

SC63 R#2: Page 20251, Line 3: Replace "address" with "addresses"

A: It has been updated.

SC64 R#2: Page 20251, Line 17: Add "the" before "underestimated"

A: It has been added.

SC65 R#2: Page 20251, Line 22: Add "As conclusion" with "In conclusion"

A: It has been replaced.

SC66 R#2: Page 20251, Line 25: The phrase "shortwave radiation at surface becoming as a relevant point due to. . ." is unclear and should be reworded

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A: We agree with this reviewer opinion. We will reword this sentence to be clearer.

Tables and Figures

SC67 R#2: Figure 1: It is recommended that this be separated into two different figures and enlarged **R#2:** Figure 3: It is recommended that this be separated into two different figures and enlarged

A: We agree with these referee's ideas. However, we will wait to the Editor's decision.