

Review comments are in black, while responses to the reviewer are in red. When text from the manuscript is quoted, new text is in bold face.

We thank both reviewers for their careful reading of the text, and find that their remarks improve the clarity and usefulness of the manuscript. We revise the text as suggested by the reviewers.

Referree 1:

Review on the paper entitled: "Modeling dust as component minerals in the Community Atmosphere Model: development of framework and impact on radiative forcing", by R. A. Scanza et al., for publication in Atmos. Chem. Phys.

General comments:

The study is a first attempt at modeling global mineralogy of dust. It is focused on building the framework required to carry mineral tracers and on synching them with radiative codes. This paper presents important model developments and a complete discussion on what are the impacts on the simulation of radiative forcing. Simulations performed with CAM4 and CAM5 model versions are presented and discussed to point out the improvement and the limits of the model developments. The paper is well-written and I recommend its publication in Atmos. Chem. Phys. Before its publication, I only have minor comments which are reported below. The main comments are related to the simulated vs observed mineral dynamic range, the optical properties used in this study, and the optimizations presented for the different simulations.

(In case the authors have any comments or questions, they can contact me at [benoit.laurent@lisa.u-pec.fr](mailto:benoit.laurent@lisa.u-pec.fr)).

We thank the reviewer for the very helpful comments, and revise the text to clarify the points addressed by the reviewer.

Specific comments:

p.17760: A table gathering optical properties or at least a discussion on the values used would be useful to complete table 3.

We modified the supplement to include a spreadsheet with the spectral range of the complex refractive indices for the eight minerals as well as the 'Zender' dust blend with and without hematite. We added the following text on p.17760 line 16 (online) or line 237:

**"The wavelength dependent complex refractive indices for all eight minerals along with the "rest of dust" blend ("Zender," Table 3) with (Mahowald et al., 2006) and without hematite (this study) are provided in the supplementary material (S2)."**

We added the following text in the supplementary material:

**“Supplementary material S2: Complex refractive indices for minerals. Illite, Kaolinite, and Montmorillonite are from Egan and Hilgeman, 1979 in SW and from Querry, 1987 in LW (<http://www.atm.ox.ac.uk/project/RI/mineral.html>.) Hematite is from <http://www.atm.ox.ac.uk/project/RI/hematite.html> cited as A. H. M. J. Triaud, private communication (2005). Quartz is the average of O-ray and E-ray data from HITRAN96. Calcite and Gypsum are calculated from data presented in Long, L.L., M. R. Querry, R. J. Bell, and R. W. Alexander (1993), Optical properties of calcite and gypsum in crystalline and powdered form in the infrared and far-infrared, *Infrared Physics* 34(2), 191-201 using code provided by, Zender, C. S., personal communication, 2013). Feldspar refractive indices are for SW only from Egan and Hilgeman, 1979.”**

p.17762: The authors made a great effort to perform several simulations and to present them as clearly as possible. Nevertheless, CAM4-t and CAM5-t simulations result of several optimizations from the initial versions that make difficult the understanding of the impact of each optimization on the results. This could be explained more in detail.

Here we are discussing the changes from the default CAM model, for CAM model users, which are explained in Albani et al., 2014, and we build from these changes. We modified the text to make this more clear on p.17762, line 23( online) We added the following text:

**“The tuning parameterizations are described in detail in Albani et al., 2014, and were used for both tuned and mineralogy runs in CAM4 and CAM5. The only changes from the default release for CAM we tested explicitly was the particle size distribution at emission (Kok (2011)). “**

In table 4, CAM4-m and CAM4-mH seem to correspond, for instance, to the same simulations (FSDBAM, Kok (2011), and table 3) if the prescription of Hematite is not indicated. Please add a column in the table or add a comment in the caption.

We modified the caption for Table 4 to clarify the difference between the mineralogy cases with (CAM4-m, CAM5-m) and without (CAM4-mH, CAM5-mH) hematite prescribed from the coarse soil mode on p.17793 (online) or line 1067:

**“Table 4: Description of the model simulation used in this study. All cases are eight year simulation with the last six years used for analysis, All cases are run at 1.9x2.5 resolution. FSDBAM indicates CAM4 physics, bulk aerosols, active atmosphere, land and sea ice components, data ocean, slab glacier and GEOS5 meteorology. FC5 indicates CAM5 physics, modal aerosols, stand alone atmosphere with land and sea ice components, data ocean, slab glacier, and GEOS5 meteorology. Default, tuned and tuned plus mineralogy cases are listed in the upper portion of the table and the lower portion of the table designates the simulations part of the sensitivity study section. **“The suffix “-m” refers to the prescription of hematite from both fine and coarse soil fractions while the suffix “-mH” refers to hematite prescribed solely from the fine soil fraction.”****

p.17766, 17767 and 17768: The authors point out that the models overestimate the dynamic range in mineral mass fraction close to source areas (Fig. 4), and do not capture the dynamic range far away from the dust sources, as it is for instance the case for K/I surface concentrations (Fig. 5) and deposition (Fig. 7 and 8). Kaolinite and Illite being clay minerals, they seem to be distributed in the same aerosol bins at the emission. If these two minerals are transported and deposited in the same way in the model, the simulated K/I ratio should thus stay constant from their emission in desert source areas and during their atmospheric transport and deposition. Does the K/I ratio, generally encountered in the main desert soil from which dust is emitted, show a dynamic range as large as the one observed in the dust surface concentration and dust deposition? If not, this may also partly explain the model difficulty to reproduce the K/I variability observed far away from emission areas. The point of view of the authors on this would be appreciated in their answer and/or added in the paper.

This is a good question and to answer this, we added the following text on p.17769 line 1:

**“Interestingly, mineral ratios in most of the main desert soils exhibit range of variability within the range of the observations of variability in mineral concentrations. This suggests that in theory, the soil maps we are using could capture the observed ranges in mineral ratios. For example, the variability of the mineral ratio K/I in N. Africa is between about 0.2 to 5. Since there were more observations in this region accounted for in the mineral maps from Claquin et al., 1999, along with N. Africa accounting for up to 80% of global dust emission, this heterogeneity is promising. However, due to the coarse resolution of the model, the mineral ratios in the simulations do not capture observations of mineral ratios in dust deposition or concentrations near the surface. In addition, the variability over desert regions in Australia is low (between 1 and 2), while in China, nearly all grid boxes of soil mineralogy K/I are around 0.5 which suggests that the assumed soil mineral variabilities are not adequate in these regions. While in the model we include kaolinite and illite with the same assumed size distribution, in reality, kaolinite tends to be in a slightly larger size fraction than illite (0.5-4 $\mu$ m and 0.1-1 $\mu$ m, respectively) (Glaccum and Prospero, 1980). So in the model these values will tend to stay constant as the model advects them downwind, while in reality these should be more fractionation occurring with transport. It is unclear how more resolution of the size fractions of the minerals in the soils would improve our simulations.”**

p.17771: A discussion on the imaginary and real parts mentioning the values used should be added.

We modified the text to make this more clear (bold language is new) on p.17771 line 12(online) or line:

“The real **part** (scattering) and the imaginary **part** (absorbing) of the refractive index at 533 nm is larger for tuned dust than for each of the minerals except for the **real part in montmorillonite and for hematite (dust( $\lambda=533$  nm): 1.515 -  $i0.00236$ , illite( $\lambda=533$  nm): 1.415 -  $i0.00103$ , kaolinite( $\lambda=533$  nm): 1.493 -  $i9.954e-5$ , montmorillonite( $\lambda=533$  nm): 1.529 -  $i0.00185$ , hematite( $\lambda=533$  nm): 2.967 -  $i0.7997$ , rest of dust blend( $\lambda=533$  nm): 1.51 -  $i0.00105$ ).**”

p.17777 l.25-p.17778 l.1: The interpretation of the figures is a little bit tricky. Please rephrase to make it more understandable.

The figure reference was incorrect. We modify the text to fix this on p.17778 line 1 (online):

“(Figure S2d, Figure 13d, Figure 3d, Table 8a)”

p.17778: Uncertainties in mineral optical properties are mentioned. The presentation of the values used could be interesting.

This is a good point, we add in the following bold text on p.17778, line 20 (online) or line 690:

“We do not have enough data to estimate the uncertainties in the mineral optical properties, although it is clear that the refractive indices for a given mineral can vary due to imperfections or inclusions which may reflect the geographic location of minerals. **For example, chemical composition can vary between two samples collected at a single location, and have different refractive indices. (Egan and Hilgeman, 1979). Additionally, two samples of the same mineral from different geographic locations can also have different refractive indices, Egan and Hilgeman, 1979).**”

Technical corrections:

p.17753 l.2: Please add (CESM) after “Community Earth System Model”

Text is modified on p.17753, line 2 (online) or line 74:

“This study addresses the direct radiative forcing (DRF) of natural mineral aerosols in the Community Earth System Model **(CESM).**”

p.17755 l.5: Saltation process is mentioned but not the sandblasting process.

The text is modified on p. 17755, line 5 (online) or line 127:

“Measurements and theory show that dust aerosols (0.1-50  $\mu\text{m}$ ) are primarily emitted through saltation, the bouncing motion of sand-sized ( $\sim 100$ -200  $\mu\text{m}$ ) particles **that disaggregate and emit dust aerosols via sandblasting from the saltating particles** (Gillette et al., 1974; Shao et al., 1993; Kok et al., 2012).”

P.17755 Eq.1: It is the normalized mass distribution which is presented. If  $M_{ij}$  refers to a mass fraction, a mass term is missing in this equation.

We add the following text to clarify this on p.17756, line 2 (online) or line 148:

**“The mass fraction in Equation 1 is 0.87 for particle diameters  $D=0.1-10 \mu\text{m}$  with the remaining fraction 0.13 centered around  $19 \mu\text{m}$ . We assume this fraction is insignificant for long range transport (Zender et al., 2003). “**

p.17756 l.3: The sum of the mass fractions is equal to 99.9% and not to 100%. Because we only include significant digits out to 2 decimal points, there is the possibility of round off error, which is not a significant source of uncertainty compared to the many other assumptions in the model.

Table 1: The sum is not equal to 100% for the Zg, Zo and ST soil types. Please check. The sums do add to 100 if another significant digit is added.

p.17756 l.3 and p.17763 l.6: Please use the same writing for the mass fractions. The sum of the mass fractions is not equal to 100%.

The text was modified on p.17763, line 6 (online) or line 305:

“For the first sensitivity study, the tuning parameterizations for dust in both CAM4 and CAM5 are kept constant except the new size distribution was replaced with the size distribution in the release version of the model with mass fractions of **3.8, 11.1, 17.2 and 67.8%** for bins 1-4 (CAM4-trs) and mass fractions of **3.2 and 96.8%** for modes 1 and 3 (CAM5-trs).”

p.17763 l.12: Please write “Cwiertny et al. (2008)” instead of “(Cwiertny et al., 2008)”.

The text was modified on p.17763, line 2 (online) or line 311:

“**Cwiertney et al., (2008)** finds...”

p.17766 l.3: Please add “in aerosols” after “The spatial distribution of minerals”.

The text was modified on p.17766, line 3 (online) or line 369:

“The spatial distribution of minerals **in aerosols** in CAM4 and CAM5”

Table 5: Replace “Isreal” with “Israel” in the Location column.

This is corrected.

p.17769 l.18: Add a space between “533” and “nm”.

The text was modified to include the space between 533 and nm on p17769, line 18 (online) or line 460:

“...are simulated for each model at **533 nm** and compared..”

p.17771 l.15: imaginary and real parts instead of imaginary and real portions

The text was modified on p.17771, line 15 (online) or line 505:

“Hematite has much larger imaginary and real **parts** “

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Referee 2:

Review on “Modeling dust as component minerals in the Community Atmosphere Model: development of framework and impact on radiative forcing” by R. A. Scanza et al. S. Nickovic (Referee)

This study for the first time explores, using two versions of a global atmospheric-dust model how multiple mineral fractions in dust affect the atmospheric radiation. This work is also a basis for authors to build a modelling framework to be used in the future to study the influence of different minerals to processes other than radiation (e.g. ocean productivity due to deposited dust carrying soluble iron; role of minerals in cloud formation).

The manuscript is well organized and clearly written. The importance of the study objective and the obtained results qualify the article to be published. Before publishing I would ask the authors to consider the following comments and suggestions:

We thank the reviewer for the very helpful comments, and revise the text to clarify the points addressed by the reviewer.

Pg 3. Lines 12-18. Long sentence and difficult to follow. It would be re-written. (Based on these simulations, we estimate the all-sky direct radiative forcing at the top of the atmosphere as  $+0.05\text{Wm}^{-2}$  for both CAM4 and CAM5 simulations with mineralogy and compare this both with simulations of dust in release versions of CAM4 and CAM5 ( $+0.08$  and  $+0.17\text{Wm}^{-2}$ ) and of dust with optimized optical properties, wet scavenging and particle size distribution in CAM4 and CAM5,  $-0.05$  and  $-0.17\text{Wm}^{-2}$ , respectively)

We modified the text to make this sentence easier to follow on p.17751, lines 12-17 (online) or line 32:

**“Based on these simulations, we estimate the all-sky direct radiative forcing at the top of the atmosphere as  $+0.05\text{Wm}^{-2}$  for both CAM4 and CAM5 simulations with mineralogy. We compare this to the radiative forcing from simulations of dust in release version of CAM4 and CAM5 ( $+0.08$  and  $+0.17\text{Wm}^{-2}$ ) and of dust with optimized optical properties, wet scavenging and particle size distribution in CAM4 and CAM5,  $-0.05$  and  $-0.17\text{Wm}^{-2}$ , respectively. “**

Pg 4. Lines 14-15. Goethite is mentioned, although not later explicitly considered; please clarify (Efforts to separate the components of absorbing dust single out the iron oxides, e.g., hematite and goethite.)

We modified the text to clarify this on p.17752, lines 14-15 (online) or line 58: “Efforts to separate the components of absorbing dust single out the iron oxides, e.g., hematite and goethite, **although in this study, we simulate the iron oxides collectively as hematite.**”

Pg 4. Line 18 Add Journet et al, 2014 reference

The text has been modified to include Journet et al., 2014 on p.17752 line 18 (online) or line 62:

“Recent modeling studies that consider the speciation of dust into its mineral components include work by Balkanski et al., 2007; Sokolik and Toon, 1999, Nickovic et al., 2012 **and Journet et al., 2014.**”

Additional text has been added to compare with the Journet study on p.17753, line 1 (online) or line 72:

**“Journet et al., 2014 expands on the soil mineralogies from Claquin et al., 1998 by including many additional soil mineralogy measurements and increasing the number of minerals; however, these maps were not available at the time the simulations in this study were performed.”**

Liu et al., 2013 not in the reference list

We remove the reference to Liu et al., 2013.

Pg 13. Lines 1-4 Why the given fractions in Mahowald are used instead of the fractions from the mineralogy database? (CAM3 optics were used (Mahowald et al., 2006), which were computed assuming Maxwell-Garnett mixing of 47.6% quartz, 25% illite, 25% montmorillonite, 2% calcite and 0.4% hematite by volume, with density = 2500 kgm<sup>-3</sup> and hygroscopicity prescribed at 0.14)

Because of the construction of the LW code in the CAM3/CAM4 model, including LW aerosol interactions is very difficult. Because the future of the model will be the CAM5 code, for which LW aerosol interactions are easy to include, we did not include these effects in the CAM4 model.

We modify the text to clarify this on p.17760, line 27:

**“In CAM4, the LW aerosol effects are ignored in the release version, and are generally very difficult to calculate accurately, which is one of the many advantages of the new radiation scheme inside CAM5. We do not have a method to calculate the LW optics in CAM4 so we have to use the LW optics from CAM3 (Mahowald et al., 2006). In place of LW optical properties for the minerals, CAM3 optics were derived from refractive indices of a dust blend provided by Zender, C. S, assuming Maxwell-Garnett mixing of 47.6% quartz, 25% illite, 25% montmorillonite, 2% calcite and 0.4% hematite by volume with density = 2500 kgm<sup>-3</sup> and hygroscopicity prescribed at 0.14.”**

Comment please the effects of using of different radiation schemes in CAM4 and CAM5 on comparability between two groups of simulations. Was this not possible to use a unique radiation model?

Unfortunately, it is not possible to run the CAM4 aerosol code with the CAM5 radiation code or vice versa. Therefore we do not include this in the paper. We think that including mineralogy in two different versions of the model, and getting similar results suggests our results are quite robust.

Pg 13. Lines 25-27. The argument of not using the same number of minerals in both model due to computational requirements does not sound convincing. Remove it or offer different justification. Personally, I think it limits the comparability of results from two models and generality of the study. (The fewer tracers in CAM5 were simply for computational efficiency; the capability to add the additional minerals included in CAM4 is feasible and future simulations may involve including these.) Effectively we have additional diagnostic tracers in the CAM4 simulations (added mineralogical resolution), which we don't use in calculating their radiative effect from their optical properties; rather we use them just to see the distribution of minerals. Therefore, they do not impact the simulations nor the comparability of the runs. We add text to clarify this point of p.17761, line 23:

**“CAM5 was modified to include five mineral tracers for each of the two modes, four minerals and an additional tracer to carry the rest of dust. As previously mentioned, neglecting the radiative properties of the additional minerals in CAM4 facilitated a comparison between CAM4 and CAM5. In effect, we have a few extra diagnostic tracers in our CAM4 simulations with mineralogy, which do not impact the simulation, and can use these in the mineralogical comparisons. However, their optical properties are identical to the “rest of dust” tracer in CAM5 and do not impact the radiative forcing differently. “**

Define the term dynamic variability

We replace this term with “range of variability.” The text has been modified to define this term on p. 17766 line 24:

**“There is one instance of the range of variability of mass with size where the CAM4 simulation did not predict this variability for gypsum (Fig. 4g).”**

It would be useful if the authors in Discussion and conclusion compare their results on radiation forcing with other similar studies (e.g. Balkanski et al, 2007, etc.) and discuss reasons for substantial differences (if any)

Balkanski et al., 2007 considers radiative forcing with different mixtures of minerals but does not include spatially explicit minerals as we do in this study. We include a reference to this and other recent papers in the conclusions to put our paper in the context of recent work, p.17780, line 7:

**“A recent study of the radiative forcing of dust as a function of mineralogical composition that does not include the spatially explicit variability of minerals estimated a TOA forcing between -0.03 and -0.25 Wm<sup>-2</sup> from mineral dust with an internal mixture of 1.5% hematite by volume (Balkanski et al., 2007). Both CAM4 and CAM5 cases with tuned dust (0.4% inclusion of hematite by volume) fall within the reported range.”**



Short Comment:

It is a very interesting paper. Would the author consider having another 1-2 tables to provide the information of emission fluxes and atmospheric loadings of different minerals? This will be very useful, and I presume it is readily available from the modeling work. Most of previous studies, as far as I know, have not provided similar information (e.g. Claquin et al., 1999; Huneeus et al., 2011; Nickovic et al., 2012)

**This is a good point. The emission flux, deposition and atmospheric loading are provided in Table S1 in the supplement for the eight minerals simulated in CAM4.**