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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Dust altitude and infrared optical depth from AIRS" *by* C. Pierangelo et al.

C. Pierangelo et al.

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ANSWERS TO COMMENTS OF ANONYMOUS REFEREE #2

1) Before publication I would like to request the authors to clarify what aerosol altitude they retrieve (the altitude of the dust layer top or some kind of average altitude of the layer)

The explanation of the altitude retrieved is given p3337, line 2, and more details have been added: the subsection 3.3 has been modified according to this recommendation (see at the end, new section 3.4)

2) better document the sensitivity of their retrievals to the assumed dust refractive index, size distribution, and vertical profile in case of multi-layers of dust

The subsection 3.3 has been modified according to this recommendation (see new section 3.3 at the end)

The size distribution and refractive indices used for the retrieval come from the OPAC data set, and more information on how these have been chosen to describe the transported mineral aerosol can be found in the OPAC reference. The size distribution is lognormal monomodal with a number mode radius of 0.5 microns and width of 2.2; the effective radius is thus 2.37 microns and the volume mode radius 3.23 nicrons. This value is in the range of in-situ observations: for example, during the SHADE campaign, Reid et al. (2003) report that ``Measured`` volume median diameter varied from 2.5 to 9 microns for various geometric, aerodynamic, optical, and optical inversion methods. Regarding the dust refractive indices, the only measurements of saharan dust refractive indices in the infrared far from the sources are those made by Volz in 1973 for Saharan dust collected at Barbados. Fouquart (1987) reported measurements of Saharan dust in Niger. The OPAC data set is a revised version of the data published in the book from d`Almeida et al. (1991), and the mineral-transported aerosol refractive index mostly comes from the measurements from Volz. A sensitivity study using the OPAC data set, the Saharan Barbados data set from Volz, the ``mineral`` and ``dust-like`` data set from d`Almeida (aiming at describing soil dust rather than desert dust), and the refractive indices reported in Fouquart (1987) has been conducted. We found that if the ``real`` aerosol is described by the original Volz data set, instead of the OPAC-mineral transported data set, then the optical depth might be slightly underestimated by about 10%, and the altitude slightly overestimated by 10%, in agreement with the observation that both data sets are very close. However, if the ``real`` aerosol is described by one of the three other data sets, the optical depth retrieved by the algorithm, even for an input 10 microns optical depth of the order of 0.9, is always below 0.5. As the retrieval applied to real observation data leads to values as high as 1 or more, we can deduce that the ``mineral``, ``dust-like``, and ``Fouquart`` data set do not represent the observed aerosol. This is consistent with conclusions of Sokolik et al. (1998) that the ``Sahara dust-Barbados`` refractive indices should be used to model optical properties of long-living airborne dust originating from the Sahara over the Atlantic Ocean (page 8824).

Other specific comments:

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3) Page 3334, line 20 and following: the terminology ``infrared``, ``thermal infrared``, ``terrestrial and atmospheric infrared`` radiation deserves to be clarified and used consistently in the manuscript. This does not seem to be the case at the moment.

We added in the introduction: Here, ``thermal infrared``, ``terrestrial and atmospheric infrared``, or more simply ``infrared`` refers to the radiation emitted by the Earth surface and the atmosphere in the wavelength range 3 to 15 microns, as opposed to the near-infrared radiation mostly emitted by the sun.

4) Page 3336, line 25 and following: it would help to know the average/typical geometric thickness of layers in the 4A model. More generally speaking, more details on the RT calculations are needed here.

The thickness of a 4A layer in the troposphere extends from 500m (near the surface) to 800m (near the tropopause). This precision has been added in the text. The website http://ara.lmd.polytechnique.fr/ (p3336, line 14) gives more information about 4A.

5) a bit more details should be given to the readers, in particular the size distributions and refractive indices used for the retrieval. How these have been chosen? A sensitivity to dust refractive index should be conducted as this is a very uncertain parameter. OPAC may not be the best aerosol model, although I agree that data on dust refractive index are very scarce in the infrared.

Please, see answer to comment 1) and new section 3.3 at the end.

6) Page 3340, section 3.3: this paragraph is not clear. More explanations (and a plot?) are needed. What is the meaning of the retrieved dust altitude if the layer has a geometric height of several kilometers. Is it the altitude of the top of the layer or an average altitude?

Please, see new section 3.4 at the end.

7) Page 3341, lines 11-12: it is not true at all that background aerosols such as sea-salt have a weak temporal variability. The sea-salt loading is very much related to the

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wind speed at the surface. The possible contamination of the dust retrievals by sea-salt would deserve to be examined properly.

As recommended, a careful study has been conducted to examine the possible contamination of the retrieval by sea-salt. Because the sea-salt optical depth is quite low (we took 0.1 and 0.2 for the 10 microns optical depth) and because this aerosol is located in the marine boundary layer, its effect is indeed negligible. The optical depth retrieved increases by 0.03 for a sea-salt optical depth of 0.2. The dispersal of the retrieval tends to increase from 0.14 to 0.26. This is because the sea-salt signature on the 8 selected AIRS channels is not consistent with the dust signature and is consequently interpreted as noise. So, we removed ``(for example sea-salt)`` p3341, line 12. We added a 5th part in section 3 (see new subsection 3.5 at the end)

8) Page 3342, line 4 and Table 3: MODIS has different algorithms for detecting cloud cover. It would be useful to give more details on the MODIS cloud cover product which is used, beyond the product number! I assume that the authors look at simultaneous and co-located scenes, but this should be clearly mentioned. Another study that shows that dust can be mistaken as cloud in the MODIS cloud product is: M. Doutriaux-Boucher and I. Chiapello, Analysis of cloud cover differences between POLDER-2 and MODIS instruments, European Geophysical Union 1st General Assembly, Nice, 25-30 April 2004.

According to our knowledge, there is only one MODIS cloud-mask by night. A description of the product can be found on http://modis-atmos.gsfc.nasa.gov/MOD06_L2/index.html We added ``for simultaneous and co-located scenes`` p 3342, line 4.

9) Page 3342, line 6: The total MODIS cloud coverage is 90.7% _: this is an inexact statement. 90.7% of the 1x1 pixels are declared as cloudy or partly cloudy in MODIS. But the cloud coverage would be smaller!

This is true, so we replaced ``The total MODIS cloud coverage is 90.7%, whereas it

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is 63.2% for our cloud mask`` by ``Because of the different spatial resolution of the two instruments, comparison is made over 0.25 grid boxes. 90.7% of these boxes are flagged cloudy or partially cloudy by MODIS, versus 63.2% for AIRS.`` Note that comparison is carried on 0.25 degree grid boxes, not 1 degree grid boxes.

10) Page 3342, lines 8-12: I am not sure that the two arguments given for the MODIS-AIRS discrepancy in cloud cover are not in fact a single one.

We think that both arguments must be presented, since we visually check that the dust is flagged cloudy by MODIS, and since a comparison in an aerosol-free area also leads to an overestimation of cloud coverage by MODIS, proving that dust in not the only explanation to the MODIS-AIRS discrepancies.

11) Page 3343: can the authors elaborate why their algorithm retrieves the dust AOD rather than the total AOD? This holds only under the assumption of a background aerosol with weak temporal variability. Since this is not the case, I see no reason why the retrieved AOD would not include other aerosol types if these are present in significant amounts. But I agree that an average background AOD has been removed from the retrieved quantity.

There are the reasons why the retrieved AOD does not include other aerosol types:

- there is no sea-salt contamination (see answer to comment 7)

- other aerosol species tend to stay lower than dust in the troposphere, which further decreases their effect.

- because biomass burning aerosols or sulfates are smaller than dust, their impact in the infrared is quite limited. The OPAC refractive indices data sets for the soluble aerosol, the sulfate aerosol, and the soot aerosol show that the infrared extinction cross-section is smaller than 1 tenth of the 0.55 microns optical depth.

- because the retrieval is designed for dust only, other aerosol species have different signature whose distance to the Look-Up-Table situations may be greater than 1, and

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are thus not considered

- then, looking at AIRS and MODIS retrieval in the 30-45 degree latitude band (Fig. 3), it is clear than the anthropogenic aerosol emitted in North America is detected only by MODIS.

A new subsection has been added: see new section 3.5 at the end.

12) Page 3343: note that there can be (significant?) differences between MODIS and AIRS due to different sampling (daytime vs night-time, different swaths, different cloud masking).

Yes, however we do not believe these differences to be significant. For the day-time vs night-time difference, as a dust event time scale is about 3 to 6 days, there is no diurnal cycle. The difference caused by the 12 hours lag between MODIS and AIRS observations changes the position where a given cloud is seen at a given day, but averaging the observations over a several day period, an a fortiori over one month as presented here, removes this difference. For the same reason, the different swaths should not produce significant differences. As far as the cloud masking is concerned, if one assumes that both cloud masks succeed in preventing dust to be flagged as cloudy, there must be no difference either.

13) Page 3344, line 10: The 7.3 microns threshold for atmospheric transport looks somewhat arbitrary to me.

It comes from the original paper from Maring et al. (2003b) and is explained by instrument specifications. However, this value is not necessary to the understanding of our paper, so we replaced ``mineral dust aerosols larger than 7.3 microns`` by ``larger mineral dust particles``.

14) Page 3344, line 12: I assume the authors plotted the monthly-average dust altitude weighted by dust AOD. Please confirm or not.

No, we plotted the monthly averaged altitude. Missing data corresponds to boxes

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where the AOD is below 0.08, this value representing the limit between almost dust-free zones and significantly dust-loaded zone. This value has been chosen looking at the AIRS AOD maps. In the legend of figure 4, we have added: ``Missing data for the altitude correspond to boxes where the AOD is below 0.08``

15) Page 3344, line 25 and following: in case of multiple dust layers, the dust retrieval must either be rejected or correspond to some sort of equivalent layer. Clearly sensitivity studies are needed here to understand how the retrieval scheme behaves (see also my previous comments).

Please, see new section 3.4. This new sensitivity study allows the sentence p3344, line 26 to 28 ``Third, our method assumesĚ loses its sense.`` to be removed.

Other technical comments and corrections have been taken into account in the new version of the paper.

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ANSWERS TO COMMENTS OF ANONYMOUS REFEREE #1

1) My main concern pertains to the retrieval of dust layer altitude and the application of the method to the real atmosphere. As the authors state, their retrieval makes many assumptions, such as a single homogeneous layer of dust, and they cite plenty of evidence that this is not the case. This must mean that the method is only applicable in a relatively small number of cases? It would be interesting to see a more detailed discussion of available observations or models of dust transport to be able to assess how often the method is likely to be in error. The method implies that it is sensitive to the middle of the dust layer (see discussion on p3340) but that there can be ambiguities when there is a very thick layer of dust. I am not convinced that it is appropriate to draw conclusions about variations in height of dust layer through the year from this method alone, when the variations in question (500m) are smaller than either the differences introduced by a thick layer of dust, and indeed the day to day variability of the dust

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altitude.

Please, see the new subsection 3.4 at the end.

This new sensitivity study allows the sentence p3344, line 26 to 28 ``Third, our method assumes... loses its sense.`` to be removed. Note that the difference introduced by a thick layer of dust in the old section 3.3 (p3340, line 25) is only 150m (geometrical altitude =(500+3500)/2=2000m, retrieved altitude=1850m) and that the seasonal variation amplitude is 700m. Moreover, even if these variations are not extremely strong, they remain very clear. The day-to-day variation of the altitude just confirms that dust transport seasonality is not a physical law but a tendency.

2) p3337, line 7. Would it be possible to use observations of aerosol size distribution instead of the OPAC model?

Analyzing the PRIDE campaign size distribution measurements from various techniques, Reid et al. (2003) show that: ``Consistent with literature, comparisons of these size distribution showed quite dissimilar results``. Therefore, we preferred using a climatological size distribution, which falls within the average of observations (see also answer to anonymous referee #2 `s comment 2)).

3) p3337, line 13,14. Please would you identify the wavenumbers of the regions you are calling short wave and long wave in figure 1. I am not entirely convinced from figure 1 that there is that much difference in sensitivity of the lower wavenumber region to altitude or AOD.

We added ``(3-5microns)`` after ``shortwave channels`` and ``(8-12microns)`` after ``longwave channels`` (this is also said previously in the introduction). We do not mean that the shortwave channels sensitivity to AOD is different from their sensitivity to altitude, but that the shortwave channels do not show the same sensitivity as the longwave channels to altitude and AOD. According to Fig.1, when the AOD increases from 0.75 to 2.5, the effect of dust on the shortwave, resp. longwave channel, increases by a

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factor of about 3.5, resp. 2. When the average altitude increases from 800m to 4000m, the effect of dust on the shortwave, resp. longwave channel, increases by a factor of about 1.7, resp. 4.

4) Could you include refractive index? There are studies that have shown this is important (Sokolik et al, Highwood et al) that you do cite in the introduction but they would seem to offer some information here too.

Please, see the answer to the second comment of anonymous referee #2, and new section 3.3 at the end.

5) p3337, line 17. Is your conclusion that IR extinction coefficient is insensitive to size distribution consistent with your conclusion about the change in SW to LW ratio with distance from source?

We do not say that extinction coefficient is insensitive to size, but that the change in the extinction coefficient caused by a change in the size is the same for all the wavelengths considered here (from 3.8 to 12 microns), i.e. the extinction coefficient NORMALIZED at 10microns is insensitive to size. It is not the extinction coefficient but the optical depth in each layer (=(extinction cross section of the aerosol) times (aerosol concentration in this layer)) which is an input to the radiative transfer equation. This is why the value of the extinction coefficient is not important for our retrieval, and it is only the variations of the extinction coefficient with wavelength (or the normalized extinction coefficient) that matter. However, the insensitivity of the normalized extinction coefficient to size distribution does not hold in the visible, and the ratio of IR to visible extinction increases with particle size. A figure and more comments are made available on the web, please go on http://ara.lmd.polytechnique.fr/ftp , login: anonymous, no password, directory ACPD-2004-0092. The figure can be downloaded in postscript or pdf format (fig_size_dust.ps or fig_size_dust.pdf), and the caption is the file caption.txt.

6) p3338, line 5. I find this discussion rather vague. Would it be useful to include a figure showing the sensitivity (or lack of) of each channel to dust, ozone and water

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vapour?

The sensitivity to dust is given in Fig.1. We used an atlas of gas absorption spectral lines to remove the channels in coincidence with significant ozone absorption lines. Because of water vapor continuum, it is not possible to find channels insensitive to water vapor; however we verified that no strong water vapor absorption lines were in coincidence with the wavelengths of the channels selected. It must also be pointed out that water vapor is intrinsically taken into account via the exhaustive representativeness of the set of atmospheric situations used to construct the Look-Up-tables.

7) p3340, line 4. Please clarify what you mean by the distance.

It is the distance D defined in equation 1, page 3339. So, we changed ``distance`` to ``distance D (see Eq.1)``

8) p3340, line 19. In reality, what is the likely uncertainty in extinction co-efficient at these wavelengths? Is it comparable to 20%?

Following both referees` recommendations, a deeper sensitivity study has been conducted since the first submission of the paper. Therefore, we modified the first part of paragraph 3.3 (see new section 3.3 at the end).

9) p3341, line 11-12 (and p3343 line 15). I dispute the fact that background aerosol such as sea-salt is not temporally variable. It depends on wind speed for example. This assumption is needed for your retrieval but I would like to see some discussion or justification of it`s suitability. Hence on p3343, AIRS is seeing the total temporally varying aerosol, and not necessarily just dust.

Please, see new section 3.5 at the end and answers to the comments 7) and 11) from anonymous referee #2.

10) p3342, line 15. The comparison with TIROS is made over different time and space scales so it is hard to judge how good a validation it is. Consider making this comparison tighter.

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The comparison with TIROS does not aim at validating our cloud-mask but just shows that the value retrieved is in agreement with climatological data.

11) p3342, line 27. Shouldn`t the night vs day argument only be a problem if there is a robust diurnal cycle in dust loading? I can conceive of how this might be true from a meteorological point of view, but is there any evidence for it?

We agree that there is no diurnal cycle of dust, still the night vs day problem remains: it is not caused by a meteorological difference between night and day but by the fact that, over a given location, the dust optical depth can change rather quickly during a few hours only, as any one-day long observation by AERONET can show. Please, see also answer to comment 12) from anonymous referee #2

12) p3344, line 10. It should be possible to alter your aerosol model to remove particles larger than the cut-off of 7.3 microns, and recalculate to see if it really is the size distribution that matters (particularly as you say the IR extinction co-efficient isn`t sensitive to size distribution). presumably this implies it is the SW part that changes?

We do not say that the extinction coefficient is insensitive to size in the IR, please see above the answer to comment 5). The value 7.3 microns is not to be considered as a measurement of the cut-off, it is just caused by the specifications of the instruments used by Maring et al. (see answer to comment 13) from anonymous referee #2). It is only a confirmation that the coarse mode to fine mode volume ratio decreases with transport. Note that the model used in our retrieval, the ``mineral transported`` model from OPAC, has a cut-off at 5 microns, but we checked that this cut-off does not have a strong impact on our retrieval. Please, see also new section 3.3 and the figure at http://ara.lmd.polytechnique.fr/ftp (login: anonymous, no password, directory ACPD-2004-0092) for the comment about size distribution sensitivity.

13) p3346, line 6. Could you use real dust measurements from the field or lab?

``Real`` dust measurements of refractive indices are extremely scarce (see new section 3.3), and those of size distribution do not seem very reliable (see the answer to comment 2) and also comment 2) from anonymous referee #2). This is why we keep the OPAC model. After the sensitivity study which has been conducted very recently, we changed the sentence p3346 lines 6 to 8 to: ``The lack of refractive index observations for saharan dust in the infrared must be underlined once again. We hope that additional measurements are to be conducted, allowing deeper study of the impact of dust composition and opening the way to promising dust mineralogical characterizations from high spectral resolution satellite observations.``

14) I would also say that the issue of multiple dust layers is a limitation of the usefulness of the altitude retrieval.

Please, see the modified subsection 3.3.

Technical comments have been taken into account in the new version of the paper.

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MODIFIED SUBSECTION

3.3 Robustness of the retrieval algorithm to aerosol model

We first checked the robustness of the retrieval to a potential error on the aerosol model, i.e. on its size distribution, shape, and refractive indices. Considering a log-normal size distribution and sampling its effective radius in the range 0.5 to 3 microns, simulations for almost 300 atmospheres, 3 AOD and 2 different altitudes show that the maximum effect of a change in the size distribution on the retrieved AOD and altitude is 10%. The effect of shape has been studied with the T-Matrix code written by Mishchenko et al. (2002), assuming prolate spheroids with aspect ratio of 2. Although this is not a realistic representation of dust (it would be more accurate to use an aspect ratio distribution) it gives an upper value for the asphericity impact, since averaging the optical properties over several aspect ratio tends to decrease the asphericity effect. The impact on the retrieval is still smaller than the size impact, below 10%. Although

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the size and shape effect can be examined quite easily, by continuously changing the effective radius or aspect ratio of dust, the impact of refractive index is trickier since it depends on both the imaginary and real part of the refractive index at the central wavelengths of the 8 channels. Besides, the only measurements of saharan dust refractive indices in the infrared far from the sources are those made by Volz (1973) for Saharan dust collected at Barbados. Fouquart (1987) reported measurements of Saharan dust in Niger. The OPAC data set is a revised version of the data published in the book from d`Almeida et al. (1991), and the OPAC-mineral transported (MITR) aerosol refractive index mostly comes from the measurements from Volz (1973). A sensitivity study using the OPAC-MITR data set, the ``Sahara dust-Barbados`` data set (Volz, 1973), the ``mineral`` and ``dust-like`` data set (d`Almeida et al.,1991) (aiming at describing soil dust rather than desert dust), and the refractive indices reported in Fouquart (1987) has been conducted. We found that if the ``real`` aerosol is described by the original Volz data set, instead of the MITR model, then the optical depth might be slightly underestimated by about 10%, and the altitude slightly overestimated by 10%, in agreement with the fact that both data sets are very close. However, if the ``real`` aerosol is described by one of the three other data sets, the optical depth retrieved by the algorithm, even for an input 10 microns AOD of the order of 0.9, is always below 0.5. As the retrieval applied to real observation data leads to values as high as 1 or more, we can deduce that the ``mineral``, ``dust``, and ``Fouquart`` data sets do not represent the observed aerosol. This is consistent to conclusions of Sokolik et al. (1998) that the ``Sahara dust-Barbados`` refractive indices should be used to model optical properties of long-living airborne dust originating from the Sahara over the Atlantic Ocean

3.4 Robustness of the retrieval algorithm to the dust vertical distribution

The vertical distribution of dust may be more complicated than a single homogeneous layer, as observations show that transport sometimes occurs in two or three distinct layers. Thus, the (unknown) physical thickness of the layer and the number of dust layers are two potential sources of error that have been investigated. As explained in section 2, the altitude retrieved is the average altitude of the dust, i.e. the altitude at which half of the dust optical depth is below and half of the optical depth is above. If the layer is homogeneous, it is the middle of this layer. For example, a layer located between 1500 and 2000m has a mean altitude of 1750m. A sensitivity study has been conducted for a very thick layer case (more than 3km) and for a 2-layer case (one layer between 2000 and 2800m, and a second layer between 3700 and 4600m), for about 300 atmospheric situations: in both cases the mean retrieved altitude over the atmospheric data-set agrees by 200 meters to this definition of the altitude. Furthermore, even if the vertical distribution of the dust cannot be retrieved, a homogeneous layer located at the retrieved altitude is an infrared optical equivalent to the real vertical profile. Therefore, it is appropriate for computing dust infrared forcing.

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NEW SUBSECTION

3.5 Contamination by other aerosol species

Possible contamination by other aerosol species has also been considered. Biomass burning or anthropogenic aerosol, like sulfates or soot, do not contain as many coarse particles as dust. As a consequence, their infrared to visible extinction ratio is very low (of the order of 1/20) and so their infrared optical depth is negligible compared with the dust optical depth. Except dust, sea-salt is the only aerosol with a predominant coarse mode. However, because its optical depth is quite low (of the order of 0.1) and because sea-salt aerosol is located in the marine boundary layer, its effect on the retrieval is negligible: simulations have shown that an amount of sea-salt with AOD=0.2 increases the retrieved dust AOD by only 0.03.

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