Atmos. Chem. Phys. Discuss., 9, S1738–S1749, 2009
www.atmos-chem-phys-discuss.net/9/S1738/2009/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Impact of dust aerosols on the radiative budget, surface heat fluxes, heating rate profiles and convective activity over West Africa during March 2006" *by* M. Mallet et al.

M. Mallet et al.

Received and published: 27 April 2009

Received and published: 21 March 2009

This article calculates the direct radiative effect of dust aerosols upon the energy balance at the top of atmosphere (TOA) and surface during a severe dust outbreak associated with the passage of a cold front over the Sahel during March 2006. The effect of dust is estimated by contrasting regional model simulations that either include or omit dust. The simulated dust effect is then compared to a number of observations taken during the African Monsoon Multidisciplinary Analyses or else previous experiments. The authors have identified an interesting test case for regional models, where an intense dust outbreak provides a strong signal that was observed by a detailed network of instruments. I hope other regional modelers follow the authors lead. In general, I enjoyed the article. I have listed a few fundamental comments about the article, along with a number of minor technical comments that I would like the authors to address prior to publication. If the authors have any questions about my review, they can contact me at rmiller@giss.nasa.gov.

1. The authors show the response of various energy fluxes to dust (what they describe as the dust "effect"; in section 5.1), but it would also be useful to know the forcing, even though this cannot be measured for comparison to model values. I believe the forcing would not be difficult to calculate. The authors would simply need to do an additional experiment where the radiative effect of the model dust distribution is calculated but not allowed to modify radiative fluxes that influence the dynamics. (The forcing then corresponds to the difference in the radiative fluxes calculated in the presence or absence of the model dust distribution.) Forcing is useful (even if as opposed to the "effect", it can't be measured) as a method to compare the importance of different external variables such as changes in greenhouse gas concentrations and solar radiation, along with other aerosol species such as carbonaceous aerosols from biomass burning. Based on previous estimates of forcing, dust is considered to be an atmospheric constituent that is of central importance to Sahel climate. It would be helpful if the authors were able to provide the dust radiative forcing calculated by their model for this case of extremely high dust levels.

A) This is now made in the new version. In order to avoid confusions, we have calculated the real dust surface radiative forcing by using the downward net irradiance (SW and LW). These calculations are now indicated in the text and in the Table 2 of the new version.

2. The authors overlook a few previous studies of the impact of dust radiative forcing on climate, particularly within the Sahel, which are cited below. In addition, a number of other articles have recently appeared, subsequent to the submission of this article, in a special section of the Journal of Geophysical Research devoted to the RADAGAST

ACPD
9, S1738–S1749, 2009

experiment. This experiment focused on a detailed set of measurements of energy fluxes at TOA by the SEVIRI instrument aboard Meteosat and at the surface near Niamey during 2006. I have provided specific citations below, and I ask that the authors look at these articles, because in many cases they provide observational values that can be compared to their model.

B) Thank you for this remark. We had a look to the different articles referenced in this special issue. Several papers have been used to perform comparisons with our results of models (McFarlane et al. 2009, Miller et al., 2009 and Bharmal et al., 2009).

3. (p.11): The authors model predicts that the downward longwave effect of dust at the surface is small and negative during the outbreak. This is contradicted by observations at Niamey presented by Slingo et al. (2006), who in their Figure 3d show that the effect of dust is positive (corresponding to increased downward radiation from the dust layer into the surface) and of the order of a few tens of W/m2. The authors explain the reduction in downward longwave in their model due to the cooling of the lower troposphere by the reduction in surface SW. This mechanism is hard to understand, since the atmosphere is actually heated by SW (as shown in Table 1). To be sure, atmospheric longwave emission is reduced by the low temperature associated with the passage of the cold front and dust outbreak, but the observations presented by Slingo et al. 2006 indicate that the dust emissivity should overwhelm this effect and increase downward emission due to the large increase in the dust load. Given the good agreement with the observed downward SW at Djougou in Figure 6, the model probably has the correct amount of dust. Is it possible that the unrealistically negative downward LW is due to an unrealistically cold air temperature computed by the model? Is the dust emissivity unrealistically low? (Alternatively, was the net (downward minus upward) surface LW plotted by mistake?) Given the discrepancy of the magnitude and sign of the model flux compared to the observed values in Slingo et al (2006), the authors need to make more effort to understand and document the cause of their small and negative value, especially because this affects their calculation of the LW

ACPD

9, S1738–S1749, 2009

divergence in a subsequent section.

C) This remark is very pertinent and effectively the net (downward minus upward) surface longwave fluxes were given in the previous version. We effectively obtained an increase in the surface downward longwave fluxes by about + 4 W.m-2 (regional mean). Furthermore, it should be noted that Table 2 indicates the regional mean only. If we focus our investigations at local scales, we obtained similar results with a positive direct forcing of mineral dust at the surface. This point is now mentioned in the text (part 4.1.2).

Minor technical comments (identified by page and line number):

p.2 line 3 of the Intro: to this list of references, the authors should add Tegen and Lacis (JGR 1996), who calculated radiative forcing by dust, along with Myhre and Stordahl (JGR 2001), who calculated the sensitivity of dust radiative forcing to various particle optical parameters.

D) This is now made in the introduction by including these two references.

p.3 line 5: Prior to INDOEX, the change to West African (and global) rainfall by aerosols was calculated for the case of dust by Miller and Tegen (J. Climate 1998). See also Miller, Tegen, and Perlwitz (JGR 2004) and Yoshioka et al. (J. Climate 2007).

E) This is effectively right and we have now added further references in the introduction dealing with the impact of dust aerosols on the global and regional West African climate : Miller and Tegen, 1998; Miller et al., 2004; Lau and Kim, 2006; Yoshioka et al., 2007; Konaré et al., 2008; Solmon et al., 2008.

p.3 line 12: Woodward (2001) is a modeling study. The authors should also cite an observational study that supports the overwhelming importance of the Sahara to the global dust load: e.g. Prospero et al. Rev Geophys 2002.

F) This is now made in the text (see the introduction).

ACPD

9, S1738–S1749, 2009

p.4 lines 10-11: please add a citation to McFarlane, S. A., E. I. Kassianov, J. Barnard, C. Flynn, and T. P. Ackerman (2009), Surface shortwave aerosol radiative forcing during the Atmospheric Radiation Measurement Mobile Facility deployment in Niamey, Niger, J. Geophys. Res., 114, D00E06, doi:10.1029/2008JD010491, who show the large AOT at Niamey in early March 2006 (Fig. 1).

G) This reference is now added in the new version of the article.

p.6 line 4: please explain "turbulent stationarity" along with how it was verified using the observations.

H) This is now more detailed in the new version (section 2) by including the following paragraph "Turbulence stationary is one of the fundamental hypotheses that should be fulfilled when determining turbulent fluxes. The presence of low frequencies, which usually are not of local turbulent origin, but can be induced by the constraint of large-cell circulations or meso-scale events in the Atmospheric Boundary Layer (ABL), implies longer scale processes in the turbulent fluctuations. They can yield significant disturbances in flux evaluation. For this reason, and as defined in Affre et al. (2000), the contribution to w'c' covariance is studied along the sample. The evolution of the integral function f(t) defined in (1) is a indication of the quality of the integral flux which is given by (f(T)-f(0))/T. There is a second way for calculating the flux which is based on a statistical approach. In that case, the flux is no more calculated on the integral slope, but on the statistical slope deducted from the least mean squares.".

p.7 line 12: The authors cite Dubovik et al. (2002) as evidence that models often assume unrealistically large absorption by dust. However, this citation is based on version 1 of the AERONET retrieval algorithm, and version 2 indicates that dust absorption is actually larger and closer to typical model values. This doesn't contradict the authors point that the radiative effect of dust is very sensitive to the assumed absorption, which is highly uncertain. Nonetheless, the authors should use a more current reference that accounts for the revision to the AERONET retrievals: e.g. Sinyuk et al, Remote

ACPD

9, S1738–S1749, 2009

Interactive Comment

Sensing of Environment 107 (2007) 90-108.

I) As suggested by the reviewer we have included more up to-to-date description of the AERONET retrievals products used here. Specifically, we have included the following text and newer references:"AERONET database provides spectral optical thickness directly measured from ground (Holben et al. 1998) and the detailed microphysical aerosol properties including size distribution, refractive index, single scattering albedo, etc, derived from both direct sun and diffuse sky-radiances measurements using inversion algorithm by Dubovik and King, 2000. Recently this algorithm was updated with several improvements (generating Version 2 retrievals used here). First, in order to account for aerosol non-sphericity, the coarse mode of desert dust is modeled as a mixture of randomly oriented spheroids (Dubovik et al. 2006). Second, the new assumed surface reflectance model accounts for reflectance directionality and based on MODIS surface reflectance climatology (Sinyuk et al., 2007; Eck et al., 2008)." Secondly, To the best of our knowledge the retrievals product of Version 2 did not revealed any significant corrections to the aerosol retrieval climatology provided by Dubovik et al. 2002. Specifically, the retrieved single scattering albedo of the desert dust retrieved for profound desert dust evens has similar magnitude with the values published by Dubovik et al. 2002 and remains significantly higher then it was previously use in the models.

p.7 third paragraph: What were the locations of the AERONET and PHOTONS radiometers used to infer the dust index of refraction? Also, the authors use a dust index of refraction taken from AERONET during the dust outbreak, and a dust size distribution calculated by their model. But AERONET also retrieves the size distribution. The authors should show a comparison of the calculated and retrieved size distribution. A comparison of calculated and observed AOT as a function of time at a radiometer site should also be included to assess the realism of the simulated dust load.

J) The locations of the radiometers are now indicated in the Figure 1. Concerning the dust optical depth, comparisons between AERONET/PHOTONS and MesoNH have been made by Tulet et al. (2008) in JGR DABEX/AMMA special issue. Concerning the comparisons of the aerosol size distribution, this is a very interesting remark. At this time, we plan to develop a new output in MesoNH to perform direct comparisons. This requires an important work as MesoNH calculates the mass size distribution at different levels while AERONET provides a volume size distribution integrated for the whole atmospheric column. Further tests should be conducted on the aerosol density and on the methodology used to calculate the whole volume atmospheric size distribution before publishing it. We plan to present this development in a future work.

Figure 3: The distinction between "bottom" and "down"; in the caption is unclear.

K) This figure is now modified in that sense.

p.8 lines 16-19: The comparison to AERONET over the Persian Gulf based upon Dubovik et al 2002 is out of date, given the subsequent change in AERONET retrieval algorithm. Revised values from Version 2 over the nearby Solar Village are given in the Sinyuk article cited above (Fig. 21).

L) Thank you for this remark. The new values and the new reference are now indicated in the text (section 3).

p.9 last two lines and Figure 5: The model downward SW fluxes should be plotted in Figure 5 for comparison to the observations at Djougou. Also, the location of Djougou should be highlighted in one of the preceding figures, along with the location of the AERONET and PHOTONS radiometers.

M) The locations of Djougou together with the radiometers are now indicated in the Figure 1. In a previous paper Tulet et al. (JGR, DABEX/AMMA special issue, 2008) display none negligible differences between AERONET/PHOTON and simulated dust optical depth at local scales (Figure 5 of Tulet et al. article). This work underlines that MesoNH was able to well reproduce the regional AOD geographical pattern observed from satellite but direct comparisons with photometer are harder, especially at

Djougou. This is due to the strong AOD horizontal gradient (Figure 1) associated with the spatial resolution used (12*12 km) in our simulations. In that sense, direct comparisons between simulated and observed downward shortwave fluxes at local scale are not conclusive as shown in the Figure 6, where some differences appear. We have now clarified this point in the article (section 4.1.1) by using the following sentence: "Differences observed between simulated and measured solar downward fluxes are mainly due to strong dust optical depth horizontal gradient together with the spatial resolution used in MesoNH (12*12km)."

Figure 6 caption: Why is the period of 10-12 of March referred to as "pure clear-sky days" if there is so much dust in the air according to Figure 4?

N) This sentence is effectively not clear. Here, we used three clear-sky days to study the effect of dust on the surface irradiance. This sentence is now rewritten in the article (section 4.1.1).

p.11 line 1: One process capable of modifying the clouds was the cold front that accompanied the dust outbreak. (c.f. Slingo et al 2006).

O) This explanation is now indicated in the text (section 4.1.1).

p.11 line 3: The text should note that the regionally averaged SW effects in the figure correspond to noon.

P) This is effectively right and we have now modified this point in the article (section 4.1.1) by using the following sentence: "Averaged at the regional scale (09-17°N / 10°W-20°E), our simulations indicate instantaneous SRF_SW at noon (obtained for the 09, 10, 11 and 12 March, see Table 2)"

p.11 lines 9-10: Please be explicit about how SRF_LW is defined. Is this the downward flux of LW from the atmosphere into the surface?

Q) The convention used is strictly identical to the one reported in the shortwave wavelengths (relation 2). This point is now specified in the text.

ACPD

9, S1738–S1749, 2009

Interactive Comment

p.13 line 6 "reduction of total solar radiation" It should be noted that the forcing by dust also includes increased downward LW due to the increased emissivity contributed by dust. See Figure 8 of Miller et al 2009 (full citation below).

R) This is effectively right and we have now modified this point in the text (section 4.1.2).

p.13 line 7 "few work have documented"; see a recent article showing the effect of dust (and other atmospheric constituents) on the surface energy balance by Miller, R. L., A. Slingo, J. C. Barnard, and E. Kassianov (2009), Seasonal contrast in the surface energy balance of the Sahel, J. Geophys. Res., 114, D00E05, doi:10.1029/2008JD010521.

S) Thank you for providing us this new reference, we have now added it in the text.

Figure 9: The authors should plot the model values at Djougou to accompany the observed time series. They could also plot the anomaly attributed by the model to dust.

T) As mentioned below, we have shown in a previous paper (Tulet et al., JGR, 2008) some differences between AERONET/PHOTON and simulated aerosol optical depth at Djougou. Due to these differences, we do not obtain conclusive comparisons on surface sensible heat fluxes at the local scale and the model is not able to well capture the observed sensible heat fluxes at Djougou. This point is now detailed in the text (section 4.2) by using the following sentence :"Although the model well captures the decrease of sensible heat fluxes at the surface, direct comparisons are not conclusive due to the difference observed between simulated and measured dust optical depth at Djougou (Tulet et al., 2008)". The second explanation could come from the resolution used in our simulations (12*12 km), which is maybe to low and not adapted to estimate correctly the surface fluxes and more specifically the sensible heat fluxes.

p.13 last paragraph. The authors should compute the reduction in the daily averaged

ACPD

9, S1738–S1749, 2009

sensible heat flux simulated at Niamey, and compare this to the reductions inferred from observations at Niamey. Miller et al 2009 (Figure 11) calculate that the daily average sensible heat flux should drop by about 7 W/m2 for a unit reduction in dust AOT, based on observations during March and April of 2006. Are the model values consistent?

U) We observed similar results than mentioned in the previous answer concerning Djougou due to difference in dust optical depth simulated at Niamey (see Tulet et al., 2008). The sensible heat fluxe is very sensitive to dust optical depth and the difference observed in AOD lead to important impacts on simulated H.

p.15 line 13 (see also p.19 line 4) "dust particles are always shown to cool". This is only true for the regional average. Figure 10 (and the text on page 14) shows that in the northern Sahel, the dust effect on upward SW at TOA is to increase the energy trapped within the earth-atmosphere column.

V) This is effectively right and we have now modified this point (section 4.3.1) by using the following sentence: "To summarize, dust particles are shown to heat and/or cool the “ăEarth-Atmosphereă” system in the solar range, depending on the surface albedo. Results of simulations display in the Table 2 indicate that dust aerosols always cool the "Earth-Atmosphere" system (in the solar range) at the regional scale".

p.16-17 (section 5.4.2): The LW cooling simulated by the model should be compared to the value calculated at Niamey by Slingo, A., H. E. White, N. A. Bharmal, and G. J. Robinson (2009), Overview of observations from the RADAGAST experiment in Niamey, Niger: 2. Radiative fluxes and divergences, J. Geophys. Res., 114, D00E04, doi:10.1029/2008JD010497. The authors combined measurements of the surface fluxes by radiometers with OLR retrieved from radiances measured by the SEVIRI instrument. Figure 10c from the Slingo article shows that the divergence increases with aerosol extinction. In addition, the model LW divergence should be compared to the value from Figure 3f of Slingo et al 2006. (One can infer from Figure 3f of Slingo et al. 2006 that the effect of dust is to increase LW cooling by about 50 W/m2). The text should also note that the model LW cooling is influenced by the erroneous downward LW at the surface, and speculate about the value of the model LW divergence were the model downward LW similar to observed values.

W) In the previous version, we included incorrect profiles of the LW Heating Rate. As shown in the new Figure 13, we obtained positive values at the surface, with values comprised between +4 and +9 K by day at the surface. Infrared heating rate values are negative just within the dusty layer with values comprised between -0.10 and -0.30 K by day. This point is now changed in the text (section 4.4.1). Such values are more consistent with those reported by Mohalfi et al. (1998), who reported a value of -1 K by day.

p.16 "values ranging from -6 to -16 K (per) day". It should be noted that these large values are found only at the surface, and that LW cooling decreases to nearly zero within a hundred meters or so above this level. Using a typical dust LW cooling of 50 W/m2 over the entire column during this period as estimated from Figure 3f of Slingo et al 2006, I estimate a column-average cooling of 0.43 K per day, which smaller than the surface value cited by the authors.

X) As reported below, we obtained a cooling effect of -0.20 K per day within the dusty layer (at midday), which is more consistent with the value mentioned by the reviewer.

Figure 13: The axis labels need to be made much larger in this figure. Also, a vertical line corresponding to zero radiative heating should be added so that negative and positive simulated values can be distinguished. (This same comment applies to Figure 12.)

Y)This is now made for the figure 12 and 13.

p.17 lines 5-6 "logically cooled" It is true that there is less upward LW emitted by the surface during the dust outbreak (see Figures 8 and 11 of Miller et al 2009 for the daily averaged reduction). However, there is also increased solar heating of the dust layer

ACPD

9, S1738–S1749, 2009

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

due to absorption. Again, the reduction in air temperature is at least partly a result of the arrival of cold air associated with the front and dust outbreak.

Z) As mentioned below, this is effectively right and we have now included this point in the article (section 4.2).

p.17 line 10 "instantaneous surface cooling of 13C" Over what period of time does the cooling of 13C correspond to?

Z-1) Slingo et al. (2006) refer for the 08 March during the dust outbreak. This is now indicated in the text.

Figures: the color scale isn't consistent among the figures: yellow sometimes corresponds to positive values (Figures 8, 10, 11) and in other figures (Figures 4, 7) to negative values. A consistent scale should be applied to all these figures.

Z-2) These different figures are now modified, with "green-blue"; for negative values and "yellow-orange-red&" for positive values in the Figure 4 and 7.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 2967, 2009.

ACPD

9, S1738–S1749, 2009