Atmos. Chem. Phys. Discuss., 11, C14708–C14714, 2012
www.atmos-chem-phys-discuss.net/11/C14708/2012/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Dust aerosol impact on North Africa climate: a GCM investigation of aerosol-cloud-radiation interactions using A-Train satellite data" *by* Y. Gu et al.

Y. Gu et al.

gu@atmos.ucla.edu

Received and published: 25 January 2012

We appreciate the comments provided by Reviewer 3. Below are our responses to these comments.

This is an interesting, timely and relevant contribution to research on global climate change. More information, however, about the performance of the model (items 1 and2) must be provided before publication. There are also questions and complaints about the clarity of the text. When a paper hits a point around which of several aspects of our field have been spinning, good writing is critical. This GCM study implements attention-getting relationships of aerosols and ice clouds reported by Jiang et al. (2008,

2011). Jiang et al. made a leap by linking the column integrated estimate of AOD from MODIS to the microphysics of ice clouds that occupy a small fraction of columns nearby. I hope that Jiang et al. are mostly correct, as an advance in this area would be welcome. Can we be confident of the claim (Jiang et al., 2008) that "dynamical conditions cannot explain the precipitation differences for the polluted and clean clouds, suggesting that aerosol cloud-precipitation interactions may play a dominant role in contributing to the suppressed rainfall when aerosol is abundant"? With such questions in mind, the reader eagerly jumps into the present Gu et al. manuscript that makes a test with a dynamical model. Unfortunately, the manuscript is not incisive enough, in its approach to a rather subtle problem. Jiang et al. (2011) are aware of the limitations of the current state of the art, for example, when noting "with the better height-resolved aerosol and cloud data from CALIPSO and CloudSat, we will continue this work to provide a height resolved Re parameterization for simulating the aerosol effect on cloud particle size." This manuscript will confuse some readers. The authors are right in describing their topic as "a challenging problem" (see lines 8-11 on page 31405). But they overstate by claiming that "Inadequate understanding of the relationship between microphysics and dynamical processes" is "due primarily to the lack of accurate global-scale observations." We actually lack the proper atmospheric observations at ANY scale.

In response to the reviewer's comments, we have added in the revision some discussion on the limitation of the De-IWC-AOD relationships employed in this study. These relationships (Jiang et al., 2011) have been derived from the climatological satellite data and are the same throughout the year. Their seasonal variation and its impact on climate simulations will require further analysis. Also these relationships were derived by using the IWC at 215 hPa, because ~200 hPa is approximately the level of convective detrainment and the IWC there is proportional to convective intensity. In order to parameterize De in a vertically inhomogeneous atmosphere, substantial research is needed and will be a subject of further investigation. Following the reviewer's comment, we have added some discussion regarding uncertainties in the application of De-IWC-AOD relationships to climate model studies (page 12, lines 308-314).

Results must be more carefully qualified and the reader duly cautioned. Investigations from decades earlier (i.e., Liou and Ou, 1989, referenced in the manuscript) used simple one-dimensional models which were adequate for calling attention to the problem. A more recent study of related effects for liquid water clouds referenced in this manuscript (Johnson et al., 2004) employed a large-eddy model. Here we have only a coarse resolution, 4 degree by 5 degree GCM. Can the essential aerosol-cloud radiation physics that is the focus of the manuscript be convincingly modeled at this coarse scale? Perhaps it can. But the authors must show us the degree to which the GCM physics at this scale are credible.

We agree with the reviewer that a higher resolution may be better to demonstrate the regional characteristic of clouds. However, because the focus of this study is on the dust climatic effect in the North Africa region, the current model resolution appears to be sufficient for this purpose. In fact, this type of resolution has been used in numerous climate simulations (e.g., Hansen et al. 2004; Köhler, 1999). Following the reviewer's comment, we have added some justification regarding the use of the current model resolution in the revision (page 7, lines 193-197).

1. How does the OLR and TOA Net Solar flux from the GCM compare with well observed satellite data over North Africa? This should be shown in two new figures (OLR bias of GCM and TOA Net Solar bias of GCM) over 10S-30N and 20W-50E.

The validation of the updated UCLA AGCM with the incorporation of Fu-Liou-Gu scheme in terms of global mean radiation budget, cloud cover, and precipitation and their geophysical distributions, including North Africa region, has been successfully carried out and discussed in our previous studies (see Gu et al. 2003). Please note that the focus of this study is to use a reliable model to perform a number of sensitivity studies to investigate the aerosol direct, semi-direct, and first indirect effects. To assess the performance of global climate models (GCMs) in simulating upper-tropospheric IWC, a

new set of IWC measurements from the NASA Microwave Limb Sounder (MLS) were used to compare with the simulation results determined from several GCMs, including the updated UCLA AGCM with the Fu-Liou-Gu radiation scheme. Results showed that the UCLA AGCM is capable of capturing the global distributions of IWC as compared to MLS data and is among the best in terms of simulated IWC values (Li et al. 2005, Figures 2 & 3). We have added some discussion regarding comparison of the model simulated IWC and available measurements from previous studies using the UCLA AGCM (page 7, lines 180-189).

2. Are the OLR differences (DIR_IND-IND) in Fig. 7c well above the noise level of the GCM? Two more figures (a plot of the interannual variability of OLR in the GCM and another with the same for satellite data) are needed to show that the space-time scale of the study is valid.

In response to this comment, we have performed significance tests. Confidence level for the significance of differences between the sensitivity experiments DIR_IND and IND typically exceeds 95% in association with major changes in the OLR, precipitation, and cloud cover fields in North Africa. Anomalies are shown to be significant in all areas at above 70% level. We have included this additional information in the revision (page 19, lines 522-524).

3. More information is needed in Section 3 (Offline studies starting on page 31413). The IR forcing in Figure 4a is a strong function of cloud altitude, which is not stated. It would also be helpful if the text called out the visible optical depths of the IWP clouds, perhaps at two points in Figure 4a-c and two in Figure 4d-f, for comparison with AOD. I like Figure 4.

The reviewer is correct in that the cloud IR forcing is a function of cloud height. For cloudy conditions, the ice cloud layer for the offline study is placed between 9-11 km. Corresponding to Fig. 4e-f, the visible optical depth of the ice clouds ranges from 0 - 3.75. For Fig. 4a-c, cloud optical depths are 0.75 and 3.0 for IWP = 20 g m-2 and 80 g m-2, respectively. Following the reviewer's comment, information for the cloud height and cloud optical depth has been added in the revision (page 15, lines 374-375; line 379; page 17, lines 413-414).

4. Page 31414 refers to Figure 4a-c with the confusing statement "while semi-direct effect can be inferred from the results for cloudy conditions." The previous page informs these calculations are "off-line", meaning that clouds were assumed a priori, not generated by a GCM under some aerosol condition. To diagnose a semi-direct effect due to aerosols, one would have to run a GCM and then note the cloud response. Figure 4a-c tells nothing about the semi-direct effect. Figure 4a-c would have information about the direct forcing of aerosols to a cloudy column, if we knew the height of the clouds.

It is very difficult to quantify the semi-direct in a GCM setting due to the intricate interactions among different physical processes. For this reason, we have performed off-line simulations to show the semi-direct effect, which has been discussed in some detail in Section 3.

When ice clouds are present simultaneously with dust aerosols, positive IR radiative forcing is enhanced since ice clouds trap substantial IR radiation, while the positive solar forcing with dust aerosols alone has been changed to negative values due to the strong reflection of solar radiation by clouds. This illustrates that cloud forcing could exceed aerosol forcing. With the presence of ice clouds, the solar, IR, and net forcings remain to increase with increasing AOD, but with a much smaller slope. As a result, when AOD is approaching 1.0, the net forcing with the combined aerosol and cloud effects is approximately equivalent to that with dust aerosols alone. This means that under heavily dusty cases, the cloud radiative forcing could be masked by dust direct radiative forcing (page 16, lines 393-404).

In a GCM setting, aerosol absorption of sunlight can heat the lower troposphere and reduce cloud cover and/or cloud IWC. When aerosol loading is small (AOD < 0.2), the net combined aerosol-cloud forcing is particularly significant for IWP = 80 g m-

2. However, the net aerosol-cloud forcing for a smaller IWP becomes substantial and increases with AOD for AOD > 0.2, indicating that the aerosol effect modulates cloud forcing. The aerosol semi-direct effect could exert an extra net forcing of about 10 W m-2 for the heavily polluted case with AOD = 1.0 along with a reduction in cloud IWP from 80 g m-2 to 20 g m-2 (pages 16-17, lines 404-411).

With the aerosol indirect effect, the net cloud forcing is reduced in the case for IWP > 20 g m-2. The magnitude of reduction increases with IWP, with a decrease of about 25 W m-2 in the net TOA forcing for IWP = 100 g m-2 and AOD = 0.8 (page 17, lines 419-421).

In AGCM simulations, differences in OLR follow the patterns in cloud cover and precipitation instead of dust loadings, indicating that the aerosol semi-direct effect plays a critical role in the dust-induced climate change (page 21, lines 517-519).

5. More information about the CTRL, IND and DIR_IND experiments is needed (pages 31415-31416). What is the surface albedo over North Africa? CTRL has "clean" clouds and "direct radiative forcing is not included." In that case, is the "background AOD of 0.1" in CTRL used to parameterize the "clean" clouds? The discussion on the bottom of page 31417 and top of 31418 on overall aerosol effect (direct+semi-direct+indirect) and the indirect effect only is interesting. But in the Conclusion that follows, there are statements for which I could not easily find support in the manuscript. Examples follow.

In the UCLA AGCM, the surface albedo and roughness length are specified following Dorman and Sellers (1989). This information has been added in the revision following the reviewer's comment (page 6, lines 175-176).

In the Control run, AOD of 0.1 is used in the parameterization of De. The direct radiative forcing of aerosols is not included.

6. The Conclusion states on page 31418 "When ice clouds are present, the aerosol semi-direct effect plays an important role." Where is this demonstrated?

It can be inferred from the off-line study that the aerosol semi-direct effect could exert an extra net forcing of about 10 W m-2 for heavily polluted case with AOD = 1.0 along with the reduction in cloud IWP from 80 g m-2 to 20 g m-2 (page 17, lines 409-411). In AGCM simulations, differences in OLR follow the patterns in cloud cover and precipitation instead of dust loadings, indicating that the aerosol semi-direct effect plays a critical role in the dust-induced climate change (page 21, lines 517-519).

7. The Conclusion states on page 31418 "In a GCM setting, aerosol absorption of sunlight heats the lower troposphere and reduces cloud cover and cloud ice water amount." The difference between experiments DIR_IND and IND should illustrate the impact of the aerosol absorption of sunlight. Then why is cloud cover enhanced (not reduced) in Figure 7b?

It can be seen from Fig. 7 that the change in cloud cover (Fig. 7b) shows a similar pattern to that in precipitation in association with the change in convection strength, in which the cloud cover over the ITCZ was reduced due to the semi-direct effect, while the increased cloud cover and precipitation were found south of the ITCZ (page 21, line 517-519).

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 31401, 2011.