

## ***Interactive comment on “A mechanism for dust-induced destabilization of glacial climates” by B. F. Farrell and D. S. Abbot***

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Replies to the reviewer’s comments follow:

"The authors should either clarify if and how they are considering dust-longwave interactions or include them in their simulations."

We do not dispute that large aerosols have long wave interactions that would oppose the radiative effects of small aerosols. However, the mechanism we propose is based on a small aerosol layer being established and stabilized hemispherically in the midtroposphere, while large aerosols are primarily confined to the vicinity of source regions.

We have added the following to the paper:

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“The SCAM model assumes small aerosols which interact primarily with short wave radiation while large aerosols have substantial long wave cross-section that would tend to oppose the upper level heating and surface cooling effect of the small aerosols involved in the dust feedback destabilization. However these large aerosols are concentrated primarily in the vicinity of source regions and it is the small ( $D_d < 2\mu$ ) aerosols that have long life- times, interact primarily with short wave radiation and produce strongly negative radiative forcing [2]. We are proposing that a hemispheric to global scale upper atmosphere layer of these fine aerosol particles was established and stabilized by feedbacks arising from the small aerosols suppression of precipitation which both decreased scavenging of aerosols and increased aridity in dust source regions. Large aerosols are confined to source regions and are rapidly removed from the column which would leave behind the small aerosol with their primarily short wave absorption properties.”

“...the choice of the range of values for the dust factor should be more accurate...”

As stated by Kohfeld and Harrison (2001): “During glacial climate stages, the world was much dustier, with dust fluxes two to five times greater than in interglacial stages” As we have pointed out in the paper and in our replies to previous reviews, this measured dust flux provides a lower bound on the column dust load in the mechanism we are proposing because the precipitation scavenging is inhibited.

We have added references to [1] and to [3] to the paper.

"p. 1723, l.1-3: The text Greenland ice cores... and reference Lambert et al., 2008 don't match..."

We changed this to: “Antarctic and Greenland...”

"p. 1723, l. 3-5: atmospheric dust co-varies with precipitation on the same time scale. Precipitation where?"

The precipitation is directly measured in Greenland by layer counting. We have

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changed the reference to [4] in which the case is made clearly: “Annual layer thickness I (estimated independently of d18O by annual layer counting) increased by 40% during the two warmings over 3 and 40 years, respectively”

"p. 1723, l. 7-11: it seems rather unclear which the link between these sentences, and the relation they have in the context of the paragraph, as they refer to disparate time scales than the main discussion"

Direct evidence of precipitation rate is only available from ice cores but indirect evidence that drying was widespread, and dust sources widely mobilized, during glacials is common in the proxy record and this fact is being referenced here.

"p. 1723, l. 11-15: yes it may be consistent, but is it the only factor contributing?"

We are only aware of precipitation as a factor on the time scale of abrupt change, on longer time scales glacier advance and sea level change could also have played a role.

"p. 1724, l. 26 p. 1725, l. 4: please deal somehow with the dust-longwave interactions problem."

This comment has been addressed above.

"p. 1725, l. 12-16: A 2-8 increase in dust input into the atmosphere cannot be simply labeled as laying well within the the range of estimated dust source increase seen in the proxy records during cold Pleistocene periods..."

The reviewer argues that the dust record in ice cores can be differently interpreted due to modifying influences of wet and dry deposition etc. We believe that such caveats are respected by our use of the qualifier "...within the range of estimated...". It is beyond the scope of this paper to critique differing interpretations of the dust proxy record. Moreover, the mechanism we propose requires no specific increase in the rate dust is input into the atmosphere as the residence time is equally as important as the input rate in determining the column dust load.

"p. 1726, l. 1-2 p. 1727, l. 1-7: the Observables section should be expanded by comparing to the relevant literature on the three predictions."

These physical consequences are predictions of the theory but this paper's purpose is to introduce this theory not to critique various contentious interpretations of the proxy climate record and it would be beyond the scope of this paper to review the literature on such issues as the hemispheric extent of precipitation during glacials.

"p. 1727, l. 13-15: while large uncertainties exist both in the observational estimates of dust deposition fluxes and in models, the ratio in Mahowald et al. (2006) is evaluated over a broad range of deposition fluxes worldwide (see also Mahowald et al., 2011), and is in relatively good agreement with the observations. Such kind of comparison should probably be included into this work to evaluate the plausibility of realization of the proposed range of the dust factor. This does not rule out at all the proposed mechanism."

In this paper we advance a mechanism that we describe as "plausible" for explaining the enigmatic abrupt climate change events. We argue that the values of dust parameters taken are compatible with the proxy record. It is beyond the scope of this work to critique controversies in the interpretation of the proxy record.

"p. 1728, l. 24-29: same as the temperature bipolar seesaw, given the temperature-dust association both in Greenland and Antarctica, dust maxima in the alternation of stadial/interstadial periods are in anti- phase in Greenland and Antarctic ice cores (e.g. EPICA community members, 2006). Please discuss this fact, and if the authors implied that the mechanism may be controlled by one hemisphere in particular, this should be noted explicitly and discussed more."

In the "paper we state: "This observation [bipolar seesaw] is in agreement with the role of the North Atlantic THC in producing global teleconnections and as an important component of the sequence of events associated with abrupt climate change."

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[1] K. Kohfeld and S. Harrison. DIRTMAP: the geological record of dust. *Earth Science Reviews*, 54:81–114, 2001.

[2] J. F. Kok. A scaling theory for the size distribution of emitted dust aerosols suggests climate models underestimate the size of the global dust cycle. *Proceedings of the National Academy of Sciences*, 108:1016–1021, 2011.

[3] B. Maher, J. Prospero, D. Mackie, and D. Gaiero. Global connections between aeolian dust, climate and ocean biogeochemistry at the present day and at the last glacial maximum. *Earth-Science Reviews*, 99:61–97, 2010.

[4] J. P. Steffensen, K. K. Andersen, M. Bigler, H. B. Clausen, D. Dahl-Jensen, H. Fischer, K. Goto-Azuma, M. Hansson, S.J. Johnsen, and J. Jouzel. High-resolution Greenland ice core data show abrupt climate change happens in few years. *Science*, 321(5889):680–684, 2008.

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