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Interactive Comment

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

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I welcome the interesting proposal of Farrell and Abbot concerning the role of dust forcing in explaining high-amplitude millennial-scale climate variability. However, I find their modeling results unconvincing for the reasons set forth below.

Based on the information provided in the manuscript, Farrell and Abbot's modeling with the Single Column Atmospheric Model (SCAM) does not consider the radiative effects of dust in the longwave. CAM3, the basis for SCAM, does not consider the longwave effects of dust; except for volcanic aerosols, aerosols like dust "affect the shortwave energy budget of the atmosphere" alone (Collins et al., 2004, p. 6). Indeed, CAM3 had to be specifically modified by Mahowald et al. (2006a) to include longwave effects.

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Dust scatters and absorbs longwave radiation as well as shortwave radiation (Sokolik and Toon, 1999). As an infrared absorber, dust acts like a greenhouse gas, absorbing and re-emitting infrared radiation in a fairly broad spectral interval, sometimes at a lower temperature than the surface, thereby reducing outgoing longwave radiation and enhancing downwelling radiation at the surface (Yoshioka et al., 2007). These effects are especially pronounced near desert dust source regions, since coarse dust absorbs better than fine dust (e.g., Wang et al., 2006); coarse dust has a very short atmospheric lifetime because of the dependence of the gravitational settling velocity on the square of the radius; and water vapor is typically low in concentration in deserts, making the atmosphere unusually transparent in the infrared (Yoshioka et al., 2007).

Simulations of dust radiative forcing in global climate models suggest that the net effect of atmospheric dust loading over source regions is to make the atmosphere a far better longwave emitter than it would ordinarily be, counteracting much of the effects of shortwave atmospheric heating. This effect also has been inferred from remote sensing observations of an outbreak of Saharan dust over the Mediterranean, where it is estimated that the longwave cooling effect compensated for ∼77% of the shortwave heating effect in the atmosphere over the Mediterranean island of Lampedusa (di Sarra et al., 2011). In addition, downwelling longwave radiation from dust compensates for much (and perhaps all) of the shortwave surface heating over dust source regions (Yoshioka et al., 2007). Away from dust source regions, longwave effects become less important, and the radiation budget is generally set by the shortwave effects. There are significant uncertainties in estimating the longwave effects, including the mineralogical ones mentioned in this manuscript, as well as uncertainties in the size distribution of dust when emitted (Kok, 2011). If Kok (2011) is correct, the longwave cooling effects of dust for the atmosphere are probably significantly underestimated.

If longwave effects indeed have been omitted, the omission has critical implications for the results presented here and the underlying theory. Farrell and Abbot argue that shortwave radiative effects of dust can produce a feedback cycle, in which: (1)

dust loading shields the surface from shortwave radiation, thereby reducing evaporation and thus precipitation; (2) higher dust loading enhances shortwave heating in the mid-troposphere, thereby stabilizing the atmosphere against moist convection and scavenging of the mid-tropospheric dust. The combined effect of (1) and (2) is to reduce precipitation, activate new dust sources, and reduce the wet deposition lifetime, thereby enhancing dust loading and closing the feedback. Longwave radiative effects, as discussed above, will tend to mute the effects of both (1) and (2), particularly in land areas near dust sources.

In the case of (1), the omission of longwave heating may appear to be an irrelevant objection to the hypothesis, since most evaporation occurs over the ocean, where the shortwave radiative forcing by dust is not as strongly compensated by downwelling longwave radiation from dust. However, Farrell and Abbot propose dust loading increases by 5-20x or more during glacials. Modeling by Mahowald et al. (2006b) suggests that global dust loading at the Last Glacial Maximum was, at most, 2.5x present. Farrell and Abbot answer this objection by noting that Mahowald et al. (2006b) underestimate dust deposition in continental interiors by one to three orders of magnitude. However, the simulations of Mahowald et al. (2006b) match the marine records fairly well. Therefore, to agree with the reconstruction of Mahowald et al. (2006b), increases in dust loading invoked by the manuscript would need to have been tightly restricted to continental interiors, where dust would have impacted the global evaporation budget much less than if it were more globally distributed, due to the compensating effects of downwelling longwave radiation from dust on the surface energy budget.

I do not think my objections are at all fatal to Farrell and Abbot's proposal. Much of my argument depends on the details of dust properties in the longwave, assumptions about how dust is distributed spatially and in size, and how longwave radiative forcing would change the vertical heating/cooling structure relative to shortwave forcing alone. At least at loadings relatively similar to the modern, simulations that include longwave effects suggest that greater dust loading results in some net global cooling and drying

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(Mahowald et al., 2006a). In addition, extremely high dust loadings would saturate longwave optical paths in the upper troposphere, which could produce strong longwave atmospheric heating by dust. The more critical question is whether the transitions between State 1 and State 2 or State 2 and State 3 in the manuscript realistically occur at mean tropical dust loadings as low as those proposed. If I am correct that the longwave radiative effects of dust have been neglected in the modeling presented here, these state transitions may occur at much higher dust loadings. The authors are well-placed to take the first necessary step to answer this question by considering the longwave effects of dust, as well as the variation in dust profiles near and far from source regions, in their modeling with SCAM.

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