Dependence of Radiative Forcing on Mineralogy in the Community Atmosphere Model

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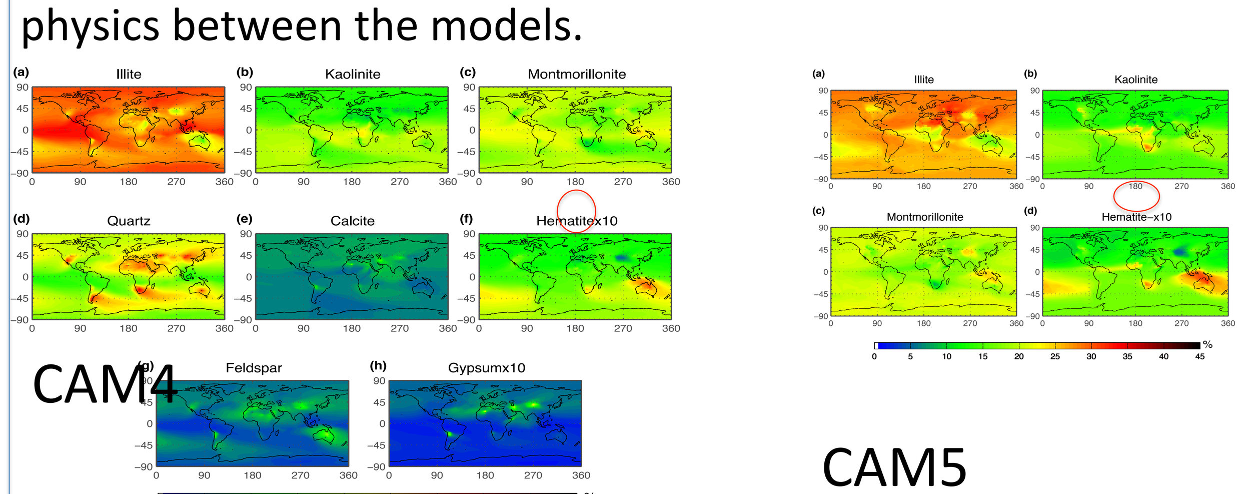
Abstract: The mineralogy of desert dust is important due to its effect on radiation, clouds and biogeochemical cycling of trace nutrients. This study presents the simulation of dust radiative forcing as a function of both mineral composition and size at the global scale using mineral soil maps. Externally mixed mineral aerosols in the bulk aerosol module in the Community Atmosphere Model version 4 (CAM4) and internally mixed mineral aerosols in the modal aerosol module in the Community Atmosphere Model version 5.1 (CAM5) embedded in the Community Earth System Model version 1.0.5 (CESM) are speciated into common mineral components in place of total dust. The simulations with mineralogy are compared to available observations of mineral atmospheric distribution and deposition along with observations of clear-sky radiative forcing efficiency. Based on these simulations, we estimate the all-sky direct radiative forcing at the top of the atmosphere as +0.05 Wm^{-2} for both CAM4 and CAM5 simulations with mineralogy and compare this both with simulations of dust in release versions of CAM4 and CAM5 (+0.08 and +0.17 Wm^{-2}) and of dust with optimized optical properties, wet scavenging and particle size distribution in CAM4 and CAM5, -0.05 and -0.17 Wm^{-2}, respectively. The ability to correctly include the mineralogy of dust in climate models is hindered by its spatial and temporal variability as well as insufficient global in-situ observations, incomplete and uncertain source mineralogies and the uncertainties associated with data retrieved from remote sensing methods.

Methods:
The CAM4 and CAM5 versions of the Community Atmospheric Model include bulk aerosols (CAM4) and modal aerosols (CAM5) which include multiple types of aerosols, including desert dust or mineral aerosols (Zender et al, 2003; Mahowald et al., 2006; Liu et al., 2011; Neale et al., 2013; Albani et al., submitted). Both CAM4 and CAM5 are modified to allow for the carrying of speciated types of dust, allowing for differences in the radiative properties of minerals to be included in the simulation. Different minerals of dust can have very different radiative properties in both the short and long wave, from dark red to clear in the visible, for example (e.g. Sokolik et al., 1999). Mineral distributions in the soils are distributed based on soil types, using the approach of Claquin et al., 1999. 5 different minerals are included in CAM5 (MAM) while 8 are included in CAM4 (BAM). Simulations are conducted using MERRA reanalyzed winds for 8 years, 2 which are neglected for spin up. Simulations are conducted at roughly 2x2 degree resolution.

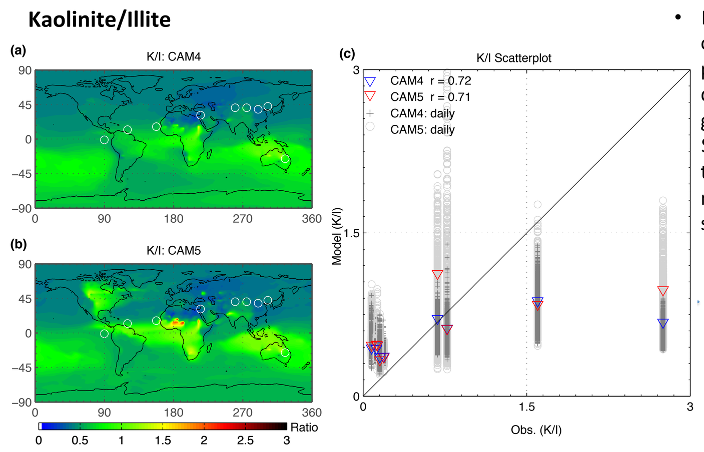
Results: Total column mineral distributions:
The distributions for the models forced with identical source distributions but the physics of transport and deposition differ between CAM4 and CAM5. Notice the very different amounts of hematite in the Sahel region, even with the same meteorology, due to differences in the physics between the models.



Unfortunately, there is limited atmospheric aerosol mineral data for comparison against the model. Here we show a sample of the limited comparisons available. Overall, they suggest the model has some accuracy, but improvements could be made.

Results: Mineral Ratio comparison

Kaolinite/Illite



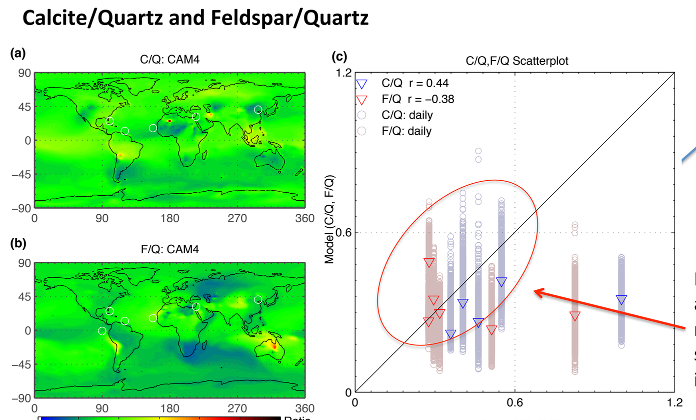
- For most observations, particle size distribution is not given
  So we compare the **ratio** of minerals with similar sizes

Model not capturing the dynamic range seen in observations

Kaoline/Illite mineral ratio of mineral mixing ratio at the surface from CAM4 and CAM5 (kg K/kg I) compared to bulk obervational ratios. Observations from Shen et al., (2005), Prospero and Bonatti, (1969), Caquineau et al. (1998), Kiefert et al., (1996), Falkovich et al. (2001).

Results: Mineral Ratio comparison

Calcite/Quartz and Feldspar/Quartz

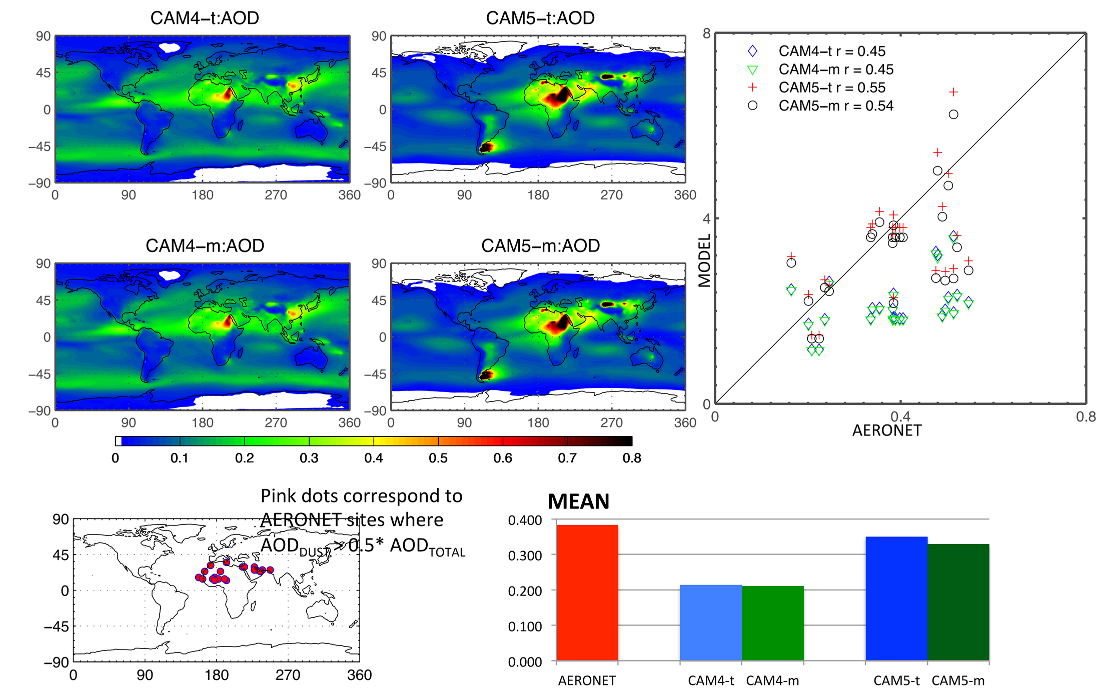


Again notice lack of dynamic range in monthly averaged model data

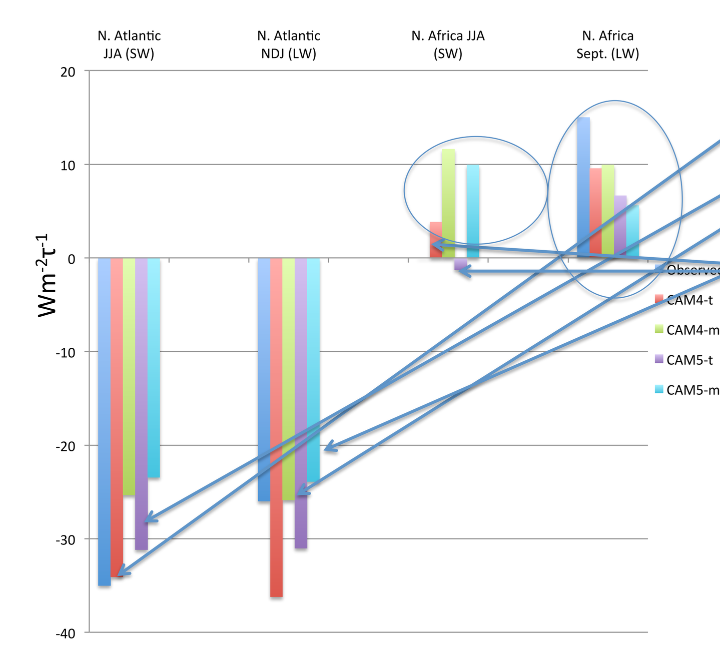
Daily averaged model output shows some improvement

Calcite/Quartz and Feldspar/Quartz mineral ratio of mineral mixing ratio at the surface from CAM4 and CAM5 (kg K/kg I) compared to bulk obervational ratios. Observations from Glaccum and Prospero (1980), Prospero and Bonatti, (1969), Falkovich et al. (2001), Shi et al., (2005).

Results: AOD AERONET vs Model



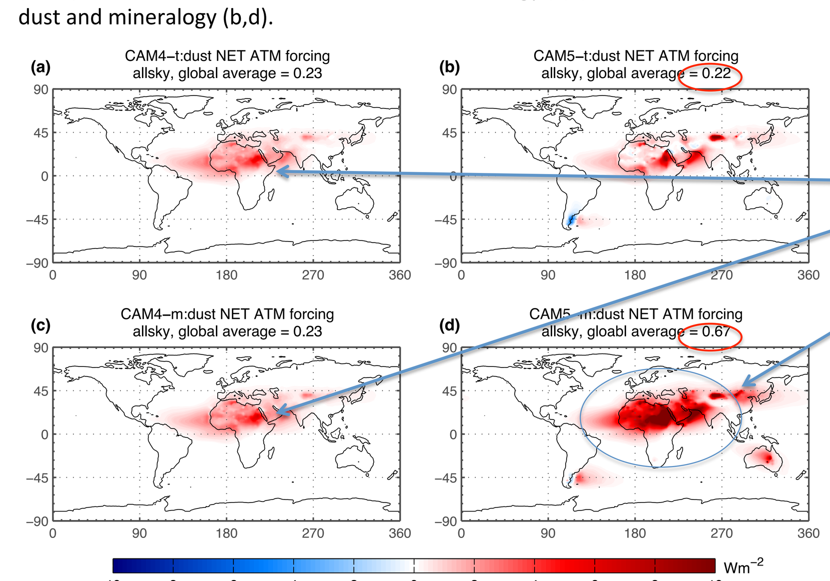
Results: Radiative Forcing Efficiency



- Observations from Li et al., 2004 over N. Atlantic:
  - CAM4t and CAM5t match observed during summer
  - CAM4m and CAM5m match during winter
- Patadia et al. observed RFE of zero over N. Africa summer
  - CAM4t and CAM5t are close to 0
  - CAM4m and CAM5m predict heating
- Chistopher and Zhang (2004) estimate LW RFE during September
  - Quartz dominates LW absorption but this property has not been included
  - All model simulations neglect scattering in LW

Results: All-sky Radiative Forcing

Spatial distribution of annual all-sky radiative forcing (SW+LW) in the atmosphere (ATM) for CAM4 with tuned dust and with mineralogy (a,c) and for CAM5 with tuned dust and mineralogy (b,d).

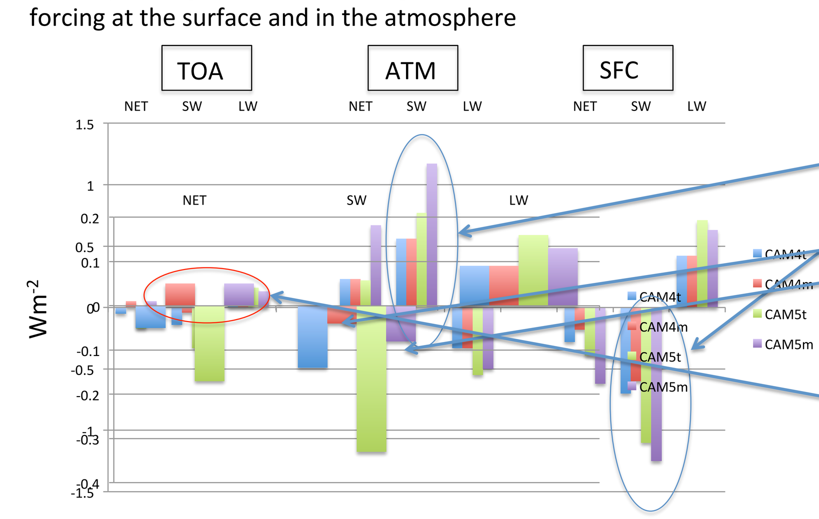


Similar heating in CAM4t and CAM4m

CAM5m → absorbing hematite results in 3X the heating in the atmosphere compared to CAM5t

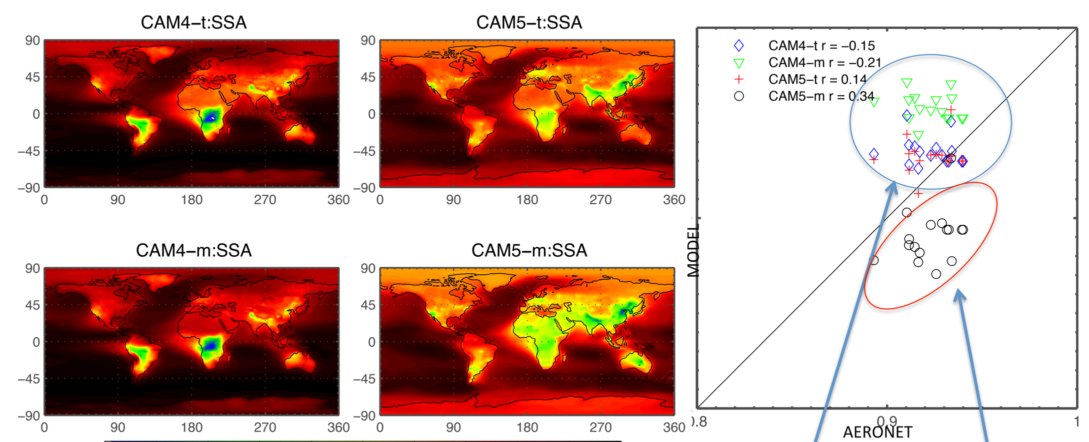
Results: Mean All-sky Radiative Forcing

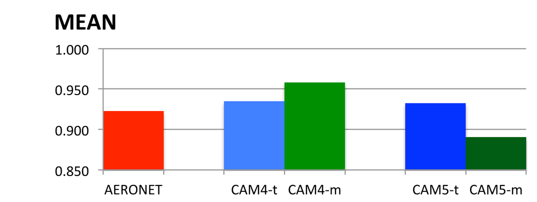
Globally averaged radiative forcing at TOA is a delicate balance between SW and LW forcing at the surface and in the atmosphere



- SW forcing dominates ATM and SFC forcing
- While CAM4m and CAM5m in SW has a small negative forcing at TOA, the overall impact from SW and LW is small positive heating

Results: SSA AERONET vs Model

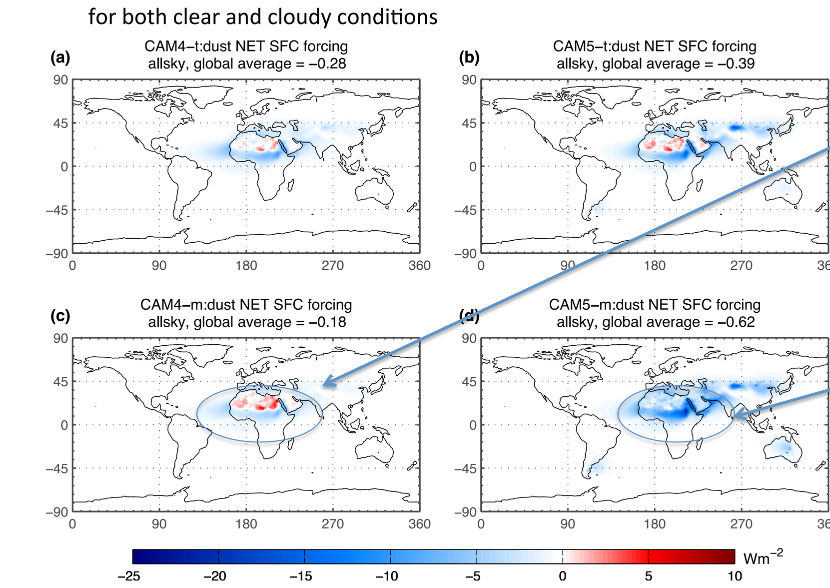




- SSA controls the amount of absorption vs scattering of particles, hematite and black carbon have very low SSA→ they dominate the absorbing nature of aerosols
- Note lack in dynamic range for CAM4t, CAM4m and CAM5t
- CAM5m is too absorbing, however it better captures the range seen in AERONET

Results: All-sky Radiative Forcing

- All-sky radiative forcing is a measure of the radiation balance from the scattering and absorption of incoming solar radiation and diffuse long wave radiation from the Earth's surface for both clear and cloudy conditions



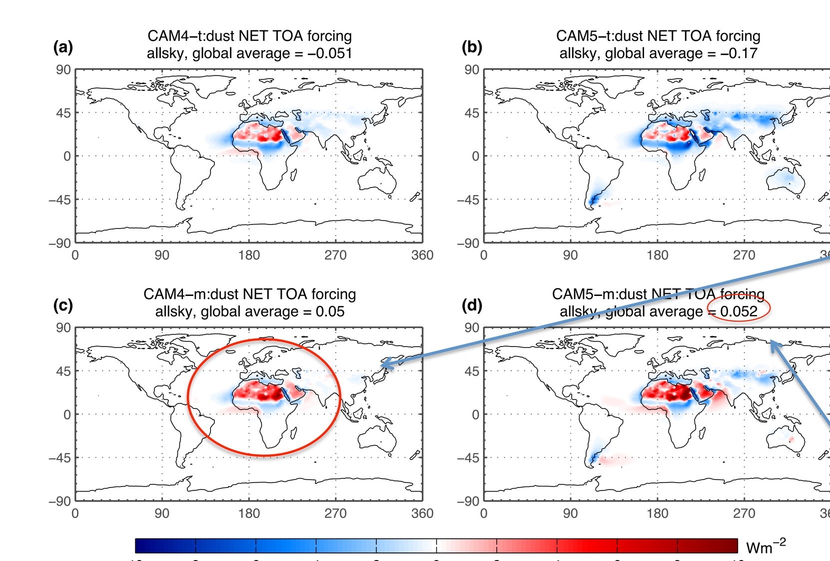
Spatial distribution of annual all-sky radiative forcing (SW+LW) at the surface for CAM4 with tuned dust and with mineralogy (a,c) and for CAM5 with tuned dust and mineralogy (b,d).

Less cooling at surface in CAM4m→ CAM4-t is more absorbing hence cools more

Significant cooling at surface in CAM5m → absorbing hematite decreases insolation reaching surface

Results: All-sky Radiative Forcing

Spatial distribution of annual all-sky radiative forcing (SW+LW) at the top of atmosphere (TOA) for CAM4 with tuned dust and with mineralogy (a,c) and for CAM5 with tuned dust and mineralogy (b,d).



- Similar atmosphere RF for CAM4t and m however differences in surface forcing lead to an overall heating at TOA
- Increased cooling at surface in CAM5m is compensated by increased atmospheric heating and an overall positive forcing at TOA

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(Full paper submitted to ACPD with full bibliography

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