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Trade-offs of simplified versus comprehensive representation of mineralogy when studying dust impacts on Earth's climate systems

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The intensity and direction of dust impacts on Earth's climate systems depend on mineral composition. For example, the presence or absence of a few percent of iron oxides in dust will determine if dust is warming or cooling the atmosphere. Similarly, feldspar will enhance ice cloud formation, while acid gases in the atmosphere will react on the surface of dust calcite limiting acid rain. Still, most climate models use a simplified representation of dust mineralogy. They assume a fixed composition at emission which stays invariant during transport and removal. Such simplification assumes spatially and temporally constant physical and chemical properties of dust, and appears to provide satisfactory results when comparing some properties with observations. The trade-off is their lack of spatial gradients, which will fail to induce circulation, cloud and precipitation changes. The two reasons to omit mineral variations are the uncertainty of current atlases of soil mineral composition in arid regions, and, more practically, an improved runtime efficiency. The former reason is losing ground with the recent launch (July 2022) of a dedicated mission (NASA/JPL EMIT) to retrieve global soil mineralogy of dust sources at high spatial resolution.

While the EMIT science team is finalizing a satisfactory global map of mineral composition of dust sources, we analyzed the interaction of dust mineralogy on radiation and its impact on the fast temperature response using different representations of mineral composition from detailed and spatially varying to simplified and globally uniform, assuming different hematite contents and methods to calculate optical properties.

Our results show that resolving dust mineralogy reduces dust absorption, and results in improved agreement with observation-based single scattering albedo (SSA), radiative fluxes from CERES (the Clouds and the Earth's Radiant Energy System), and land surface temperature from CRU (Climatic Research Unit), compared to the baseline bulk dust model version. It also results in distinct

radiative impacts on Earth's climate over North Africa. From our 19-year simulation, we will show that it leads to a reduction of over 50% in net downward radiation at top of atmosphere (TOA) across the Sahara and an approximately 20% reduction over the Sahel. We will explain how the surface temperature response affects the monsoon flow from the Gulf of Guinea.

Interestingly, we find similar results by simply fixing the hematite content of dust to a globally uniform value of 0.9% by volume. We will discuss the underlying reasons for such results and show that they may be unrelated to the distribution of soil mineralogy. Still, an accurate representation of soil mineralogy is necessary to better understand dust impacts on the Earth's climate systems.