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The impact of dust on the Neoproterozoic climate

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The land surface during the Neoproterozoic (1000 – 540 million years ago; Ma) should be more susceptible to dust emission than that of the present day since land plants have not evolved yet during that time. The impact of dust on the Neoproterzoic climate, however, to the best of our knowledge has not been studied. This impact could have important implication to the formation of snowball Earth events that occurred in the late Neoproterozoic. As an initial investigation, we use a fully coupled atmosphere-ocean general circulation model to study the sensitivity of the Neoproterozoic climate to different land surface erodibility. The model employed in this study is CESM1.2 developed by the National Center of Atmospheric Research's (NCAR), and is run at F19g16 horizontal resolution. The atmospheric component of the model is CAM4, in which dust is arranged into four size bins (0.1–1.0, 1.0–2.5, 2.5–5.0, and 5.0–10 μm diameter), and the volume fraction emitted into each bin is independent of wind speed, and distributed following brittle fragmentation theory. The emission, transportation, dry and wet deposition processes of dust, as well as its impact on the snow albedo, are all simulated by the model. Only the direct and semi-direct radiative effect of dust is considered in this version of the model. The solar luminosity is assumed to be 94% of the present-day value. The concentration of CO_2, CH4 and N2O are set to be 2000 ppmv, 805.6 ppbv and 276.7 ppbv, respectively. The super-continental configuration for the 720 Ma is employed. The land surface is characterized as desert, but the surface erodibility is set to 0, 0.0375, 0.07, 0.15, and 0.3 in four simulations, respectively. The global mean optical depth due to dust in the visible band obtained by model is 0, 0.312, 0.504, 0.764, and 1.36 in the four sensitivity runs, respectively. Therefore, even with mild surface erodibility, the optical depth due to dust alone is much greater than that ($\sim$0.15) due to all the aerosols on the present-day Earth. The global mean temperature decreases dramatically from 15°C when there is no dust to 3.3°C when the surface erodibility is set to 0.0375. It decreases further to 0.0°C and -2.5°C when the surface erodibility is increased to 0.07 and 0.15, respectively. The temperature even decreased to -5.4°C when erodibility is increased to 0.3. Such large effect means that previous estimates for the CO_2 threshold for the formation of snowball Earth events might need to be increased substantially. Moreover, it is found that the distribution of sea-ice thickness is significantly impacted by the presence of dust, and shows some strikingly different patterns than when there is no dust.