We monitor aerosols today using ground-based and satellite-borne remote sensing devices, and by in situ sampling on the ground and via aircraft, both at local and global scales (for example, the NASA Global Aerosol Climatology Project). But, despite the large number of observations of aerosols, there are large uncertainties in their distribution in space and time and their characteristics, because of their variability in space, time, and composition (Mahowald et al. 2001, Formenti et al. 2011). In addition, aerosol deposition can be studied using passive or human-made collectors, such as snow pits or marine sediment traps (Kohfeld and Harrison 2001). Increasingly complex atmospheric transport and chemistry models and Earth-system models complement the set of tools for the study of the aerosol-climate interactions (Stier et al. 2006).

In its fourth assessment report, the Intergovernmental Panel on Climate Change (IPCC) noted that the direct effect – by scattering and absorption of solar and terrestrial radiation – leads to an RF value of 0.55 W m⁻² compared to the +1.7±0.1 W m⁻² estimated for rising CO₂ levels (Forster et al. 2007). The net simulated climatic effect of dust and other natural aerosols can be additionally enhanced by the additional absorption of outgoing long-wave radiation by dust particles (Takemura et al. 2007). Paleoclimate records spanning the last 130,000 years reveal large increase in dust sources during glacial terminations (Mahowald et al. 2006). The new generation of Earth system models therefore requires the incorporation of these processes into the next generation of Earth system models.

Paired Perspectives on Global Change

Paleoclimate records spanning the past several million years reveal large variability in the deposition of aeolian dust and other natural aerosols. Understanding this variability represents both a challenge and a useful test for Earth system models. The production, transport and deposition of natural aerosols are controlled by numerous physical and biogeochemical processes that are still not well understood. On the other hand, aerosols affect the climate via a number of physical and biogeochemical processes (see the accompanying article by Albani and Mahowald). On short time scales (several years), sulfate aerosols from volcanic eruptions play a significant role in forcing climate. On longer time scales, it is believed that climate-aerosol feedbacks amplify climate changes caused by other factors, such as changes in Earth’s orbital parameters and concentrations of greenhouse gases. Variability of the dust cycle is especially significant at glacial-interglacial time scales (Fig. 1). Paleoclimate data and model simulations suggest that during the Last Glacial Maximum (ca. 21,000 years before present) dust deposition in tropics was several times higher than at present and over Antarctica and Greenland the dust deposition rates increased by more than an order of magnitude. Such large increases in atmospheric dustiness cannot be explained without invoking a large increase in dust sources during glacial times (Mahowald et al. 2006).

Aerosols and climate - How sensitive is earth’s climate to atmospheric aerosols?

Aerosols are a potent source of feedbacks to the climate (Carslaw et al. 2010). The impact of stratospheric aerosols on climate is seen in the response of the surface cooling to large volcanic events (e.g. Mt. Pinatubo), which can be as large as -0.2°C globally averaged (Robock 2000). Because of the potency of aerosols for climate perturbation, they are also being considered for tools in geoengineering the climate (e.g. Shephard et al. 2009).

Humans have significantly increased the amount of aerosol in the atmosphere over the last 130 years. In the future, because of public health concerns as well as efforts to reduce combustion of fossil fuels, it is likely that emissions of anthropogenic aerosols will decrease (Fig. 1). This reduction in aerosols in the future is likely to both increase the rate of warming (Andreae et al. 2005), as well as make reductions in carbon dioxide harder to achieve (Mahowald 2011), because of the complicated and central role of aerosols in modulating climate and biogeochemistry.

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Figure 1: Modeled dust deposition under preindustrial climate conditions (left) and Last Glacial Maximum (right) based on Mahowald et al. (2006).

Figure 1: Historical and projected aerosol emissions relative to 2000 AD emissions. Sulfur dioxide forms sulfate aerosols, while about half the ammonia and nitrogen oxides form nitrogen-based aerosols in the atmosphere. Carbonaceous aerosols include both black and organic carbon and the estimated emissions here do not include secondary aerosol formation in the atmosphere. Calculations based on Mahowald (in press).