Arctic climate: Unique vulnerability and complex response to aerosols

Mark G. Flanner
Department of Atmospheric, Oceanic & Space Sciences
University of Michigan, Ann Arbor MI

Aerosols play a unique and complex role in Arctic climate. Here we summarize the current understanding of Arctic aerosol forcing mechanisms and present recent studies characterizing the Arctic climate response to aerosol forcings exerted over different spatial and temporal domains. Because of the pervasiveness of reflective clouds, snow, and sea-ice within the Arctic, direct radiative forcing by aerosols is inherently more positive in the Arctic than elsewhere. Over pure snow, essentially all aerosol mixtures other than pure sulfate exert a positive top-of-atmosphere forcing. Extremely small concentrations of absorptive aerosols (including black carbon, brown carbon, and mineral dust) exert further positive forcing when they deposit to snow and sea-ice because multiple scattering of photons by ice grains enhances the probability of photon—impurity encounters. Indirect aerosol forcings are also unique and uncertain. Counteracting the first and second indirect effects on shortwave cloud forcing, Arctic aerosols also exert a positive longwave forcing by increasing the emissivity of clouds. This effect is only substantial in optically thin clouds, which prevail over much of the Arctic.

Despite the likelihood of positive aerosol forcing within the Arctic, it is still unclear how local climate responds to Arctic forcing. Observations show slight declines in absorptive aerosols within the Arctic atmosphere and snowpack over the last 30 years, coincident with strong Arctic warming. One source of complexity in linking radiative forcings to local climate effects is that the seasonality of Arctic insolation and surface energy components is extreme, implying very different roles for shortwave and longwave forcing mechanisms. One set of GCM studies indicates that Arctic surface air may cool in response to positive atmospheric aerosol forcing, owing to changes in meridional energy transport that result from direct atmospheric heating (*Shindell and Faluvegi*, 2009). This result demonstrates an important role for dynamics in linking local Arctic climate change to forcings. Conversely, strong warming is expected in response to surface forcings caused by cryosphere darkening because 1) the forcing tends to be largest coincidentally with maximum seasonal melt rates, helping drive snow/ice albedo feedback that amplifies surface energy anomalies, and 2) atmospheric stability in the Arctic helps constrain surface energy anomalies to the near-surface atmosphere, enhancing the local temperature response. Here we will discuss recent experiments that apply the NCAR Community Earth System Model to characterize the sensitivity of Arctic climate to within-Arctic and extra-Arctic atmospheric forcing and surface darkening from absorptive aerosols.