

Distinct impacts of climate forcings on Arctic sea ice since the mid-twentieth century

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Arctic sea ice has undergone non-monotonic changes since the mid-twentieth century, with relatively small changes before the 1980s followed by rapid decline in subsequent decades. We leverage historical all-forcing and single-forcing large-ensemble simulations with CESM1, together with CMIP5 and CMIP6 models, to isolate the impacts of well-mixed greenhouse gases, anthropogenic aerosols, and biomass burning on Arctic sea ice. From 1956 to 1980, the greenhouse-gas-induced sea ice decline was largely compensated by aerosol-induced sea ice growth, resulting in minimal net changes. This balance was disrupted during 1981–2005, when intensified greenhouse-gas warming and a transition in the role of anthropogenic aerosols jointly contributed to pronounced sea ice loss. Sea ice volume budget analysis further shows that these changes are primarily driven by thermodynamic processes. Greenhouse gases enhance summer surface melting, whereas aerosols and biomass burning reduce it through changes in surface shortwave radiation. Meanwhile, forcing-induced changes in the Atlantic Meridional Overturning Circulation modify ocean heat transport and basal ice growth and melting. Together, these processes highlight the combined roles of local radiative forcing and remote oceanic adjustments in shaping Arctic sea ice change.

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