

## Arctic surface air temperature changes in the 20th century by climate models and observations

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Observed decadal mean surface air temperatures (SAT) in the Arctic in the 20th century increase during 1910-1940, decrease during 1940-1970 and increase rapidly since 1970. This change is different from a monotonic increase of carbon dioxide concentration. We conducted the multi-model analyses using state-of-the-art climate models participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6) and CMIP6 Detection and Attribution Model Intercomparison Project (DAMIP) to evaluate contributions from the external/internal factors to the Arctic warming during 1910-1940 and the cooling during 1940-1970. DAMIP historical simulations indicate 0.5°C increase in the Arctic mean SAT from 1910 to 1940, which is mainly attributed to external natural forcing that raise the Arctic mean SAT by 0.6°C ( $\pm 0.4^\circ\text{C}$ ). Contributions from other external forcings are small. Multi-decadal internal variability with magnitude of 0.5°C was also main component of the observed Arctic warming (1.3°C). DAMIP historical simulations also indicate  $-0.2^\circ\text{C}$  ( $\pm 0.2^\circ\text{C}$ ) decrease in the Arctic mean SAT from 1940 to 1970, which is mainly attributed to anthropogenic aerosol forcing that contributed cooling of  $-0.7^\circ\text{C}$  ( $\pm 0.4^\circ\text{C}$ ) to the Arctic mean SAT. Well-mixed greenhouse gas forcing offsets this cooling by  $0.4^\circ\text{C}$  ( $\pm 0.2^\circ\text{C}$ ). Considering the multi-decadal internal variability with magnitude of 0.5°C, which is estimated by the model simulations, the modeled Arctic cooling ( $-0.9^\circ\text{C} \sim -0.5^\circ\text{C}$ ) corresponds to the observed Arctic surface cooling of  $-0.8^\circ\text{C}$ . We find that external natural forcing, and anthropogenic aerosol forcing and multidecadal internal variability played important roles in the Arctic SAT changes prior to 1970. As anthropogenic sulfur emissions and sulfate aerosols will decrease in any future scenarios of shared socioeconomic pathways (SSPs) in the 21th century, Arctic warming will continue over the near-term future even under strong cooling fluctuations generated by internal variability.

Keywords: Arctic warming/cooling, External natural forcing, Anthropogenic aerosol, Climate model, Multimodel analysis