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Drivers of past and future Arctic sea-ice evolution in CMIP5 models

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The Arctic sea-ice cover has been melting rapidly over the last decades. The main drivers of this sea-ice retreat are assumed to be changes in sea-ice thermodynamics, driven by changes in atmospheric surface fluxes and the oceanic heat flux at the base of the ice. To identify the fluxes most affecting past and future sea-ice evolution (under the RCP4.5 scenario) in climate models, we analyzed the surface energy budget over the Arctic Ocean in global climate models involved in the Coupled Model Intercomparison Project 5 (CMIP5) framework.

In the multi-model ensemble annual mean, the sum of atmospheric fluxes increases from 1990 to 2045, mainly driven by an increase of the radiative surface fluxes and decreases from 2045 to 2099, mainly driven by an increase in upward turbulent heat fluxes. However, due to the large model spread, the future changes in the sum of atmospheric fluxes are not significant.

These non-significant changes result from several effects counteracting each other under climate change. On the one hand, a higher CO_2 concentration, air temperature and air moisture lead to a higher incoming energy flux (incoming longwave radiation). On the other hand, the resulting melt of sea ice leads to higher outgoing energy fluxes (outgoing longwave radiation, sensible heat flux, latent heat flux). Shortwave radiation behaves differently, but also in two counteracting ways, as higher air moisture leads to a decrease in incoming shortwave radiation and less sea-ice cover leads to a decrease in outgoing shortwave radiation.

The small changes in the atmospheric fluxes can be converted to an energy gain or loss by the ocean/sea-ice system, either as sensible heat by changing the oceanic heat content or as latent heat by changing the sea-ice volume. Such analysis in the multi-model ensemble mean shows that the loss of energy at the surface due to atmospheric fluxes is decreasing during the 21st century, leading to an increase in oceanic heat content and an increase in energy available to melt the sea-ice cover. After 2025, the ocean/sea-ice energy system contains less energy than it should gain due to the increase in atmospheric fluxes, probably due to a lower northward heat transport through the meridional oceanic circulation.

The individual models do, however, not all agree on these results. The strongest model spread is found in the representation of net longwave radiation, turbulent heat fluxes and cloud cover. Additionally, they do not agree on the conclusion found with the multi-model ensemble mean. In 12 models, the changes in sea-ice cover and oceanic heat content can be explained entirely by the changes in the atmospheric fluxes. In eight other models, the changes in atmospheric fluxes could not explain the ice melting and increase in oceanic heat content.