Study on the Mechanisms of Atmospheric and Oceanic Warming in the Arctic Based on Heat Budget Analysis of the Upper Ocean

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Arctic warming is pronounced in the recent global climate change and is widely studied under the context of "Arctic Amplification”. Previous research has focused on local, energy-balance-related feedback processes within the Arctic region, such as albedo feedback. Additionally, the role of atmospheric heat transport from lower latitudes, having dry-static and latent energy components, has been examined. Meanwhile, a multi-model analysis by Hwang et al. (2011) pointed out that models with larger increase in the poleward ocean heat transport to the Arctic tend to exhibit stronger Arctic Amplification, suggesting that the contribution of oceanic heat transport cannot be ignored. However, mechanisms underlying the warming of oceanic interiors and the atmospheric feedback processes have often been studied in isolation.

To address this gap, our study employed a climate model to perform warming experiments, specifically extracting all terms contributing to the temperature tendency equation of seawater to carry out a comprehensive heat budget analysis. We applied this analysis to the upper ocean (down to 230 m from the surface). Additionally, we conducted a mass budget analysis of sea ice to clarify how and from where the source of energy for the sea ice reduction is provided in the coupled atmosphere and ocean system. Our aim is to holistically investigate the mechanisms that amplify Arctic warming through interactions among the atmosphere, ocean, and sea ice.

Our results reveal that the advection term and the surface term which accounts for heat exchanges with the atmosphere are the two most influential components for the temperature tendency in the Arctic's upper ocean on average. On the annual mean, the advection term leads to a warming while the surface term shows a net cooling effect, in agreement with Shu et al. (2022). At the seasonal time scale, however, the surface term drives upper ocean temperature anomalies. From the atmospheric point of view, this means that excess heat absorbed by the ocean surface layer during the summer months, mediated by albedo feedback, is released back into the atmosphere from autumn to winter, contributing to atmospheric warming. In our model simulation, the reduction of sea ice is initiated by basal melting due to seawater temperature increase, followed by a decrease in bottom growth, an increase in surface melting, and a decrease in ice production at the open water. While the similar analysis for multi models were presented by Keen et al. (2021), we additionally made attempt to link these processes for sea ice reduction to the heat budget of the upper ocean as well as the air-sea heat exchange.

In the Arctic Ocean, the way the heat budget changes depend on regions, and thus we add discussions on the regional differences regarding the above results.

References

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