Assessment of the Changing Role of Lower Tropospheric Temperature and Water Vapor Advection under Arctic Amplification Using a Large-scale Ensemble Model Dataset

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The near-surface temperature over the Arctic experiences an increased amount of warming compared to the global average under the elevated concentration of greenhouse gases in a phenomenon known as the Arctic Amplification (AA). One of the leading topics of debate concerning the AA is the relative importance of locally driven feedback such as ice albedo feedback against the remote transport of heat into the Arctic from the mid-latitudes via the advection of temperature and water-vapor. While many studies emphasize the importance of locally driven processes such as sea-ice reduction and change in radiative feedbacks, studies such as Clark et al. (2021) points out that horizontal temperature advection driven by large-scale atmospheric patterns also plays a role in maintaining the AA.

In this study, we further investigate the role of temperature advection in the lower troposphere under changing level of global warming. We use the Database for Policy Decision-Making for Future Climate Change (d4PDF; Mizuta et al. 2017) which is a large ensemble AGCM dataset designed to quantify the response in atmospheric processes under changing state of greenhouse gasses and sea surface temperature as well as sea-ice boundaries. Using the 30-year climatology of the non-warming simulation (HPB-NAT) as a reference, the difference in temperature advection under changing basic states of the historical experiment (HPB) and 2K and 4K warming experiments (HFB-2K and 4K) is examined. Here, we use the modified formulation of Wang et al. (2019) to decompose the temperature and moisture advection into components relative to dynamical changes and thermodynamical changes under global warming. The formulation allows to quantify the contribution of changes in the mean state of the wind and the temperature/moisture field under difference simulations.

Applying this method to the temperature in the lower tropospheric level of 925hPa, it is found that under the HPB experiment, the total change in temperature advection is overall positive in the Arctic driven by a stronger dynamical component of advection along the sea-ice boundary in the North Atlantic and the Northern coastline of the Eurasian continent. However, this feature drastically changes under elevated global warming experiments of HFB-2K and HFB-4K where the thermodynamical component of advection turns negative due to weaker temperature gradient. The contribution of the eddy term which is related to the effect of sub-monthly transient eddies dissipating the heat released from the ocean also turns negative and dominates in the region where sea ice retreats in comparison to the HPB-NAT experiment. Taking an average over the Arctic, the total role of atmospheric advection in the lower troposphere turns negative under the HFB-2K and HFB-4K experiments. Reduction in sea ice along the Eurasian continent leads to larger sensible heat released in the region which is dissipated by the transient eddies. From an atmospheric advection point of view, this leads to a more negative signal in the eddy term which overcomes the effect of a stronger dynamical component in horizontal temperature advection under elevated global warming.

Further analysis is made focusing on the water vapor advection and its role under the changing basic state of wind and specific humidity. Increase in water vapor advection driven by the dynamical component is evident along the North Atlantic for HPB / HFB-2K / HFB-4K experiments which agrees with the positive Arctic Oscillation pattern in the models. In our presentation, we will further explore the role of water vapor advection in driving the regional lower tropospheric moistening including the seasonality and regional variability.

References

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