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A Physics-informed Deep Learning Based Clustering to Investigate the Impact of Regional European Radiative Forcing on Arctic Climate and Upper Atmospheric Dynamics

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Heterogeneous radiative forcing in mid-latitudes, such as those caused by aerosols, has been observed to influence the Arctic climate, although the underlying mechanisms continue to be a subject of scientific discussion. In this research, we employed Deep Learning (DL) methodologies to explore the complex response of the Arctic climate system to localized radiative forcing over Europe. We performed sensitivity experiments using the Max Planck Institute Earth System Model (MPI-ESM1.2). By applying a DL-driven clustering approach, we classified atmospheric circulation patterns within a reduced-dimensional framework, with a particular focus on Poleward Moist Static Energy Transport (PMSET) as our primary parameter of interest. Additionally, we developed a new methodology to assess the contributions of these circulation patterns to anomalies in various climatic parameters.

Our results demonstrate that anomalous negative forcing over Europe alters existing circulation patterns and their occurrence frequency without leading to the emergence of new patterns. The clusters change between the Experiment and Control runs in two main ways: variations in their frequency of occurrence and seasonal shifts between the class mean characteristics in the Experiment and Control runs. While pronounced changes in seasonal occurrence frequency can substantially contribute to the observed seasonal anomaly, even subtle alterations in the seasonal differences between class mean characteristics can profoundly affect the class's contribution to the anomaly, especially if that cluster occurs with a high frequency.

We identify changes in the circulation pattern with the high-pressure system over Scandinavia as a key driver for reduced sea ice concentration (SIC) in the Barents-Kara Sea in autumn through enhancing the PMSET. The alterations in this circulation pattern also impact the dynamics of the middle atmosphere. However, its influence is relatively minor compared to other circulation patterns that are analogous to the various phases of the North Atlantic Oscillation (NAO).

These results shed light on the complex interactions between diverse atmospheric circulation

patterns and climatic variables, revealing the underlying mechanisms responsible for the anomalies observed across different seasons. Notably, a complex interplay of different circulation patterns, particularly those mirroring the distinct phases of the NAO, plays a crucial role in dictating wave propagation and the dynamics within the stratosphere. While our study did not specifically investigate the stratospheric pathway, our findings highlight that regional negative radiative forcing over Europe can lead to changes in both Arctic climatic parameters and the dynamics of the stratosphere.