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Achievements in 2025

The subpolar gyre as ocean–atmosphere bridge between AMOC variability and European summer extremes

Previous research suggests a link between enhanced cooling in the subpolar North Atlantic, often referred to as the North Atlantic Cold Blob, and extreme events (e.g. heat waves in summer) across Europe. Here, we investigate this link and the role of internal versus forced variability in shaping the near-term evolution of the Cold Blob with the MPI-M Grand Ensemble of historical/scenario simulations.

We find that oceanic heat transport driven by the Atlantic Meridional Overturning Circulation declines, while the subpolar gyre intensifies. This enhances ocean heat transport divergence across the subpolar North Atlantic, promoting surface cooling and the emergence of the Cold Blob. However, there is a spread across the ensemble members' responses to 21st century forcing: some members simulate a weak and transient Cold Blob followed by warming, while others sustain strong winter cooling.

We also investigate the different impacts downstream over the European continent, driven by the subpolar Cold Blob. Specifically, we demonstrate that a dipole pattern in North Atlantic SST anomalies (with cold subpolar anomalies) is linked to subsequent heat extremes over Central Europe in summer, with the warmest anomalies moving eastwards in August (Figure 1). Our study highlights North Atlantic SST anomalies as a potential source of skill for predictability of extreme summer weather in Europe in the 21st century.

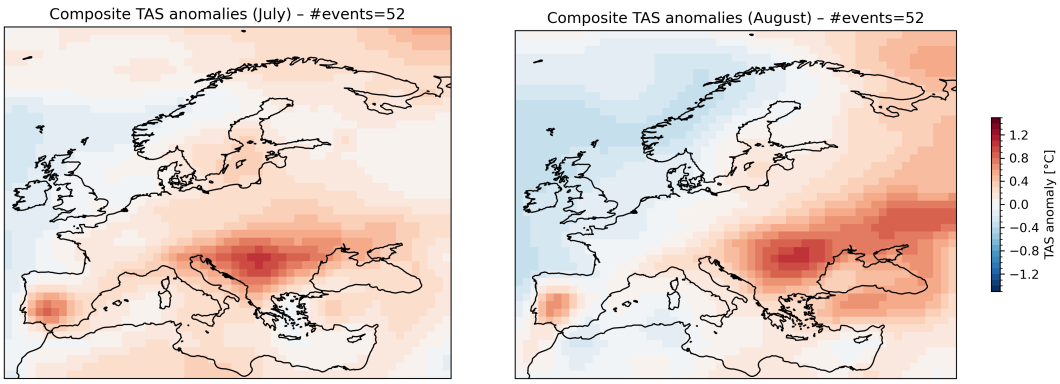

Figure 1: Surface air temperature anomalies in July and August during years with a *dipole pattern in North Atlantic SST anomalies (with cold subpolar anomalies), selected from the MPI-M Grand Ensemble.*

Interaction between the atmosphere and ocean in the North Atlantic and North Pacific

We investigate the role of large-scale atmospheric variability in the extratropics in linking the variability of the North Atlantic and North Pacific. In addition to standard statistics, we use the innovative method of the so-called "Causal Effect Network" (CEN), applied to the MPI-M Grand Ensemble of historical/scenario simulations. We find a global decline in atmospheric quasi-stationary near-surface eddy heat flux in the Northern Hemisphere, which is associated with warmer sea surface temperature anomalies in the North Atlantic at mid-latitudes. This global reduction is not an expression of an internal variability pattern of atmospheric vortices, as the internal variability of the atmosphere typically exhibits an anti-correlation between

Atlantic and Pacific atmospheric meridional heat transports near the surface. To determine whether atmosphere-ocean interaction has the potential to amplify these global extratropical anomalies, we performed a CEN analysis on a monthly timescale.
Our results show that a weaker Aleutian Low leads to warm anomalies in sea surface temperature in the North Pacific and a lower near-surface heat flux over the North Pacific (Figure 2). For the Atlantic, there is a direct negative correlation between near-surface heat flux and sea surface temperature anomalies in the North Atlantic.

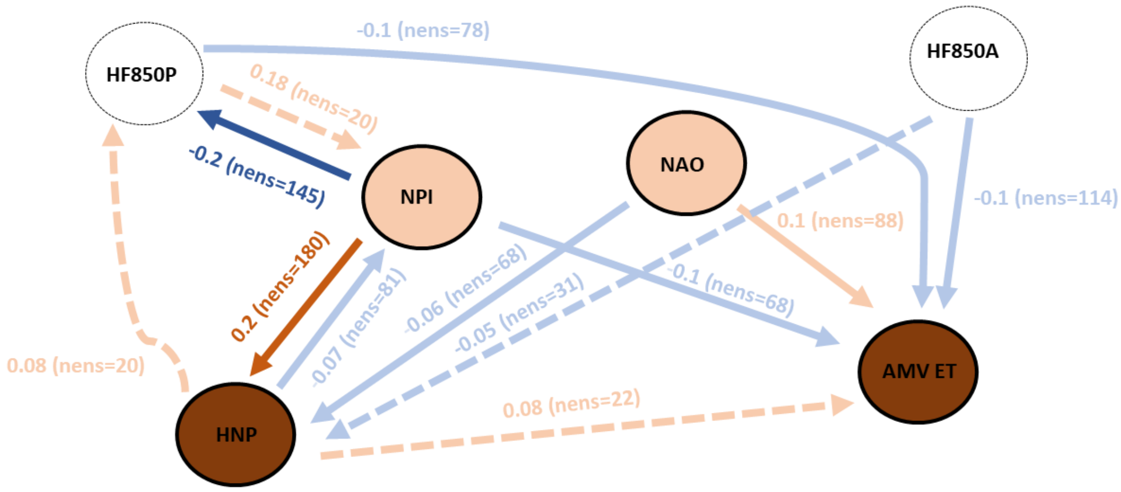

Figure 2: Causal effect network: HNP and AMV ET represent the variability of extratropical anomalies in sea surface temperature in the North Pacific and North Atlantic, respectively. HF850P and HF850A represent the variability of atmospheric quasi-stationary near-surface vortex heat flux over the extratropical North Pacific and North Atlantic, respectively. NPI is the North Pacific Index for sea level pressure, a measure of the variability of the Aleutian Low. NAO is the North Atlantic Oscillation Index for sea level pressure.

ROADMAP PhD Thesis Quan Liu (defense on 28.10.2025, currently PostDoc within CVR)

<u>Changes in atmospheric eddies by global warming contribute to more summer North Atlantic Oscillation extremes</u>
The summertime North Atlantic Oscillation exhibits an enhanced variability in a transient warming climate. This enhancement would cause more contrasting severe weather over different parts of Europe, but its driving mechanism is yet to be understood. We conduct composite analysis that is physically motivated by "eddy-mean-flow" interactions in daily output of the MPI-M Grand Ensemble of historical/scenario simulations. We show that transient eddies drive the summer NAO variability through momentum forcing at upper-level, while quasi-stationary eddies modulate it through thermal forcing at lower-level. Under global warming, the variability of the thermal forcing by quasi-stationary eddies increases in response to an enhanced land-ocean temperature contrast, ultimately leading to the enhancement in the variability of the summer NAO. Our study underscores the role of eddy fluxes in explaining the transient atmospheric response to global warming.

Liu, Q., Bader, J., Jungclaus, J.H. and D. Matei. More extreme summertime North Atlantic Oscillation under climate change. Nature Commun Earth Environ ***6****, 474 (2025). https://doi.org/10.1038/s43247-025-02422-x.*

Liu, Q., J. Bader, J.H. Jungclaus and D. Matei (2025) Changes in atmospheric eddies by global warming contribute to more summer North Atlantic Oscillation extremes. To be submitted