Disparate climate response to regional Arctic sea ice loss explained by atmospheric feedback

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Motivation & Goals

Spatial pattern of Arctic sea ice loss is one of the least consistently predicted feature of climate change among models.

Sea ice loss may feedback on the climate, attenuating or amplifying global warming impact on global and regional climate.

There is a poor agreement among studies on the impact of sea ice loss on the climate

What is the impact of Arctic sea ice loss on the Northern Hemisphere climate?

How sensitive is this feedback on the pattern of the sea ice loss?

Can we devise a mechanism that explains climate sensitivity to regional sea ice loss?

Experimental protocol

We run **9** experiments with prescribed sea surface temperature (SST) and sea ice concentration (SIC), made of **1** Control, **1** pan-Arctic sea ice loss, and **7** regional sea ice loss experiments (region defined below). See Smith et al., 2019 for more details on the protocol.

Control: present-day monthly-mean SST and SIC (1980-2014)
Pan-Arctic: warm future (+1K global-mean surf. temp CMIP5 global warming simulations) monthly-mean SIC, but present-day SST
Regional: As pan-Arctic but changes are applied only over individual regions as shown on Fig.1

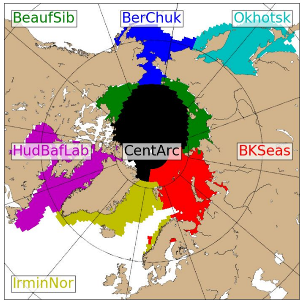

Figure 1 | predefined regions over which monthly-mean SIC and SST are changed

Results

We focus on the zonal-mean zonal wind anomalies in each experiment (anomalies wrt to the Control) in Winter (Dec-Jan-Feb average).

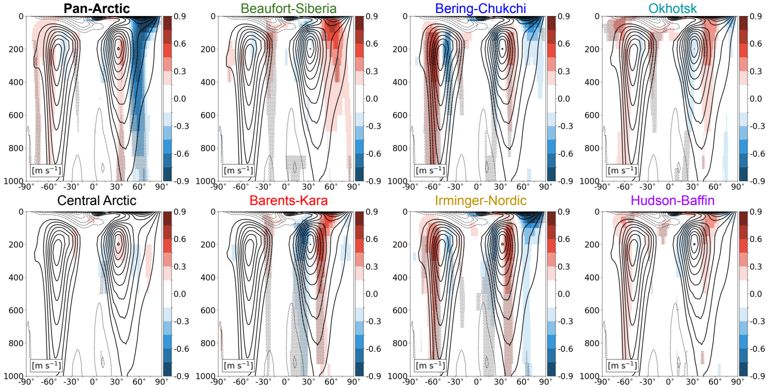

Figure 2: **| Zonal-mean zonal wind anomalies in DJF for the pan-Arctic and all regional sea ice loss experiments.** Anomalies (shown in colors) are computed as the difference between the future experiments and the present-day experiment climatologies. The present-day climatology is shown in black contours (increments of 4.m.s^{-1}), with dashed and solid lines for negative and positive values respectively. All panels are pressure level [hPa] - latitude [deg] cross-sections. Dotted areas indicate regions where the sign of the anomalies agrees in at least 95% of the 1000 bootstrapped samples.

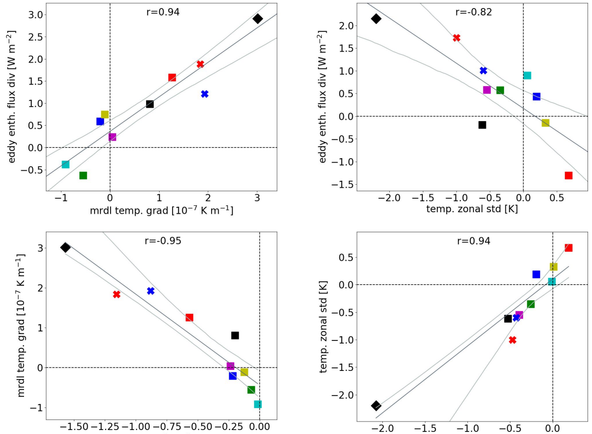

Figure 4: **| Mechanism of changes in transient and stationary poleward heat flux into the Arctic.** (a) Scatter plot of the Arctic-mean (φ>60°N) tropospheric transient eddy heat flux divergence anomaly against the anomaly of the meridional temperature gradient at 60°N and 850hPa for all the future Arctic experiments. (b-d) as in *a* but between the anomalies of: (b) meridional temperature gradient at 60°N and 850hPa and total Arctic sea ice extent, (c) Arctic-mean tropospheric stationary eddy heat flux divergence and zonal standard deviation of temperature at 850hPa, (d) Arctic-mean zonal standard deviation of temperature at 850hPa and total Arctic zonal standard deviation of sea ice concentration.

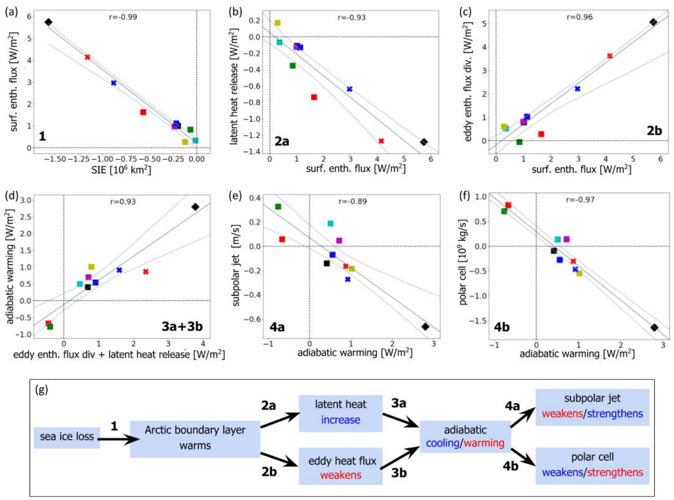

Figure 3 | **Feedback mechanism behind the enhanced Pan-Arctic climate response**: (a) Scatter plot of the Arctic-mean surface heat flux anomaly against the total Arctic sea ice extent anomaly for all the future Arctic experiments (arrow 1 in schematic *g*). Both quantities are computed over an Arctic polar cap north of 60°N. Anomalies are computed as the differences between the ensemble mean in each future Arctic experiment and the ensemble mean in the present-day control. The least-square regression line and its 95% confidence envelope are included as thin black lines. (b-f) as in *a* but between the anomalies of: (b) Arctic-mean latent heat released by precipitation (LvP) [arrow 2a] and surface heat flux. (c) Arctic-mean tropospheric eddy heat flux divergence and surface heat flux [arrow 2b]; (d) Arctic-mean tropospheric adiabatic warming and the combined effect of latent heat released by precipitation and tropospheric eddy heat flux divergence [arrow 3]; (e) subpolar jet at 60°N [arrow 4a] and Arctic-mean tropospheric adiabatic warming; and (f) polar cell strength at 60°N and Arctic-mean tropospheric adiabatic warming [arrow 4b]. (g) Schematic diagram of mechanism detailing how pan-Arctic or regional sea ice loss influences the zonal-mean tropospheric circulation (blue/red fonts refer to climate response associated with adiabatic cooling/warming).

Summary

Inconsistent response of zonal-mean zonal wind to sea ice loss (Fig. 2), with subpolar jet strengthening or weakening depending on pattern of sea ice loss.

Changes in subpolar jet are explained primarily by changes in poleward eddy heat flux, which responds to changes in both zonal-mean and zonally asymmetric near-surface temperature anomalies over the Arctic driven by sea ice loss (Fig. 3).

Zonal-mean near-surface temperature over the Arctic always increases in response to sea ice loss, regardless of pattern and in proportion with the net area of sea ice loss. This tends to weaken poleward eddy heat flux, and thus the subpolar jet (Fig. 4).

Zonally asymmetric near-surface temperature over the Arctic may increase or decrease with sea ice loss depending on its pattern, strengthening or weakening the poleward eddy heat flux respectively (e.g. Barents-Kara vs. Pan-Arctic) (Fig. 4).

Our study highlights the need to better constrain the spatial pattern of future sea ice when assessing its impacts on the climate in the Arctic.

Smith, D. M. et al, 2019: The Polar Amplification Model Intercomparison Project (PAMIP) contribution to CMIP6: investigating the causes and consequences of polar amplification. *Geosci. Model Dev.* **12**, 1139–1164
Levine et al.: Atmospheric feedback explains disparate climate response to regional Arctic sea ice loss, *npj Climate and Atmospheric Science*, *in review*.