Barcelona Supercomputing Center
Centro Nacional de Supercomputación

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Advanced prediction in polar regions and beyond

Assessing the climate response to regional sea ice change across all Arctic regions

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Motivations

Sea ice cover has dramatically shrunk in the past 3 decades (e.g. Stroeve et al., 2012).

Sea ice cover is expected to shrink further in the coming decades, but intermodel agreement in regional pattern of sea ice loss is poor (Collins et al. 2013).

Sea ice loss, whether regional or global, has a noticeable impact on the Winter climate (Vihma, 2014; Cohen et al., 2014), but its influence seems to depend on pattern of sea ice loss (Petoukhov and Semenov, 2010; Semenov and Latif, 2015; Chen et al., 2016; Screen, 2017).

How does the Northern Hemisphere Winter climate respond to regional sea ice loss in the Arctic?

Goals

1. Describe the climate response to regional sea ice loss in a set of atmosphere-only experiments (“AMIP”) run with EC-EARTH.

2. Assess the degree of linearity of the climate response to regional sea ice loss.

3. Propose a mechanism explaining qualitatively the similarities and discrepancies in the climate response to regional and pan-Arctic sea ice loss.

Protocol

Model: EC-Earth v3.3 (CMIP6 production): atmosphere IFS T255, 91 vertical levels.

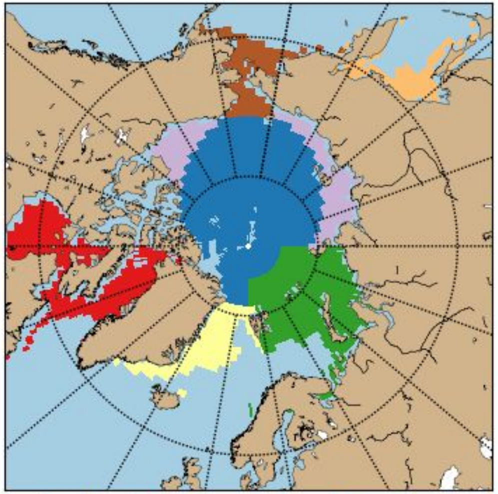
Configuration: atmosphere-only 1-year simulations* (150 members)

Setup: Combining the present-day (**pdSST-pdSIC**) and projected future Arctic SIC and SST masks (**pdSST-futArcSIC**), we define new masks by setting SIC and SST to its present-day state everywhere except over *specific* regions, where the projected future Arctic state is chosen instead.

Experiments are run for each sea ice loss regions:

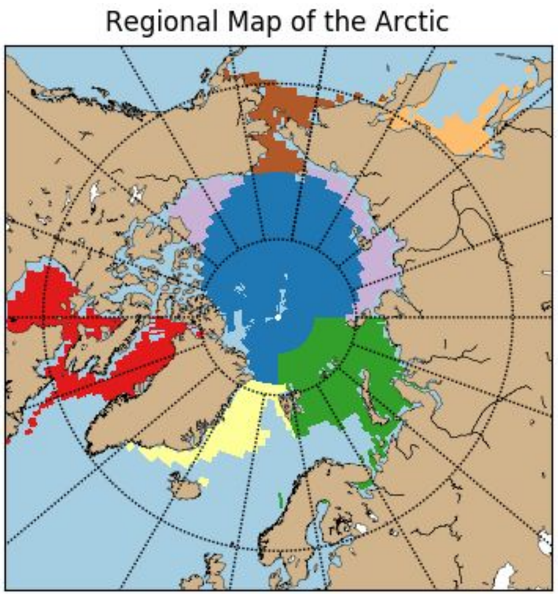
1. Central Arctic (pdSST-fut**CentArc**SIC)
2. Barents-Kara (pdSST-fut**BKSeas**SIC)
3. Hudson-Baffin-Labrador (pdSST-fut**HudBafLab**SIC)
4. Okhotsk (pdSST-fut**Okhotsk**SIC)
5. Beaufort-East Siberian-Laptev (pdSST-fut**BeaufSib**SIC)
6. Irminger-Nordic Seas (pdSST-fut**IrminNor**SIC)
7. Bering-Chukchi (pdSST-fut**BerChuk**SIC)

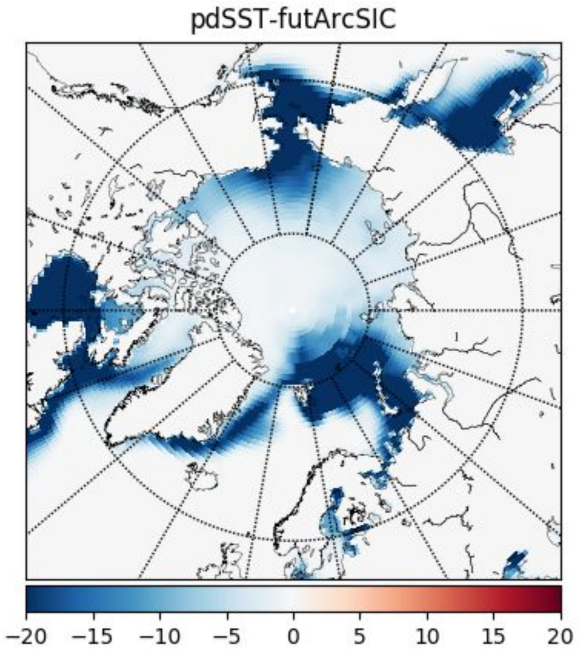
Regional Map of the Arctic



Note: pdSST-pdSIC and pdSST-futArcSIC masks are provided by the PAMIP consortium

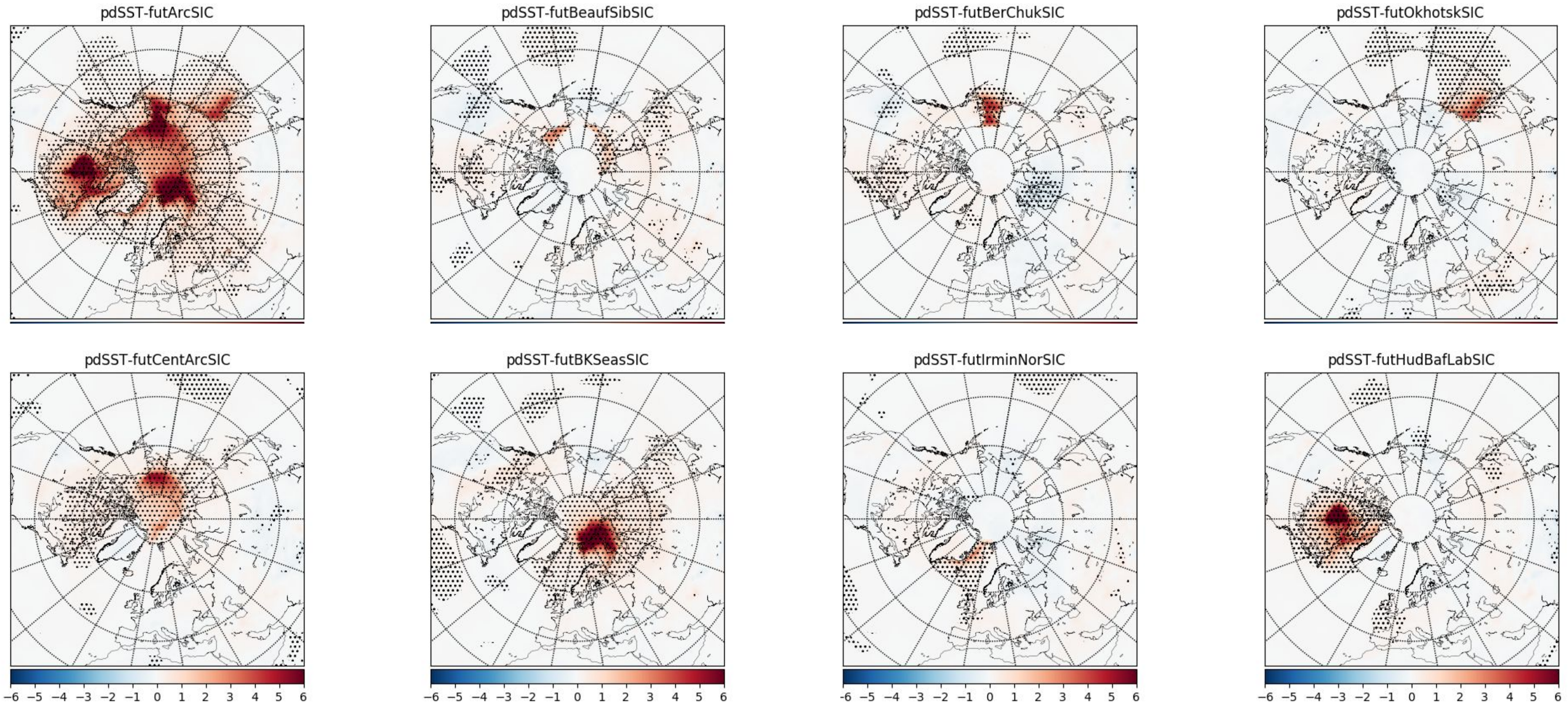
Surface forcing pattern:
(Left) predefined regions (Right) prescribed sea ice loss pattern in Winter





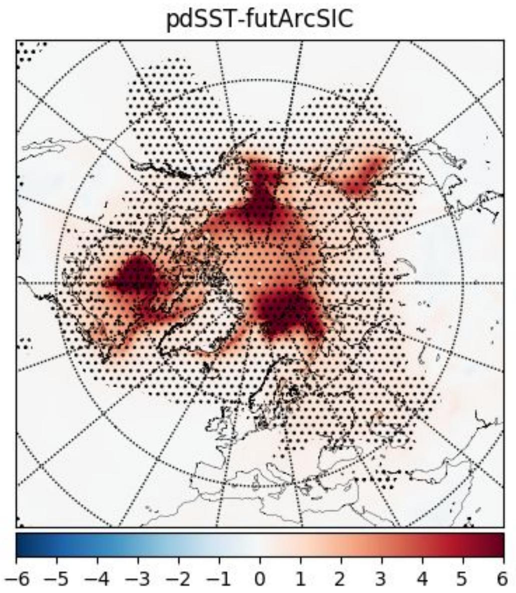
Winter sea ice loss predicted to be largest over marginal areas of the Arctic:
Hudson-Baffin Bays, Nordic-Irminger, Barents-Kara, Okhotsk and Bering-Chukchi seas.
Note relative invariance over Central Arctic

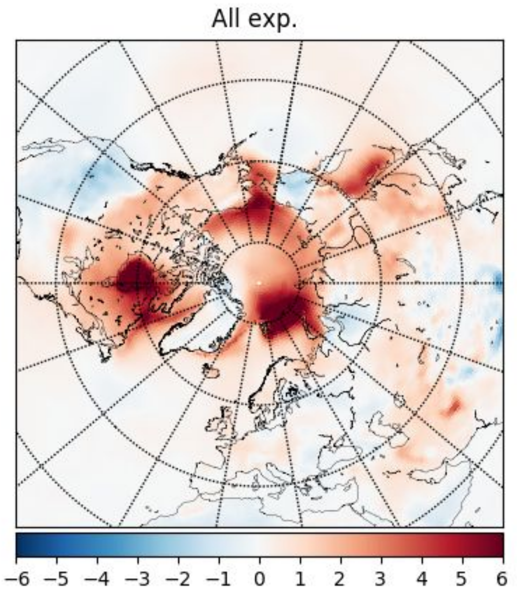
2-m air temperature anomalies in Winter (DJF)



Near-surface warming is confined to areas of sea ice loss

2-m air temperature changes:
(left) in pan-Arctic, and (right) sum of all regional experiments.





Near-surface warming is qualitatively additive when comparing the added climate response to sea ice loss in regional experiments with the pan-Arctic experiment.

Let's investigate impact of regional sea ice loss on the tropospheric circulation

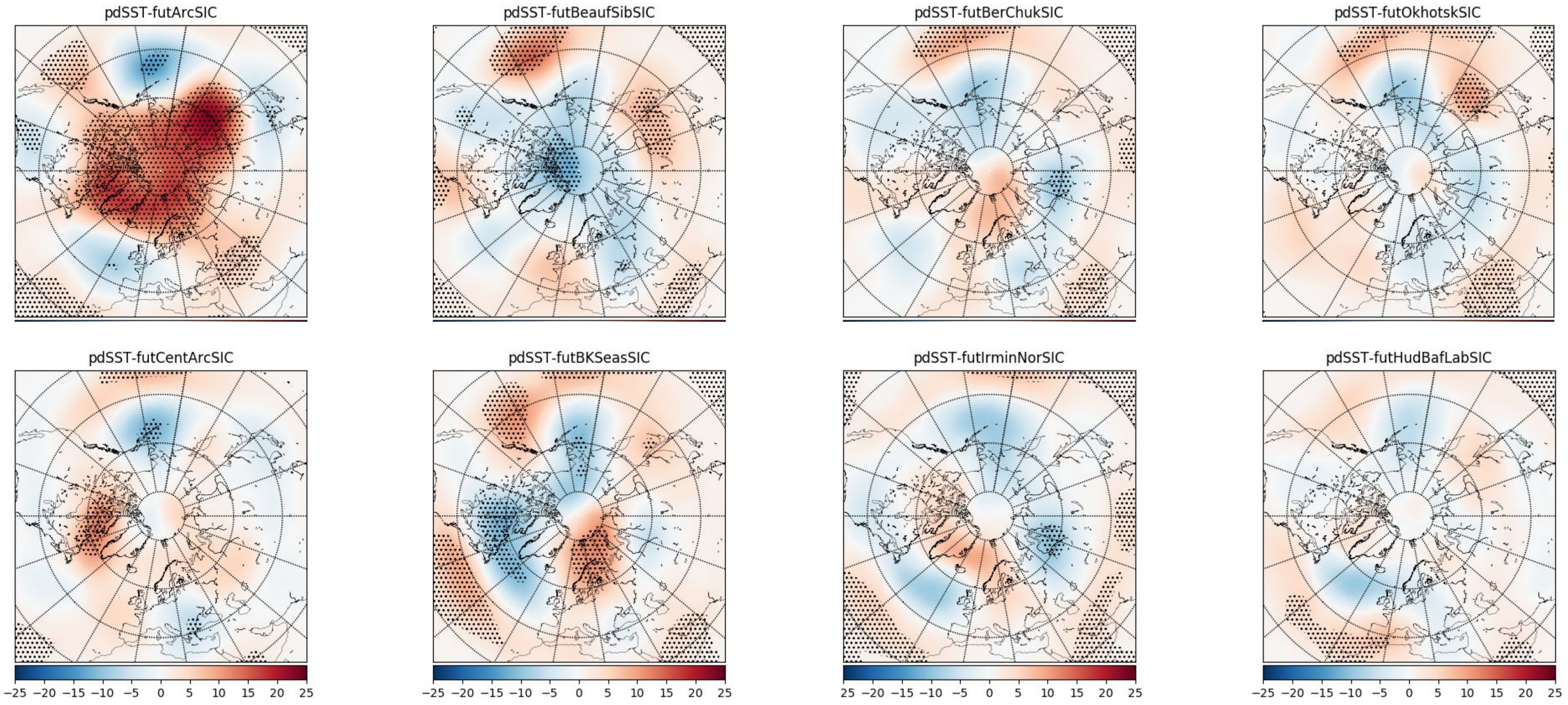
Due to its dominant role in driving the large-scale circulation (e.g. geostrophy), we focus on the geopotential height response to sea ice loss.

$$f\mathbf{u} = \nabla\phi$$

Here, we focus on the mid-tropospheric (500 hPa) anomalies.

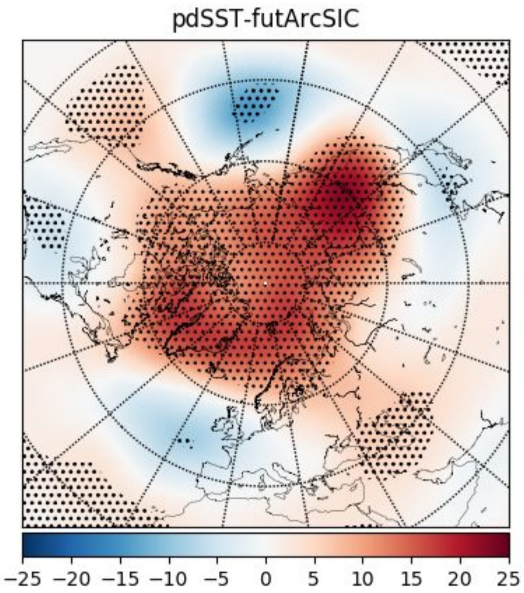
$$\phi(\mathbf{x}, p) = \int_{p_s}^{p} T(\mathbf{x}, p)\, \mathrm{d}\log p$$

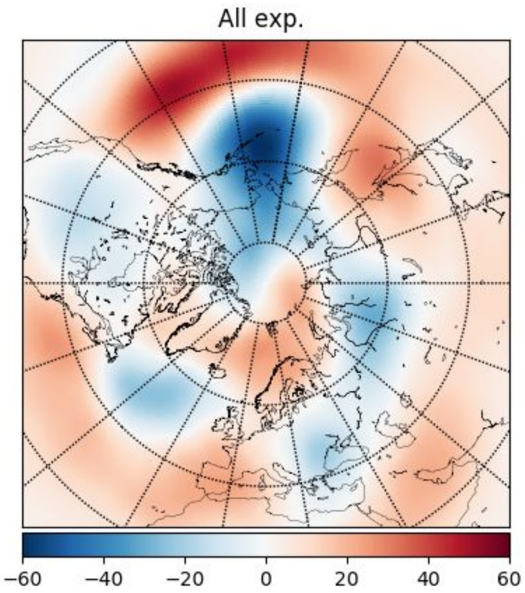
Geopotential height anomalies at 500hPa in Winter



Thermal High in Pan-Arctic experiment not found in other (regional) experiments!

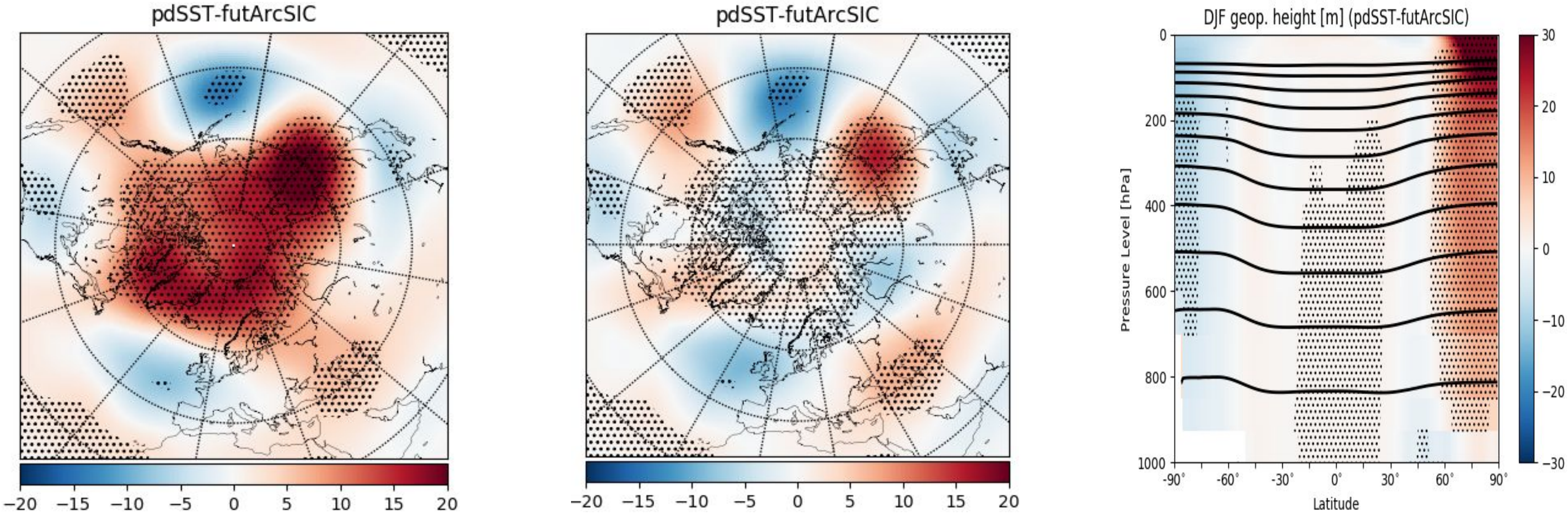
Geopotential height changes at 500hPa
(left) in pan-Arctic, and (right) sum of all regional experiments.





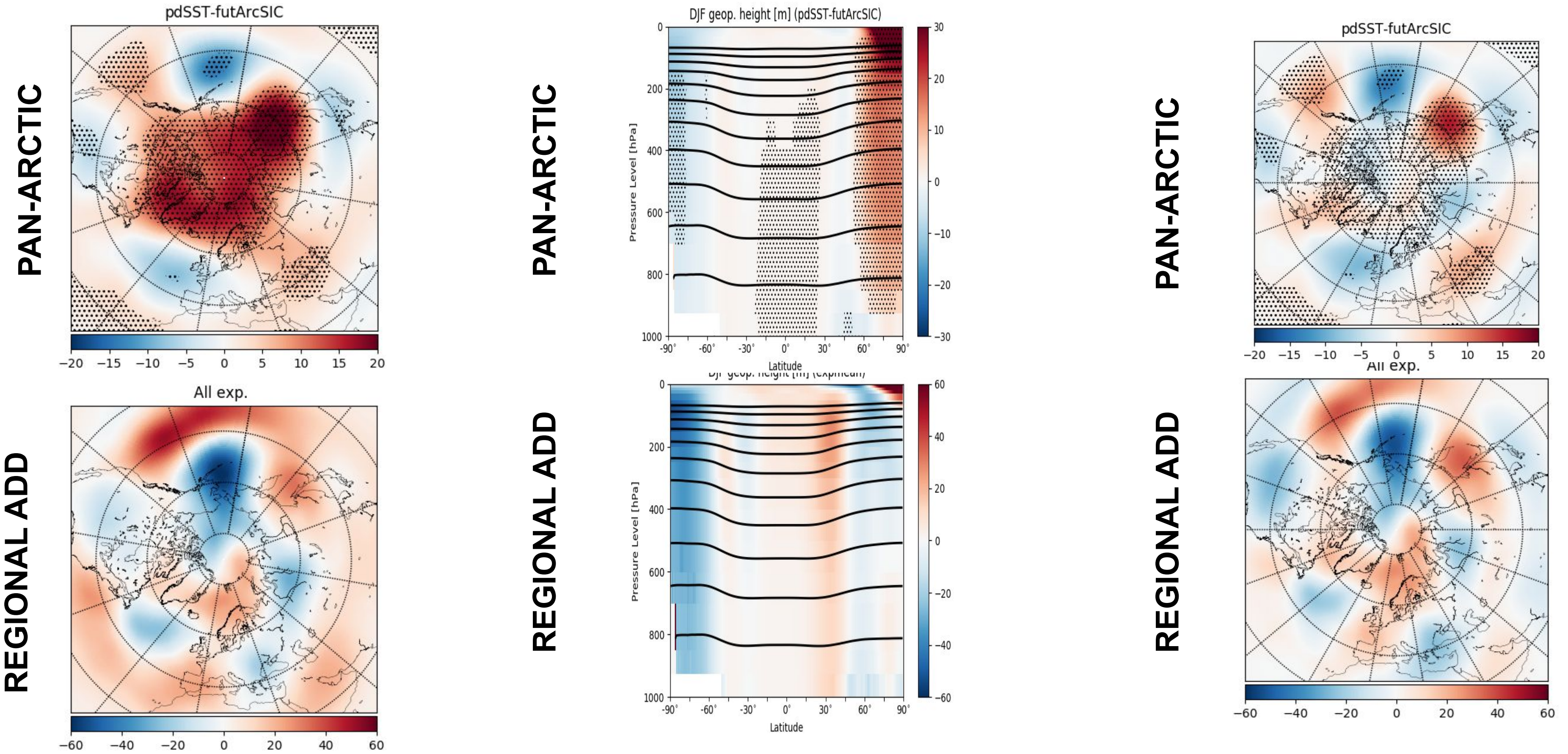
Tropospheric circulation changes from regional sea ice loss are not linearly additive

Pan-Arctic sea ice experiment:
(left) total, (middle) stationary, (right) zonal-mean components



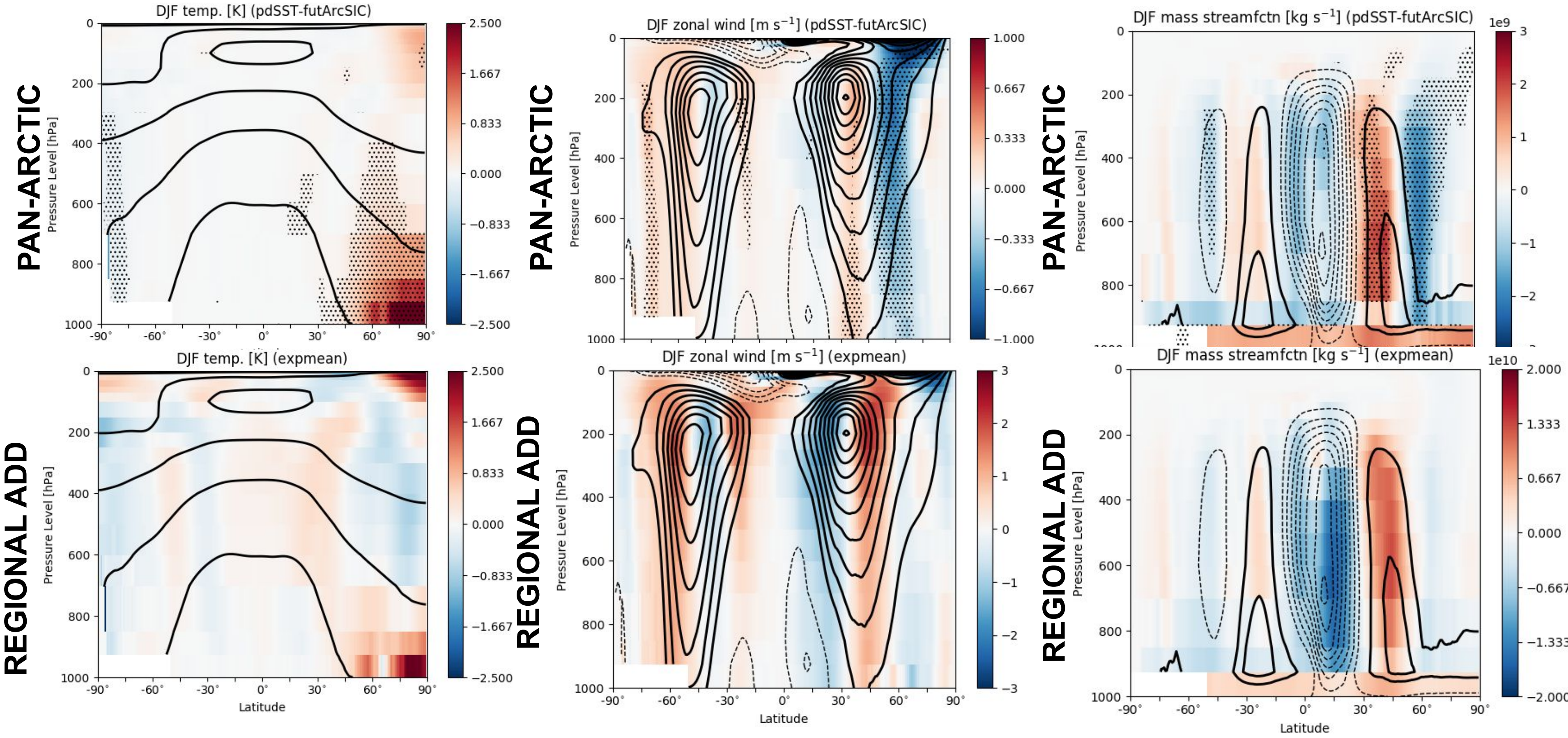
Arctic High projects mostly on its zonal-mean component

Zonal-mean vs. stationary components



Non-additivity of climate response to regional sea ice loss derives from the zonal-mean atmospheric circulation response.

Zonal-mean anomalies in temperature, zonal wind, streamfunction



Zonal-mean fields are non-additive, esp. the zonal-mean jet

How does sea ice loss impact the zonal-mean flow?

Why is its influence seemingly non-additive?

Proposed mechanism of sea ice loss impact on zonal-mean climate

Regional or pan-Arctic Sea ice loss....

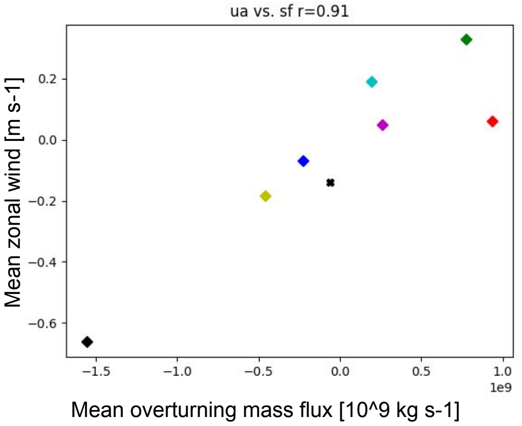
1. …. warms the atmospheric boundary layer in the Arctic,...
2. … leading to a reduction of near-surface baroclinicity at the polar front.
3. This drives an anomalous polar cell,...
4. … which enhances subsidence over the Arctic,….
5. … leading to adiabatic warming of the tropospheric column,….
6. This weakens the tropospheric meridional temperature gradient.

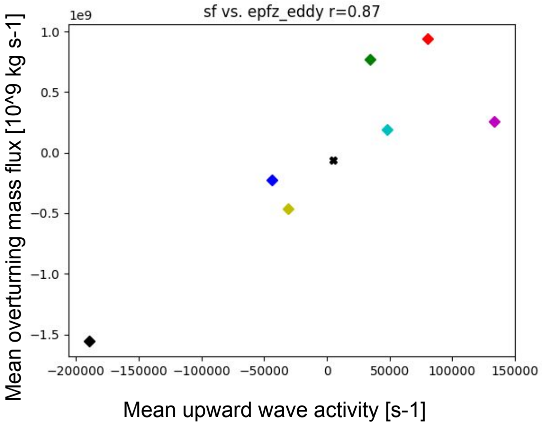
=> zonal-mean tropospheric subpolar jet weakens.

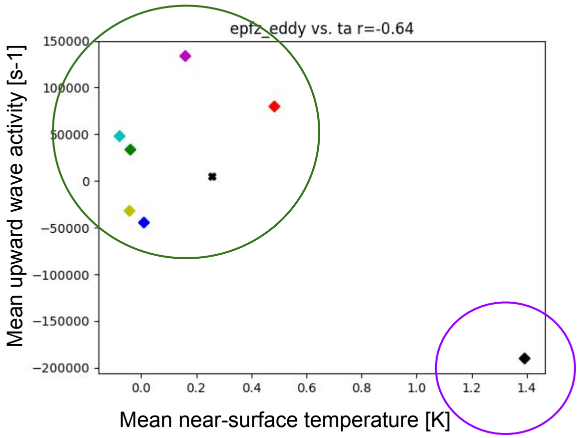
This mechanism is expected to be found in all experiments,

However, stationary waves activity in Winter or preceding Fall will also be playing a role

Pathway between sea ice loss between tropospheric jet weakening







Pan Arctic (diamond), Central Arctic (cross), Okhotsk, Bering-Chukchi, Beaufort-East Siberian-Laptev, Hudson-Baffin, Irminger-Nordic Seas, Barents-Kara

(3) *Stronger polar cell leads to weaker tropospheric subpolar jet* (increased adiabatic warming)

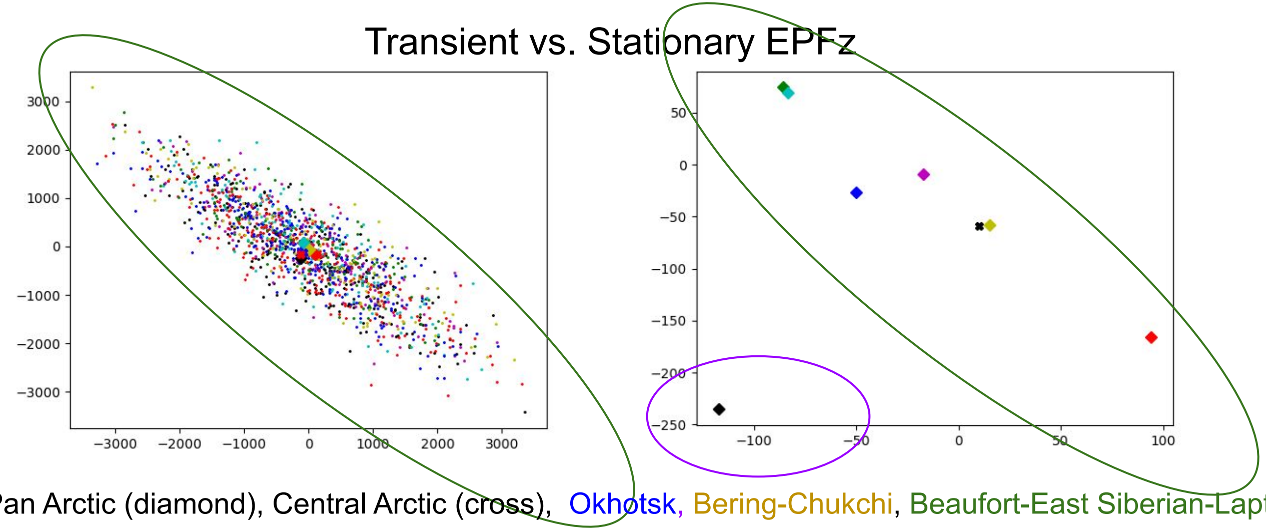
(2) *Weaker baroclinic wave activity leads to a stronger polar cell at subpolar front* (reduced upward wave activity)

(1) *Near-surface Arctic warming weakens baroclinic wave activity at subpolar front* (reduced baroclinicity)

Subpolar jet weakening and polar cell strengthening can be related to upward wave activity from surface

Upward wave activity is only qualitatively related to the near-surface baroclinicity

Stationary and transient waves changes generally cancel each other …..

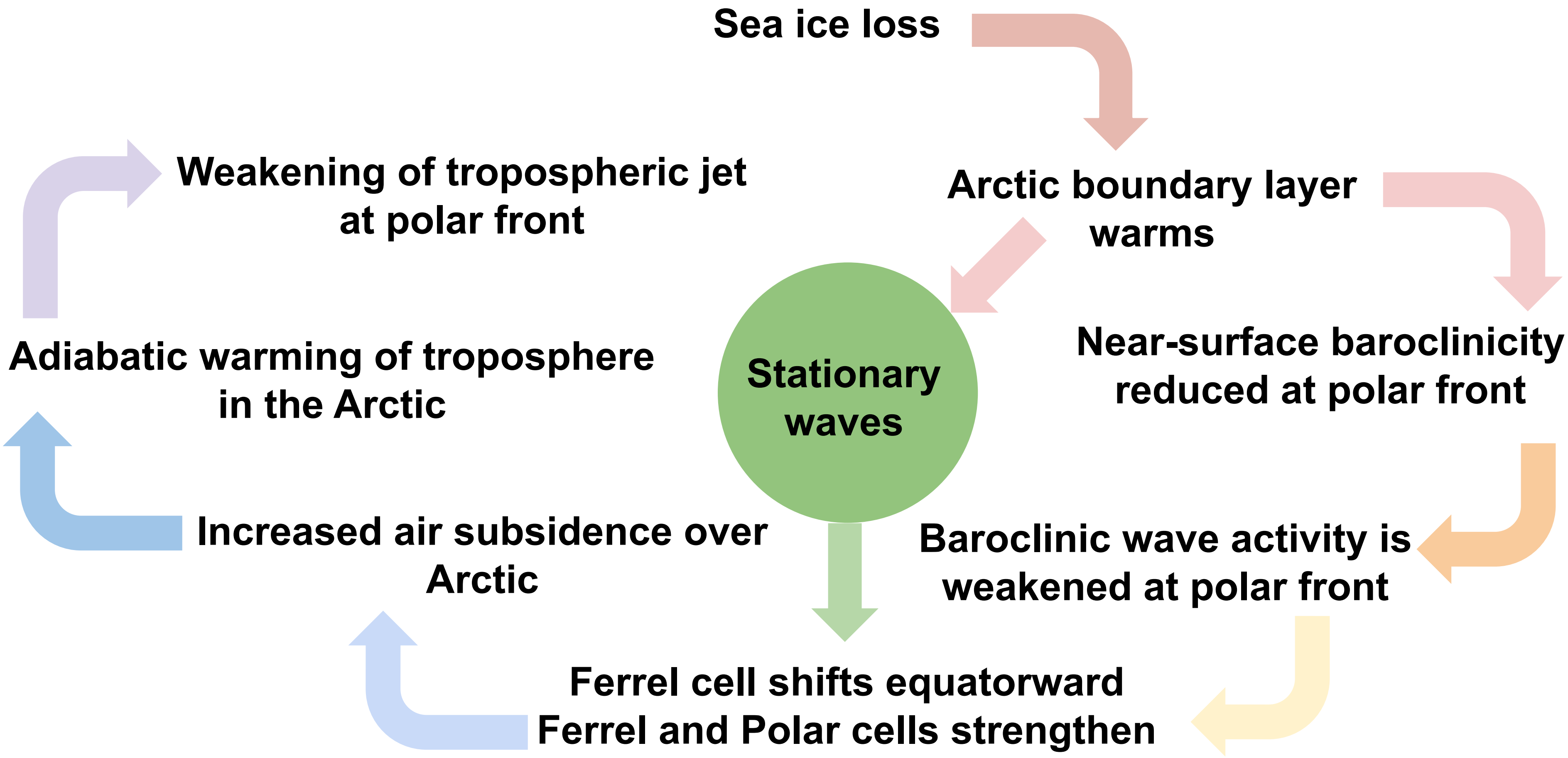


… except in the pan-Arctic experiment

Pan Arctic (diamond), Central Arctic (cross), Okhotsk, Bering-Chukchi, Beaufort-East Siberian-Laptev, Hudson-Baffin, Irminger-Nordic Seas, Barents-Kara

- **In natural variability, stationary and transient eddy activity changes cancel one another.**
- **This cancellation holds when comparing the ensemble-mean of the regional experiments**
  => cancellation of wave activity, lack of strong response in subpolar jet or polar cell strength
- **In the pan-Arctic experiment, however, the decrease in transient eddy activity is not compensated by a 1-to-1 increase in stationary wave activity**
  => strong decrease in wave activity strengthens polar cell and weakens subpolar jet.

Cartoon


Sea ice loss
Arctic boundary layer warms
Near-surface baroclinicity reduced at polar front
Baroclinic wave activity is weakened at polar front
Stationary waves
Ferrel cell shifts equatorward
Ferrel and Polar cells strengthen
Increased air subsidence over Arctic
Adiabatic warming of troposphere in the Arctic
Weakening of tropospheric jet at polar front

Summary

- We ran 7 regional Arctic sea ice loss experiments, and compared their climate anomalies with the future pan-Arctic sea ice loss experiment)

- Zonal-mean tropospheric circulation response to sea ice loss is non-additive:
    - In regional experiments, stationary wave and baroclinic eddy activity nearly cancel one another, leading to a small response of the zonal-mean climate.
    - In Pan-Arctic experiments, baroclinic eddy activity weakens but without compensation from stationary waves, leading to strong weakening of the polar jet and strengthening of the polar cell.

- What controls the compensation between transient and stationary eddies is key for understanding the nonlinearity of the tropospheric response to sea ice loss.

THANK YOU! Questions?

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MARIE CURIE ACTIONS

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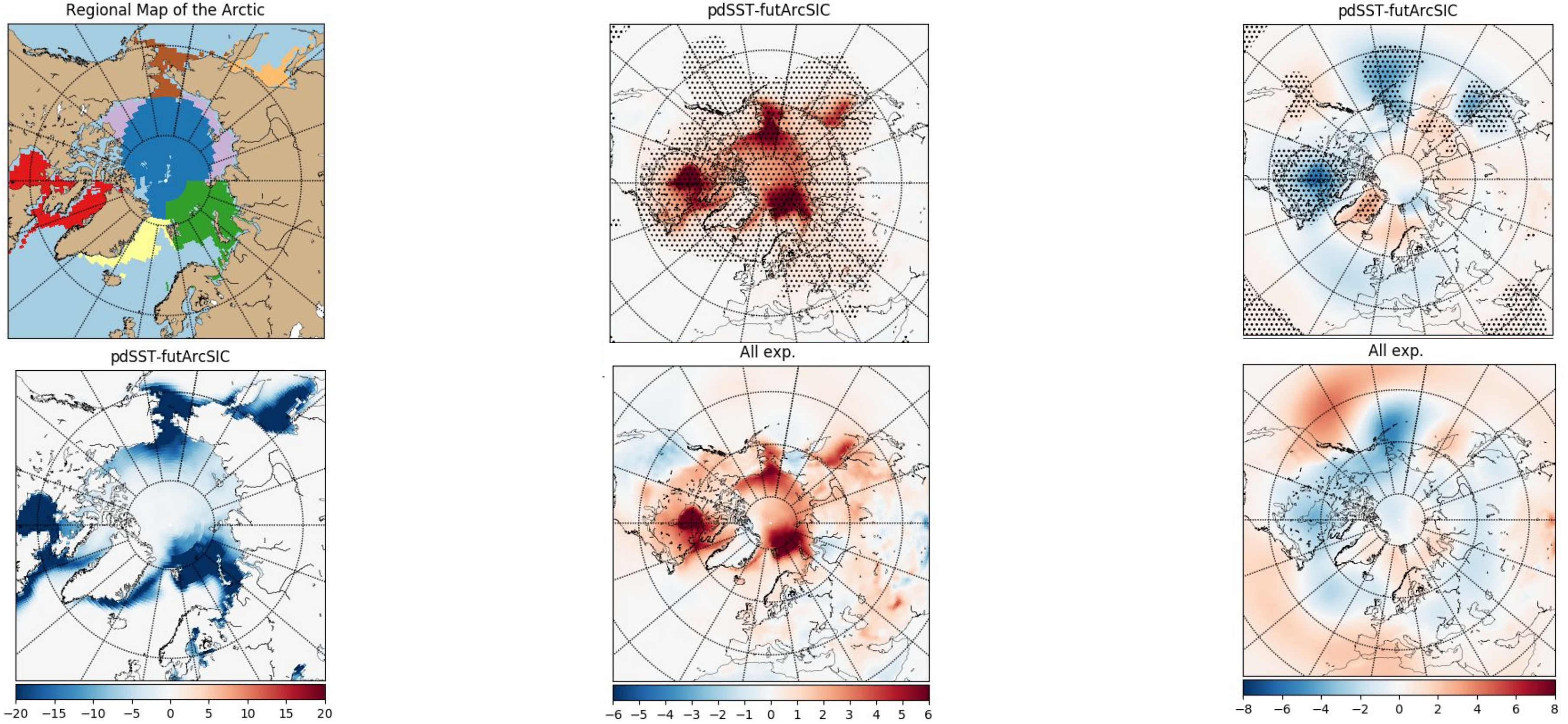
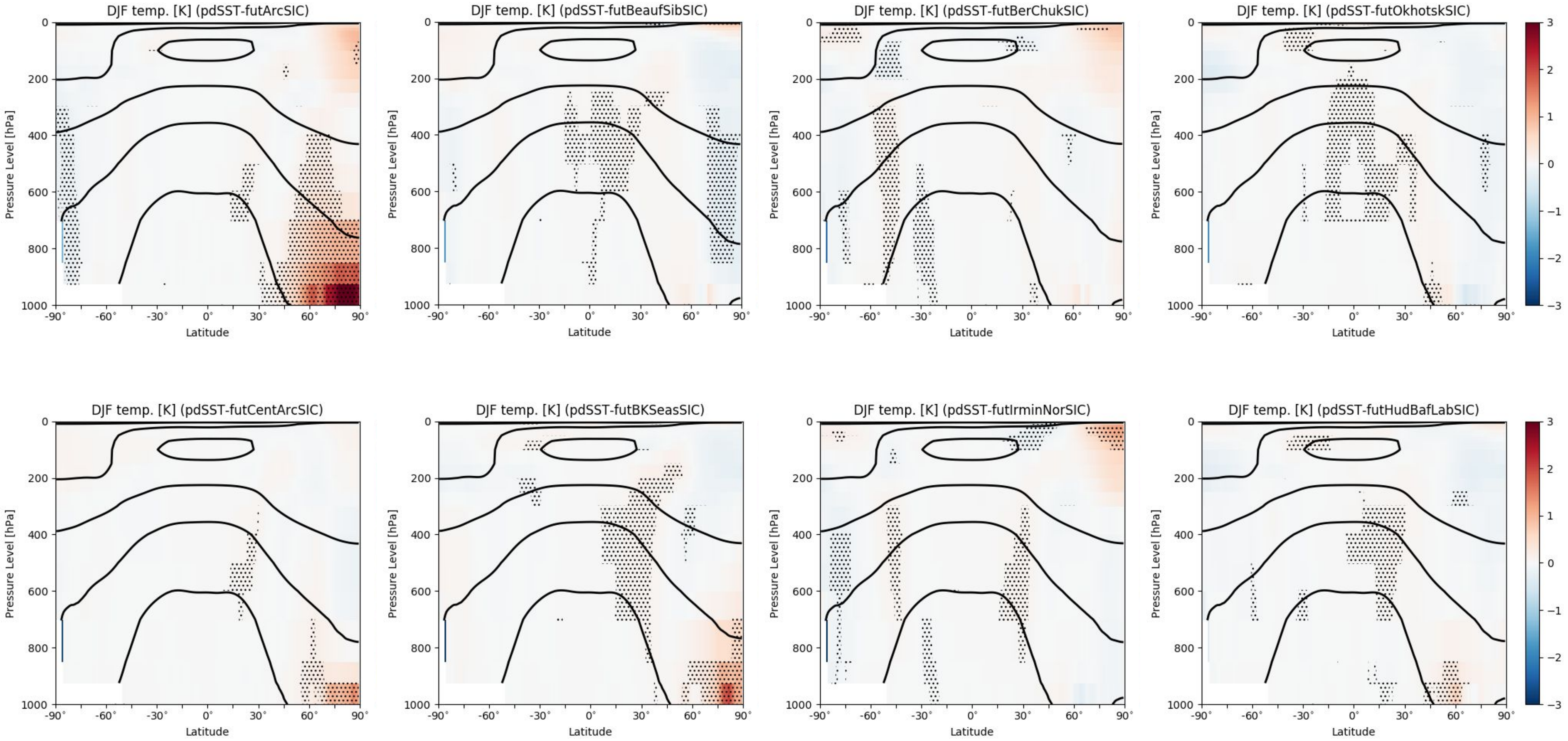
Appendix

Surface climate anomalies

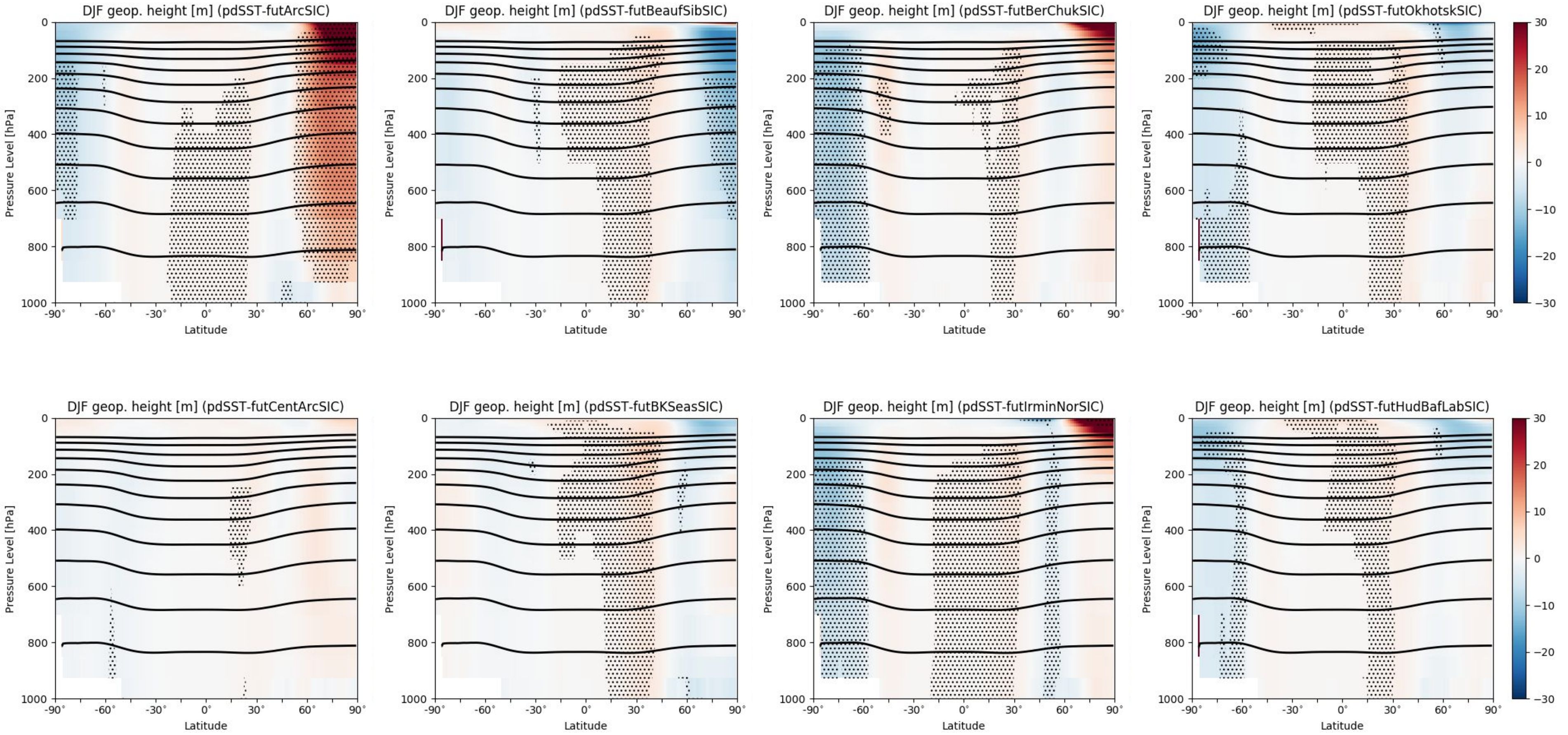


Near-surface warming is qualitatively additive when comparing the added climate response to sea ice loss in regional experiments with the pan-Arctic experiment.

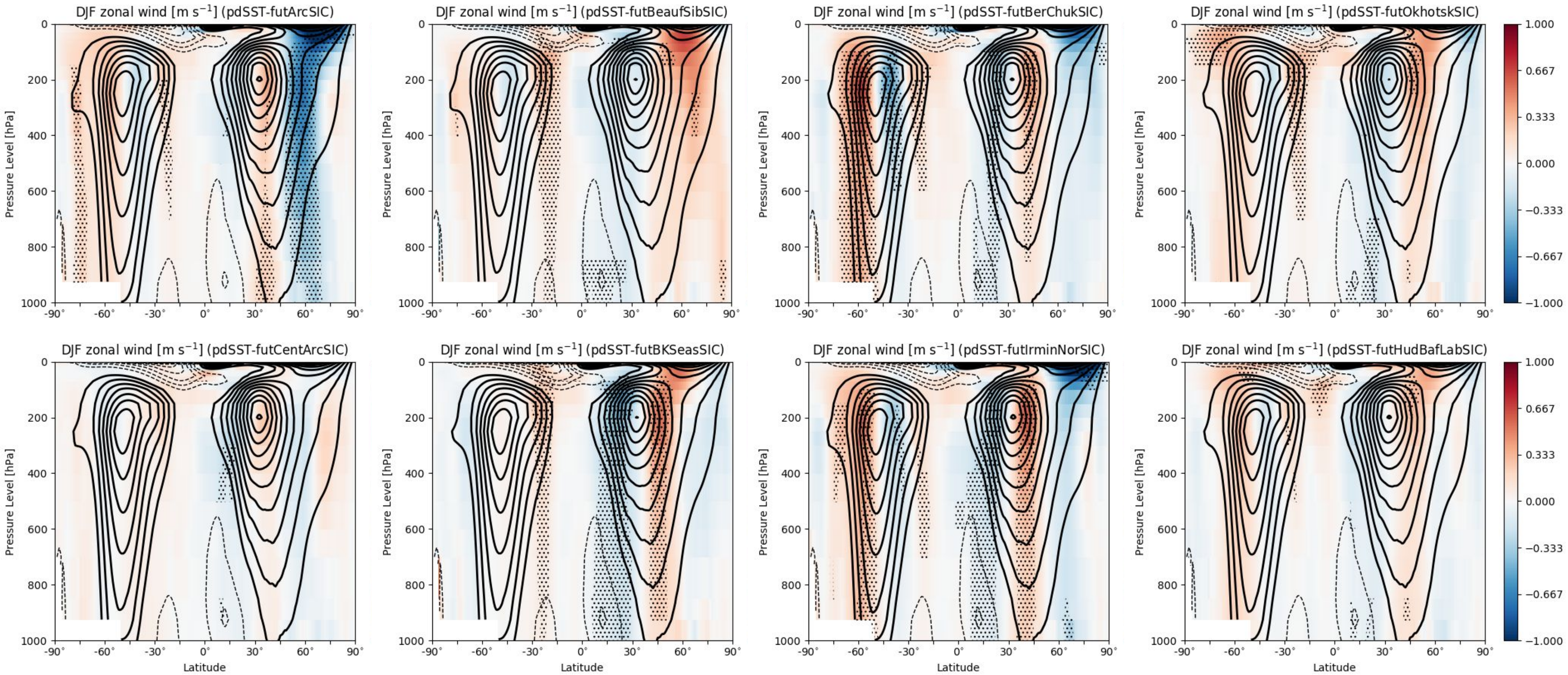
Zonal-mean temperature anomalies



Zonal-mean changes in Geopotential Height



Zonal-mean changes in the Zonal Wind



None of the regional expt shows a robust weakening of the tropospheric subpolar jet

Precipitation in DJF