Atmospheric Precursors of and Response to Anomalous Arctic Sea Ice in CMIP5 Models

Michael Kelleher*, James Screen
Exeter Climate Systems, Department of Mathematics, University of Exeter

Introduction

Goal

- Better understand the coupled relationships between Arctic sea ice, the stratospheric polar vortex and cold winter temperatures over Eurasia

Background

- Arctic winter sea ice area is approx. 14 million km^2
- Local surface heat and moisture flux changes from sea ice loss can cause near surface warming, further ice loss
- Remote changes, including impacts on the stratospheric polar vortex, have also been observed
- CMIP5 models relatively underused in investigating this area, excepting Boland et al. (2016)

Mechanisms

- Sea ice albedo-temperature feedback,
- Increased humidity and longwave radiation, and
- Increased poleward ocean and atmosphere transports (Walsh, 2014).
- Changes dependent on region of ice loss (Sun et al., 2015), though competing impacts reduce the total effect.

Data and Methods

Data

- Pre-industrial control simulations used (focus on natural variability)
- Subset of models selected that had different model genealogy (Knutti et al., 2013) and can be considered independent of one another.

Parameters of interest

- **Polar cap averaged** (66 – 90 °N)
  - Geopotential height
  - Sea ice area (concentration × grid cell area)
- **Mid latitude averaged** (45 – 65°N)
  - Zonal mean meridional eddy heat flux ($\overline{v'T'}$)
- Hemispheric sea level pressure
- Hemispheric surface air temperature

Methods

- Compute standardized climatological anomalies: $x' = (x - \overline{x})/s_x$ where $\overline{x}$ and s_x are the monthly long-term mean and standard deviation for the nearest 30 years to the calculated monthly x.
- Standardized sea ice area anomalies regressed against each diagnostic variable anomalies
- Using leads/lags of up to 14 months.
- Sea ice was masked so only anomalies from each individual season were regressed against the atmospheric variables.

Areas of Interest

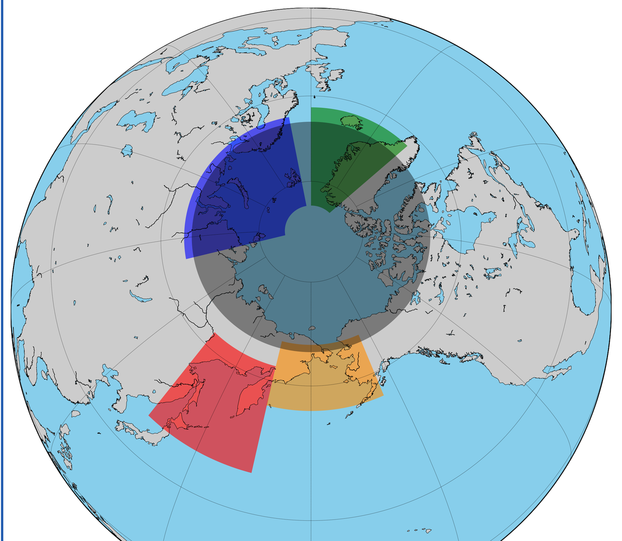

Figure 1: Geographic areas used. Dark grey is "polar cap", green is the Greenland Sea, blue denotes Barents-Kara, red is Okhotsk Sea, orange is Bering Sea.

Vertical Profiles: Pan-Arctic

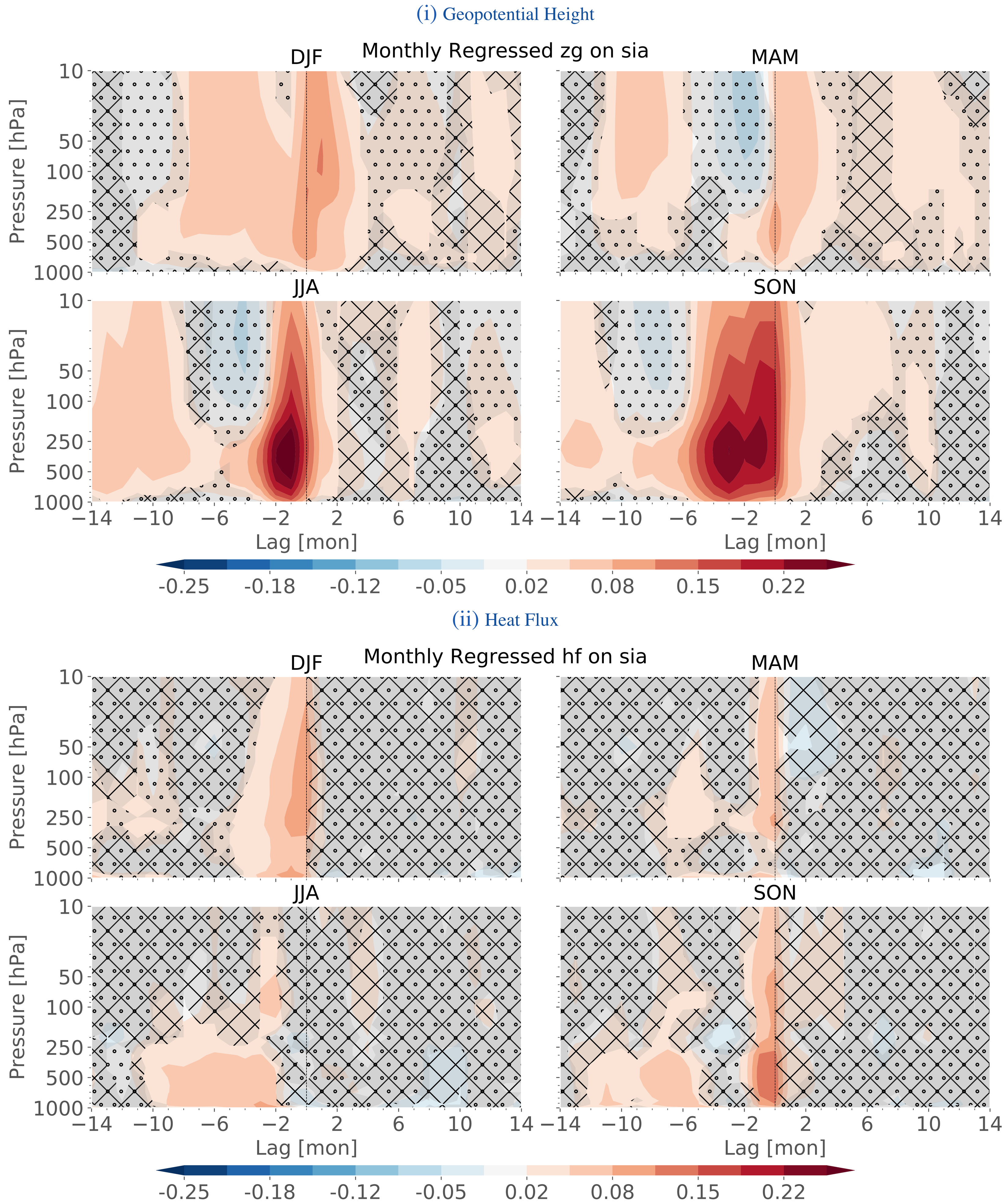

Figure 2: Negative regression slope of polar cap sea ice area anomaly against (i) polar cap height anomalies and (ii) mid-latitude meridional eddy heat flux anomaly, for each season. Hatching [x] covers areas not statistically significant to α=0.01, stippling [o] covers areas where less than 75% of models agree with sign of mean slope. Negative lags indicate atmosphere leading sea ice. Units are standard deviations of geopotential height per standard deviations of sea ice area in (i) and standard deviations of heat flux per standard deviations of sea ice area in (ii).

Vertical Profiles: Regional

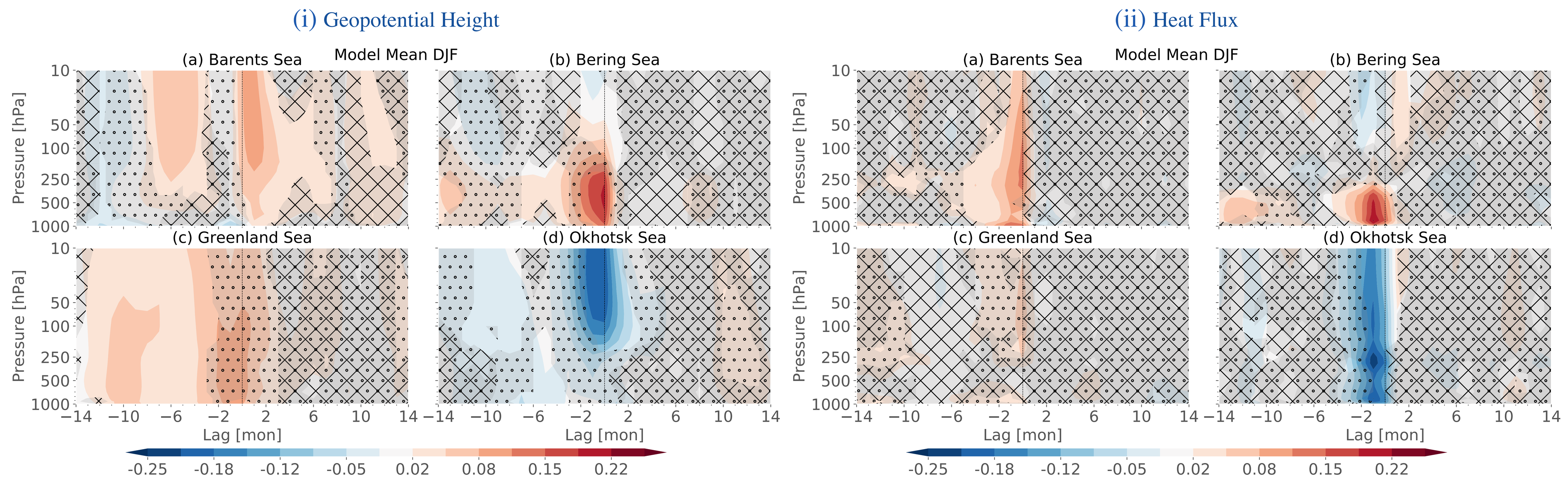

Figure 3: As in Figure 2 but for winter (DJF) sea ice standardised anomalies in (a) Barents-Kara Sea (b) Bering Sea (c) Greenland Sea and (d) Sea of Okhotsk, see Figure 1 for locations.

Surface Temperature

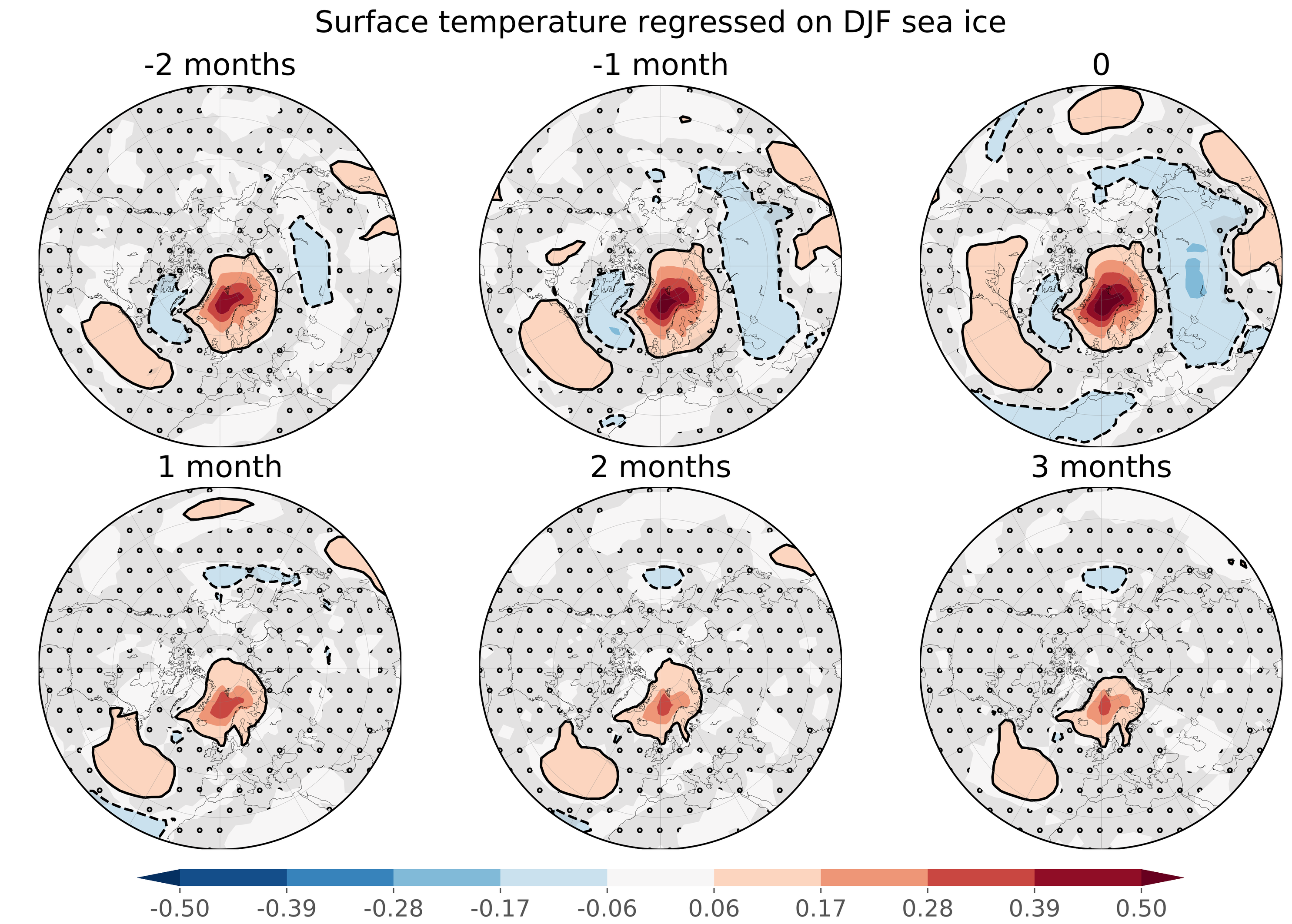

Figure 4: Negative regression of winter (DJF) polar cap sea ice area standardised anomaly against standardised surface temperature anomalies between lag -2 months to lead +3 months. All colours plotted are statistically significant to $\alpha = 0.01$ and stippling as in Figure 2i. Units are standard deviations of temperature per standard deviations of sea ice area.

Key Points

- Positive geopotential height anomalies dominate most of the atmosphere
- Stronger regressions when atmosphere leads sea ice: *sea ice not forcing changes in the polar mid-to-upper troposphere and lower stratosphere*
- Summer and autumn sea ice particularly sensitive to the atmospheric conditions in preceding months
- Significant positive stratospheric anomalies after low winter and spring sea ice
- Enhanced poleward heat flux is possibly one cause of the low sea ice anomalies.
- Little evidence for sea ice causing a change in the heat flux
- Probable that the sea ice and polar cap height are both responding to this enhanced mid-latitude heat flux, similar to the results of (Perlwitz et al., 2015; Screen et al., 2012) with respect to sea surface temperatures
- Barents-Kara (inside polar cap) similar to that of the total polar cap ice
- Bering Sea has larger lower troposphere precursors, smaller response
- Sea of Okhotsk has opposing precursor, associated with stronger polar vortex
- Warm Arctic cold Eurasia surface temperature pattern is apparent as precursor

References

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