Winter atmospheric circulation response to eastern Arctic sea ice loss in a seasonal prediction system

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Rationale & Scientific Goal

Rationale:

1) Not all regions on Earth follow the global surface warming trend that has been observed over the recent decades (FIGURE 1), such as northern Eurasia for example. Sea ice loss in the eastern Arctic sector is suggested to play a role in this warm-Arctic-cold continent pattern through a chain of feedback processes.
2) For this reason, November arctic sea ice has been identified as source of predictability for winter Euro-Atlantic climate[2,3]. This finding is based on the significant (yet small) impact of sea ice anomalies on Euro-Atlantic winter climate by a some proposed mechanisms[4,5]. A detectable influence of sea ice has potential implications for the severeness of European winters with conseqnces for the economy.
3) Yet, different model studies show partly contrasting results with respect to the North Atlantic Oscillation (NAO) response to sea ice loss, the leading mode of internal variability of northern hemisphere atmospheric circulation. These differences may be due to the experimental set-up and the model being used.

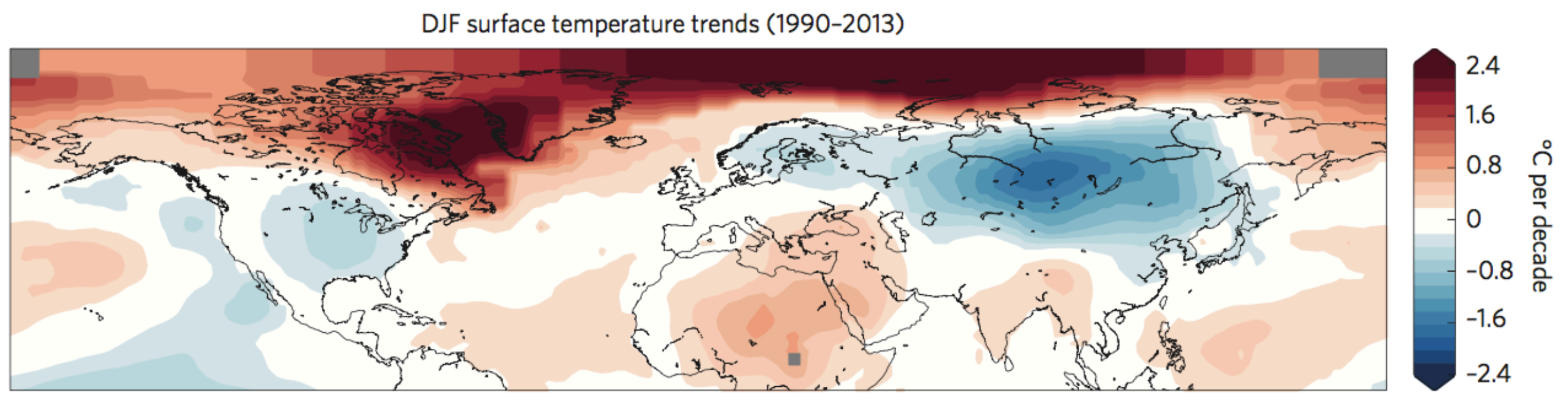

FIGURE 1: Linear trend (°C per 10 years) in DJF mean surface air temperatures over the period 1990-2013 *(adopted from Cohen et al.2014[6])*

Scientific Goal:

The goal is to assess the impact of reduced sea ice conditions in the Barents-Kara Seas (BKS) during late fall (November) on late winter Euro-Atlantic atmospheric circulation by generating a large ensemble of hindcast simulations which have the BKS sea ice cover perturbed (reduced). This will be achieved using the seasonal prediction system CMCC-SPS version 3. In this way the response to sea ice reduction in BKS is assessed taking into account the different climate background states, as well as accounting for the internal variability of the atmosphere.

Methods I: Experimental set-up

The impact of sea ice extent (SIE) anomalies is studied by performing initialized ensemble forecasts simulating the boreal winter seasons (November to April) using a fully-coupled **state-of-the-art seasonal prediction system**, the **CMCC-SPS3:**

- based on CESM1.2 with an ocean model component replacement (NEMO 3.4 instead of POP2)
- CAM 5.2 with model top at 0.3hPa
  → *stratosphere-resolving*

Experiment / Characteristics	ICE-FREE	CTRL
Start date	November 1st	
Period simulated	1993-2015	
Integration length	6 months	
Ensemble size	10	
Ocean component (horizontal resolution)	NEMO 3.4 (0.25°)	
Atmosphere component (horizontal resolution)	CAM 5.2 (1°)	
Ocean upper boundary restoring	dQ/dT = -5000 W/m²	-

FIGURE 2: The seasonal prediction system CMCC-SPS3.

Methods II:
Implementing sea ice-free conditions: Heat supply to the upper ocean

Eqn. 1:

$$Q_{ns} = Q_{ns}^0 + \begin{cases} \frac{dQ}{dT}(SST_{Model} - SST_{Target}), & if\ SST \leq -1.5 \\ 0 & otherwise \end{cases}$$

Q_{ns} = *non-solar heat fluxes (after nudging)*
Q_{ns}^0 = *initial non-solar heat fluxes (before nudging)*
SST_{Target} = *Target model sea surface temperature (-1.5°C)*
SST_{Model} = *Actual simulated sea surface temp.*
dQ/dT = *retroaction term (heat supply; W/m²/K)*

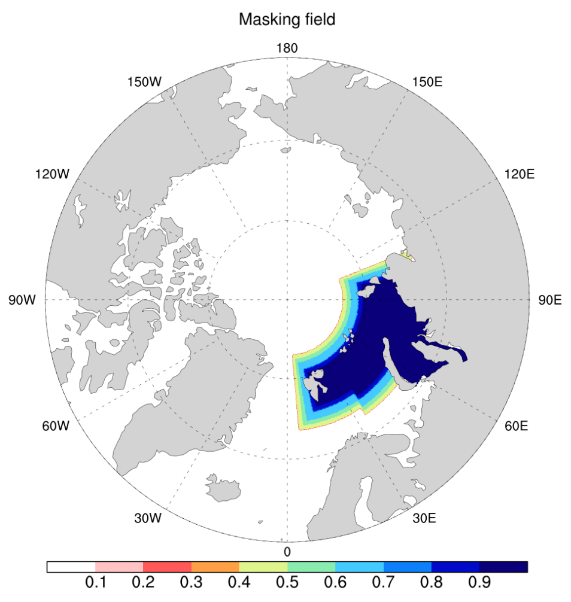

FIGURE 3: Masking field by which Eqn. 1 is weighted.

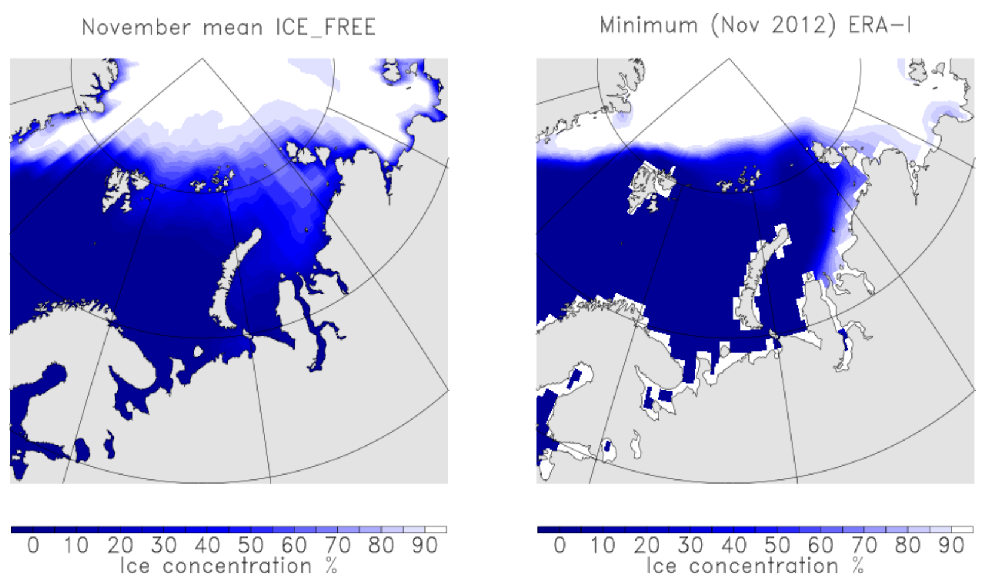

FIGURE 4: November mean sea ice concentration in ICE-FREE (averaged over all years and members; *left*), and during a typical minimum year (November 2012, ERA-I; *right*).

Results I: Model bias and predictive skill of Arctic sea ice

CMCC-SPSv3 shows some biases with regard to the Arctic sea ice cover for the winter season. Yet there is comparatively high prediction skill in the Barents-Kara Seas (BKS; FIGURE 5 lower panel).

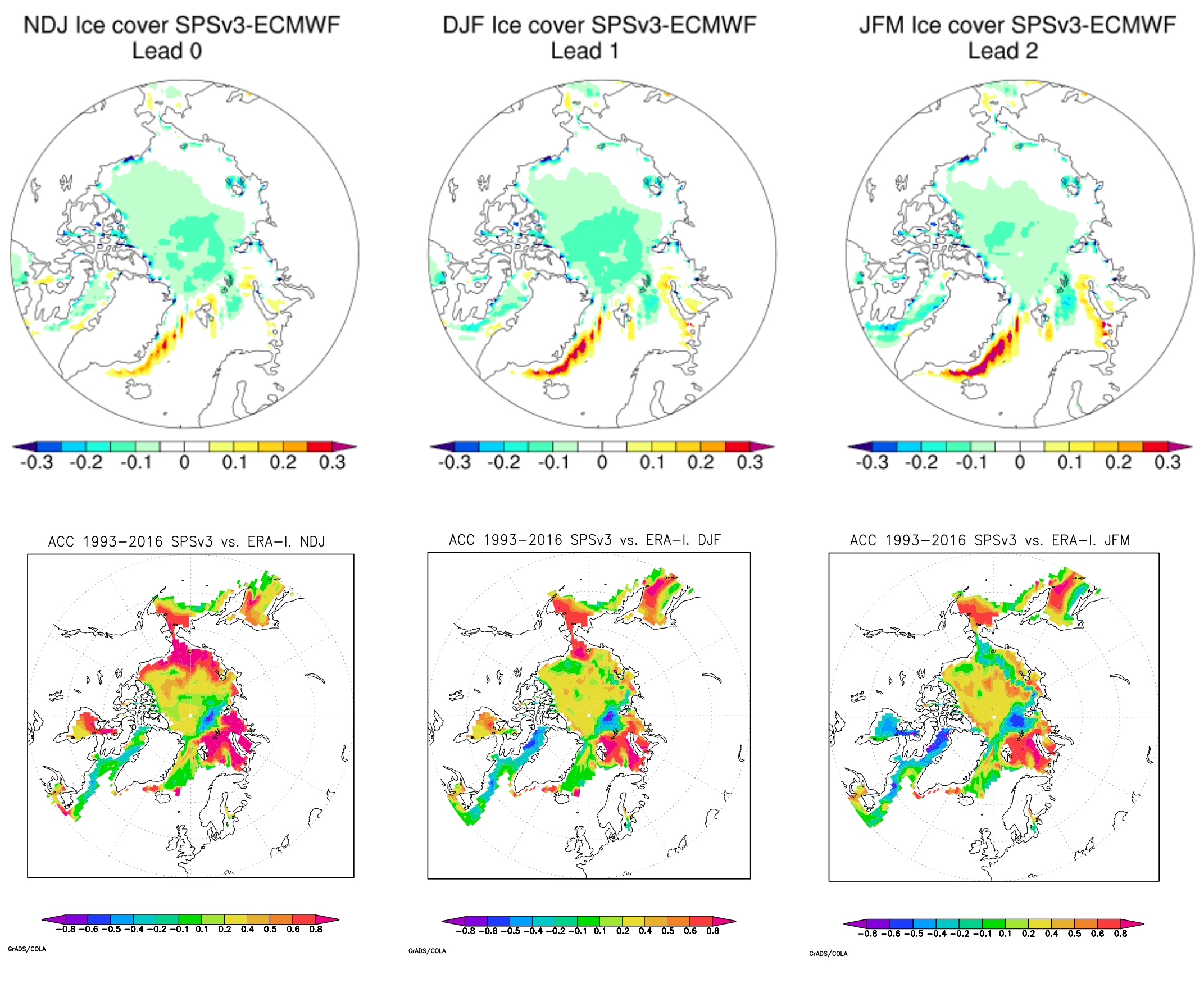

FIGURE 5: *Top:* Boreal winter model bias of Arctic sea ice concentration (%), *Bottom:* Anomaly correlation coefficient (ACC) of sea ice cover.

Results II:
Response to November sea ice loss

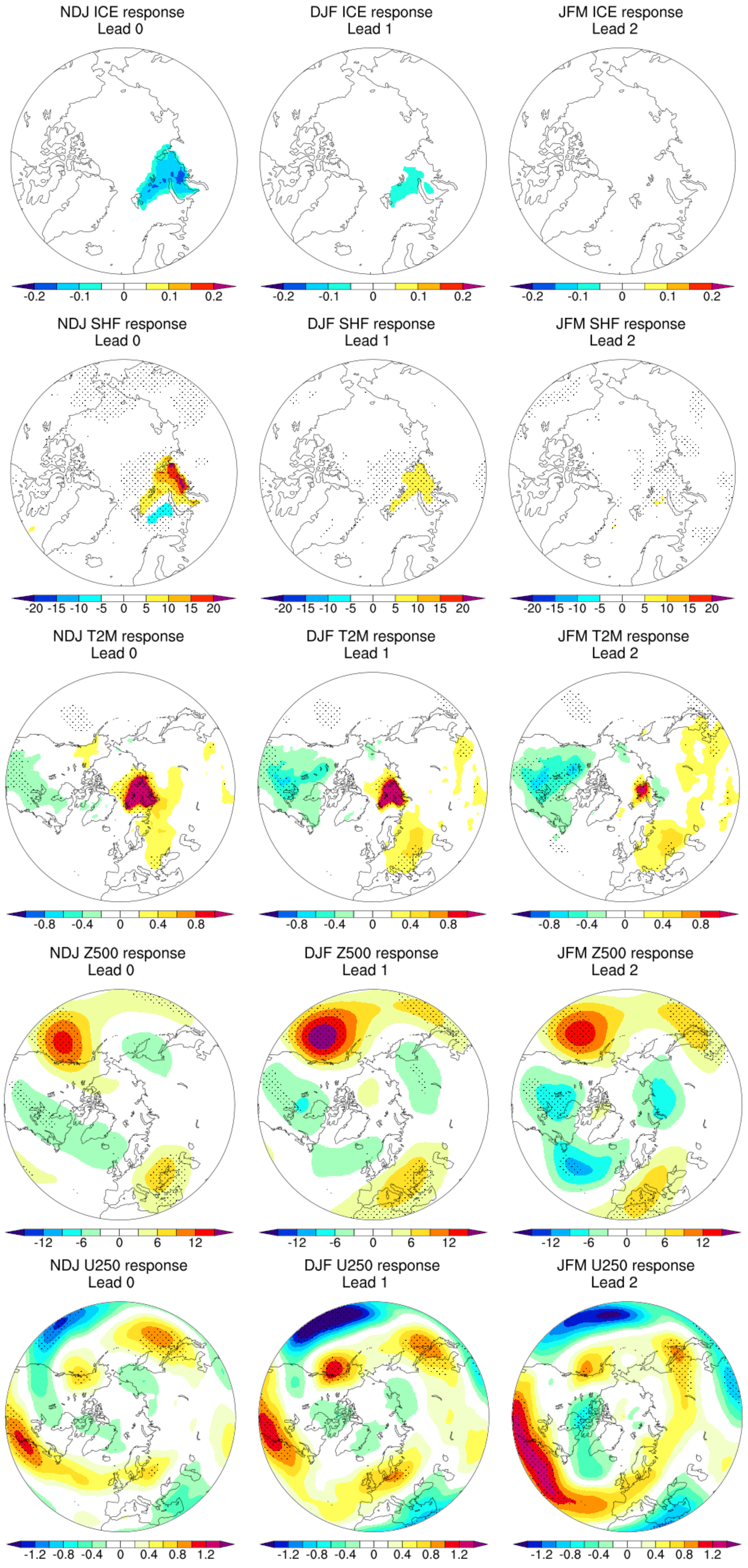

FIGURE 6: ICE-FREE minus CTRL fields of ice fraction, 2m-temperature, surface heat fluxes, Z500 and U250 computed over lead season 0 (NDJ), lead season 1 (DJF), amd lead season 2 (JFM). Hatching denotes 95% confidence of statistical significance.

Conclusions

- The ensemble mean surface response to sea ice loss show features typical of a minimum sea ice year: a fast, local, thermodynamic reponse (warming) as result of increased surface heat fluxes particularly in lead season 0 (NDJ)
- There is no indication of a warm-Arctic-cold continent pattern over Eurasia (2m-temperature), instead there is a persistent cooling over the Northamerican continent in all lead seasons.
- The northeast Pacific sector reveals positive geopotential height anomalies persistent throughout the winter, which has shown to have have effect on large-scale temperature and precipitation patterns in this area[7].
- There is a systematic southward shift of upper-level zonal winds over the western Atlantic/central-east American continent.

References

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