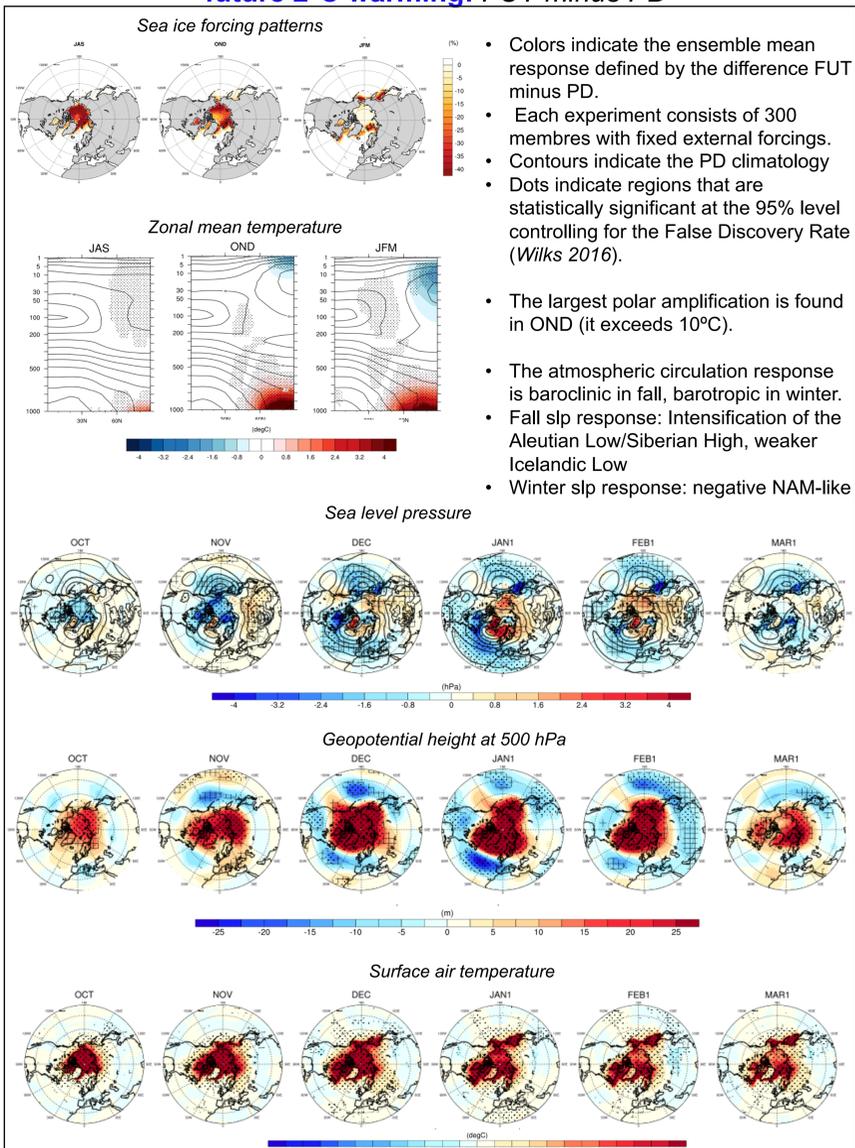


Description of the study

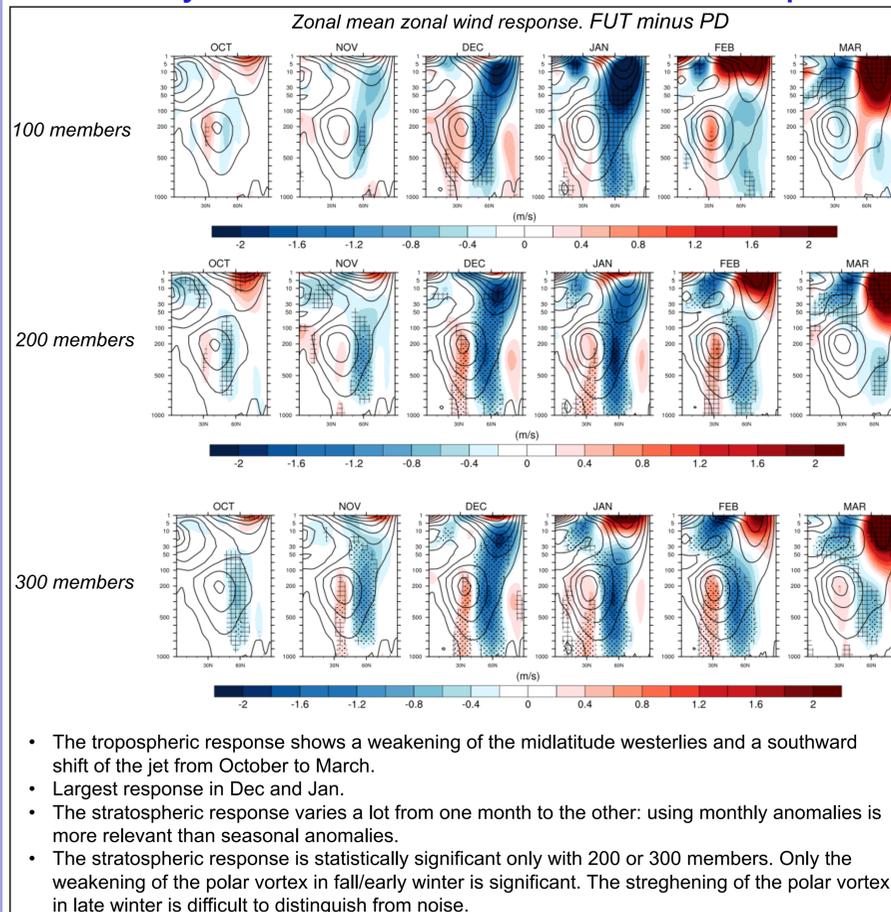
We analyze the Northern Hemisphere atmospheric response to Arctic sea ice decline in the CNRM-CM6 model (130km resolution, 91 vertical levels) using atmosphere-only experiments that follow the PAMIP protocole described in Smith et al. (2019). The high-top atmospheric component of CNRM-CM6 is forced by the same pattern of SST but different idealized patterns of sea ice that correspond to i) pre-industrial conditions (PI), ii) present day conditions (PD), and iii) future conditions (FUT) associated with a 2°C warming with respect to i). Each experiment is run for 14 months starting in April, using at least 100 members. We focus on the cold season response (October to March) and describe the atmospheric response for different sea ice forcings applied either in to whole Arctic or to specific regions in the Arctic.

1- Atmospheric response to sea ice decline corresponding to a future 2°C warming: FUT minus PD

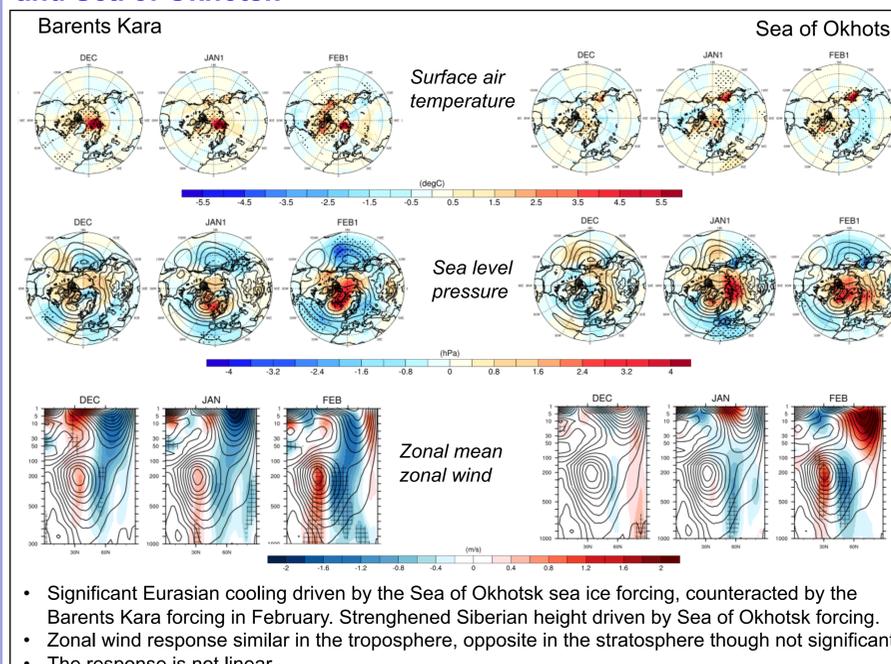


- Colors indicate the ensemble mean response defined by the difference FUT minus PD.
- Each experiment consists of 300 members with fixed external forcings.
- Contours indicate the PD climatology
- Dots indicate regions that are statistically significant at the 95% level controlling for the False Discovery Rate (Wilks 2016).
- The largest polar amplification is found in OND (it exceeds 10°C).
- The atmospheric circulation response is baroclinic in fall, barotropic in winter.
- Fall slp response: Intensification of the Aleutian Low/Siberian High, weaker Icelandic Low
- Winter slp response: negative NAM-like
- Warming over Siberia, North America, Eastern Europe, North Africa.
- Weak cooling over Eurasia, significant in February/March consistent with an enhanced Ural blocking.
- Storm track v850 response based on the daily difference method of Booth et al. (2017).
- Storm tracks intensified over Southern Europe/Mediterranean region, reduced over the North Atlantic basin/Northern Europe.
- Consistent with a negative NAM and a southward shift of the jet. Similar results with other metrics (high-pass filtered Z500, tracking algorithm).
- Polar cap (60°N-90°N) geopotential height response: Largest positive anomalies in the stratosphere in Dec 1 month after the max surface warming. Consistent with a negative NAM and a weakening of the polar vortex.
- Downward propagation to the troposphere in Jan/Feb.

2- How many members are needed to detect a robust response?

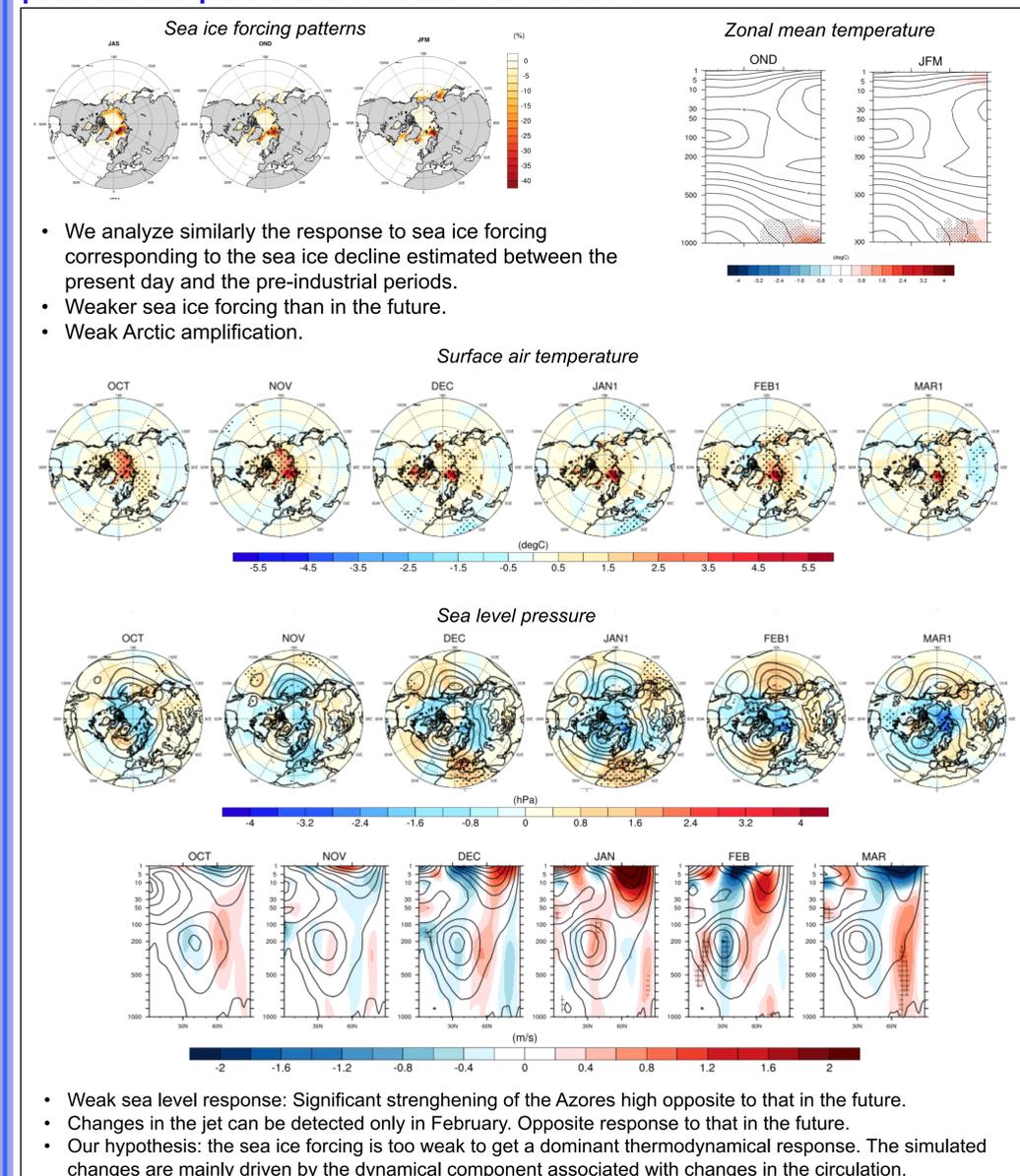


3-Influence of regional sea ice forcing from the Barents-Kara Sea and Sea of Okhotsk



- The tropospheric response shows a weakening of the midlatitude westerlies and a southward shift of the jet from October to March.
- Largest response in Dec and Jan.
- The stratospheric response varies a lot from one month to the other: using monthly anomalies is more relevant than seasonal anomalies.
- The stratospheric response is statistically significant only with 200 or 300 members. Only the weakening of the polar vortex in fall/early winter is significant. The strengthening of the polar vortex in late winter is difficult to distinguish from noise.
- Significant Eurasian cooling driven by the Sea of Okhotsk sea ice forcing, counteracted by the Barents Kara forcing in February. Strengthened Siberian height driven by Sea of Okhotsk forcing.
- Zonal wind response similar in the troposphere, opposite in the stratosphere though not significant
- The response is not linear.

4-Can we detect an atmospheric response to sea ice decline since the preindustrial period in the model? PD minus PI



- We analyze similarly the response to sea ice forcing corresponding to the sea ice decline estimated between the present day and the pre-industrial periods.
 - Weaker sea ice forcing than in the future.
 - Weak Arctic amplification.
 - Weak sea level response: Significant strengthening of the Azores high opposite to that in the future.
 - Changes in the jet can be detected only in February. Opposite response to that in the future.
 - Our hypothesis: the sea ice forcing is too weak to get a dominant thermodynamical response. The simulated changes are mainly driven by the dynamical component associated with changes in the circulation.
- ### Conclusion
- Significant atmospheric response to sea ice decline associated with a future 2°C warming.
 - The polar amplification is associated with a southward shift of the jet and a weakened polar vortex in late fall/early winter. The winter response is barotropic and consistent with a negative NAM.
 - The stratospheric response is noisy and requires more than 100 members to be detected.
 - Both Barents Kara Sea and Sea of Okhotsk seem to contribute to the midlatitude jet response but not linearly.
 - A weak but significant cooling over Eurasia is found in late winter in response to the full Arctic sea ice forcing and to the Sea of Okhotsk forcing. The influence of the Barents Kara Sea seems to counteract this cooling.
 - The weaker sea ice forcing between pre-industrial and present day periods yields a smaller response than in the future that is hardly significant.
 - Other PAMIP experiments will allow us to look at the effect of background mean state, coupling with the ocean, effect of SST forcing etc. in a multi-model framework.