Arctic influence on mid-latitude weather and climate: recent progress and future prospects

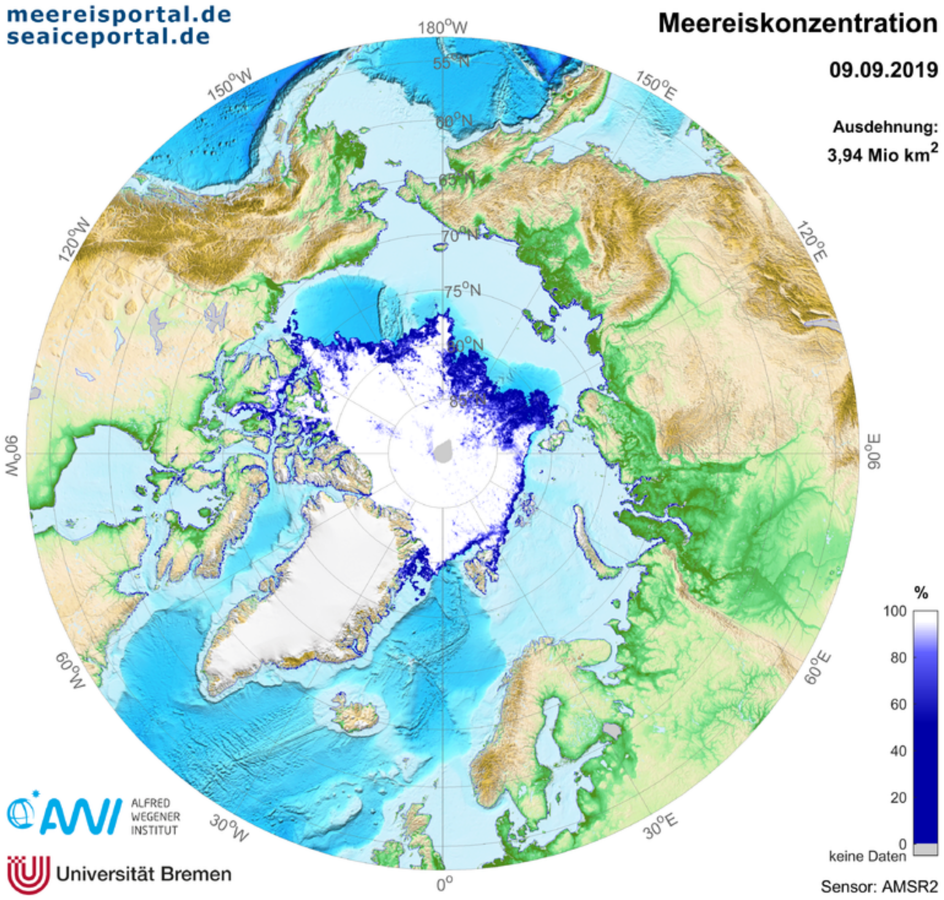
Tido Semmler, Thomas Jung

Overview

1. Current situation
2. Step back (early work)
3. Challenges and future work

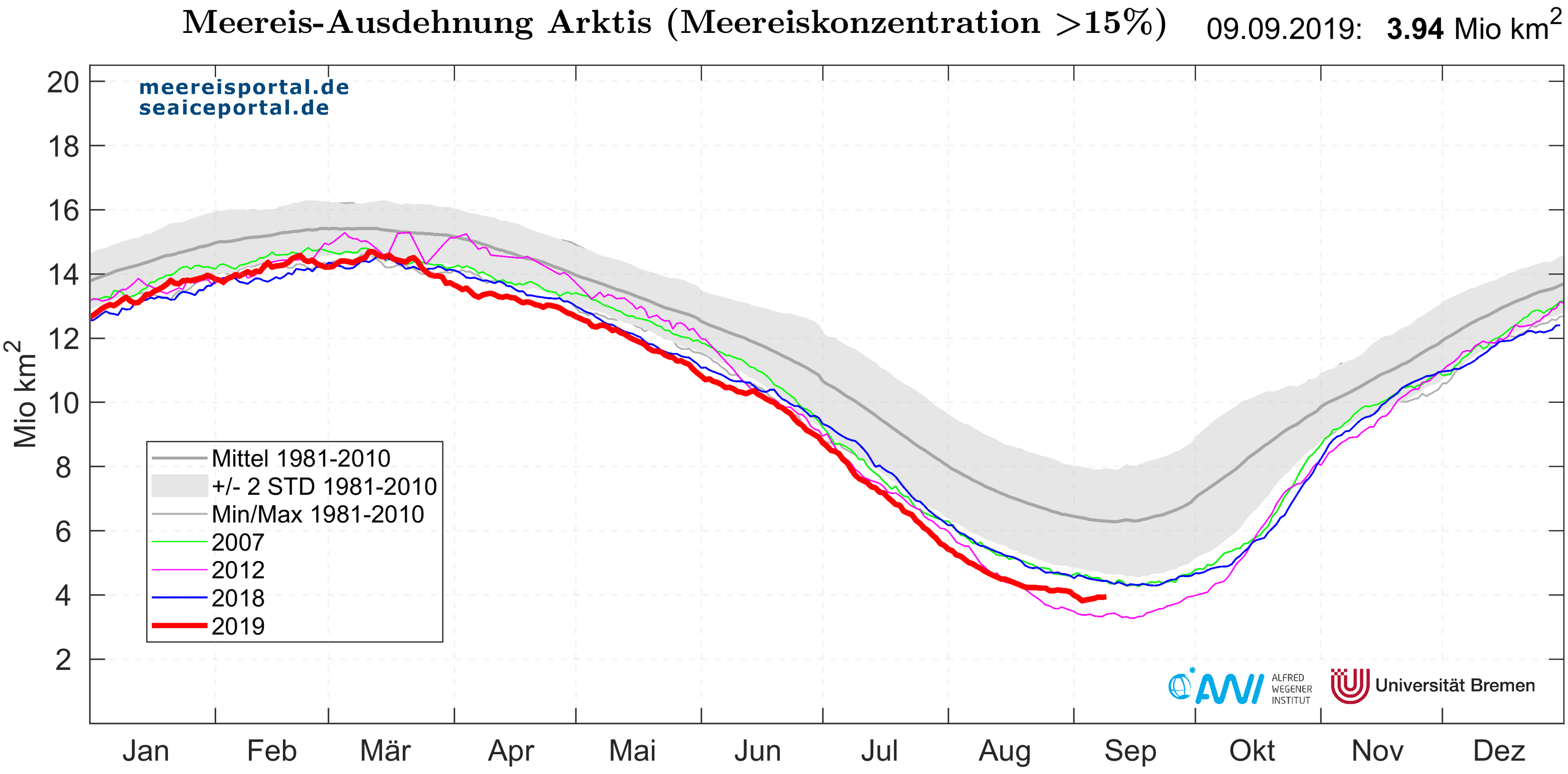
Introduction

Everybody knows: Arctic sea ice has been strongly declining over the last 3 to 4 decades



Northeast passage free

Introduction



Introduction

Many studies have investigated the impact of such Arctic sea ice decline on the Northern mid-latitude climate – obviously we want to know what the Arctic sea ice decline means for us

Already in the 1970s to the 1990s Arctic sea ice removal experiments have been performed

While some response features have been well established there is lively discussion and controversy over some features owing to the strong internal variability of Arctic and mid-latitude weather and climate

Workshops

Barcelona 2014

SPONSORS

The workshop is supported by:
IC³, AWI, WWRP, WCRP, SPECS-FP7, ECRA, GFCS, EGU, European Commission

Polar-Lower Latitude Linkages Workshop
Barcelona
10 - 12 December 2014

Recommendations from the workshop (Jung et al., 2015):

Improved process understanding

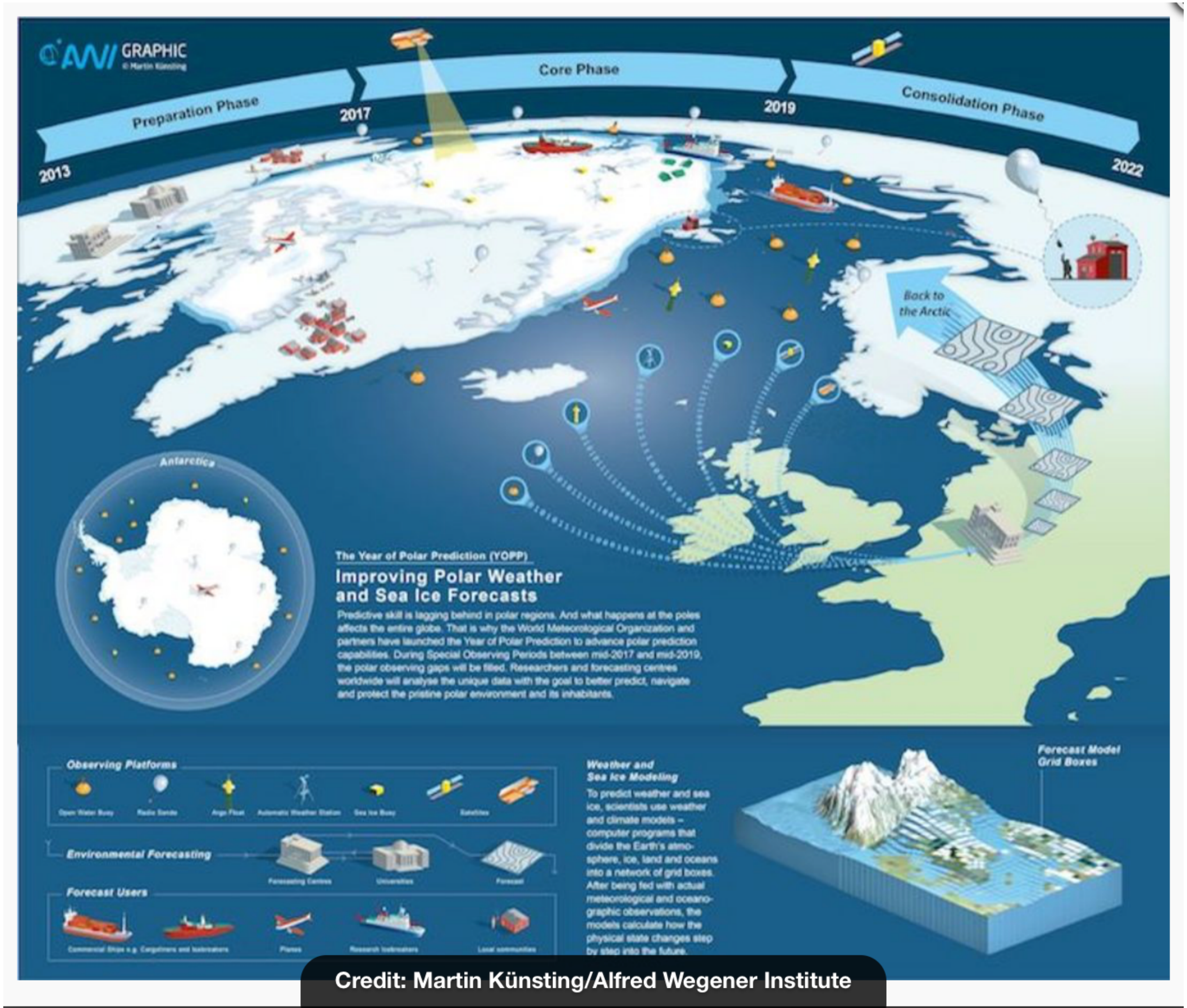
Weather and climate forecasting (synergies)

Coordinated model Experiments

EU project APPLICATE based on these ideas

Year Of Polar Prediction (YOPP)
Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC)

Year of Polar Prediction (YOPP)



The Year of Polar Prediction (YOPP)

Improving Polar Weather and Sea Ice Forecasts

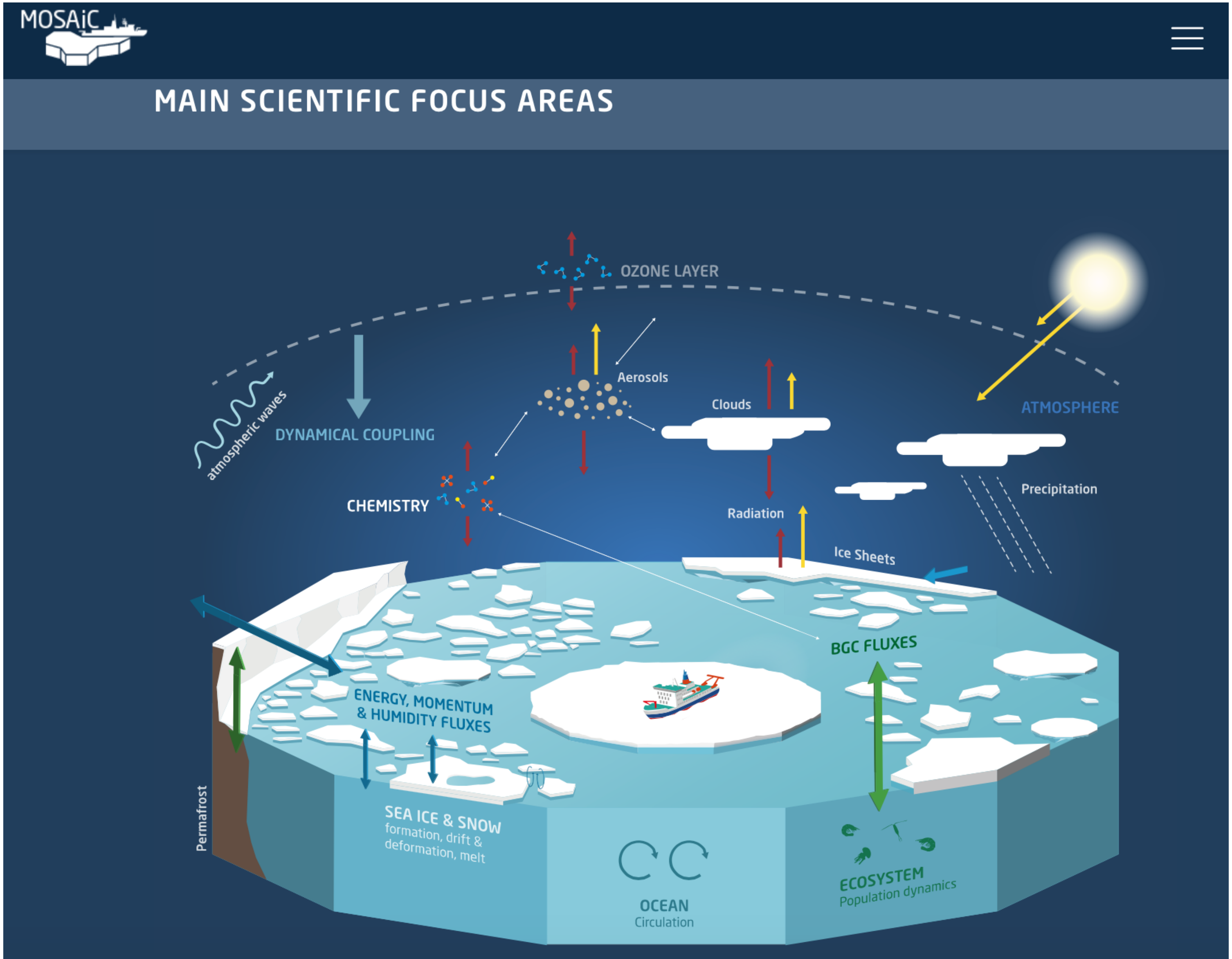
Predictive skill is lagging behind in polar regions. And what happens at the poles affects the entire globe. That is why the World Meteorological Organization and partners have launched the Year of Polar Prediction to advance polar prediction capabilities. During Special Observing Periods between mid-2017 and mid-2019, the polar observing gaps will be filled. Researchers and forecasting centres worldwide will analyse the unique data with the goal to better predict, navigate and protect the pristine polar environment and its inhabitants.

Weather and Sea Ice Modeling

To predict weather and sea ice, scientists use weather and climate models – computer programs that divide the Earth's atmosphere, ice, land and oceans into a network of grid boxes. After being fed with actual meteorological and oceanographic observations, the models calculate how the physical state changes step by step into the future.

Credit: Martin Künsting/Alfred Wegener Institute

Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC)



MAIN SCIENTIFIC FOCUS AREAS

APPLICATE.eu
Advanced prediction in
polar regions and beyond

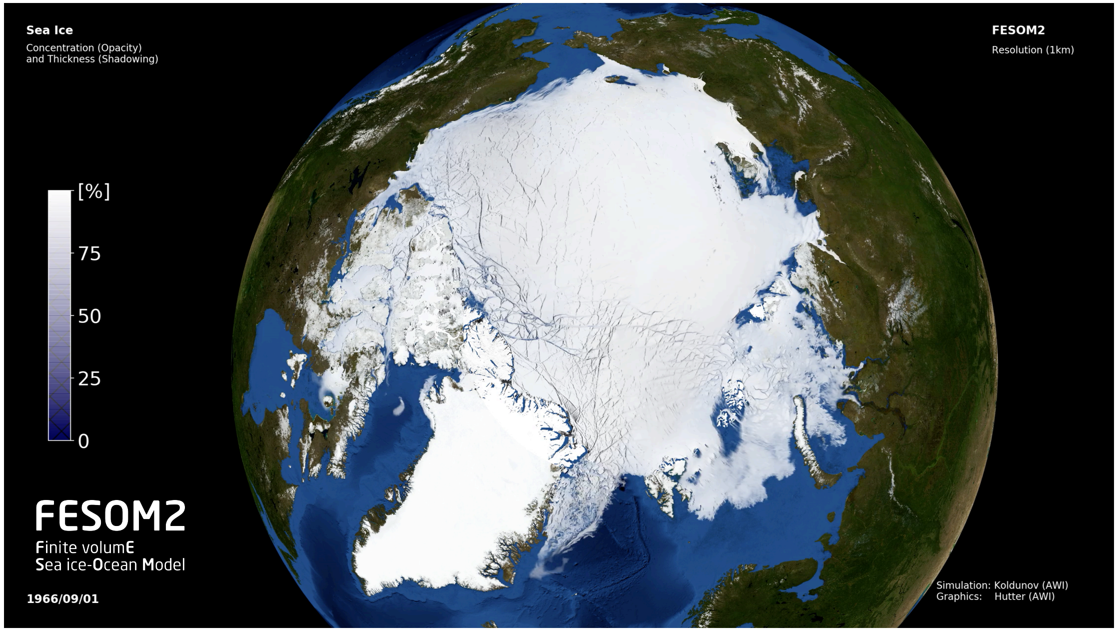
APPLICATE

Advanced **P**rediction in **P**olar Regions and Beyond

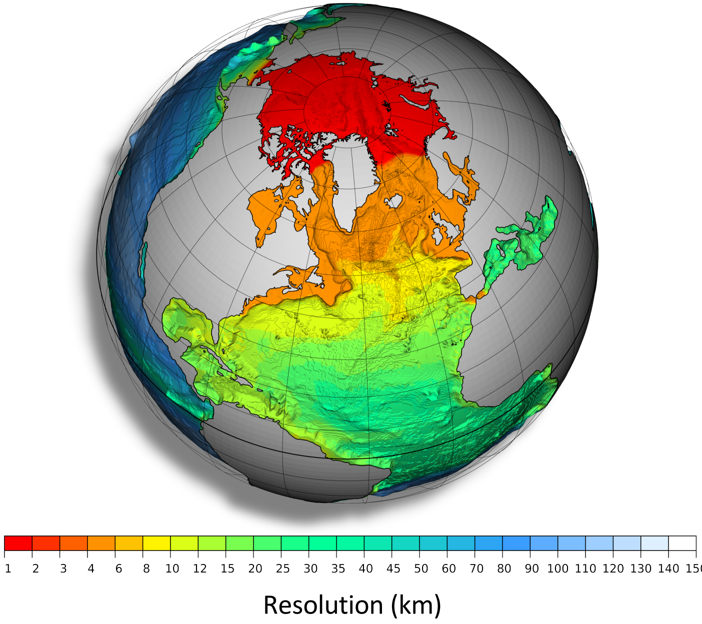
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727862.

Delivering enhanced predictions

Enhance models—The example of increased resolution



Simulation: Koldunov (AWI)
Graphics: Hutter (AWI)



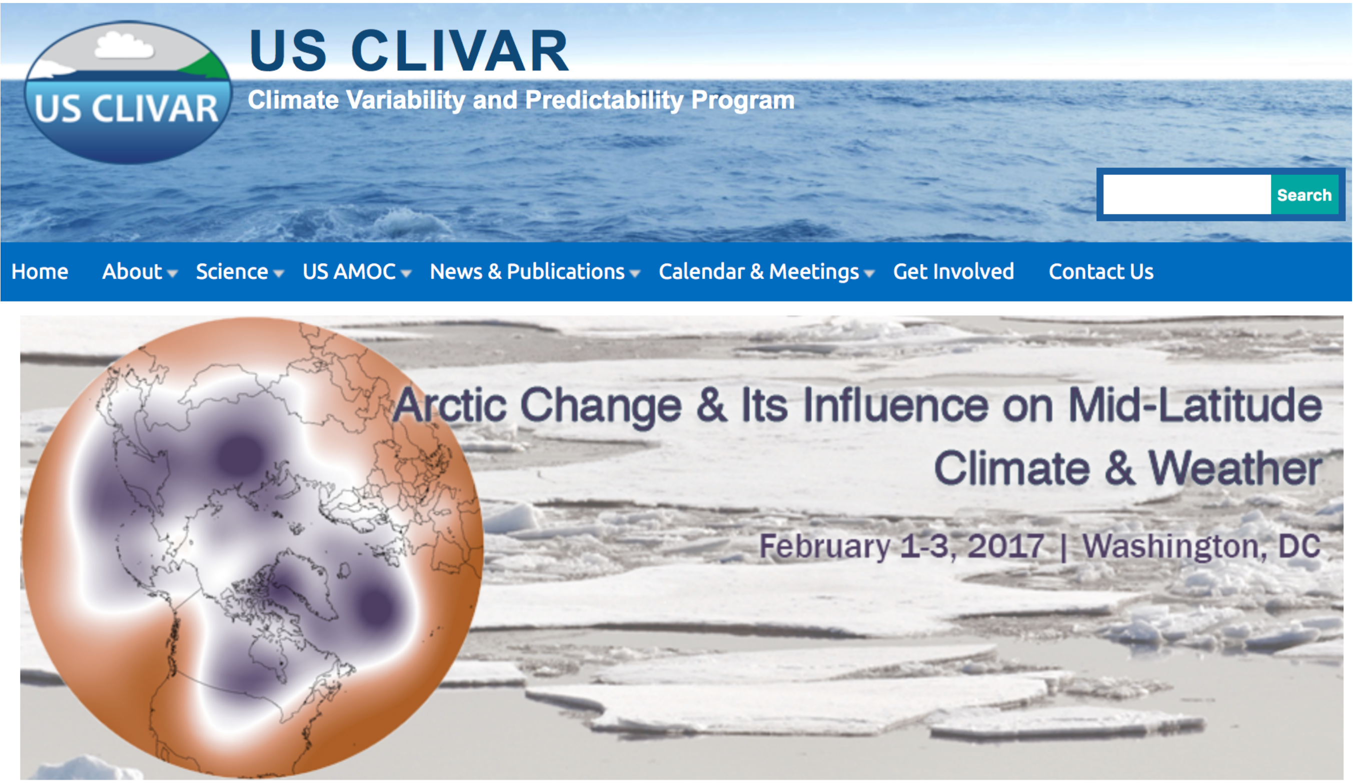
Strategy

Understand Arctic-midlatitude linkages

- Coordinated multi-model approach (CMIP6-PAMIP)
- Employ atmosphere-only *and* coupled models
- Study linkages also from a short-term prediction perspective
- Repeat some of the experiments with enhanced models

Workshops

Washington, D.C. 2017



Arctic Change & Its Influence on Mid-Latitude Climate & Weather

February 1-3, 2017 | Washington, DC

Recommendations from the workshop (Cohen et al., 2018):

Synthesis of available observations

Use paleo data

Coordinated model experiments (using the full range of models: conceptual to full earth system)

PAMIP within CMIP6

PAMIP workshop Totnes (2019)

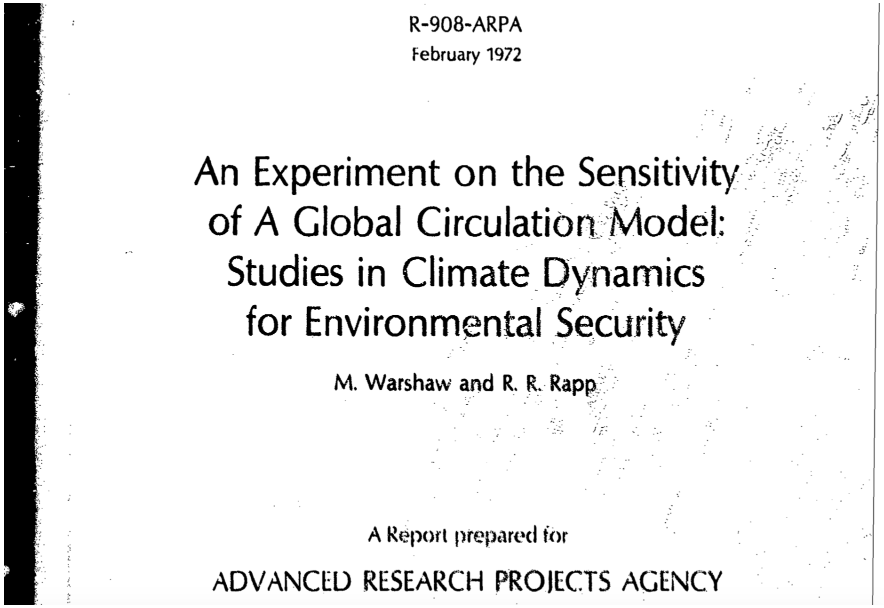
Participants of the PAMIP workshop in the surroundings of Exeter, UK (photo: Jinro Ukita, Niigata University, Japan).

First PAMIP workshop held close to Exeter, UK to exchange first results of the coordinated model experiments

Outcome: groups of scientists established who work on multi-model analysis of specific aspects

Series of papers planned on this basis

Early report: Warshaw and Rapp (1972)



R-908-ARPA
February 1972

An Experiment on the Sensitivity of A Global Circulation Model: Studies in Climate Dynamics for Environmental Security

M. Warshaw and R. R. Rapp

A Report prepared for
ADVANCED RESEARCH PROJECTS AGENCY

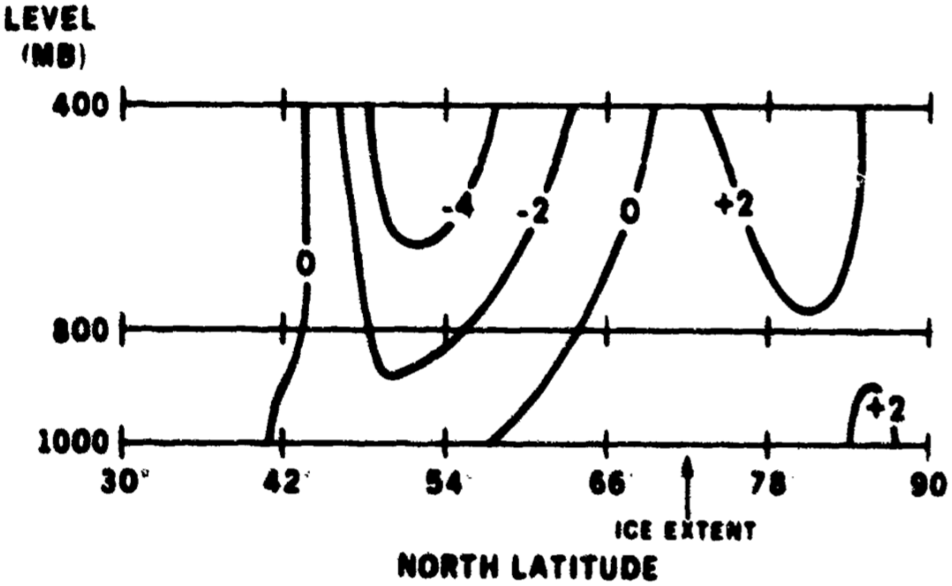
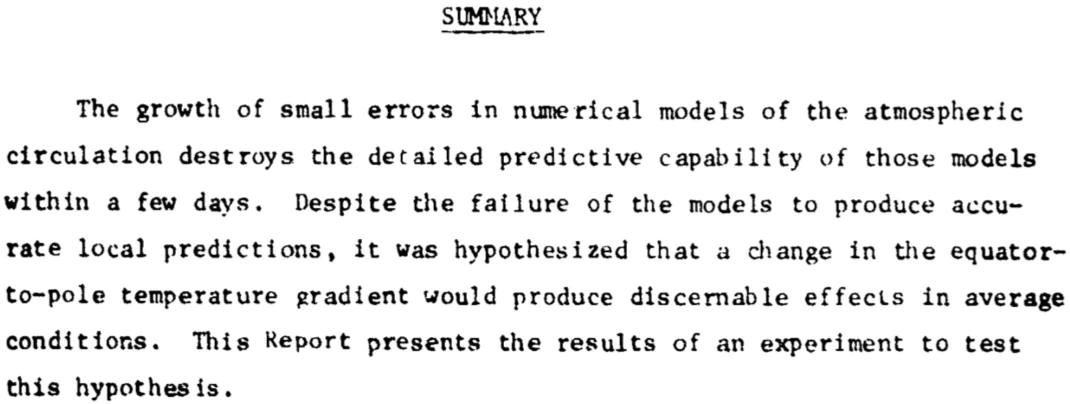


Fig. 8 -- East/west wind differences (m/sec); (ice out) - (ice in).



SUMMARY

The growth of small errors in numerical models of the atmospheric circulation destroys the detailed predictive capability of those models within a few days. Despite the failure of the models to produce accurate local predictions, it was hypothesized that a change in the equator-to-pole temperature gradient would produce discernable effects in average conditions. This Report presents the results of an experiment to test this hypothesis.

Report based on findings of a two-level global circulation model

Early papers: Newson (1973), Royer et al. (1990)

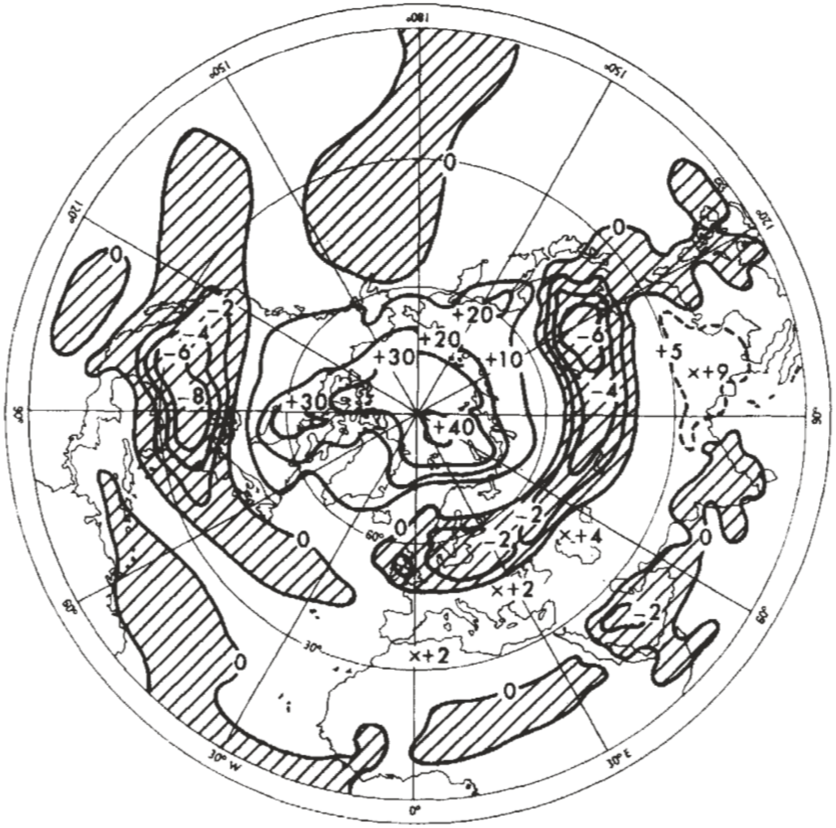


Fig. 1 Temperature differences, in °C near the model surface, between the computation with an ice-free arctic and the computation with ice at the mean climatological position. Hatched areas indicate regions of cooling in the ice-free experiment.

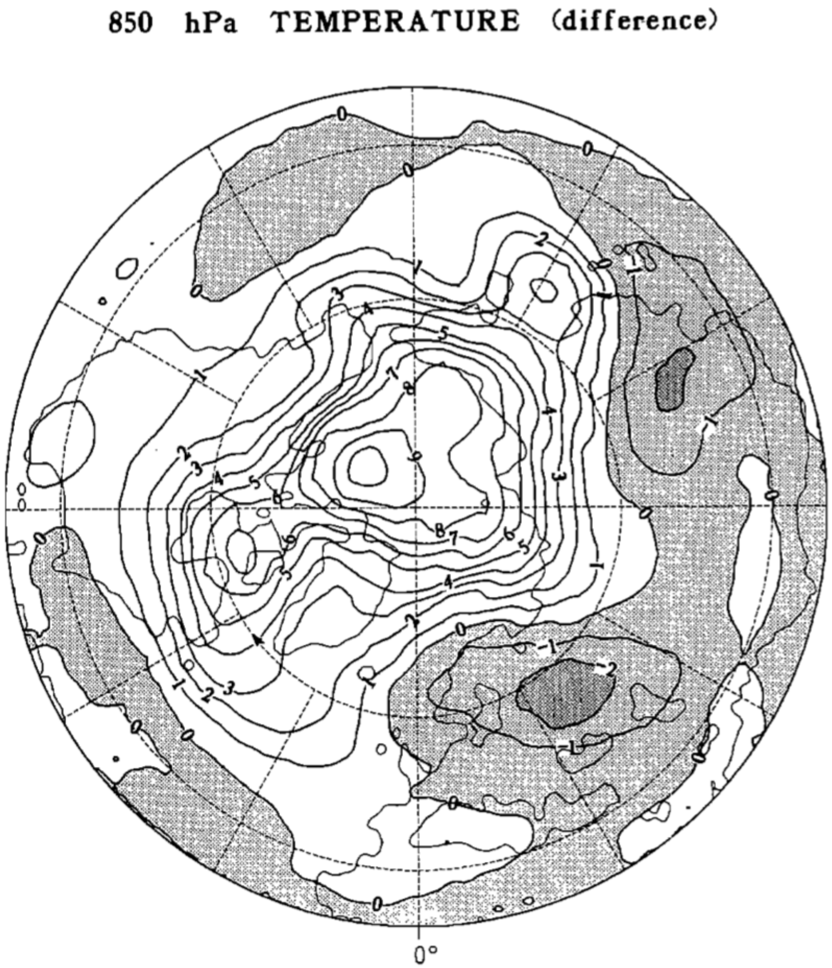


Fig. 10. Change in DJF mean temperature (K) at the 850 hPa level between "ice-out" and control. Negative values are shaded

Early papers: Royer et al., 1990

Sea ice removal experiment with low resolution T42 atmospheric global model

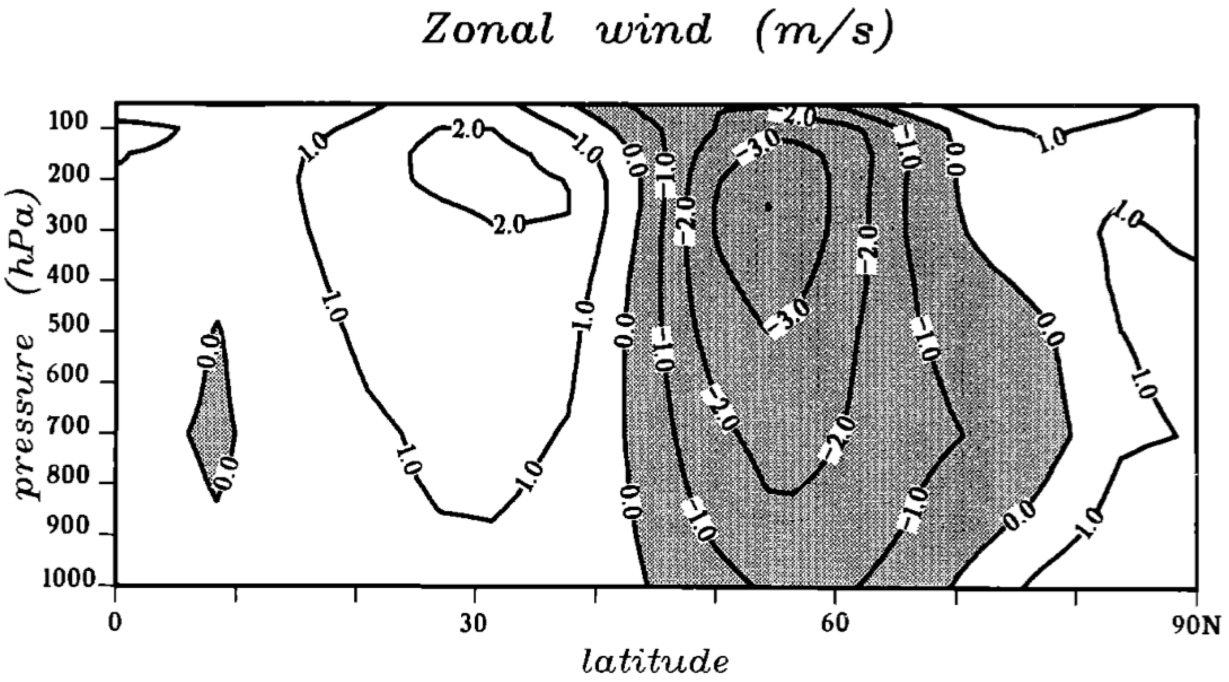


Fig. 5. Change in zonally averaged DJF mean zonal wind (m/s) between "ice-out" and control

Deser et al., 2010

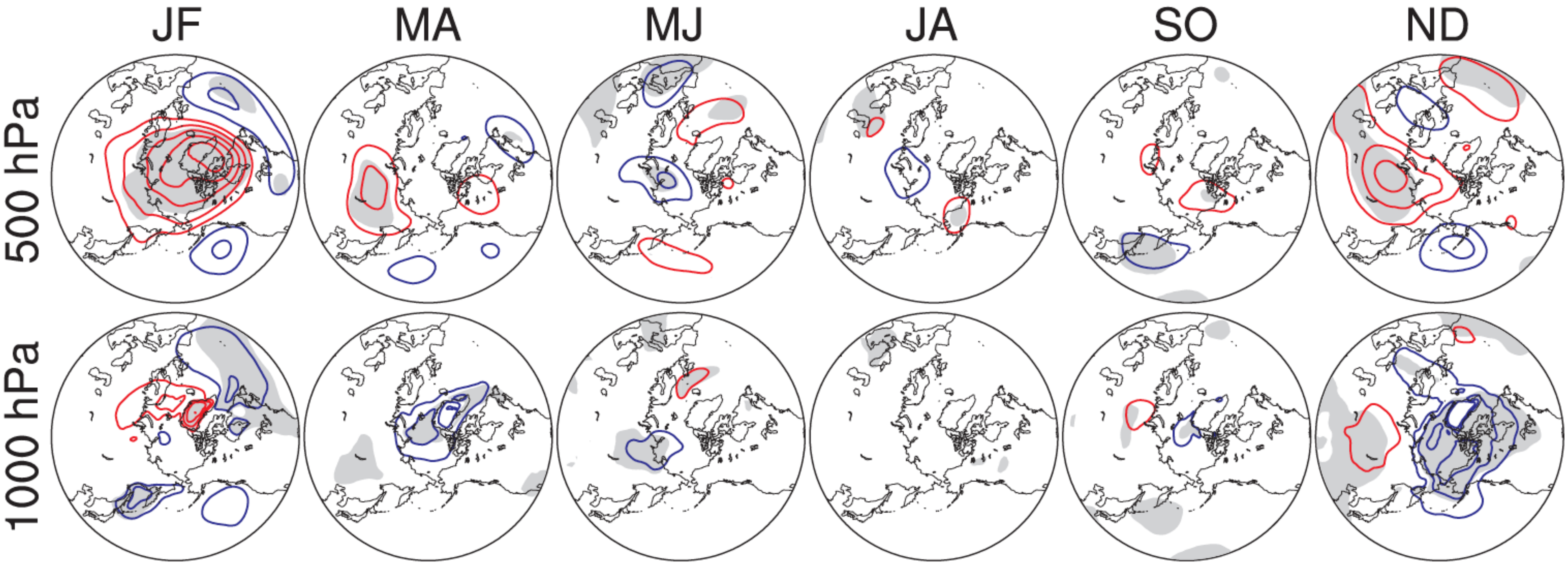


FIG. 12. Bimonthly geopotential height responses at 1000 and 500 hPa. The contour interval is 10 m, with positive (negative) values in red (blue) and the zero contours omitted. Shading indicates values that exceed the 5% confidence level based on a two-sided Student's *t* test.

Started to think about more real-world set-ups instead of complete removal of Arctic sea ice

Semmler et al., 2012

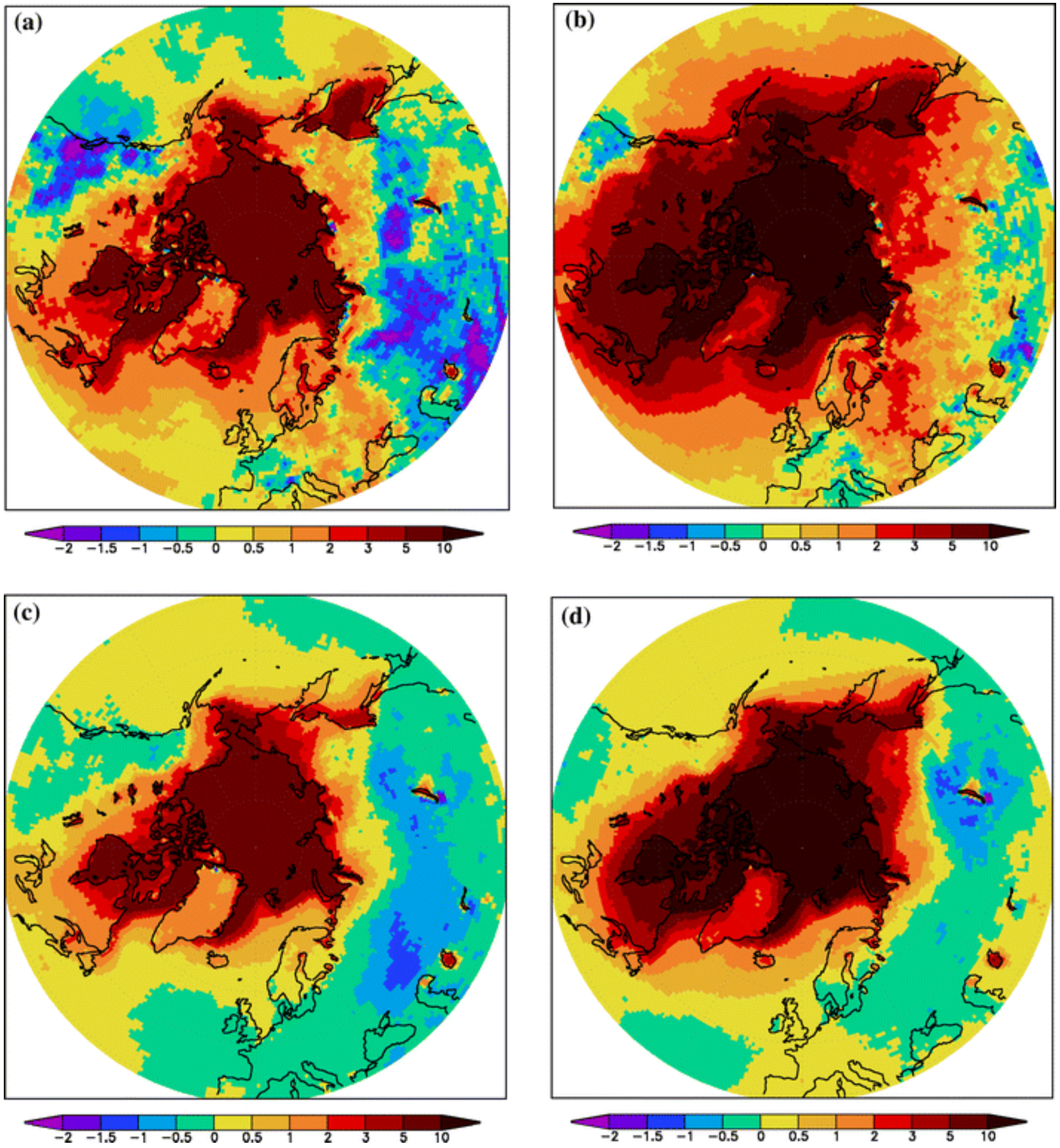


Fig. 9
Difference in 1st percentiles of daily mean 2 m temperature (°C) in winter 1960-2000 over the Arctic and the Northern mid-latitudes **a** ice-reduced minus reference experiment and **b** ice-free minus reference experiment. **c, d** same as **a, b** but for 50th percentiles

$$\mathrm{SIST} \leq \mathrm{T}_{\mathrm{freeze}} - 10\,^{\circ}\mathrm{C} \rightarrow \mathrm{SIST} = \mathrm{SIST} + 10\,^{\circ}\mathrm{C}, \quad \mathrm{SIC} = \mathrm{SIC}$$
$$\mathrm{SIST} > \mathrm{T}_{\mathrm{freeze}} - 10\,^{\circ}\mathrm{C} \rightarrow \mathrm{SST} = \mathrm{Max}\,(T_{\mathrm{freeze}}, \mathrm{SIST})\,, \quad \mathrm{SIC} = 0$$

with T_{freeze} being the freezing temperature of sea water (−1.7 °C).

Started to think about more real-world set-ups instead of complete removal of Arctic sea ice

Atmospheric nudging / relaxation

Jung et al. 2014

Idea:

Control experiments: free global atmospheric forecasts (medium-range to seasonal)

Sensitivity experiments: relax / nudge the atmosphere to observed state in a certain area (for example the Arctic and for comparative purposes mid-latitudes or tropics)

Large ensembles can be performed

Could be also done for coupled models

Atmospheric nudging / relaxation

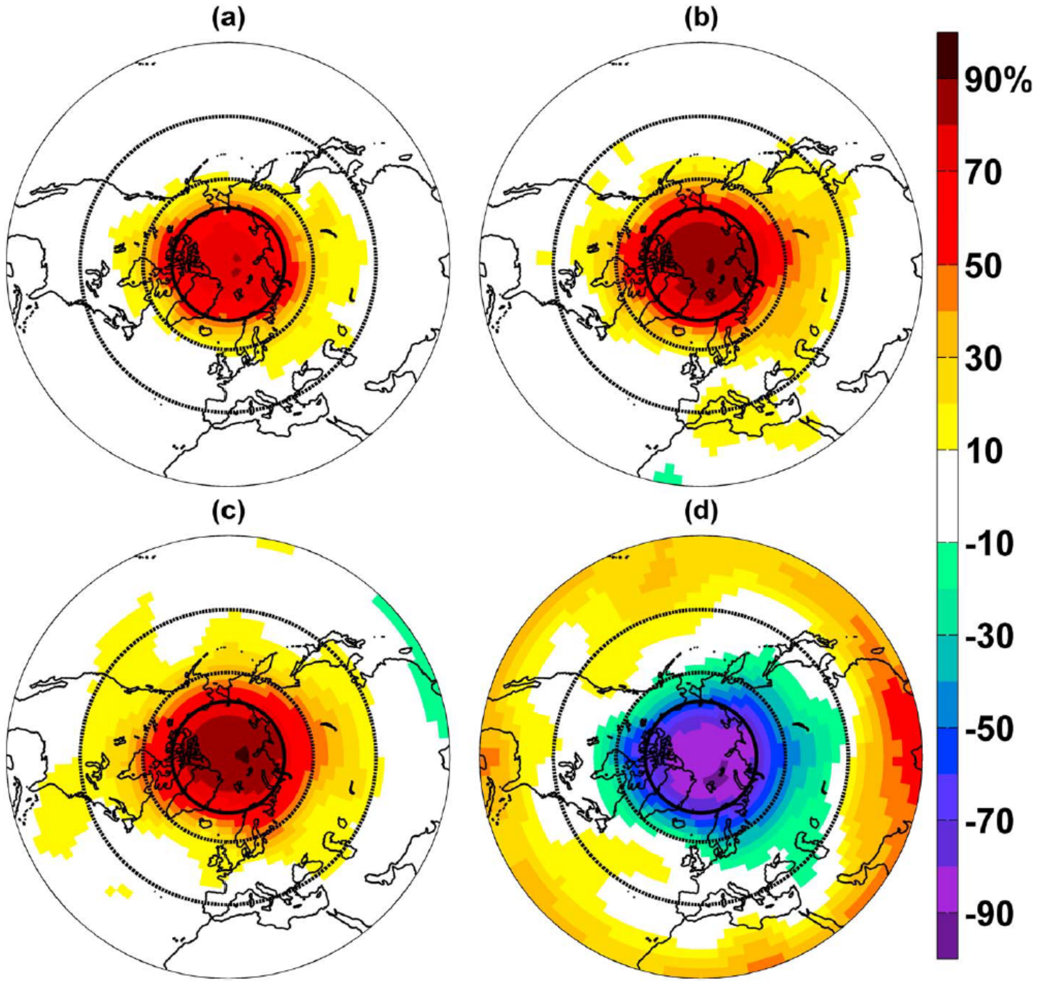


Figure 1. (a–c) Relative reduction (in %) of the root-mean-square error of 500 hPa geopotential height forecasts during wintertime through Arctic relaxation (north of 70°N, solid circle) for day 1–5 in Figure 1a, day 6–10 in Figure 1b, and day 11–30 in Figure 1c forecasts. (d) Difference in the relative reduction of forecast error for day 11–30 between experiments with tropical and Arctic relaxation. Negative values in Figure 1d indicate that Arctic relaxation is more efficient than tropical relaxation in reducing Z500 forecast error. The dashed circles indicate the midlatitudes as defined in this study

Started to think about alternative techniques to tackle the question of Arctic – mid-latitude linkages

Possible to study relative influence from other regions

Up to now: atmosphere-only experiments; next slides: coupled experiments

Jung et al., 2014

Importance of coupling

Deser et al., 2016

Stronger response both with slab ocean model (SOM) and full ocean model (FOM) compared to no ocean model (NOM)

„Mini global warming“

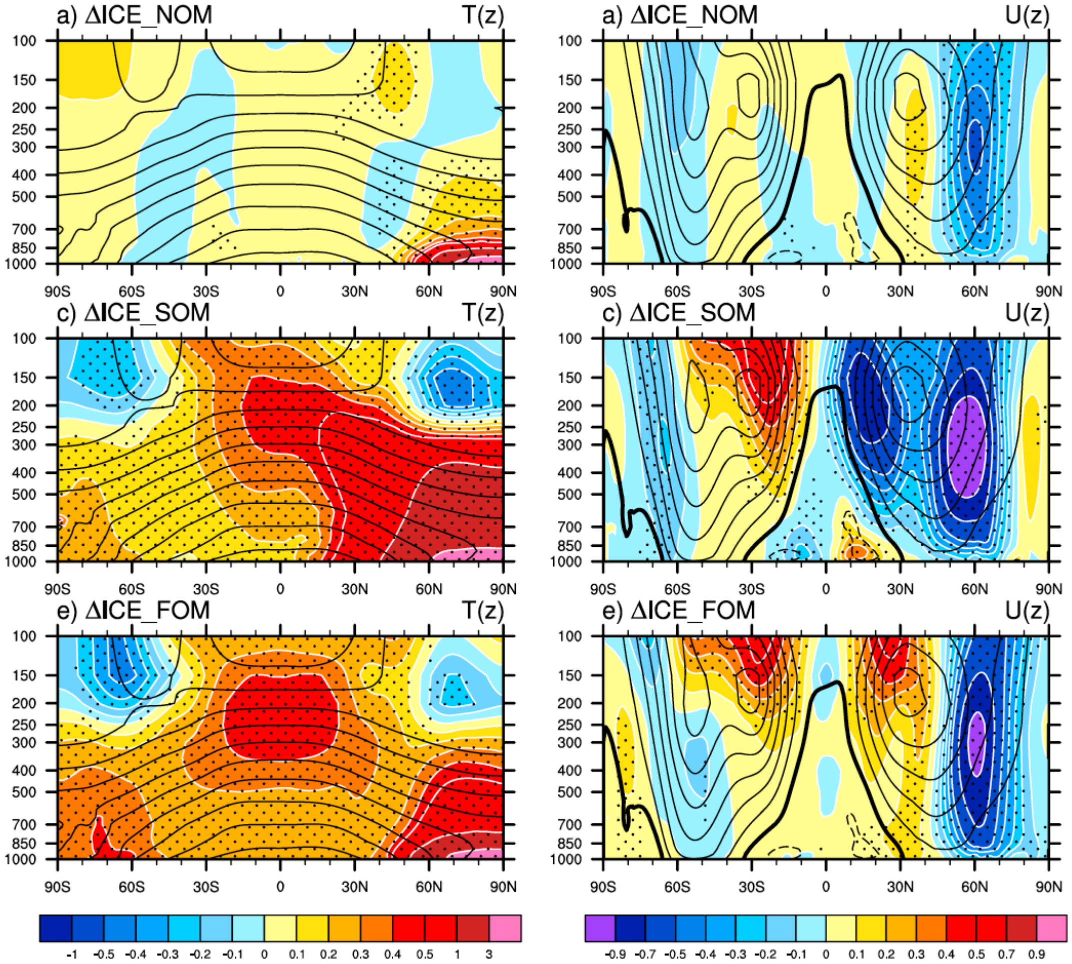
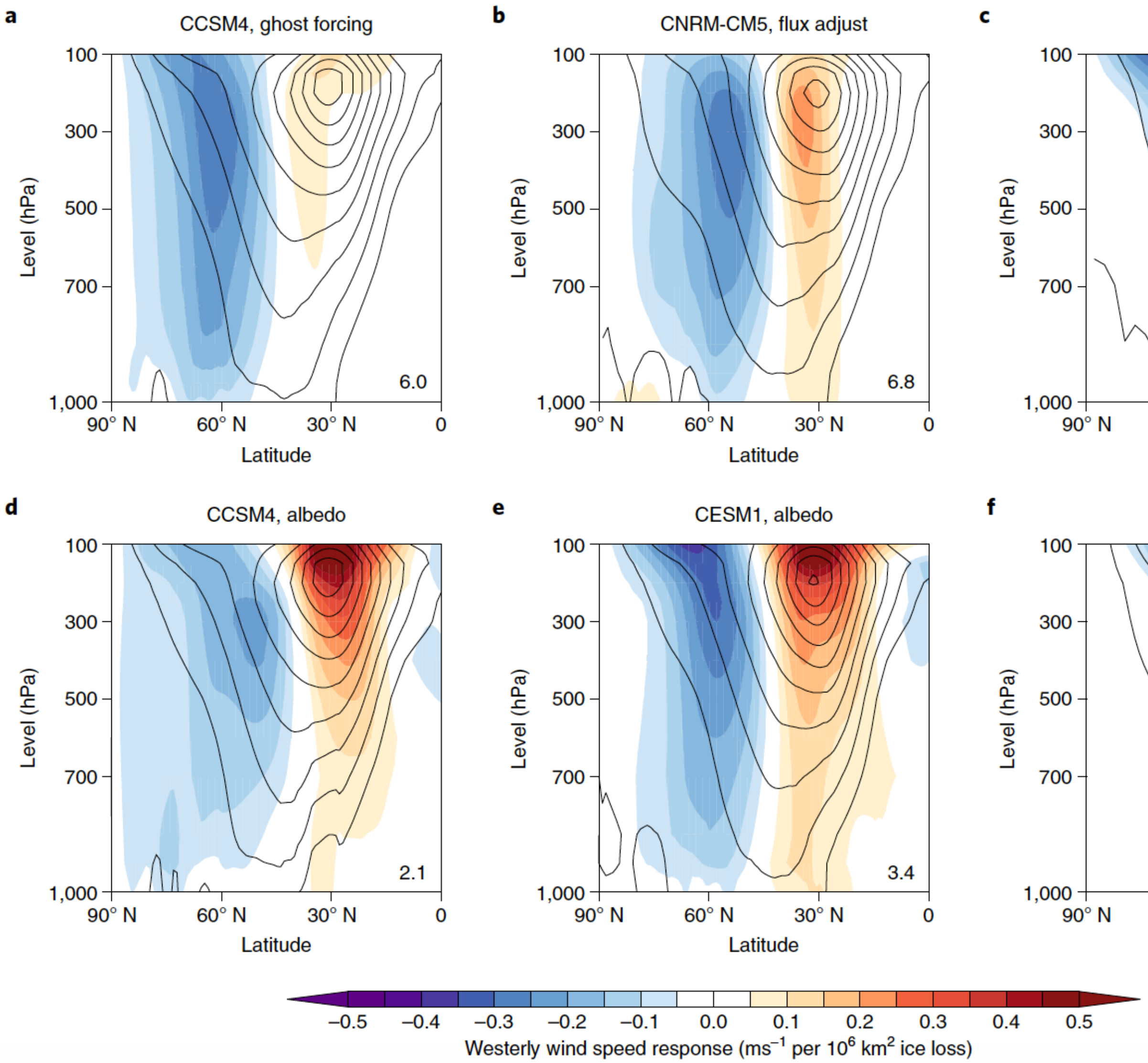


Figure 1. Annual zonal mean (a, c, e) temperature (°C) and (b, d, f) zonal wind (m s^{-1}) responses to Arctic sea ice loss in the in ΔICE_NOM (Figures 1a and 1b), ΔICE_SOM (Figures 1c and 1d), and ΔICE_FOM (Figures 1e and 1f) model configurations (color shading: color bars at the bottom of each column; note the nonlinear color scales). Stippling indicates where the response is statistically significant at the 95% confidence level. Contours indicate the twentieth century climatology (contour interval of 10°C for temperature and 5 m s^{-1} for zonal wind with the zero contour thickened).

Recent paper: Screen et al. (2018)



Synthesis of results from long coupled experiments

Good news: general agreement on zonal mean zonal wind

Regional 4*CO2 approach

Stücker et al., 2018 / Semmler et al., 2019 (in review)

Idea:

Control experiments: free coupled simulations with constant baseline CO2 concentrations

Sensitivity experiments: branching off from control experiments and suddenly increase CO2 to 4*CO2 in a certain area (for example the Arctic and for comparative purposes mid-latitudes or tropics)

Heat uptake and transport

Stücker et al. (2018) regional 4*CO2 simulations

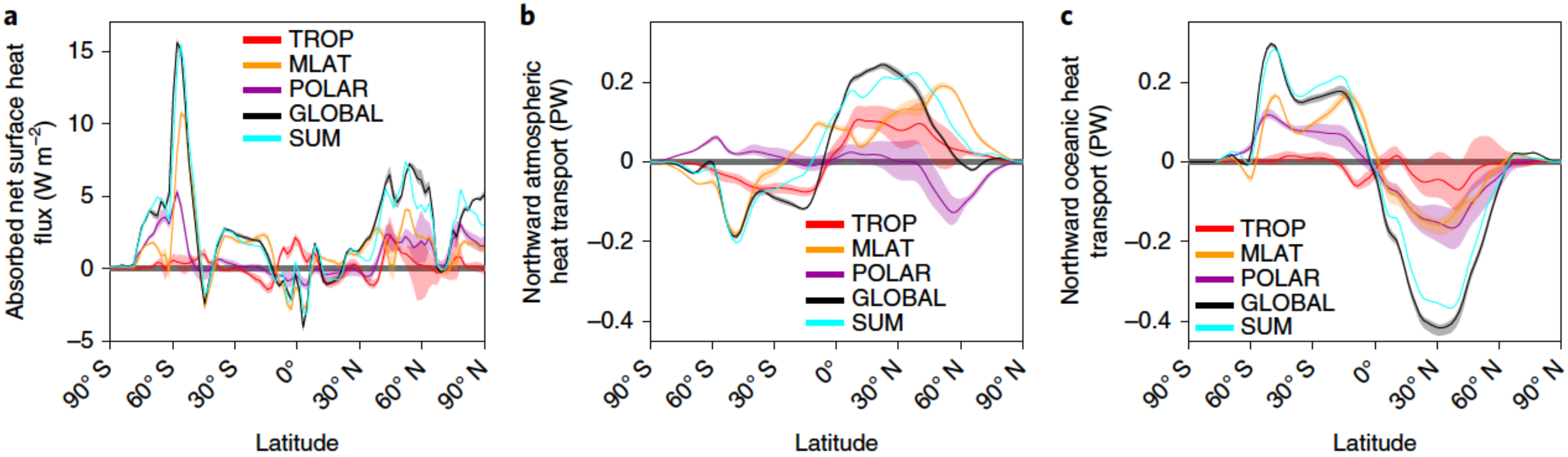
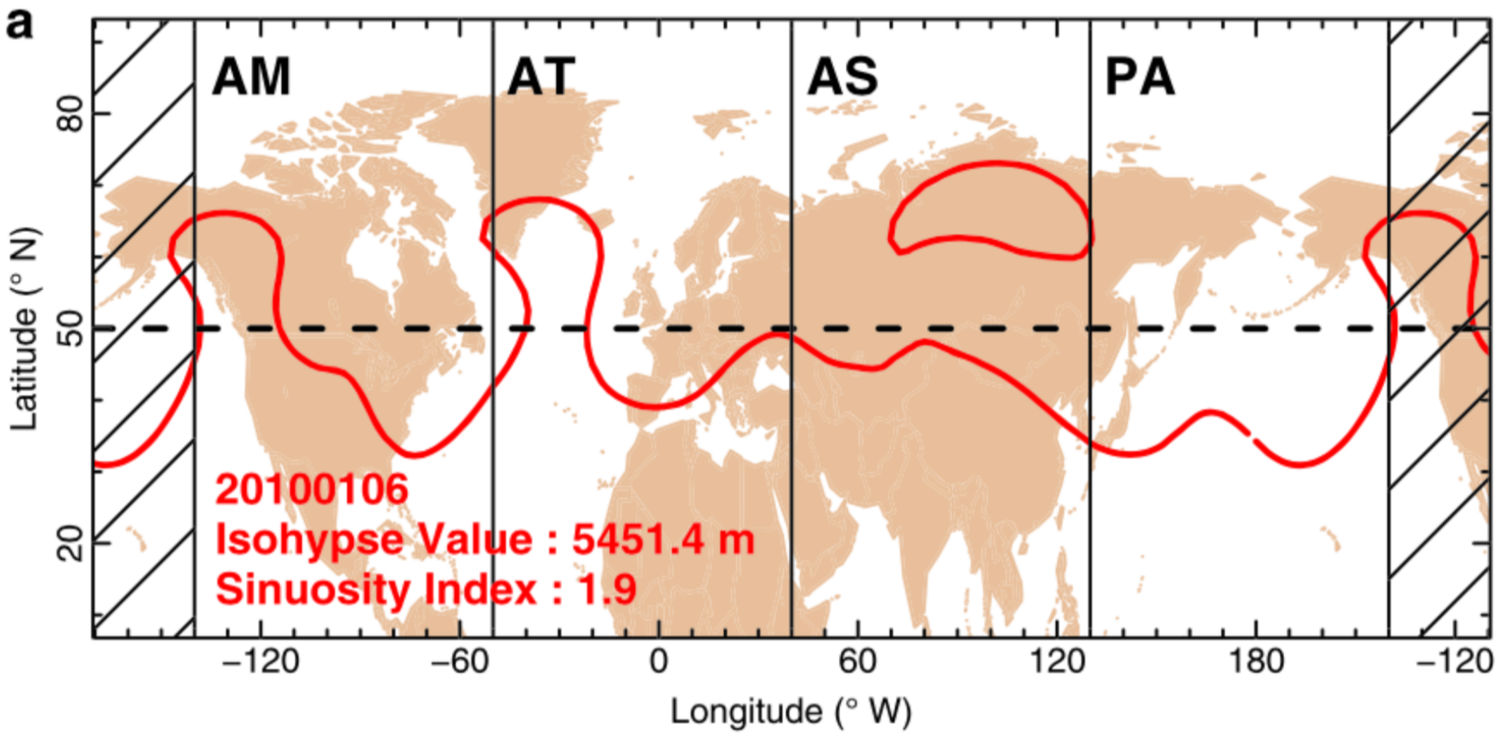


Fig. 3 | Heat uptake and transport by the ocean and atmosphere. Zonal mean climate response for TROP-CPL (red), MLAT-CPL (orange), POLAR-CPL (magenta) and GLOBAL-CPL (black). Shading indicates the ensemble range. The sum for the regional experiments is displayed in cyan. **a**, Absorbed net surface heat flux by the ocean. **b**,**c**, Northward heat transport response in the atmosphere (**b**) and ocean (**c**).

Waviness of the jet stream

Sinuosity Northern Hemisphere



Cattiaux et al., GRL (2016)

SI = length of isohypse / length of 50°N latitude circle

The chosen isohypse is the area average of Z500 over 30 to 70°N

Waviness of the jet stream

Francis 2017

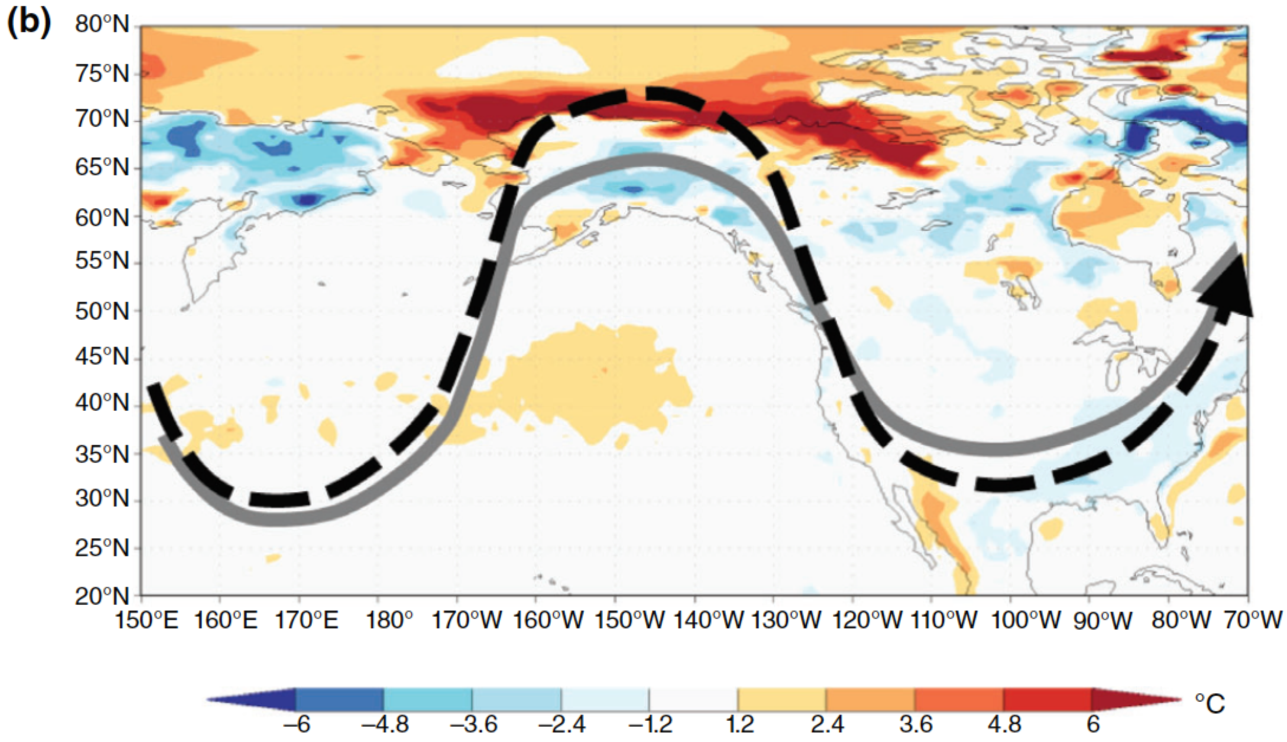
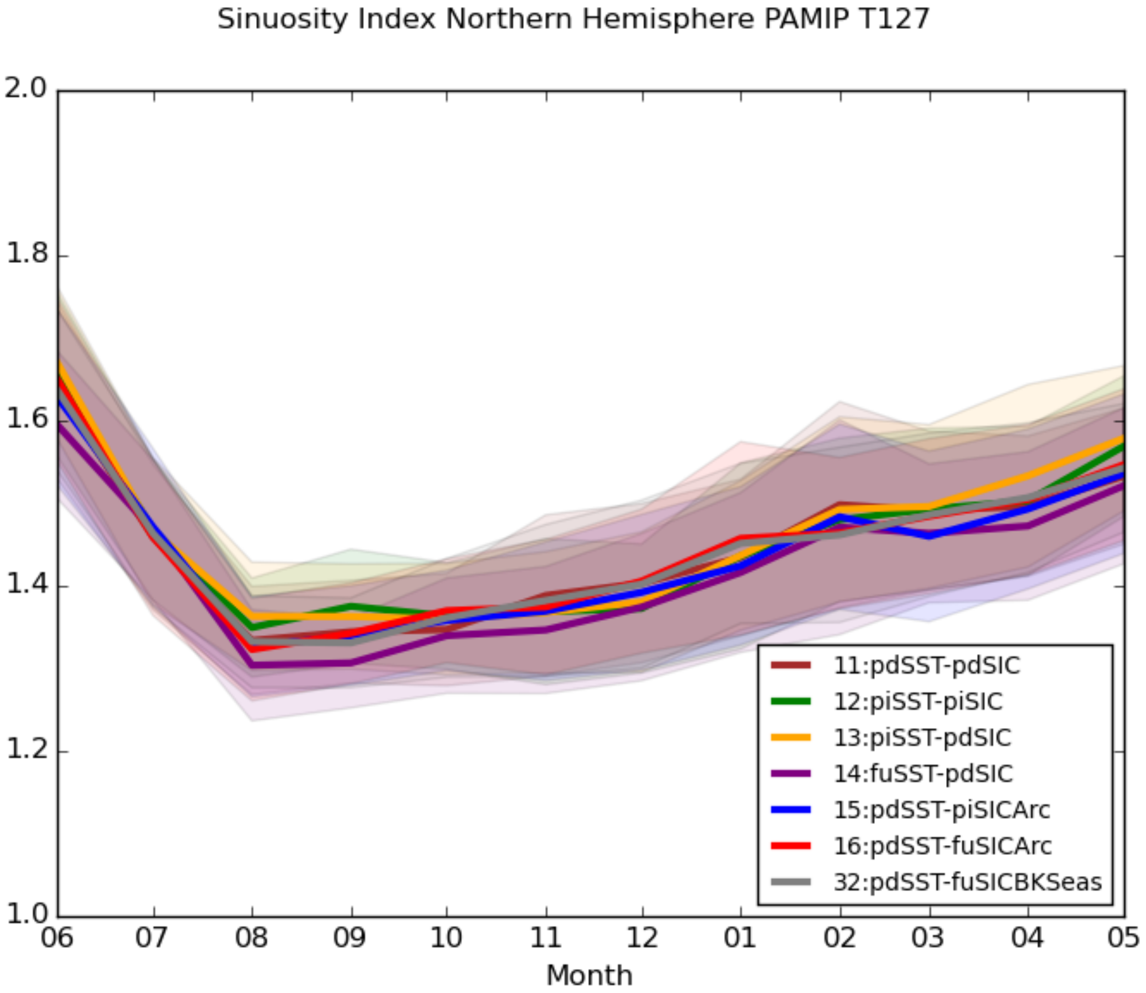


FIGURE 4 | Schematic illustrating ‘It Takes Two to Tango’ concept. Shading depicts surface temperature anomalies during November 2013 (relative to 1979–1996). (a) A possible jet stream configuration (gray curve) with ridges over the western Pacific and over the central United States, along with a trough in the eastern Pacific. (b) Another possible jet stream configuration with a ridge in the eastern Pacific, where anomalous heating owing to above-normal Chukchi sea surface temperatures augments the intensity of the ridge (black dashed line). Temperature data are from the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis-Interim, plotted using the Koninklijk Nederlands Meteorologisch Instituut (KNMI) Climate Explorer (http://climexp.knmi.nl/).

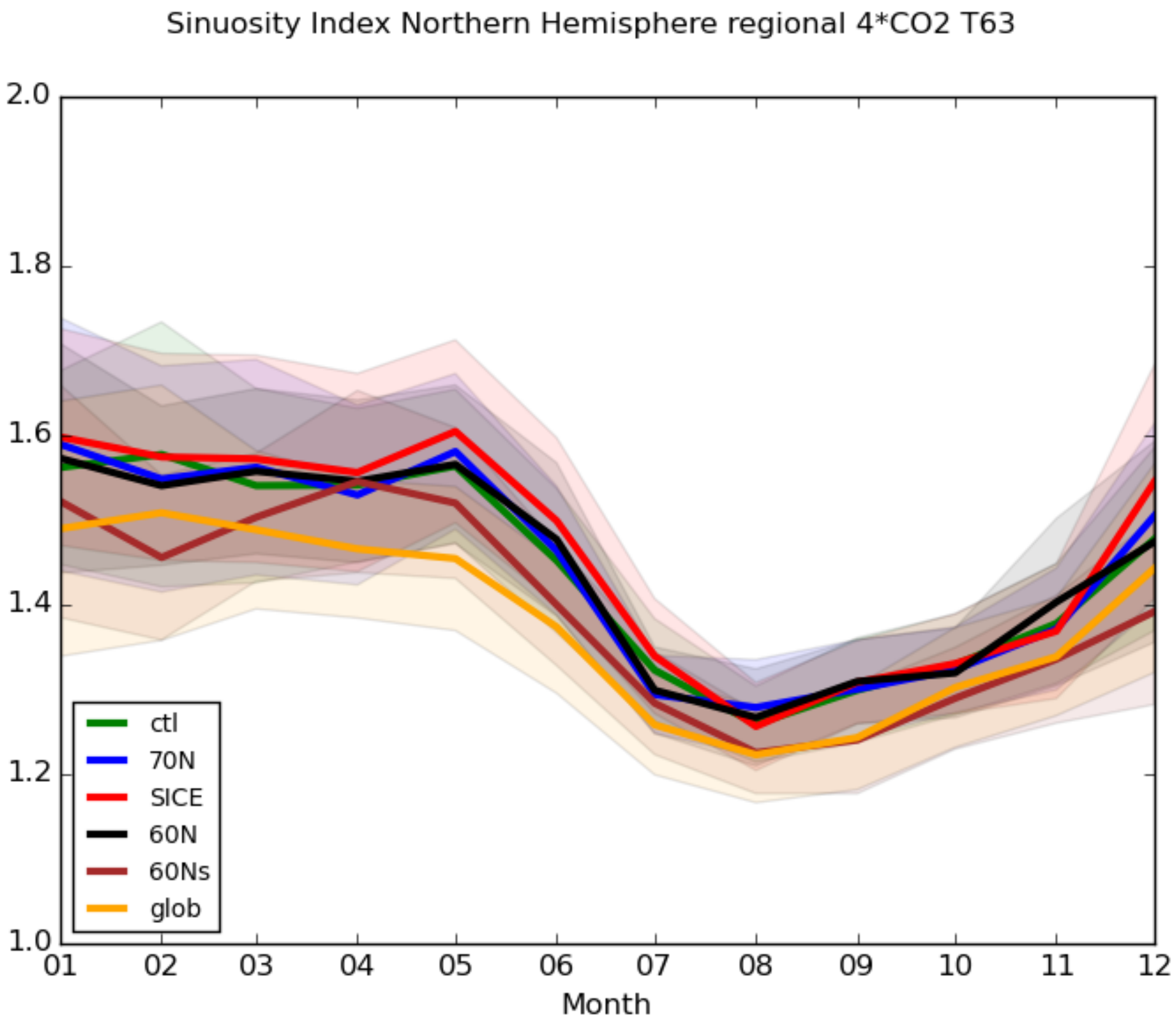
Waviness of the jet stream

However, PAMIP results with AWI-CM (and other models?) do not show increased waviness



Waviness of the jet stream

Neither the regional 4*CO2 experiments



Eastern continental cooling without increased waviness but with robust weakening of the westerly flow.

Alone the decreased westerly flow seems to be sufficient to cause this slight cooling

Semmler et al., 2019; in review

Stratosphere – troposphere coupling

Kretschmer et al., 2016

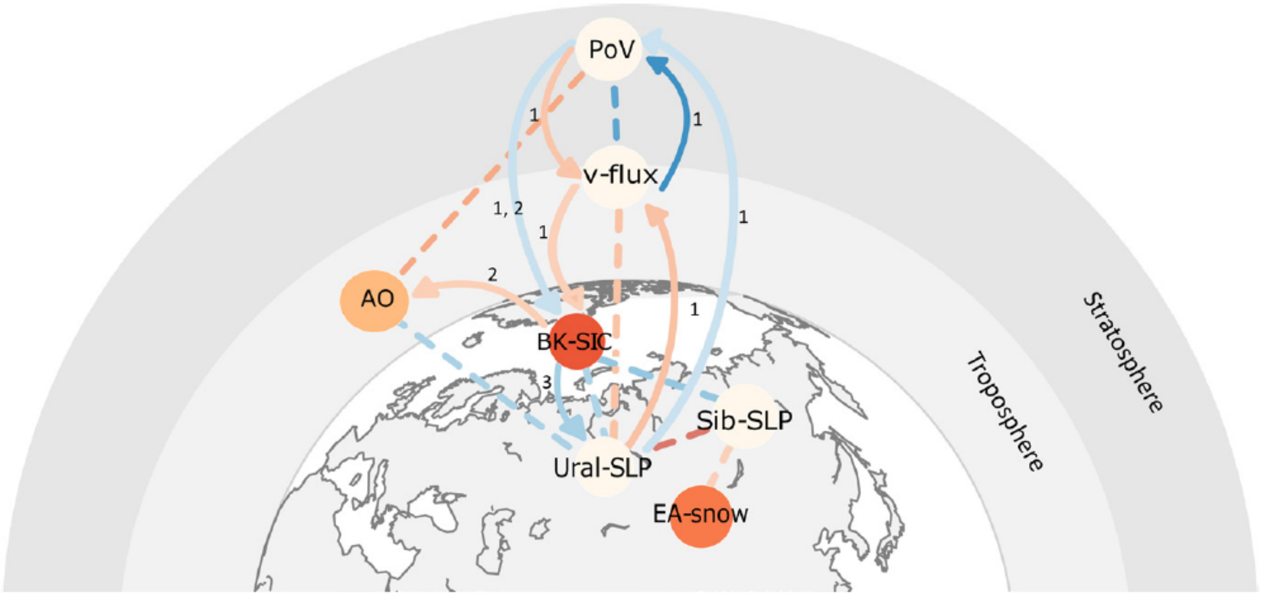


Figure 9. Causal pathways between different Arctic actors extracted from observations. Blue arrows indicate a negative causal influence, red arrows a positive causal influence, and the number next to the arrows indicates the lag in months. The regional actors, Barents-Kara sea ice concentration (BK-SIC), Ural region sea level pressure (Ural-SLP), Siberian sea level pressure (Sib-SLP), and East Asia snow cover (EA-snow), are presented according to their approximate geographical location. The hemispheric actors (Arctic Oscillation (AO), upward wave propagation (v-flux), and polar vortex (PoV)), are presented according to their approximate latitude and pressure levels. (Figure from Kretschmer et al. 2016).

Stratosphere – troposphere coupling

De et al., 2019

High-top models from CMIP5 pre-industrial simulations show robust response to Barents-Sea / Kara-Sea ice variability

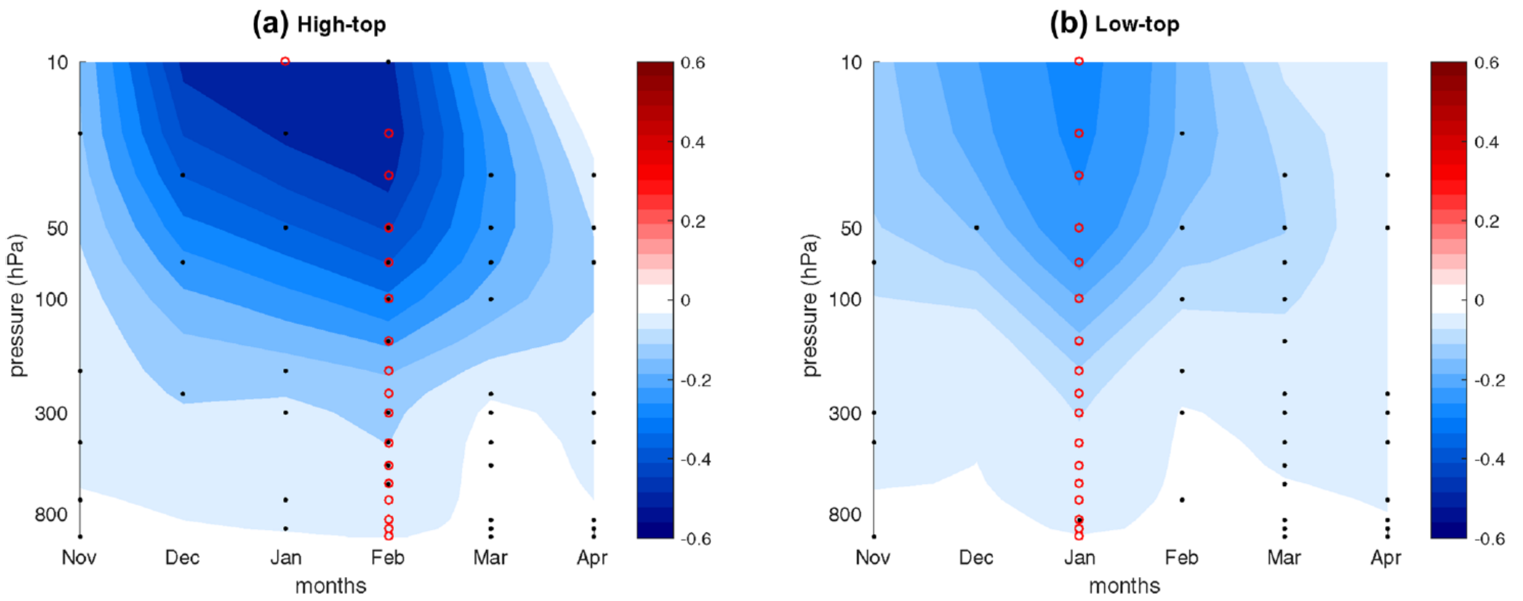
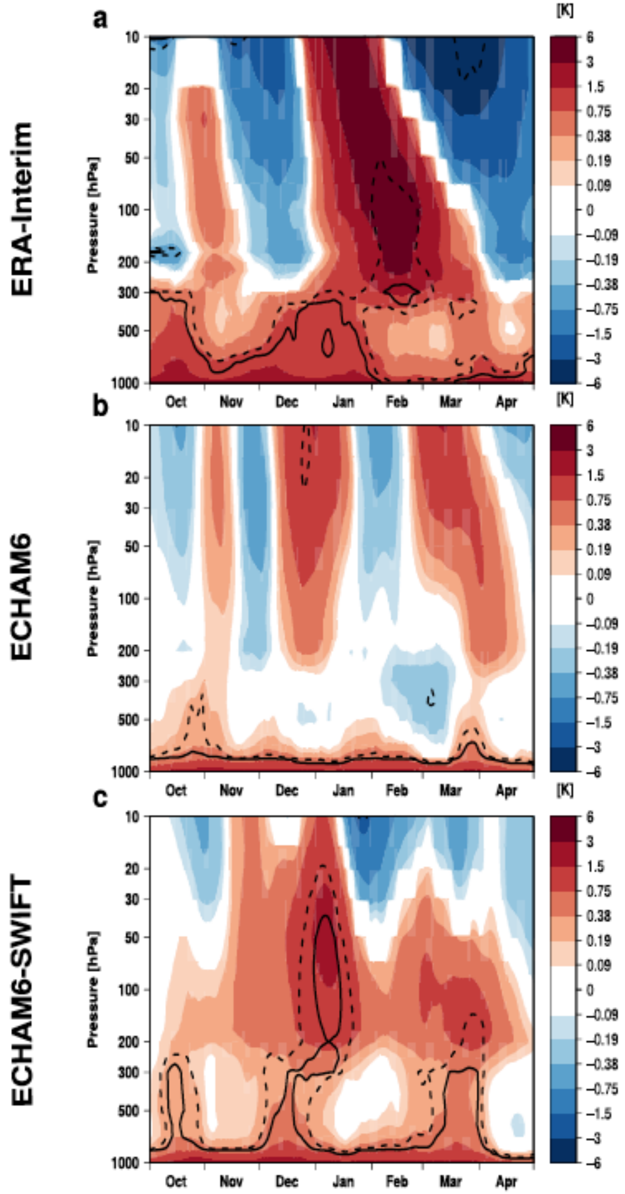


Fig. 2 Monthly evolution of zonal mean zonal wind (in m/s per 1 standard deviation of BKS SIC loss) averaged between 50°–70°N from November to April, associated with BKS SIC variability in November and December in **a** high-top models and **b** low-top models (color shadings). The red circles represent the months with minimum values at given pressure levels. The black dots indicate that at least 80% models agree on sign of change

Stratosphere – troposphere coupling



Time-height cross sections of climatological mean temperature differences (K) from 65°N to 90°N (LICE minus HICE)

Romanowsky et al., 2019

Implementation of interactive stratospheric ozone chemistry helps to realistically simulate stratospheric response to Arctic sea ice loss and downward propagation

Atmosphere driving the ice

Blackport et al., 2019

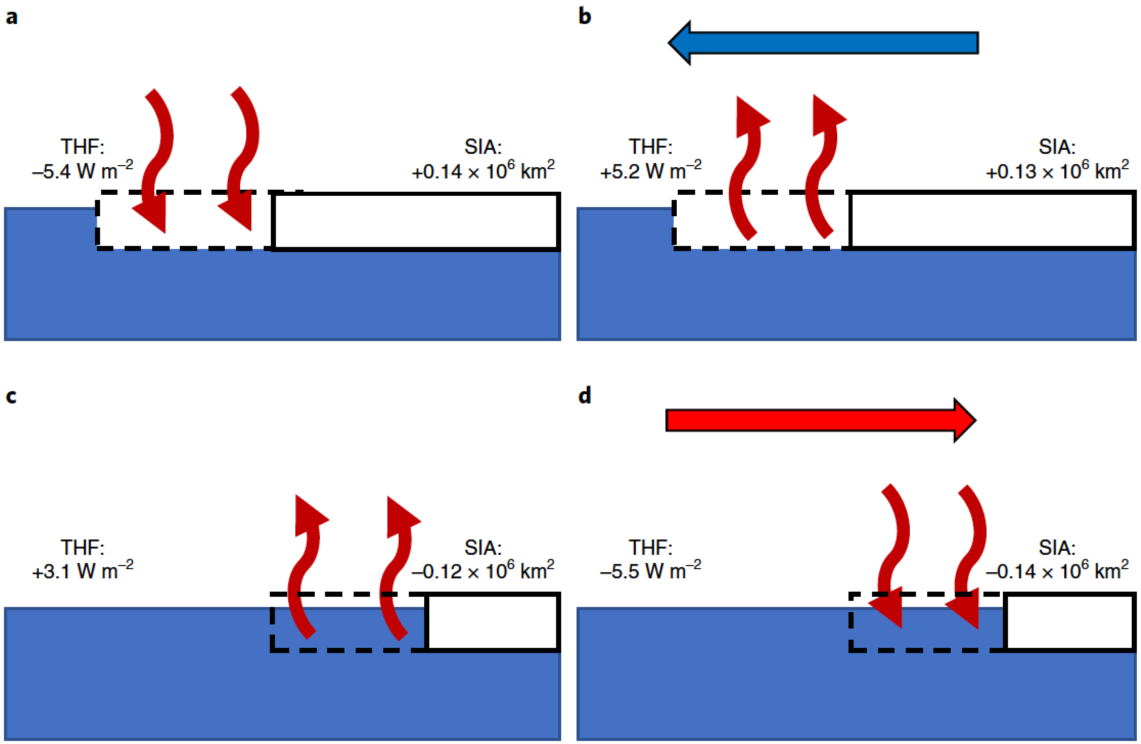


Fig. 1 | Schematic representation of sea ice driving and being driven by the atmosphere. a–d, An illustration of sea ice and THF during winters when the sea ice is driving the atmosphere (**a**,**c**) and when the atmosphere is driving the sea ice (**b**,**d**). White rectangles represent sea ice, with the dotted outline indicating the anomalous high or low ice cover. Curved arrows represent the surface THF anomaly, and horizontal arrows represent warm (red) and cold (blue) air advection. Composite values for the THF and SIA anomalies averaged over the CBS region for ERA-Interim during winter (December–February) are shown.

Atmosphere driving the ice

Comment by Fyfe, 2019:

- **„This brings the case to an end!** Midlatitude cooling in winter is not caused by Arctic sea ice loss. Rather, it is a side effect of regional circulation changes that precede and then simultaneously drive Arctic sea ice loss and midlatitude cooling.“

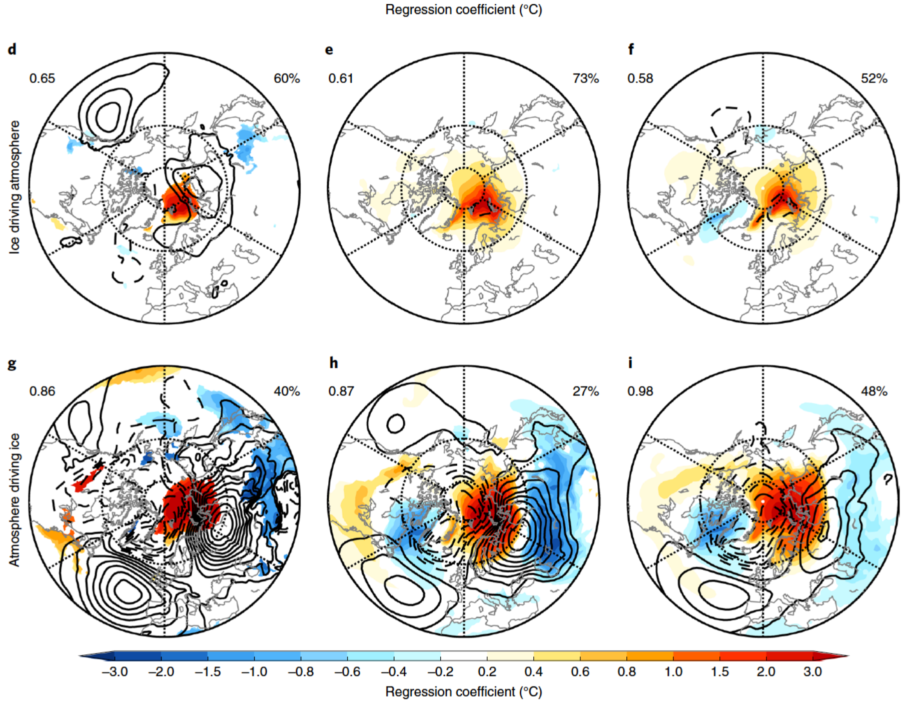
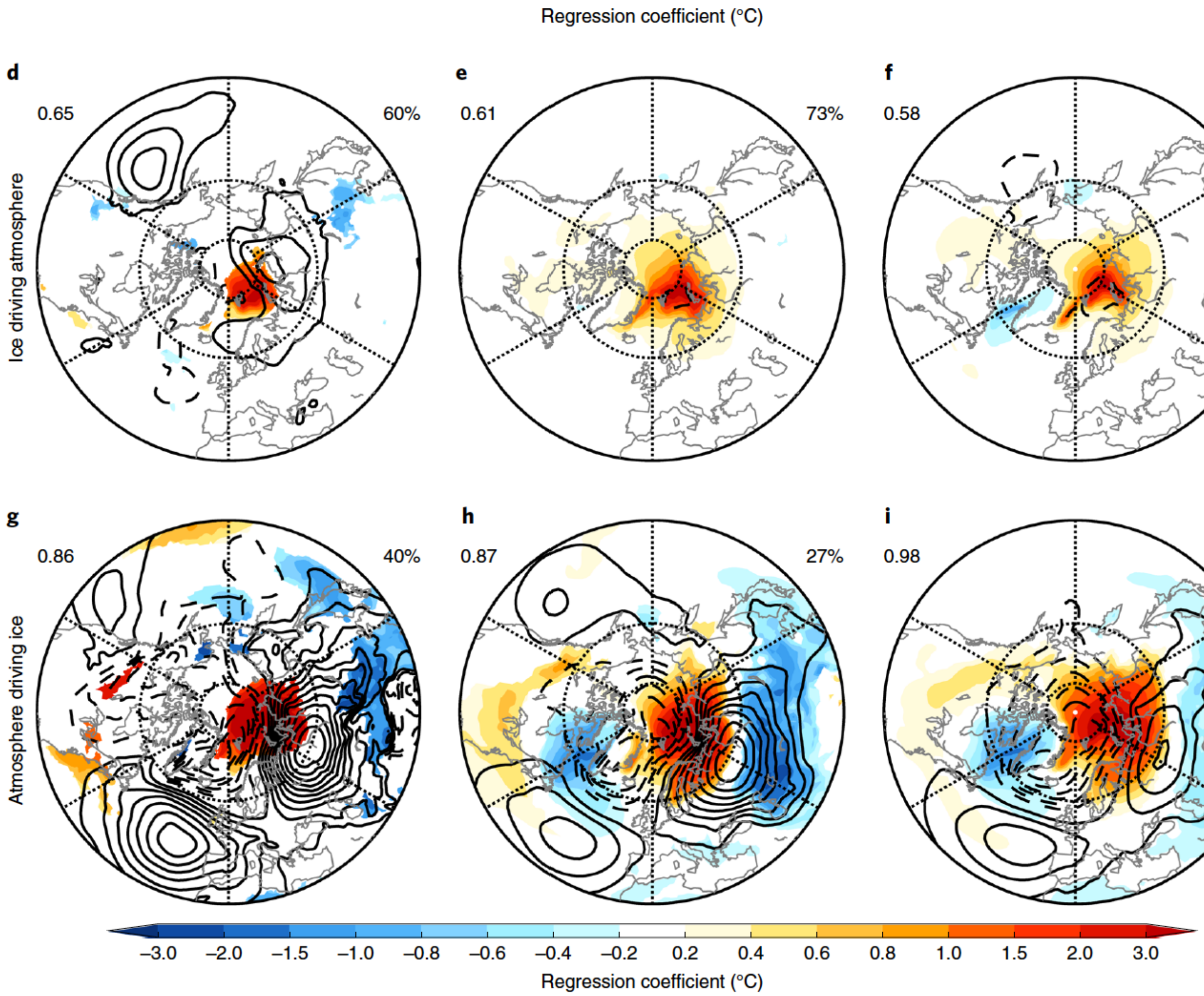


Fig. 4 | Temperature and circulation links with BKS ice. a–c, Winter SLP (contours; 0.25 hPa intervals) and SAT (colour scale) regressed on the standardized BKS SIA index for ERA-Interim (**a**), HadGEM2 (**b**) and EC-Earth (**c**). The sign is reversed so that the maps represent the field associated with a 1 s.d.

Atmosphere driving the ice



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279 mm

Based on reanalysis and model data.

Improved process understanding necessary.

Use Arctic observations!

Questions

Some robust features from model simulations (weakening of westerlies, increase of Z500 over the Arctic …), but:

Observed increase in frequency of cold extremes in winter (e.g. Vihma et al., 2019) and hot extremes in summer in mid-latitudes (e.g. Coumou et al., 2018)

Nothing to do with Arctic sea ice decline?

Part of decadal to multi-decadal variability?

Caused by circulation changes outside the Arctic?

Are we missing important processes in models / reanalyses?