The influence of regional Arctic sea-ice decline on mid-latitude weather and climate

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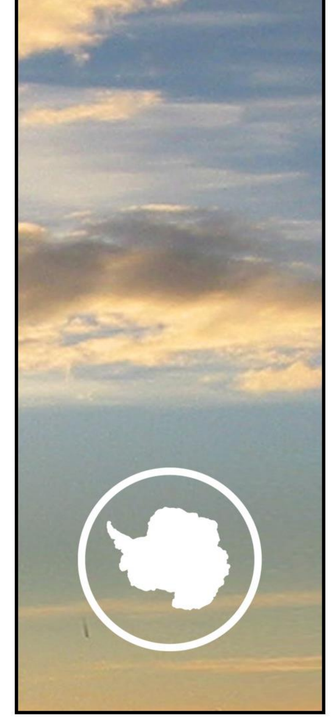
NERC SCIENCE OF THE ENVIRONMENT



1. Context

Arctic sea-ice extent has rapidly declined over the past few decades (Fig. 1) and most climate models project a continuation of this trend during the 21st century in response to greenhouse gas forcing. This has led to much research into whether ice retreat influences weather and climate in lower latitudes.

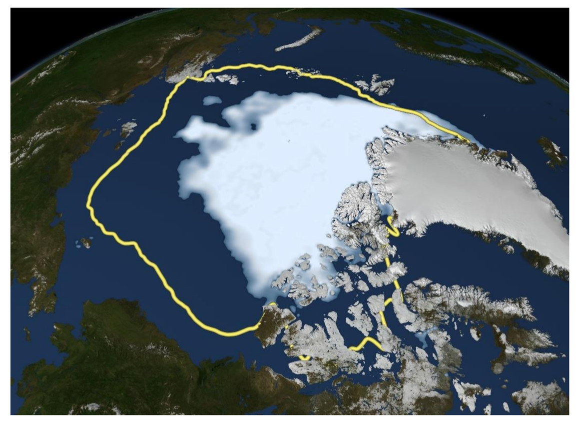


Fig. 1: Sept. 2012 sea-ice extent & the 1979-2012 mean (yellow line). *NASA.*

2. Coupled stratospheric/tropospheric mechanisms

- Many studies show that sea-ice loss weakens the stratospheric polar vortex.
- Very weak vortex events are often followed by a negative AO/NAO (Arctic Oscillation/North Atlantic Oscillation)[1]. This causes a wavier & more southerly tropospheric jet stream, which brings colder Arctic air into mid-latitudes.
- However, the response of the vortex may depend on the region of sea-ice loss.
- Sun et al. (2015) find that when sea-ice loss occurs in the Atlantic/Pacific sector of the Arctic, the vortex weakens/strengthens (Fig. 2). This is because the forcing of upward propagating Rossby waves is enhanced/suppressed (Fig. 3).

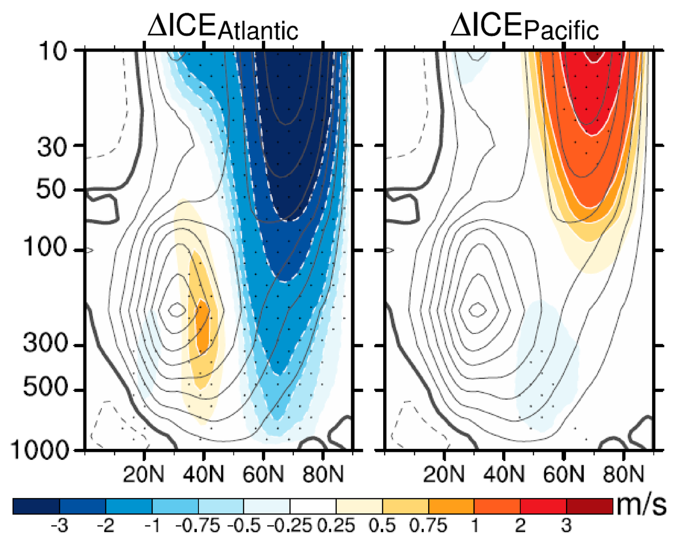


Fig. 2[2]: Response of Dec-Feb zonal mean zonal wind (U) to projected sea-ice loss in the Atlantic & Pacific sectors of Arctic. Contours: control run climatology.

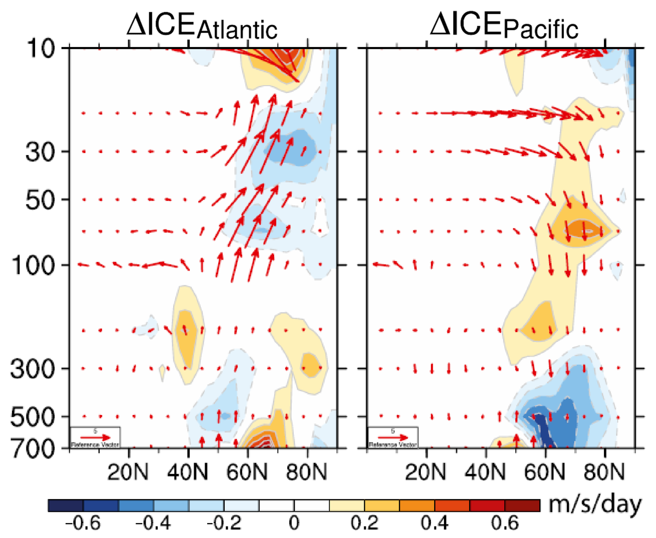


Fig. 3[2]: Response of Dec-Jan EP flux (arrows, shows direction of wave propagation) & EP flux divergence (shaded, shows acceleration of U).

3. Aim

- To investigate whether the results of Sun et al. (2015) are robust to a different model.
- We do this using IGCM4[3], an intermediate complexity climate model - see Box 1.

Box 1: Numerical model - IGCM4

- 13 out of 35 model levels in the stratosphere, so the stratosphere is well resolved.
- Does a good job of representing stratospheric processes (e.g. sudden stratospheric warmings).
- Parameterises the effects of sea-ice (albedo, roughness, heat capacity) through the SST field.

4. Experiments

- 100 years long
- Atmosphere only mode
- **Control run (CTL)**: impose annually repeating cycle of historical mean surface conditions (ERA-interim).
- **2 sea-ice loss runs**: impose annually repeating cycle of surface temperature anomalies in the Barents-Kara Seas **(BAKA)** & Chukchi-Bering Seas **(CHUBER)** (Fig. 4).

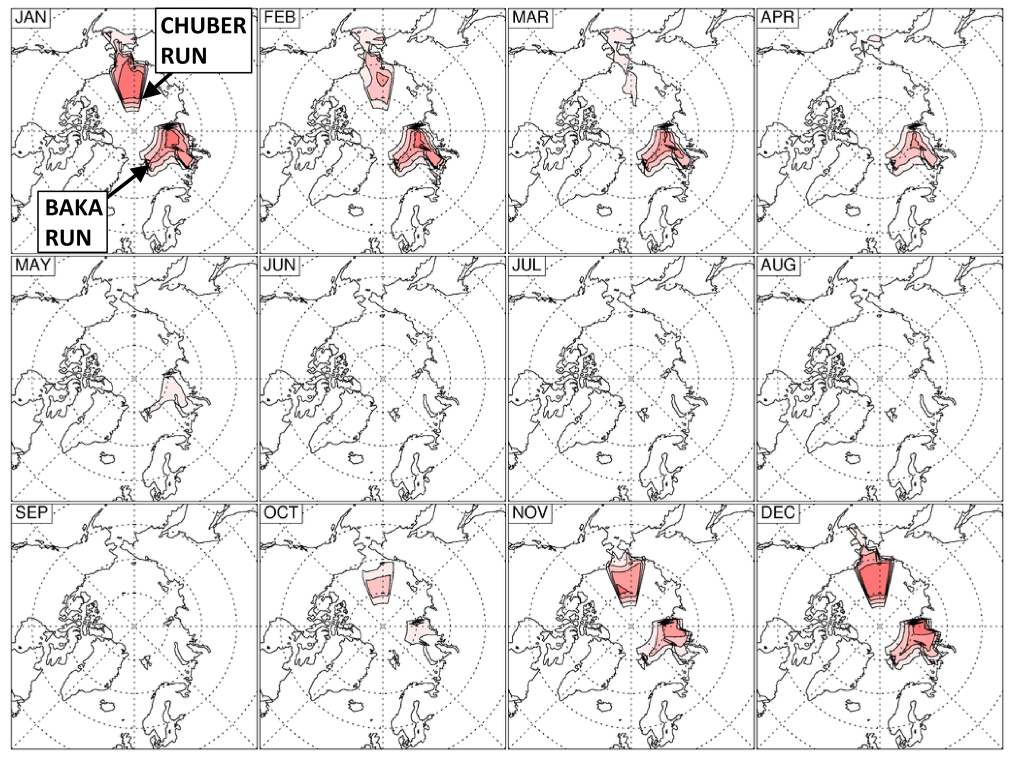


Fig. 4: Surface temp. (Ts) anomalies used in the 2 sea-ice loss runs, BAKA & CHUBER (contour interval of 5°C). Based on HadGEM2-ES RCP8.5 projections of sea-ice for 2070-99: where there is 100% loss in future ⇒ bring Ts to 0°C; 50% loss ⇒ bring Ts halfway to 0°C (etc).

5. Results

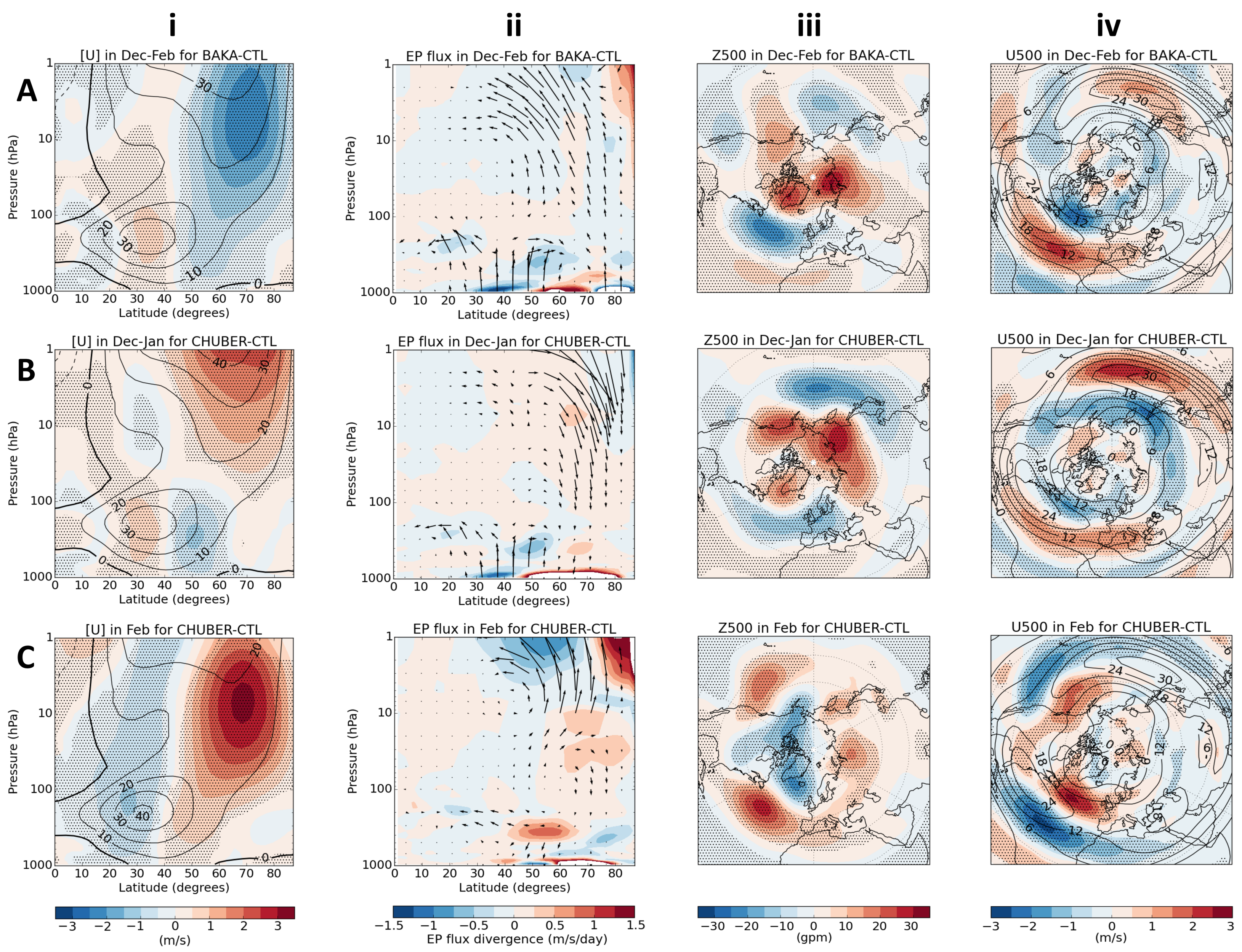


Fig. 5: Response of various fields to projected sea-ice loss in the Atlantic (BAKA) & Pacific (CHUBER) sectors of the Arctic. **(i)** zonal mean U, **(ii)** EP flux, **(iii)** 500 hPa geopotential height (Z), & **(iv)** 500 hPa U in **(A)** BAKA Dec-Feb, **(B)** CHUBER Dec-Jan, & **(C)** CHUBER Feb. Contours: control run (CTL) climatology; stipples: significant.

5.1 Stratospheric response

- In the BAKA/CHUBER run, the polar vortex weakens/strengthens in Dec-Feb (Fig. 5i; cf. Fig. 2). In CHUBER, the stratospheric wind anomalies are stronger & lower in height in Feb compared with Dec-Jan.
- Upward Rossby wave propagation is enhanced/suppressed in BAKA/CHUBER (Fig. 5ii; cf. Fig. 3).
- Sun et al. (2015) suggest this is because Rossby waves forced by Atlantic/Pacific sea-ice loss constructively/destructively interfere with climatological waves. This appears to be the case for wave-1 waves at high latitudes in BAKA/CHUBER (Fig. 6).

5.2 Tropospheric response

- In the mid-troposphere there is a negative AO/NAO pattern in Dec-Feb in BAKA & Dec-Jan in CHUBER (Fig. 5Aiii,Biii). The eddy-driven jet shifts south (Fig. 5Ai,Aiv,Bi,Biv).
- Thus, the stratosphere appears to have little influence on the early winter tropospheric response in both BAKA & CHUBER.
- In Feb, however, there is a positive AO/NAO pattern & northward shift of the jet in CHUBER (Fig. 5Ci,iii,iv).
- This could be due to the stronger & lower stratospheric wind anomalies in Feb, but may also reflect the monthly changes in surface temperature forcing.

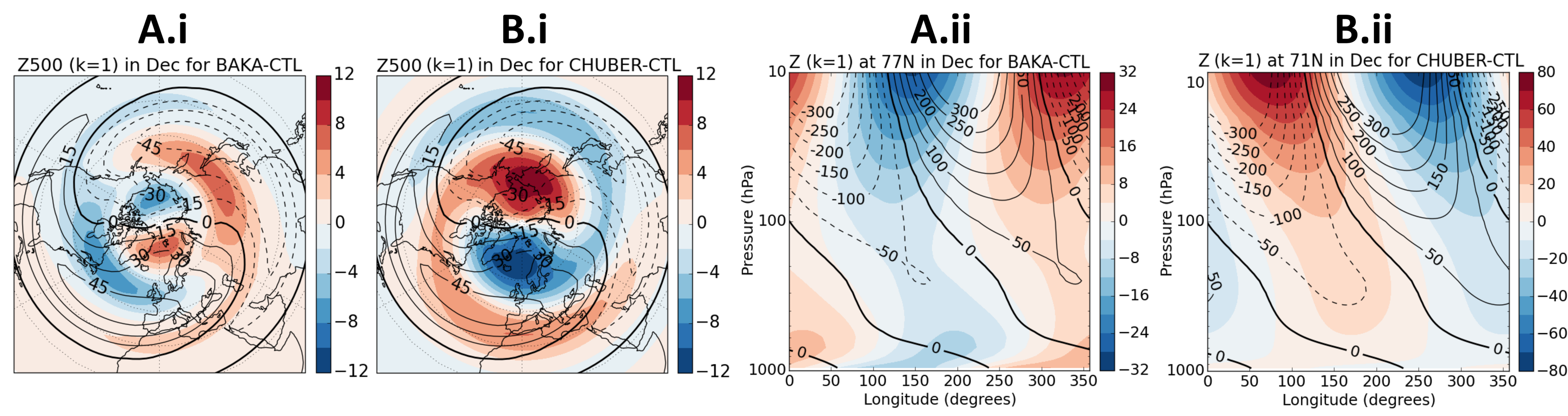


Fig. 6: Response of Dec zonal wave-1 Z at **(i)** 500 hPa & **(ii)** 77/71°N to projected sea-ice loss in the **(A)** Atlantic (BAKA) & **(B)** Pacific (CHUBER) sectors of the Arctic (units: gpm). Contours: control run (CTL) climatology.

6. Future research

- In another run, we could damp the stratosphere to isolate its role in the undamped case.
- Impose sea-ice anomalies with no monthly cycle to remove any additional complication this causes.

7. Summary

- Sea-ice loss in the Atlantic/Pacific (BAKA/CHUBER) sector of the Arctic weakens/strengthens the stratospheric polar vortex.
- Despite this, in both cases the early winter mid-tropospheric response resembles a negative AO/NAO pattern. This implies little influence from the stratosphere.
- However, in the Pacific case the AO/NAO does become positive in late winter.

References
1. Baldwin, M. P., & Dunkerton, T. J. (2001). Stratospheric harbingers of anomalous weather regimes. *Science*, *294*(5542), 581-584.
2. Sun, L., Deser, C., & Tomas, R. A. (2015). Mechanisms of Stratospheric and Tropospheric Circulation Response to Projected Arctic Sea Ice Loss. *J. Climate*, *28*(19), 7824-7845.
3. Joshi, M., Stringer, M., Wiel, K., O'Callaghan, A., & Fueglistaler, S. (2015). IGCM4: a fast, parallel and flexible intermediate climate model. *Geosci. Model Dev.*, *8*(4), 1157-1167.