The influence of regional Arctic sea-ice loss on the stratosphere, and mid-latitude weather and climate

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1. Context
The spatial pattern of Arctic sea-ice loss varies year to year (Fig. 1.1) and is very uncertain in projections. Thus, it is important that we understand the different mid-latitude impacts of different regions of sea-ice loss and the mechanisms involved. Decomposing sea-ice loss into regions may also make it easier to understand the response to pan-Arctic anomalies.

2. Stratospheric-tropospheric mechanisms
- Sun et al. (2015) find that sea-ice loss in the Atlantic/Pacific sector of the Arctic weakens/strengthens the stratospheric polar vortex (Fig. 2.1)
- A weaker/stonger vortex is often followed by a more negative/positive AO/NAO (Arctic Oscillation/North Atlantic Oscillation) and, thus, colder/warmer weather conditions in mid-latitude regions.
- The weakening/strengthening of the vortex is due to enhanced/suppressed forcing of upward propagating Rossby waves (Fig. 2.2). This occurs because of destructive/constructive linear interference between anomalous and climatological waves.

3. Research questions
- Do Atlantic and Pacific sector sea-ice lose have different mid-latitude impacts, and is the stratosphere key? What is the combined impact of these regions of sea-ice loss?
- To answer these questions we use SCM4, an intermediate complexity climate model (Box 1).

Box 1: Numerical model - SCM4
- Has a well resolved stratosphere model (height at 0.1 hPa, 10 km over 30 model levels in stratosphere).
- Allows long simulations, but still represents complex dynamical wave (e.g., stratospheric processes)
- Parameterizes the effects of sea-ice (albedo, roughness, heat capacity) through the SST field.

4. Experiments
- 200 years long
- Atmosphere only mode
- Control run (CTL): impose annually repeating cycle of historical mean surface conditions (using ERA-interim data).
- 3 sea-ice loss runs: same as CTL, but add an annually repeating cycle of surf. temp. anomalies in the (1) Atlantic sector (Barents-Kara Seas – BAKA run), (2) Pacific sector (Chukchi-Bering Seas – CHUBER run), & (3) both sectors (BAKA&CHUBER run) (Fig. 4.3).

5. Results: Atlantic versus Pacific sea-ice loss

Figure 5.1: Key meteorological fields

Figure 5.2: EP flux and linear wave interference

Figure 5.3: Linear vs. nonlinear wave interference

6. Results: combined Atlantic and Pacific sea-ice loss
- For zonal mean zonal wind (U) and surface temp., the Nov-Feb response to combined Atlantic & Pacific sector sea-ice loss (BAKA&CHUBER run) is a linear addition of the separate BAKA and CHUBER responses (Fig. 6.1).
- In U & geopotential height 2 at 500 hPa, the negative AO/NAO pattern is weaker for BAKA&CHUBER than for BAKA+CHUBER (Fig. 6.1).II, ⇒ nonlinear.

7. Future research
- In another set of runs, we will relax the stratospheric zonal mean climate. This will help to quantify the role that the stratosphere played in the original runs.
- We could use a stationary wave model to look at the tropospheric mechanisms involved in the negative AO/NAO response.

8. Summary
- Atlantic/Pacific (BAKA/CHUBER) sea-ice loss weakens/strengthens the polar vortex, but results in a tropospheric negative AO/NAO in both cases. This implies little stratospheric influence.
- Surface cooling occurs in Northern Europe in CHUBER only & not in BAKA. In BAKA, thermodynamic warming counteracts dynamical cooling.
- Hence, tropospheric mechanisms explain the different impacts of Atlantic & Pacific sector sea-ice loss.
- Response to Atlantic & Pacific sea-ice loss combined is not a linear addition of the BAKA and CHUBER responses.