Contrasting Antarctic and Arctic atmospheric responses to future sea-ice loss

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The effect of Arctic sea ice loss has received a lot of attention.
Motivation

Yet the effect of future Antarctic sea ice loss has received far less attention.

- *Kidston et al 2011 (GRL)* found no impact from a reduction in Antarctic sea ice extent using CAM3.
- *Bader et al 2013 (Clim. Dyn.)* investigated sea ice loss in Austral winter and found a robust impact on the jet, in agreement with previous work by *Menendez et al 1999 (Clim. Dyn.)*.

So the effect of projected Antarctic sea ice loss on the atmosphere is still largely an open question.
The main questions which we aim to address are:

- Is there a significant impact of Antarctic sea ice loss on the tropospheric circulation?
- How do these impacts differ from the response to Arctic sea ice loss in the
  a) Strength
  b) Seasonality
  c) Regional structure
- What role does the stratosphere play?
Experimental Setup

- Perform three time-slice experiments in atmosphere only mode, each for 150 years
  1. Control experiment 1955-1969 averaged sea ice conditions
  2. Same as control but with Antarctic sea ice at 2085-2099 conditions
  3. Same as control but with Arctic sea ice at 2085-2099 conditions
- All other forcings (CO₂, ODSs etc.) are kept at 1955 values.
- Future sea ice predictions averaged from three members of WACCM run out to 2100 under RCP 8.5 conditions.
- Change SSTs to future SSTs only in areas where ice has melted
- Similar approach to Sun, Deser and Tomas 2015 (J. Climate)
Community Earth System Model (CESM)
Whole Atmosphere Community Climate Model (WACCM):

- High top model which participated in CMIP5
- Ran in atmosphere-only mode
- 2° by 2.5° horizontal resolution
- 66 vertical levels with model lid extending up to lower thermosphere
- Simulates climatological Arctic and Antarctic sea ice conditions well
Imposed Sea Ice

**ARCTIC:**

**1955-1969**

**2085-2099**

**Difference**

[Images of Arctic sea ice for different time periods]
Imposed Sea Ice

ANTARCTIC:

1955-1969

2085-2099

Difference
Imposed Sea Ice

Arctic sea ice seasonal cycle

Antarctic sea ice seasonal cycle

Total forcing from heat flux to the atmosphere
ANTARCTIC:

Temperature changes due to Antarctic SI loss
Temperature changes due to Arctic SL loss

ARCTIC:

Summer (JJA)  Autumn (SON)  Winter (DJF)  Spring (MAM)
- Temperature response trapped at high latitudes and near the surface.
- Antarctic response is of weaker amplitude but less seasonally varying.
- Weaker stratospheric response to Antarctic sea ice loss.
Antarctic Surface Temperature Change

- **Summer (DJF)**
- **Autumn (MAM)**
- **Winter (JJA)**
- **Spring (SON)**
Zonal Wind Response

U 500hPa, Arctic SI loss
- Equatorward jet shift in each hemisphere due to sea ice loss
- Negative feedback on poleward jet shift associated with increased greenhouse gas emissions
- Response to Antarctic sea ice loss can evident year round.
Zonal Wind Response

- Equatorward jet shift in each hemisphere due to sea ice loss
- Shift is less seasonally varying in Southern Hemisphere
- Sea ice loss results in a jet weakening, with a much larger amplitude in the Antarctic response (Bracegirdle et al, 2018)
In this model, Arctic response is largest in Pacific region.

Antarctic response is zonally symmetric.
Stratospheric response largest in winter in Arctic and autumn in Antarctic.

Stratospheric response much smaller in response to Antarctic sea ice loss.

Response is, if anything, opposite.
For the Arctic winter, despite very similar experiments with same model, response is opposite to that of Sun et al (2015) either because of:

a) Large internal variability

b) Highly sensitive to difference in sea ice conditions or climatological conditions
- Arctic sea ice loss results in reduction in total column ozone for winter and spring.
- Antarctic sea ice loss results in a small, but statistically significant, increase in polar total column ozone throughout much of the year (apart from austral spring).
Conclusions

- Response to Antarctic sea ice loss is of comparable amplitude to the Arctic but different in character:
  - Response to Antarctic sea ice loss is evident throughout the year
  - More zonally symmetric.
  - Amplitude is somewhat smaller
- Temperature response is limited to high latitudes and trapped near the surface.
- Surface temperature response does not penetrate continent of Antarctica.
- Sea ice loss produces a negative feedback on the circulation shift, but jet strength is also important in the Antarctic
- Stratospheric response seems highly sensitive
Our results confirm and extend findings of *Bader et al 2013 (Clim. Dyn.)*, but more climate model studies are needed.

- How important is coupling with an interactive ocean for the response to future Antarctic sea ice losses?

- Current Antarctic sea ice observations do not fall within the model simulations.
  - Our results offer an idea of the amplitude of errors if sea ice loss does not occur.