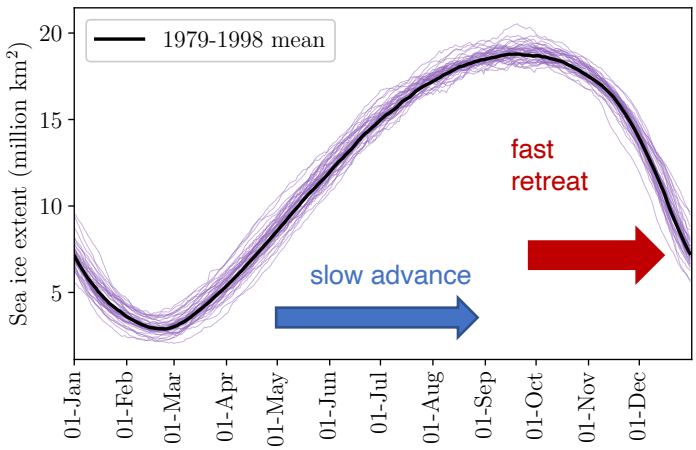
SCAR Fellowship Report

The influence of nonlinear physical processes on the seasonal cycle of Antarctic sea ice



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Introduction

The cycle of sea ice growth and melt in the polar oceans is one of the largest seasonal signals on Earth. In Antarctica, the melt season is much shorter than the growth season, creating an asymmetry in the cycle of sea ice extent. Various mechanisms been suggested to explain this (Eayrs et al. 2019), including upwelling of warm water (Gordon 1981, Peixoto & Oort 1992) and the position of the mean wind field (Enomoto & Ohmura 1990, Eayrs et al. 2020). Yet the causes of the asymmetry have not been systematically investigated.

In our original proposal, we hypothesized that nonlinear processes might be important. For example, one process that has not previously been investigated in detail is the ice-albedo feedback, a nonlinearity introduced when reflective sea ice melts, exposing a darker ocean surface and permitting more absorption of solar radiation, which in turn enhances ice retreat and could shorten the melt season. The situation is complicated by other nonlinearities in the thermodynamics of sea ice growth and melt. Ice growth slows down as the ice thickens, since the heat flux is inversely proportional to ice thickness. Furthermore, the transition from open water albedo to ice-covered albedo is not abrupt, since thin ice is partially transparent and appears darker than thick ice. The goal of the proposed work is to disentangle the roles that these individual processes may play in setting the asymmetric Antarctic sea ice seasonal cycle.

Project Objectives

To improve understanding of the seasonal cycle of Antarctic sea ice, by:

- Quantifying the difference in the length of growth and melt seasons in satellite sea ice observations
- Examining whether the short melt season and longer growth season is captured in global climate models
- Investigating the role of potential drivers of this asymmetry using an idealized climate model

Methods, Execution and Results

During my visit at UNCW, I was able to complete the first two objectives listed above: quantifying the difference in the length of growth and melt seasons in satellite sea ice observations, and examining whether the short melt season and longer growth season is captured in global climate models. We discovered that the asymmetry was captured in new global climate models, and even in more dated climate models including simpler physics. This suggested that it was reasonable to consider processes driving asymmetry in an idealized climate model.

With Till's guidance, during my visit, I learnt to how to run and modify the idealized model he developed (Wagner & Eisenman 2015), and started to develop some intuition around the key physical processes driving sea ice melt and growth. We were both happy with what we had achieved during my visit, but did not have a clear answer yet as to what might be driving the asymmetry.

After the visit, we kept in touch and thought more about next steps, but progress was slow due to a combination of parental leave, both of us moving institutions, and the disruption caused by COVID19. Once I was settled into my postdoc at the University of Washington, I picked up the project again, involving Till's former postdoctoral advisor, a colleague at UW and my postdoctoral advisor. After considering a number of different physical processes and different analysis methods that came to dead ends, we realized that insolation was an important factor.

We then conducted more targeted experiments using the idealized climate model, finding that one should expect an asymmetry (of over 1 month) in the seasonal cycle of sea ice extent based simply on the seasonal cycle of top-of-atmosphere solar radiation. Because insolation in southern high latitudes departs from a sinusoid by having a narrow peak of intense brightness in summer and a long period of low light in winter, there is rapid summer ice retreat and gradual winter ice advance. This simple physical explanation is markedly different from those proposed in previous studies.

Project Outcomes

In terms of the research, our results suggest that the striking asymmetry in the seasonal cycle of Antarctic sea ice extent has a simple but previously undiscovered explanation. This clears up a long-running misunderstanding regarding Antarctic sea ice, and prompts a reconsideration of our understanding of the seasonal cycle of Arctic sea ice.

In terms of personal development, I really benefitted from the fellowship especially the opportunity to work with my host, Till. Working with an idealized climate model helped me to develop better intuition for fundamental climate physics. Using many different types of data - from observations and a range of climate models - helped me to improve my data management and analysis skills. I learnt a lot from Till and his approach to science. He is a skilled communicator and I think that working with him improved my own confidence and ability to express myself. In particular, I appreciated the inclusive culture he helped to set within his research group and my experience there has since influenced how I interact with students and mentees.

Publications, Presentations and Products

An article that grew out of the work initiated during the fellowship has just been accepted at Nature Geoscience.

Roach, L. A., Eisenman, I., Wagner, T. J., Blanchard-Wrigglesworth, E., and Bitz, C. M.. Asymmetry in the seasonal cycle of Antarctic sea ice due to insolation (2022). *Nature Geoscience* (accepted).

I have discussed this work during the following presentations:

- Mar 2022, Colloquium, AOS, University of Wisconsin Madison, US. *Antarctic sea ice in a hierarchy of models*
- Feb 2022, Seminar, Polar Oceanography Group, Brown University, US. *Antarctic sea ice asymmetry*
- Jan 2022, Seminar, Lamont-Doherty Earth Observatory, Columbia University, NY, US. *Sea ice from the large-scale to the small-scale*
- Jan 2022, Seminar, NASA GISS, NY, US. *Antarctic sea ice asymmetry*
- Dec 2021, AGU Fall Meeting, New Orleans, US. *Asymmetry in the seasonal cycle of Antarctic sea ice driven by insolation*
- Feb 2021, Seminar, SOEST, University of Hawai'i, US. *Antarctic sea ice: is it really such an enigma?*
- Nov 2020, Seminar, University of Manitoba, Canada. *Contrasting seasonality in Arctic and Antarctic sea ice*

Our code, analysis of observational data and processed model output is publicly available at https://doi.org/10.5281/zenodo.5865073. I also plan to use these products in future research.

Capacity Building, Education and Outreach Activities

During my visit at UNCW, I met with undergraduate and Masters-level students in the department to discuss my work and learn about the projects they were working on. I am currently in the process of exploring opportunities to convey my research to a broader audience, following the acceptance of our journal article.

Future Plans and Follow-ups

I continued to collaborate with Till after my visit to UNCW. We have worked closely together since, resulting in the acceptance of our paper. In late 2021, I wrote a NOAA Climate and Global Change Fellowship proposal, inspired by our results casting

Arctic sea ice seasonality in a new light. My NOAA proposal was successful and I accepted a Visiting Fellowship position to continue work in this area (with Till's former postdoctoral advisor). I plan to continue to collaborate with Till on this subsequent project.

Personal Impact

The SCAR Fellowship has had a huge impact on my research, allowing me to explore a new research topic and new research methods. Eventually discovering the fundamental physics driving the asymmetric seasonal cycle was a truly satisfying scientific achievement, and I'm really glad that the SCAR Fellowship started us off on this path.

My visit took place in between the completion of my PhD in New Zealand and the beginning of my postdoc in the US. I think this turned out to be great timing: meeting Till and his collaborators was a great first step in building my scientific network in the US. It also meant that I began my postdoc feeling inspired by our initial findings during the period of the fellowship. The visit also helped me to develop my thinking around my scientific approach and career goals. The visit was a lot of fun and kept me excited about research. I have recently accepted a position as an Associate Research Scientist at NASA GISS and am looking forward to future Antarctic research!

Financial Statement

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Acknowledgements and References:

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