SCAR/COMNAP Fellowship Report

Modelling the Antarctic Sea Ice Floe Size Distribution

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Host Institution: NIWA, Wellington, NZ.
Host Institution Collaborators: Dr. Sam Dean, Dr. Alison Kohout, Dr. Lettie Roach.
Home Institution: Harvard University.
Visiting Period: March-May 2017.

1 Background and Work Plan:

Antarctic sea ice area has remained constant or perhaps even increased in extent over the past 40 years, in contrast to the declining extent of Arctic sea ice, but this variability has not been captured in current climate models (*Roach et al.*, 2020). The failure of current sea ice models to simulate the observed evolution of the Antarctic sea ice has prompted a reconsideration of the methods in which sea ice is modeled in the Southern Ocean. Sea ice models used in global climate models (GCMs) typically assume that sea ice is a thin, viscous, semi-infinite fluid. The Southern Ocean is, however, a region populated by thin, seasonal ice that grows in the winter and melts in the summer. There, sea ice is a mosaic of many individual pieces, called floes, which range in their horizontal size from tens of centimeters to tens of kilometers, described by their floe size distribution (FSD). In a region of comparable area to a typical GCM grid cell, the size of floes may have a strong influence on sea-ice rheology, the exchange of heat and momentum between the ocean and atmosphere, and the evolution of the sea-ice cover itself. When sea ice is melting, the difference in the time it takes all of the sea-ice in such a region to melt, when it is made up of floes of diameter of either 1 km or 50 km, may be as high as 3 months (*Horvat et al.*, 2016). While the impact of floe size variations on Antarctic climate is potentially dramatic, no current GCMs take into account variations in the floe size distribution. The fellowship proposed focused on improving a model of floe size evolution for GCMs originally developed by *Horvat and Tziperman* (2015) by incorporating it in a coupled climate model and using it to understand Antarctic sea ice and ocean evolution.

2 Results from Fellowship Work:

During the fellowship period, I mainly sat at NIWA Wellington, working with Lettie Roach and Sam Dean. I twice visited Christchurch to discuss model improvements and wave-ice modeling with Alison Kohout. I also visited the Department of Physics at the University of Otago to present my research and the ongoing work at NIWA. The primary task I was involved in was assisting now-Dr. Roach in incorporating the FSD theory of *Horvat and Tziperman* (2015) into the Community Ice Model (CICE). During the fellowship period itself this consisted of coding efforts for incorporating interactions between sea ice melting and the FSD.

While completing the task of writing a new sea ice model was not feasible within the short fellowship window, this time in early 2017 kicked off what is now longstanding and highly productive collaboration. As a consequence of my exciting initial period at NIWA funded by SCAR/COMNAP, I returned to New Zealand in September 2017 to continue working with this team, while employed at Brown University. I have hardly left. First as a postdoc and now a professor, I have spent a majority of the period from 2017-2021, still employed by Brown, but sitting at NIWA and in New Zealand, working with Dr.s Roach, Dean, and Kohout on topics related to the coupled modeling and observation of sea ice floes and oceans.

This fellowship drove significant research outcomes, and as of 2021 we have published 9 peer-reviewed articles together. In early 2017 I particpated in the development of what is now the state-of-the-art sea ice model, completed as a part of Lettie Roach's graduate education. We published the first study on a coupled wave-ice-ocean model using the floe size distribution in 2018, along with a number of follow-up studies (*Roach et al.*, 2018a, 2019; *Horvat et al.*, 2019). Details on the elements of the FSD model and its implementation can be found in *Roach et al.* (2018b).

Collaborating with Dr.s Roach and Dean I have since published papers on observing the FSD (*Horvat and Roach*, 2019) from satellite, which began during my time at NIWA in 2017. Within my own group I have continued to use the *Roach et al.* (2018b) model to understand the FSD's influence on ocean wave and eddy variability (*Horvat and Tziperman*, 2018; *Horvat et al.*, 2020). The model that we worked on during my time under the felloship at NIWA now is being implemented in parallel, or has already been implemented in, nearly all major sea ice codes deployed in IPCC-class models across the world.

3 Ongoing and Future Work:

Work using the FSD code developed at NIWA is ongoing and broad. The core FSD code forms the backbone for a 6-year, NZ15m project entitled the "Scale Aware Sea Ice Project", funded throught the Ventures in Earth System Research Initiative through 2027. Our objective is to produce a brand-new bespoke sea ice and ocean model, which depends sensitively on the ability to model the FSD.

Work also continues on the refinement of the FSD code itself along with many other related efforts. Together we collaborate intently on a number of projects. Dr. Roach and I are currently working on the use of machine learning to accelerate the core model code, which has been largely successful and is in preparation for publication. Dr. Roach, Dr. Dean and I are collaborating on a funded Smart Ideas proposal that uses floe size information for shipping forecasts in the Ross Sea. All four of us are currently collaborating on a project, funded through the NASA ICESat-2 project, to use satellite data and in-situ wave buoys to measure the propagation of waves in sea ice.

4 Expenditures

Of the US $7500, spending broke down approximately as follows:

- Flights to and from NZ: ∼$1500
- Accommodation 8 weeks ∼$3500
- Travel within New Zealand (Wellington-Christchurch, Wellington-Dunedin): ∼$1000.
- Living Expenses: ∼$1500

5 Acknowledgements:

This report is written in Wellington in 2021, with the benefit of years of hindsight and memories. I cannot express my gratitude enough to SCAR/COMNAP for enabling my travel to New Zealand. Here I met an amazing team of researchers who incorporated my small piece of work and built a highly sophisticated sea ice model, the benchmark by which others are judged. This code, developed in New Zealand, likely will be the foundation of future sea ice models. It is likely I never would have come to New Zealand without the support of SCAR/COMNAP, and I hate to imagine what my life would be like without that chance.

In New Zealand I have found scientific success, yes, but also a permanent home, a community, and a partner too. The bulk of the responsibility for this happiness can be attributed to the efforts of Lettie Roach, an elite scientist who could not have been a better collaborator. Hers will be a career I'm too happy to tag along with as I can. Her PhD supervisors Sam Dean and Alison Kohout allowed me to take an active role in a project that I was not originally a part of, and saw the clear ways we could all benefit from one another. To them, and to SCAR, COMNAP, and NIWA I owe an immense debt of gratitude. Ngā mihi.

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