

# PROJECT SUMMARY

## CMG COLLABORATIVE RESEARCH: Mathematics and Electromagnetics for Monitoring Transport Processes in Sea Ice

A broad array of geophysical and biological processes in the polar marine environment are mediated by fluid, thermal, and electromagnetic transport through sea ice – a porous composite of pure ice with brine and air inclusions. The fluid permeability, for example, controls brine drainage, surface flooding, snow-ice formation, and the evolution of melt ponds and salinity profiles. Melt pond evolution, in turn controls sea ice albedo, a key parameter in understanding the decline of the summer Arctic ice pack. Snow-ice formation, a dominant process in the Antarctic, may well become more important in the Arctic as the ice pack thins. Such processes are not treated realistically in many current ice-ocean or climate models. The permeability also controls microbial colonization and nutrient fluxes, which are important in modeling the response of polar ecosystems to climate change. Heat exchange between the polar oceans and atmosphere depends on the thermal conductivity of sea ice, which is affected by brine convection. The electromagnetic (EM) response of sea ice in remote sensing is characterized by its complex permittivity. Key techniques for monitoring ice thickness – central to gauging the impact of global warming – depend on ice electrical properties. Sea ice microstructure, in turn, determines fluid, thermal, and electromagnetic transport properties.

Here we propose to develop methods of electromagnetically monitoring the internal state of sea ice, the thermal evolution of its microstructure, and the transport processes it controls. We will conduct fundamental mathematical studies, as well as field experiments in the Arctic and Antarctic, directed at recovering microstructural profiles and their evolution at critical phases in the seasonal cycle of the ice pack. We will develop *in situ* tomographic methods to obtain the complex permittivity profile of sea ice at low frequency, and mathematical techniques to use this data to reconstruct the evolution of the *spectral measure* of the composite microstructure, which contains detailed information about brine geometry and connectedness. We will investigate the critical behavior of this measure near the percolation threshold, where fluid flow turns *on* or *off*. Our work will yield novel spectral representations for fluid and thermal transport coefficients, and characterizations of the spectral measure as a free energy minimizer, as in statistical mechanics. We will analyze the thermal evolution of the distribution of eigenvalue spacings for the spectral measure as a powerful way of characterizing the order/disorder transition in the brine microstructure of sea ice, as motivated by the theory of random matrices. We will also develop multiscale numerical models of the complex permittivity and other transport properties from random graph representations of the microstructure to aid reconstruction calculations. Our results will yield valuable information on snow-ice formation, melt processes, and flood-freeze cycling, and provide insights on parameterizing these processes in climate and biogeochemical models. Key features of the proposed work include:

- Development of cross-borehole tomography and direct measurement techniques on cores. Initial testing, validation and refinement in the lab and the Arctic near Barrow, with Antarctic measurements in McMurdo (time series) and from the *Aurora Australis* (ice-station sampling).
- Development of cross-property relations connecting EM, thermal, and fluid transport via the spectral measure, and related methods for EM imaging of transport processes in sea ice.

The **intellectual merit** of our proposal is that it helps to provide the experimental and theoretical basis for probing the internal structure of sea ice and processes which are critical to understanding and predicting the key role of sea ice in the context of climate change and ecosystem response. Through novel outreach opportunities and educational initiatives, in particular an interdisciplinary sea-ice field course and workshop that brings together a diverse spectrum of students and experts, the investigators are in a unique position to facilitate the **broader impact** of the proposed research. Our work will help link the geophysics and mathematics communities, convey to general audiences the importance of mathematics in climate research, and attract young investigators across disciplines into polar science through the proposed REU activities – like bringing Math and Engineering undergraduates to the Arctic and Antarctic.