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What Happens in the Arctic Does NOT Stay in the Arctic

Big Idea. From micro to macro in the Arctic climate system. Understanding signature indicators of planetary warming – the loss of sea ice and thawing of permafrost – at the micro level and building up from there will help to make better models and predictions of what's happening in the Arctic and enable us to better understand and respond to the cascading effects experienced both in the United States and globally. The small-scale effects that add up to control the larger scale mechanisms are not understood at the physical level for models in the Arctic. Multiscale hierarchical modeling offers an approach through the development of complex cross-scale models to transfer the critical information from microscales to the macro behavior. Upscaling can be physics-informed and data-driven where possible but may rest on mathematical constructs when the physics is not yet determined, and experimental data are not available.

Reasoning and Justification. Warming in the Arctic has led to rapid, precipitous declines in sea ice and to thawing of the permafrost, with both contributing to further warming on a global scale. These dramatic changes in the Arctic environment affect not only the climate, ecology, economics, infrastructure, transportation and human activities in the region, but also impact the rest of the world and the U.S. Significant, transformative advances are needed to rigorously compute effective material properties of sea ice and permafrost from information about the composite microstructure and microscale processes and build up hierarchically from there. Success of mathematical theories and computational frameworks, statistical mechanics, and rigorous homogenization methods in the theory of composite materials have helped trigger the widespread use of composites throughout today's technological world. The time is right to develop the next generation of sea ice and permafrost modeling which thoroughly leverages modern math, physics, and vast data sets, including those from the recent Arctic expedition, MOSAiC. NSF has the needed scale, the interdisciplinary culture, the resources, and stature to leverage additional support for all aspects of the program – to facilitate the success of the first sustained effort to establish a new multiscale paradigm, from micro to macro, for modeling sea ice, permafrost and complex Arctic systems. **It is time to bring these advances to Arctic research.**

Requirements.

- Create a community of interdisciplinary teams of researchers, engineers, and stakeholders to develop a new paradigm for sea ice and permafrost modeling.
- Funding for smaller and larger interdisciplinary and multi-institutional teams for pilot/exploratory studies, and research projects with 2-3 cycles of 3–5-year awards.
- Establish a center coordinating the various types of theoretical, computational, and experimental efforts over 10 years.
- Fund two dedicated expeditions to the Arctic region over 10 years to inform and validate models, and to "piggy-back" on other expeditions around the world.

Value and Impact.

- Educate new generations of scientists on the basics of interdisciplinary math and science, developing their ability to build and use advanced models.
- Develop new multiscale methodologies, computational tools, data collection, storage, and imaging technologies suited to multiscale analysis for complex Arctic systems.
- Connect the broader public to the goals of climate research and specific deliverables, exciting research and field experiments in one of the most extreme environments on Earth.

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