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W. M. Keck Foundation Concept Paper

Project Title: Ultra-Realistic Modeling and Simulation of Sea Ice

Overview: The opening of the Arctic Ocean is accompanied by expanding navigational, economic and scientific opportunities. The Arctic sea ice pack is the dominant feature of the marine environment that impacts such development. A central and yet to be solved challenge in advancing the science of the Arctic, and climate modeling more broadly, is to improve our ability to simulate, predict and visualize the dynamic behavior of sea ice. This is particularly daunting since sea ice is a polycrystalline, porous composite material of pure ice with brine and air inclusions, and the sea ice cover itself has a multiscale composite structure of snow-covered ice floes in an oceanic host. While much of sea ice modeling has been geared toward coarse representation in large scale climate models, here we focus on the emerging methodology of ultra–realistic simulation of key intermediate scale processes – such as the formation of ridges and leads, the evolution of melt ponds, and the interaction of sea ice with surface waves. We propose to build a mathematical and computational framework to transform the simulation and visualization of sea ice dynamics, with the goal of accurately simulating the rheologies – from fluid to solid – relevant in sea ice scenes. Our approach will expand the boundaries of applied mathematics and drive major advances in mathematical and computational modeling of sea ice and other complex multiscale materials with a broad range of rheological characteristics (e.g., land ice, biomaterials, concrete, tectonic plates).

Methodologies: Our project will be built upon an interdisciplinary melding of computational physics and mathematics of homogenization for composites, as well as participation in major field campaigns on Arctic sea ice dynamics, with access to extensive shipboard, aerial, and satellite data to constrain and validate our simulations. The principal computational thrust is to develop a Material Point Method (MPM) to simulate thermo-mechanical viscoelastoplastic constitutive laws describing sea ice. These types of methods have shed new light on modeling snow dynamics, and rapid failure in slope-scale snow avalanches in particular (utilizing dynamic mixture theories and anti-crack plasticity formulations). However, snow is but one component of the sea ice system. Significant computational and mathematical breakthroughs will be needed to build an MPM framework that can handle the rheologies displayed by sea ice over relevant length and time scales. To account for the composite structure of sea ice we will use techniques of homogenization, such as variational and analytic continuation methods, to determine the effective rheological properties in our scenarios, which are the key parameters for realistic MPM modeling of sea ice.

Key personnel: **U. of Utah** PI Kenneth M. Golden, Distinguished Prof. of Mathematics, co-PI Elena Cherkaev, Prof. of Mathematics. **UCLA** co-PI Joseph Teran, Prof. of Mathematics. **Oregon State U.** co-PI Jennifer Hutchings, Associate Prof., Physics of Oceans and Atmospheres.

Justification of the need for Keck support: These ideas received enthusiastic reviews, though were ultimately not funded by the DoD Vannevar Bush Fellowship program. Our proposed work has the potential to transform the modeling of rheology and complex multiscale materials. Keck's appetite for high-risk/high-reward research and track-record of supporting pioneering science – science that underpins our broad understanding of earth systems – aligns perfectly with this project.

Estimated budget: $1,000,000 over 3 years. Average Annual Budget – Salaries & Benefits: Faculty $120,000, Postdoctoral Researcher $80,000, Graduate Students $70,000, Undergraduate Students $25,000; Travel $20,000; Materials and Supplies $8,000; Computing $10,000.