PROJECT SUMMARY: Ocean Surfaces on Snowball Earth

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Intellectual merit: The climatic changes of the Neoproterozoic time, 600-800 million years ago, included episodes of extreme glaciation, during which ice may have covered nearly the entire ocean for several million years, according to the "snowball earth" hypothesis. The proposed work is to study processes that would have been important on the ice-covered ocean during such an event. The study focuses on the albedos of snow and ice surfaces, which, because of their positive feedback, are crucial to the initiation, maintenance, and termination of a snowball event, as well as determining the ice thickness on the ocean. Some kinds of ice that are rare on the modern Earth may have been pivotal in allowing the tropical ocean to glaciate. The research will aid in evaluation of the snowball-earth hypothesis, and help identify possible liquid-water refugia for photosynthetic surface life that apparently survived these events. The refugia may have been small and isolated, thereby causing extinctions, or promoting evolution of diversity, or both. Alternatively, the refugia may have been widespread and connected. To evaluate these alternatives, the oceanic surfaces that would have existed at various times and places during a snowball event will be investigated, with fieldwork in Antarctica, laboratory work in a coldroom, and modeling of radiative transfer, heat transfer, and ice flow.

In tropical regions of net sublimation, ice surfaces may have included (a) bare sea ice, cold enough that sodium chloride precipitated, (b) sea ice with a salt crust formed as a lag deposit, and (c) cold glacier ice exposed by sublimation of "sea-glaciers" (self-sustaining ice shelves) flowing from polar seas into the dry tropics. These ice types would have been widespread on the tropical ocean of a Snowball Earth, but they now exist only in Antarctica. Their albedos and surface properties will be investigated on naturally-occurring modern analogues: (a) bare cold sea ice near the coast of Antarctica in early spring; (b) a salt-encrusted lake in the McMurdo Dry Valleys; (c) "blue ice" areas of the Transantarctic Mountains that have not experienced melting.

Laboratory work will investigate the migration of salt in sea ice, the optical properties of a salt crust, and its cohesiveness.

Radiative transfer models will be used to determine the penetration of solar radiation into ice as a function of bubble content, which determines both the ice thickness and the availability of light for photosynthesis below. A two-layer model will be used to investigate the effect of a salt crust overlying clear ice, and the effect of dust deposition onto both snow and ice.

One proposed refuge for photosynthesis is under thin clear ice on a nearly enclosed sea, similar to the modern Mediterranean Sea or Black Sea. A model of glacier flow will be used to determine the dimensions of the channel, connecting the sea to the ocean, necessary to allow the sublimation rate to exceed the sea-glacier inflow rate, to evaluate whether the required geometry is improbable.

Broader impacts: The results of this research will be used to constrain climate models of Snowball Earth, thus aiding in understanding the dramatic climate changes of the Neoproterozoic glaciations. It will have implications for biological evolution through this climatic bottleneck, and for interpretation of Neoproterozoic glacial deposits. The work will also illuminate processes in sea ice and glacier ice that occur on the modern Earth, and will aid in understanding surface-albedo feedbacks in the present climate. It may also aid in understanding the behavior of ice and salts on the surfaces of satellites of Jupiter and Saturn.

The project will involve a graduate student, whose work should lead to a Ph.D. dissertation. An undergraduate student will also be employed in the cold laboratory. Some of the fieldwork will be in collaboration with a New Zealand IPY project. As with our previous projects, the results of this research will be incorporated into the curricula for undergraduate and graduate courses at the University of Washington on climate, glaciology, and radiative transfer.