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Albedo of bare ice near the Trans-Antarctic Mountains as an analogue of sea-glaciers on the tropical ocean of Snowball Earth

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The albedos of snow and ice surfaces are, because of their positive feedback, crucial to the initiation, continuation, and termination of a snowball event, as well as for determining the ice thickness on the ocean. Despite the name, Snowball Earth would not have been entirely snow-covered. As on modern Earth, evaporation would exceed precipitation over much of the tropical ocean. After a transient period with sea ice, the dominant ice type would probably be sea-glaciers flowing in from higher latitude. As they flowed equatorward into the tropical region of net sublimation, their surface snow and subsurface firn would sublimate away, exposing bare glacier ice to the atmosphere and to solar radiation. This ice would be freshwater (meteoric) ice, which originated from snow and firn, so it would contain numerous air bubbles, which determine the albedo.

The modern surrogate for this type of ice (glacier ice exposed by pure sublimation, which has never experienced melting), are the bare-ice surfaces of the East Antarctic Ice Sheet near the Trans-Antarctic Mountains. These areas have been well mapped because of their importance in the search for meteorites. A transect across an icefield can potentially sample ice of different ages that has traveled to different depths en route to the sublimation front.

We examined a 6-km transect from snow to ice near the Allan Hills (77 S, 158 E, 2000 m ASL), measuring spectral albedo and collecting 1-m core samples. This short transect is a surrogate of a north-south transect across many degrees of latitude on the Snowball ocean. Surfaces on the transect transitioned through the sequence: new snow - old snow - firn - young white ice - old blue ice. The transect from snow to ice showed a systematic progression of decreasing albedo at all wavelengths, as well as decreasing specific surface area (SSA; ratio of air-ice interface area to ice mass) and increasing density. The measured spectral albedos are integrated over wavelength and weighted by the spectral solar flux to obtain broadband albedos. These range from 0.8 for snow to 0.55 for blue ice.

Although what determines the albedo is the SSA of bubbles or snow grains, the broadband albedo also shows a systematic relation to the snow or ice density, suggesting that density might serve as a surrogate variable that will be easier to predict than SSA in an ice-sheet model, using a parameterization for firn densification.

The ice cores were analyzed by micro-CT (computer tomography) for bubble morphology, cracks (mainly thermal cracks), and SSA. The SSA is used in a radiative transfer model to explain the measured albedo spectra. We found that thermal cracks in the Allan Hills may be more important than in the equatorial region of Snowball Earth. We tried to separate the effects of cracks from original air bubbles by separately computing their individual SSAs in the CT images, and using those SSAs in the albedo model. These methods allow us to estimate a range of albedos for the different possible regions and climatic conditions on low latitudes of Snowball Earth.