Albedo of firn and bare ice near the Trans-Antarctic Mountains to represent sea-glaciers on the tropical ocean of Snowball Earth

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The "Snowball Earth" events of the late Precambrian, 600-800 million years ago, were the most dramatic climatic changes of the past billion years. They are of interest both for their challenges to climate theory (How did Earth enter the snowball state, and how did it escape?) and for their effects on biological evolution (What types of refugia for photosynthetic life remained in an ocean covered by thick ice?)

The albedos of snow and ice surfaces are, because of their positive feedback, crucial to the initiation, maintenance, 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 tropical sea glaciers (glacier ice exposed by sublimation, which has never experienced melting), are the bare-ice surfaces of the 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 sample ice of different ages that has traveled to different depths en route to the sublimation front.

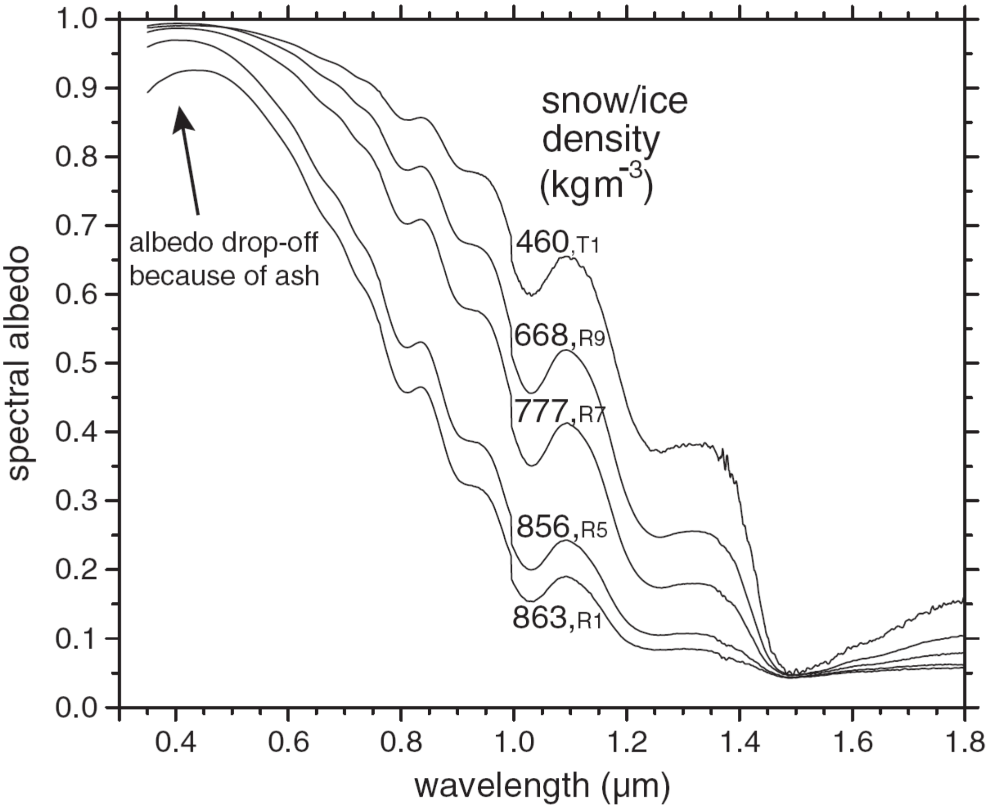
Spectral albedo was measured on a 6-km transect near the Allan Hills. This short transect is meant to represent a north-south transect across many degrees of latitude on the snowball ocean. Surfaces on the transect transitioned through the sequence: new snow - old snow - firn - young white ice - old blue ice. The transect from snow to ice showed a systematic progression of decreasing albedo at all wavelengths. The measured spectral albedos are integrated over wavelength and weighted by the spectral solar flux to obtain broadband albedos. Broadband albedos under clear sky range from 0.80 for snow to 0.57 for blue ice, and from 0.87 to 0.65 under cloud.

For modeling of radiative transfer, snow is normally described as ice grains surrounded by air, in contrast to the description of glacier ice as scattering by air bubbles surrounded by ice. But a unifying principle allows media of all densities between snow and ice, including intermediate states (firn), to be described by their "specific surface area" (SSA), the area of air/ice interfaces per unit mass of ice (m2/kg).

In ice, sunlight is scattered by both air bubbles and cracks; their separate contributions to the SSA were determined by X-ray tomography on core samples of the ice. Although albedo is governed primarily by the SSA (and secondarily by the shapes) of bubbles or snow grains, albedo also correlates highly with porosity, which, as a proxy variable, would be easier for ice-sheet models to predict than bubble sizes, using a parameterization for firn densification. Albedo parameterizations are therefore developed as functions of snow/ice density for three broad wavelength bands commonly used in GCMs: visible, near-infrared, and total solar.

At the equator of Snowball Earth, climate models predict thick ice, or thin ice, or open water, depending largely on their albedo parameterizations; our measured albedos appear to be within the range that favors ice hundreds of meters thick.

Reference: Dadic, R., P.C. Mullen, M. Schneebeli, R.E. Brandt, and S.G. Warren, 2013: Effects of bubbles, cracks, and volcanic tephra on the spectral albedo of bare ice near the Trans-Antarctic Mountains: implications for sea glaciers on Snowball Earth. J. Geophys. Res. (Earth Surfaces), 118, doi:10.1002/jgrf.20098.



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
spectral albedo
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
wavelength (μm)
snow/ice density (kgm-3)
albedo drop-off because of ash
460,T1
668,R9
777,R7
856,R5
863,R1