# Shortwave Radiation Modeling and Measurement Requirements for the North Slope of Alaska ARM Site

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## Introduction

Radiative energy is a major component of the surface energy balance in the Arctic. The North Slope of Alaska (NSA) Atmospheric Radiation Measurement (ARM) site will quantify the contribution of solar ($\lambda < 3.5$ µm) and terrestrial radiation ($\lambda > 3.5$ µm) to the total surface energy flux. Realistic simulations of this radiation environment require knowledge of the meteorological state and chemical composition of the atmosphere as well as the optical properties of the surface. The Arctic atmosphere is characterized by cold temperatures, strong temperature inversions, and low moisture content. It presents a challenging environment in which to make accurate measurements. We are using a comprehensive radiative transfer model to elucidate to what extent the surface properties and clouds influence the Arctic shortwave radiative energy fluxes.

In this study, we are using a discrete-ordinates radiative transfer model developed by Tsay et. al (1989) to calculate the vertical profile of solar radiative energy fluxes. The model has 24 spectral bands (0.28 to 4.0 µm), which include gaseous absorption by $H_2O$, $CO_2$, $O_3$, $O_2$ and Rayleigh scattering. The cloud optical properties needed for radiative transfer computations are the volume extinction coefficient $\beta$, the single-scattering albedo $a$, and the asymmetry factor $g$. These are calculated by Mie theory and parameterized with respect to the cloud equivalent radius and the liquid water content (Hu and Stamnes 1993). To account for the vertical inhomogeneities in the gaseous and cloud optical properties, the atmosphere is divided into multiple layers. A snow layer is also included and the spectral surface albedos are calculated self-consistently within the model as the ratio of upward flux to the downward flux.

For this preliminary study, we chose to work with a baseline atmosphere from early April 1992 (see Figure 1). The baseline atmosphere was divided into 62 layers with resolution from 20 m near the snow surface to 20 km at the top of the atmosphere. Below 7 km, a Barrow clear-sky sounding is used while the atmosphere above 7 km is represented by an average of the subarctic winter and subarctic summer standard atmosphere (McClatchey 1972). A 0.5 m snow layer is included and no aerosol or Arctic haze layers are present. The solar zenith angle is 66.7°.

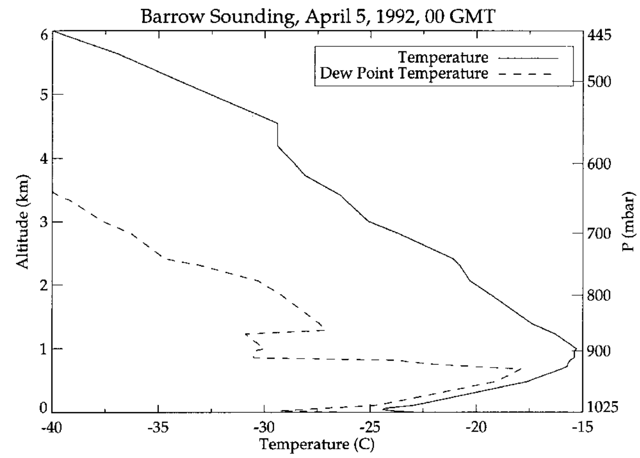


**Figure 1**. Baseline atmospheric profile used in this study from Barrow, Alaska. Note the strong temperature inversion, reaching to nearly 1 km, that is common in the Arctic spring.

In this paper, we only present preliminary results illustrating that different snow surfaces will give rise to different shortwave surface fluxes. A dominant feature in the Arctic is the highly reflective snow and ice surface. In our model, the optical properties of the snow layer are computed by Mie Theory as a function of its density and grain size (Wiscombe and Warren 1980). The snow surface albedo is not independent of wavelength and, in fact, is a complex function of the snow properties, the solar zenith angle, and cloud optical depth.

The variability of spectral albedo with grain radius is shown in Figure 2. Snow with the smallest grain size (r = 0.125 mm), often associated with new snow or wind-packed snow (Grenfell and Perovich 1984), returns the largest fraction of downwelling radiation to space while the largest size

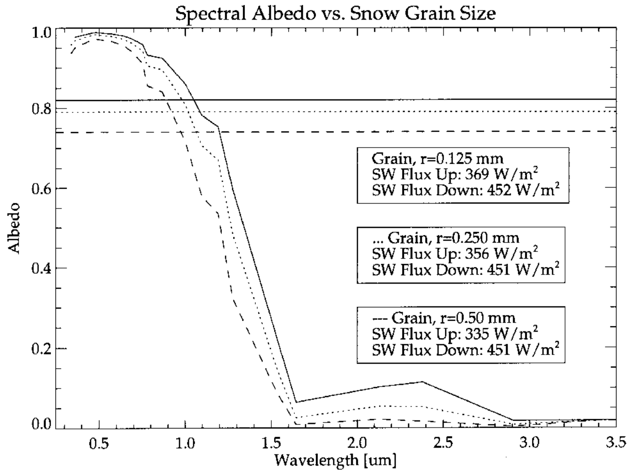


**Figure 2**. The spectral albedo was computed as a function of snow grain size while the density, ρ=0.30 g/cm$^3$, was kept constant. Typically, new snow has a higher albedo than older snow, which has larger grain sizes. The horizontal lines indicate the computed broadband albedo (the ratio of the total outgoing flux to the total incoming flux).

(r = 0.500 mm), characteristic of melting snow, returns the smallest fraction. Additionally, model results show that using a broadband albedo (ratio of the total outgoing flux to the total incoming flux) instead of a wavelength-dependent albedo may underestimate the outgoing flux in this case by more than 10 W/m$^2$. This is a particularly important result because broadband radiometers only yield a wavelength-independent albedo. Thus, in the Arctic we need spectral flux and albedo measurements.

Another important consideration for the NSA site is contamination of the snow in the area from human activities. We added soot, characterized by the mass fraction of soot in the snow, to our snow layer to study this effect (Warren and Wiscombe 1980). Figure 3 shows that soot can considerably alter the snow albedo in the visible region and, while keeping the incoming flux nearly constant, may decrease the upward flux by more than 10 W/m$^2$.

A third comparison between clear and cloudy sky surface fluxes was also done in this study. Stratus clouds are persistent throughout the late spring and summer months. To examine a cloud's influence on the surface albedo, a 120-m-thick, stratus cloud was artificially inserted into the baseline atmosphere at 0.5 km. The cloud is assumed to be vertically homogeneous with an equivalent radius of 7 µm and liquid water content of 0.1 g/m$^3$. The model results are shown in Figure 4. The spectral albedo of the snow under a cloudy

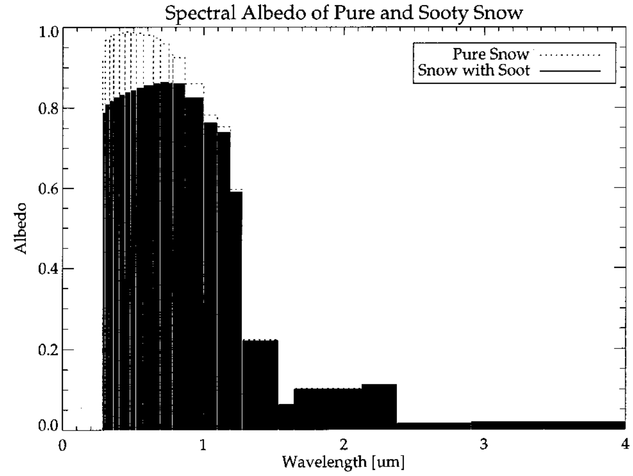


**Figure 3**. Snow with impurities introduced by human activities lowers the visible surface albedo considerably. This is an important consideration when taking measurements in an Arctic population center such as Barrow, Alaska.

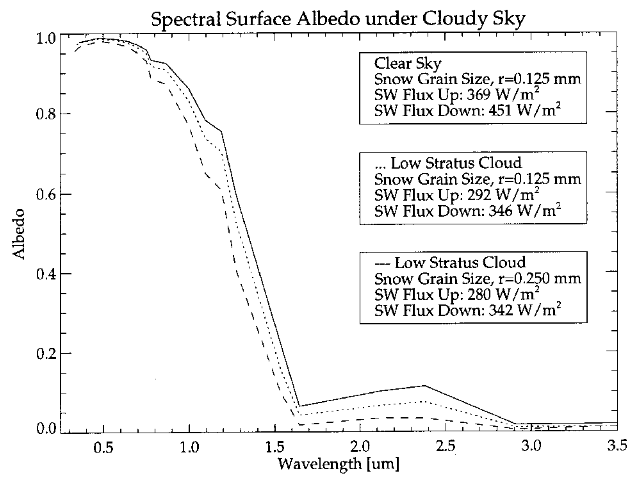


**Figure 4**. Arctic stratus clouds highly influence the magnitude of shortwave radiation received at the surface. Under completely overcast conditions, the downward shortwave flux is decreased by 105 W/m$^2$ and is nearly all diffuse radiation. A further decrease in spectral albedo is seen as the grain size is increased under a cloudy sky.

sky is lower in each wavelength interval than under a clear sky, particularly outside the visible region. Clouds convert the direct beam into diffuse flux with an anisotropic angular distribution. This is important when considering surfaces that are not Lambertian reflectors. Further studies will be done to quantify how a cloud's thickness, droplet size, and liquid water content modulate the shortwave surface flux. Another important issue to be addressed is atmospheric absorption due to the phenomena called Arctic haze.

This paper has only touched on the importance of the surface conditions and cloud cover characteristics when calculating the downward and upward shortwave fluxes. Our computations show that the magnitude of change in the fluxes with changing surface conditions rival that of the hypothetical 3-5 $W/m^2$ warming due to doubling of atmospheric carbon dioxide. As work on the NSA site progresses, we will continue to use our model in conjunction with experimental data from the site to determine under which environmental conditions knowledge of the surface properties is most critical. The lessons learned from these exercises will be used to design appropriate field experiments.

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