Retrieval of Surface Snow Grainsize and Melt Water from AVIRIS Spectra

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ABSTRACT

The Earth's energy balance and hydrology are effected by the distribution and characteristics of snow cover on the surface. Snow grainsize and snow melt, influence surface albedo and hydrology. A model of snow reflectance that depends on both grainsize and surface melt water was developed to derive these parameter from remote spectral measurements. This reflectance model is based on a discrete ordinate radiative transfer approach that uses Mie calculations of snow optical properties which are based on the complex refractive index of ice and water. This snow model was linked to an atmospheric radiative transfer code and a nonlinear least squares fitting algorithm. The resulting combined algorithm was applied to an AVIRIS snow data set acquired over Mammoth Mountain, California. Maps of grainsize and surface snow melt were generated that are consistent with the expected ranges and distributions for condition at the site.

INTRODUCTION

Snow is an important component of the Earth system with influences on the Earth's energy balance and hydrology. The high albedo of snow effects the amount of solar radiation reflected from the surface to space. The storage and release of water by snow is an essential component of the hydrologic cycle in many regions. Snow occurrence and snow properties are variable over space and through time, in the mid and high latitudes of the Earth. The spatial and temporal variability of snow, coupled with the importance to the Earth's energy balance and hydrology, justifies pursuit of new measurements and algorithms for the remote derivation of snow parameters.

Two important properties of snow are grainsize and snow melt. The abledo of snow is a function of grainsize and the release of liquid water from snow, which occurs through melting. The reflectance of snow in the solar reflected spectrum was shown to be sensitive to grainsize (Wiscombe and Warren, 1980; Dozier, 1987). This sensitivity was used with spectra acquired by the Airborne Visible/Infrared imaging Spectrometer (AVIRIS) to estimate grainsize remotely (Nolin and Dozier, 1993). AVIRIS spectra are measured from 400 to 2500 nm at 10 nm intervals and are acquired as images of 11, up to 100 km with 20 by 20 m spatial resolution. More recently, the presence of liquid water in melting snow was shown to be expressed in the reflectance spectrum (Green and Dozier, 1995). This paper presents a new algorithm and results showing the simultaneous derivation of grainsize and snow melt water from calibrated AVIRIS spectra.

MEASUREMENTS

AVIRIS data were acquired over Mammoth Mountain, in east central California on 21 May 1994 at 18:35 UTC. The air temperature at site, at 2926 m was measured at 15 minute intervals during the day preceding the AVIRIS data acquisition. At this location the air temperature remained above freezing, the night of May 20 it rose to 6°C by the time of the overflight on May 21. These temperature conditions are consistent with snow melt water at the surface over portions of Mammoth Mountain when the AVIRIS data were acquired.

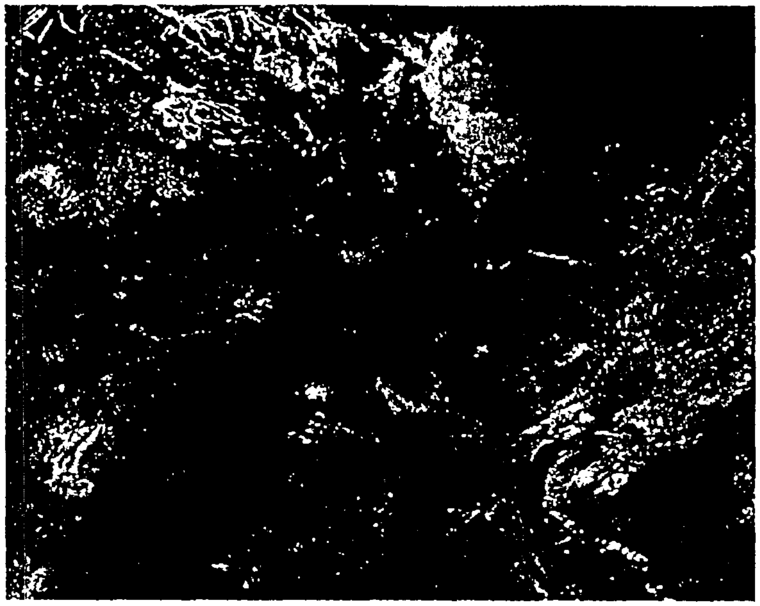

Figure 1. AVIRIS image of Mammoth Mountain, CA acquired on the 21st of May 1994.

MODELS

Snow reflectance is modeled as a function of grainsize and liquid water based on the inherent optical properties of ice and liquid water. The real and imaginary components of the complex refractive index for ice and water (Warren 1984, Kou et al. 1994) are shown in Figure 2 and 3.

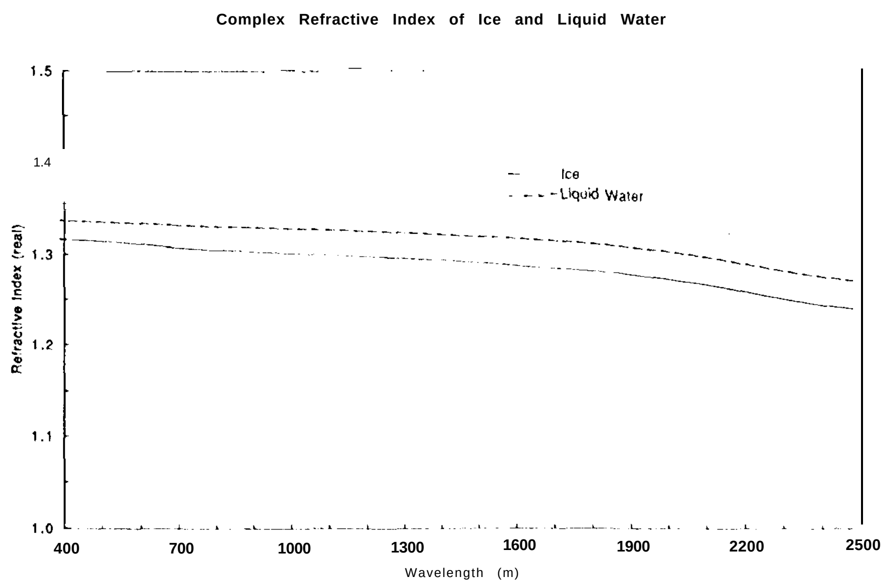

Figure 2. Real components of the complex refractive index of ice and liquid water.

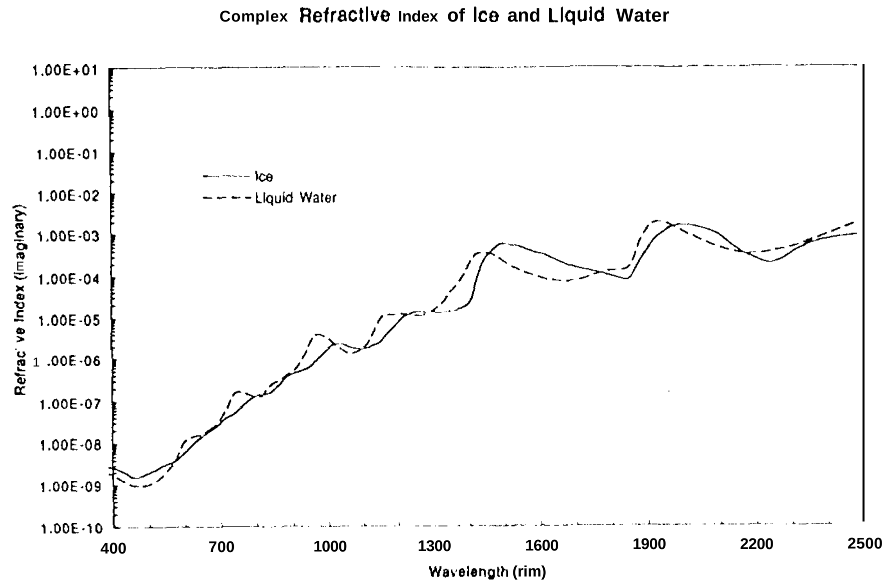

Figure 3. Imaginary components of the complex refractive index of ice and liquid water.

The refractive indices were used to model snow reflectance as a mixture of ice and liquid water spheres. This approach allows the use of Mie (Wiscombe, 1982) calculations for the single- scattering- albedo and scattering phase functions for different grainsizes and liquid water amounts. Figure 4 shows these parameters for 500 μm grainsize snow with 0.0 and 25.0 % liquid water of total water by volume. The presence of the liquid water decreases and shifts the regions of spectral absorption towards shorter wavelengths.

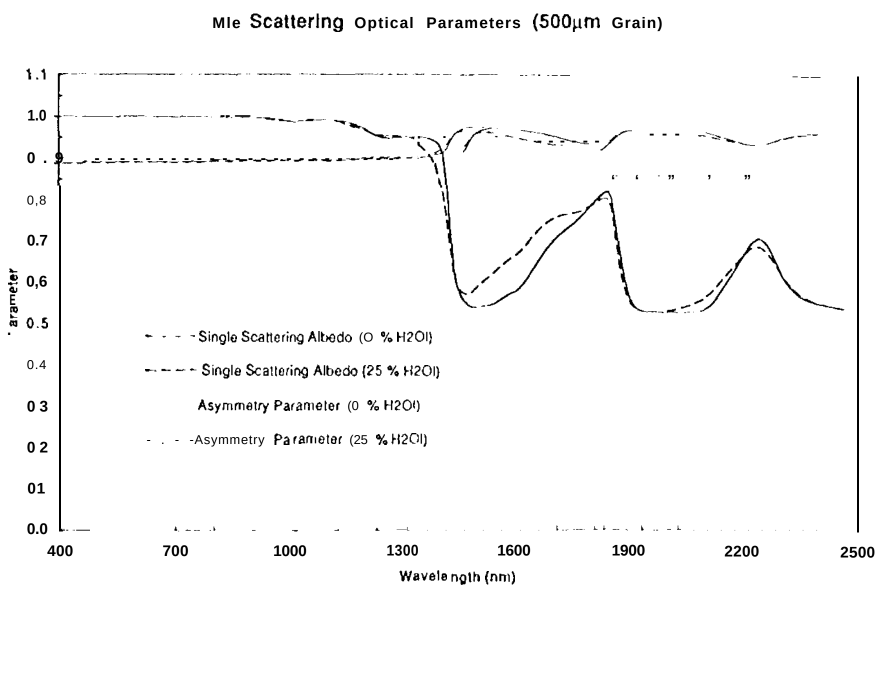

Figure 4. The single-scattering-albedo and asymmetry parameter from Mie calculations for 500 pm grainsize snow with 0.0 and 25.0 % liquid water.

These Mie parameters were used to constrain a discrete ordinate radiative transfer code, DISORT (Stamnes, 1988), and model the directional-hemispherical reflectance of snow. A semi-infinite snow thickness was adopted. The solar illumination angle was 19.3°. The same as at the time of AVIRIS data acquisition. Modeled reflectance for 500 μm grainsize with 0.0 and 25.0 % liquid water is shown in Figure 5. The presence of liquid water modifies the regions of absorption in the modeled reflectance. 'l'his effect is strong] y apparent near the 1030 nm ice absorption where the reflectance of the snow is high.

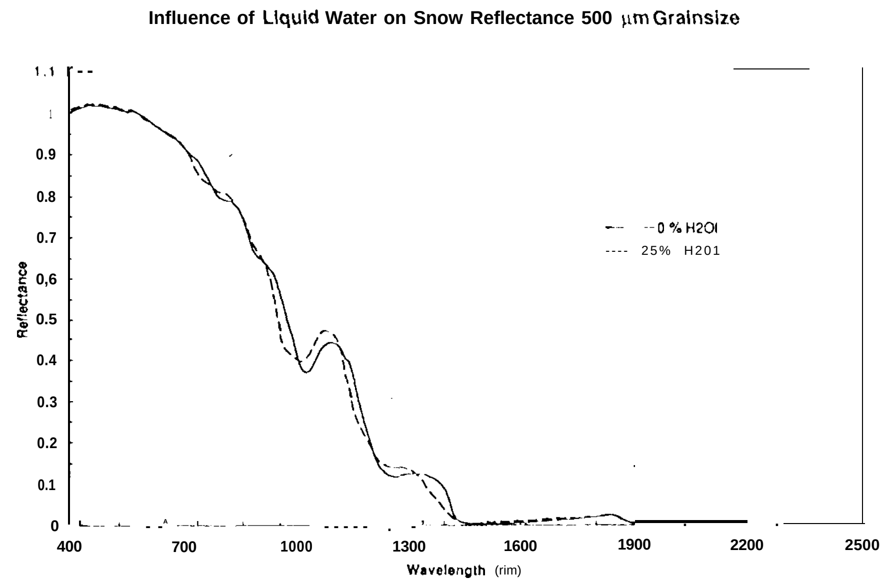

Figure 5. Directional-hemispherical DISORT modeled snow reflectance for 500 μm grainsize snow with 0.0 and 25.070 liquid water.

To derive the snow grainsize and liquid water of snow melt from AVIRIS data, the MODTRAN3 (Kneizys, 1988, Berk, 1989) radiative transfer code was linked to the snow reflectance model to allow compensation for the atmosphere (e.g., water vapor). The combined surface and atmosphere model was integrated with the simplex nonlinear least squares fitting algorithm (Press, 1987).

ANALYSIS AND RESULTS

The resulting combined snow parameter algorithm was applied to every spectrum in the AVIRIS Mammoth Mountain data set. A spectral range from 8500 to 1100 was used in the fit, based on the expressed dependence of the reflectance on grainsize and melt water in this region. A spectral fit result at low elevation and high elevation on the Mammoth Mountain are given in Figure 6 and 7 respectively. At low elevation a grainsize of 900 μm and melt water of 15.9 % is required. For the high elevation case, a grainsize of 230 μm and melt water of 2.1 % is derived. Figures 8 and 9 show the grainsize and snow melt maps for the entire image. Over the full data set, the distribution of grainsize ranges from 1000 to 100 pm from the lower mountain to the summit. Melt water ranges from 16 to 2 % for homogeneous snow regions from the lower mountain to the summit. Snow melt water values are anomalously high in regions where vegetation occurs on the mountain. The expression of liquid water in the. leaves of the vegetation, results in over estimates of the melt water in snow,

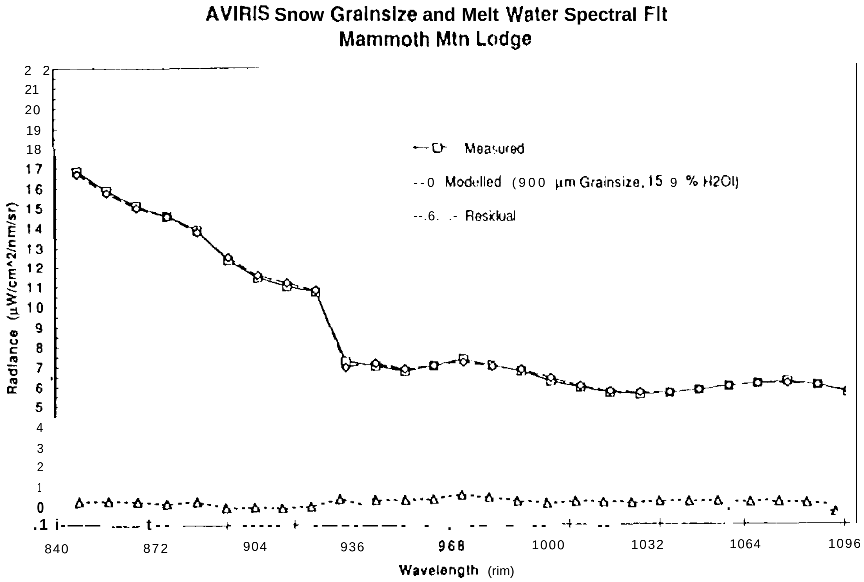

Figure 6. Snow grainsize and melt water spectral fit. This result is from a homogeneous snow area low on the mountain. A large grainsize and high melt water content are required for the fit.

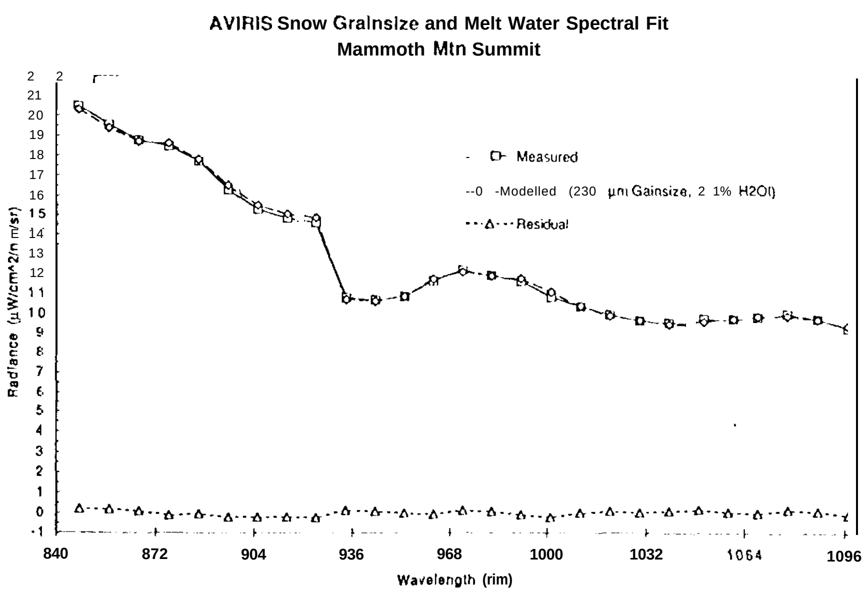

Figure 7. Spectral fit from high on Mammoth Mountain. A small grainsize and low melt water content are produced from the algorithm.

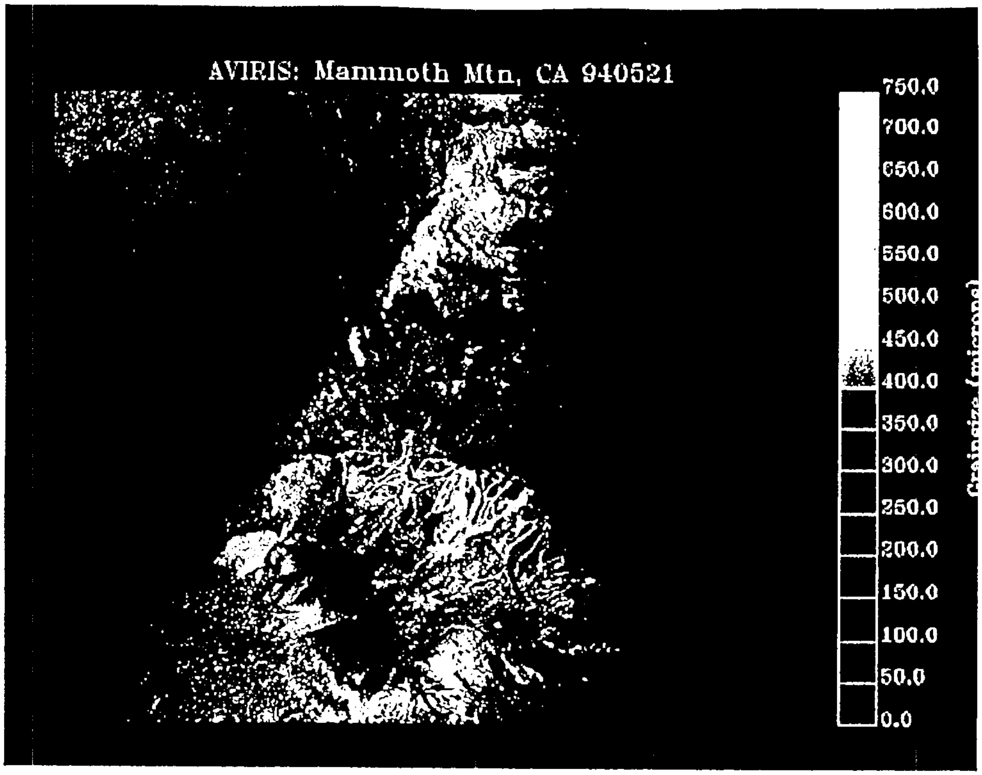

Figure 8. Image result of grainsize distribution for the AVIRIS Mammoth Mountain data set.

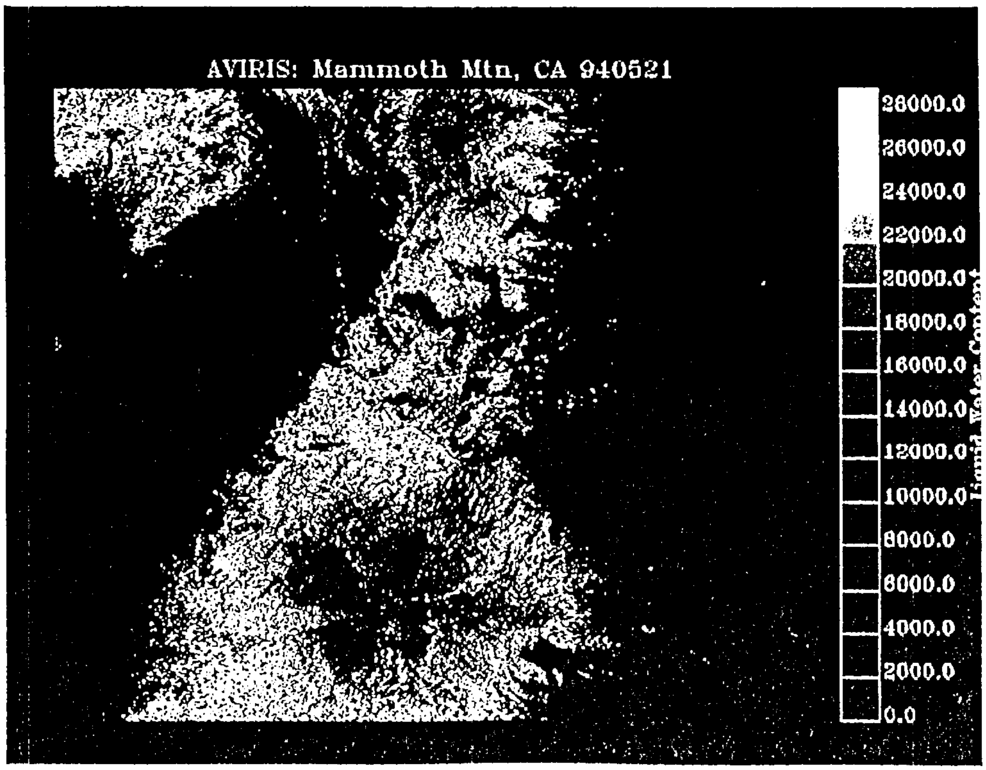

Figure 9. Snow surface melt water distribution from AVIRIS data set. Anomalously high melt water is derived in areas where vegetation and leaf water is present with snow.

CONCLUSION

The optical properties of ice and water were used to develop a model of snow reflectance based on grainsize and surface melt water. This model was linked with the MODTRAN3 atmospheric radiative transfer code and a nonlinear, least squares fitting algorithm. The resulting integrated snow grainsize and surface melt water algorithm was applied to an AVIRIS data set acquired over Mammoth Mountain, California. Derived grainsize and melt water distribution where consistent with the range of elevations and temperatures for the data set, Anomalous estimates of melt water where observed when vegetation leaf water was present with the snow. This methodology and algorithm demonstrate a basis for derivation of the snow parameters of grainsize and surface melting from remote measurements. Derivation of snow parameters remotely is essential to detect, measure and monitor snow in the Earth system through space and time.

FUTURE WORK

Results of snow grainsize and surface melt will be validated with available in situ measurements for these and other data sets. "l"he model will be augmented to account for and compensate for the presence of vegetation with the snow. An alternate approach to modeling liquid water in snow as liquid water coated spheres of ice will be developed and evaluated with respect to this model. Sensitivities to the hi-directional distribution function of snow and the dependence on grainsize and melt water will be investigated.

ACKNOWLEDGMENTS

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REFERENCES

Dozier, J. (1989), "Spectral signature of alpine snow cover from the Landsat Thematic Mapper", *Remote Sens, Environ.* 28:9-22.

Green, R.O., Dozier, J. (1995), "Measurement of the spectral absorption of liquid water in melting snow with an imaging spectrometer", *Summaries of the Fifth Annual JPL Airborne Earth* Science *Workshop., 95-1, Vol 1,91-94.* , ,

Kneizys, F.X., Shettle, E.P., Abreu. 1.. W., et al. (1988), *"User's Guide* to LOWTRAN7", Rep. AFGL-TR-88-0177, Air Force Geophys. Lab., Bedford, MA,

Nolin, A. W., Dozier, J. (1993), "Estimating snow grain size using AVIRIS data", *Remote Sens. Environ. 44:231-238.*

Press, W.H., *Numerical Recipes: The Art of Scientific Computing*, Cambridge University Press, Cambridge, 1986.

Stamnes, K., Tsay, S., Wiscombe, W., and Jayaweera, K. (1988), "Numerically stable algorithm for discrete-ordinate-method radiative transfer in multiple scattering and emitting layered media", *Appl. Opt.* 27:2502-2509.

Warren, S.G. (1982), "Optical properties of snow", Rev, *Geophys. Space Phys.* 20:67-89.

Wiscombe, W. J., and Warren, S.G. (1980), “A model for the spectra albedo of snow, I, Pure snow”, *J. Atmos. Sci.* 37:2712-2733.

Wiscombe, W. J. (1 980), “Improved mie scattering algorithms”, *Appl., Opt.*, 19, 1505-1509.