Maps of snow cover, especially from sensors with spatial resolution of several hundreds of meters to a few kilometers, are more accurate and have less systematic bias if the mapping algorithm estimates the fractional snow cover in each pixel. Specifically, if snow cover increases with elevation, as is often the case, a "binary" method of mapping snow, which classifies each pixel as either snow-covered or snow-free, systematically underestimates snow at lower elevations and overestimates snow at higher elevations. In addition to estimating the snow-covered area in each pixel, we want to know that snow's albedo. The radiation balance of a bright surface like snow is particularly sensitive to the albedo, because when albedo exceeds 0.5, an error in an albedo measurement translates to a larger relative error in the absorption. Therefore, a distributed hydrologic model that uses energy-balance calculations of snowmelt requires an accurate map of the spatially variable albedo

Therefore, models of snowmelt and metamorphism depend on the spatial distribution of the surface energy balance, often in areas where topographic variability causes huge differences in incoming solar radiation. At a spatial scale fine enough to consider the terrain, we want to estimate snow-covered area, along with other optical effects such as grain size, contamination by absorbing impurities, and liquid water near the surface. Spectral mixture analysis with AVIRIS (the Airborne Visible and Infrared Imaging Spectrometer) allows the retrieval of subpixel variability of snow-covered area, along with the snow's albedo.

Uncommon among Earth's surface materials, snow is bright in the visible wavelengths, moderately reflective in the near-infrared, and dark in the shortwave-infrared. This characteristic allows remote sensors to separate snow from other common surface covers and from clouds. Vegetation is dark in the visible wavelengths but brighter than snow in the shortwave-infrared. Clouds and snow have similar reflectance in the visible, but clouds are brighter in the shortwave-infrared. Soil and rock have relatively flatter spectral signals than other materials. Open water is especially dark in the near-infrared and shortwave-infrared.

In addition to being spectrally distinct from other materials, snow's spectral reflectance varies considerably with its physical properties, perhaps more so than any other Earth surface material. In the visible wavelengths, snow reflectance is not sensitive to the size of the grains, but is sensitive to the presence of absorbing impurities such as dust or soot. In the near-infrared, show reflectance is sensitive to grain size. In the shortwave-infrared, all but very fine-grain new snow is dark.

In the following equations, we use ρ to indicate the reflectance of a substance and *R* to indicate measured reflectance from a pixel. Although radiative transfer calculations of snow reflectance are computationally intensive, for a given wavelength the variability of reflectance with grain size is generally a smooth function. Therefore, one can pre-compute coefficients for each wavelength for a regression equation with independent variables grain radius *r* and contaminant amount *y*, in a form like:

$$\rho_{snow}(\lambda, r, y) = a_0 \left(\frac{2\pi r}{\lambda} \right)^{a_1} y^{a_2}$$

Instead of the grain radius r directly, we express grain size using the dimensionless Mie size parameter $2\pi r/\lambda$. Similarly, the contaminant content y is expressed as a mass fraction. The **a** coefficients depend strongly on wavelength —because of the variability in the complex refractive index of ice—and weakly on viewing geometry.

Snow-covered area, especially in alpine terrain, usually varies at a scale finer than that of the sensor's spatial resolution. This spatial heterogeneity poses a mixed pixel problem in that the sensor may measure radiance reflected from snow, rock, soil, and vegetation. Spectral mixture analysis is a method of inverting multispectral or hyperspectral data to enable mapping land cover at subpixel scale. Linear spectral mixture analysis assumes that the radiance measured at the sensor is a linear combination of radiances reflected from individual surfaces, endmembers. The assumption is appropriate for spatial scenarios such as snow and rock cover above timberline where the surface is near planar. In a particular wavelength band b, where the radiance is integrated over a wavelength range from $\lambda_{\min}$ to $\lambda_{\max}$, a pixel's reflectance is a linearly weighted average of its endmembers' reflectances:

$$R_b = \varepsilon_b + \sum_{m=1}^{M} \rho_{b,m} F_m$$

If there are N spectral bands and $N \geq M$, then a set of simultaneous equations can be solved for the F values. In the typical case when $N > M$, the solution typically minimizes the sum of squares of the errors ε, but other minimization criteria can be used. Because the reflectance values for the snow endmember vary with snow properties, we can add two unknowns for the snow grain size and contaminant fraction, fitting the values with known coefficients.

Much of the snow cover of interest is in alpine terrain with topographic relief. The resulting topographic variability in solar illumination complicates an analysis with a straightforward implementation of spectral mixing. With a fine-resolution sensor, we have to co-register the image data with a digital elevation model. With a coarse-resolution sensor, we have to deal with the variability of illumination within a pixel. Vegetation also affects the signal: we measure the *projected* snow-covered area, and we therefore need to estimate actual snow-covered area using knowledge of the vegetation, possibly from viewing the scene at different angles. Finally, among the remaining challenges is the adaptation of algorithms from an imaging spectrometer to frequent, large-scale processing with a multispectral sensor such as MODIS (Moderate-Resolution Imaging Spectroradiometer).