IMPROVING ALPINE-REGION SPECTRAL UNMIXING WITH OPTIMAL-FIT SNOW ENDMEMBERS

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INTRODUCTION

Surface albedo and snow-covered-area (sCA) are crucial inputs to the hydrologic and climatologic modeling of alpine and seasonally snow-covered areas (Dozier, 1989). Because the spectral albedo and thermal regime of pure snow depend on grain size, areal distribution of snow grain size is required. Remote sensing has been shown to be an effective (and necessary) means of deriving maps of grain size distribution (Dozier and Marks, 1987; Nolin, 1993) and snow-covered-area (Dozier, 1989; Nolin, 1993; Rosenthal, 1993). Developed here is a technique whereby maps of grain size distribution improve estimates of SCA from spectral mixture analysis with AVIRIS data.

BACKGROUND

The spectral signature of snow is distinguished by very high reflectance in visible wavelengths and moderate reflectance in NIR wavelengths. While visible reflectance is strongly affected by absorbing impurities and nearly independent of grain size,NIR reflectance is primarily dependent on grain size with reflectance decreasing as grain size increases. Most sensitive to grain size is reflectance in the wavelength region from 1.0- 1.3 microns which spans the diagnostic ice absorption features at 1.03 microns and 1.26 microns. These relationships are exploited in grain size mapping, most quantitatively by Nolin (Dozier and Marks, 1987; Nolin, 1993). When deposited on the surface, snow grains undergo a process called 'metamorphism' through which larger grains grow at the expense of smaller grains. Metamorphism is in most cases heightened with increased temperature, therefore snow covered regions exhibit grain size distributions inversely related to elevation.

Spectral mixture analysis has as an objective the definition of subpixel proportions of spectral endmembers which maybe related to mappable surface constituents (Adams et al., 1993). The spectral mixture approach has been shown to be effective in mapping SCA in alpine regions with Thematic Mapper data (Rosenthal, 1993) and AVIRIS data (Nolin, 1993). These efforts have incorporated fixed endmember suites of snow, vegetation and rock (shade considered complementary). However, fixed suites of spectral endmembers are not necessarily optimal for image-wide endmember detectability (Sabol et al., 1992). It is theorized that the NIR-dependence of snow reflectance on grain size renders a single snow endmember inadequate for regions of significant grain size gradient. In this study we utilized multiple mixture models on a suite of snow endmembers (corresponding to the scene's grain size range) to optimize SCA estimates, pixel by pixel choosing the snow fraction estimated by the model with least mixing error (RMS).

DATA and METHODS

This theory was tested on an April 5,1994 AVIRIS scene of Mammoth Mountain, CA. Calibrated radiance data was converted to apparent surface reflectance using the atmospheric transmittance model MODTRAN2 and a non-linear least-squares water vapor fitting routine (Green et al., 1993). A map of snow grain size was generated using the method of Nolin (1993).
Spectral mixture analysis used the following mixing rules (Roberts et al., 1990):

$$Rc = \sum_{i=1}^{N} FiRi,c + Ec$$

R_c *is* the apparent surface reflectance in AVIRIS band c, F_i if the fraction of endmember i, $R_{i,c}$ is the reflectance of endmember i in AVIRIS band c. N is the number of spectral endmembers and E_c is the error in AVIRIS band c for the fit of the N endmembers. The average root mean squared (RMS) error is calculated as follows

$$RMS = \left[M^{-1} \sum_{i=1}^{M} E_c^2 \right]^{1/2}$$

where M = number of AVIRIS bands in spectral mixture analysis.

The spectral mixture band-subset was chosen as per Nolin (1993). This consists of 4 VIS channels and 13 NIR channels spanning the diagnostic 1.03 micron ice absorption feature. Mixing models may be evaluated in three ways; RMSE analysis, fraction under/overflow analysis, and residuals analysis. In this work, RMSE analysis is emphasized while snow fraction under/overflow is used as a secondary qualitative tool.

Image endmembers were chosen for vegetation and rock. Guided by the grain size map for the scene, five image endmembers were chosen for snow of varying grain size, ~75microns to ~500microns. With vegetation and rock endmembers fixed, mixture models using the Modified Gram-Schmidt method were run with each snow endmember. RMSE and snow fraction images were produced for each. Optimization was then carried out by choosing for each pixel the lowest RMSE and its respective snow fraction estimate from among the five models to create a MIN RMS image (Figure 1) and accompanying snow fraction image.

RESULTS

Figure 1 shows RMS images for each mixing model and the RMS image for the minimum pixel by pixel RMS among the five models. As reference, Mammoth Mountain Ski Area lies just left of center in the lower half of each image and is the main above-timberline feature in the scene. The summit ridge runs from upper left to lower right. North is toward the upper right corner. Inspection of the model RMS images demonstrates that a single snow endmember is inadequate to model the entire domain. The SW SNOW endmember (-125 microns grain size) has very low RMSE in those regions of smaller grain sizes (high elevation), yet the RMSE increases to 2.5%+ where grain sizes approach 500 microns (lower elevation). The E SNOW endmember (-500 micron grain size) however gave near O% RMSE in large grain domains and 2.5% RMSE in the smallest grain domains, A comparison of the N1 SNOW and S SNOW RMSE results gives preliminary indication that this technique may be insensitive to aspect: both endmembers are from regions of-350 micron grain size but opposite aspects (different illumination). Nonetheless, spatial RMSE distribution and magnitude are very similar. Likewise, snow fraction estimates for this pair are nearly identical. The N2 SNOW endmember (extracted from north aspect with ~75 micron grain size) RMSE image poses an important question. Is the coincidence of its near 0% RMSE domain with high north aspects due to a sensitivity of image endmembers to aspect or the likely case that the smallest grains will be high on a northerly aspect? Most encouraging is the MINRMS image. The multiple snow endmember approach significantly bounds RMSE and serves to better characterize the spectral domain of this scene.

RMSE alone, however, is not sufficient to test the model results. Inspection of snow fraction images is also necessary. These images (not shown) showed in the individual models that where RMSE was lowest, snow fraction estimates were within reasonable bounds (0.0 - 1.0) and appropriate given location and spectral signature. Where RMSE increased, fraction overflow and/or inappropriate values dominated. All images showed underflow (snow fraction < 0.0) in regions of dense vegetation, indicating the vegetation end member was contaminated by snow. The snow fraction image for MINRMS is well bounded (but for the vegetation) and spatially appropriate throughout.

DISCUSSION and FUTURE PLANS

Preliminary results indicate that multiple snow endmembers representing a range of grain sizes are necessary to spectrally characterize a scene containing significant snow grain size gradients. Further work will incorporate reference endmembers for vegetation and rock. Snow endmembers will be calculated for a range of grain sizes and illumination angles to more accurately determine grain size and aspect sensitivities. Tests will be run on temporally and spatially different AVIRIS cubes.

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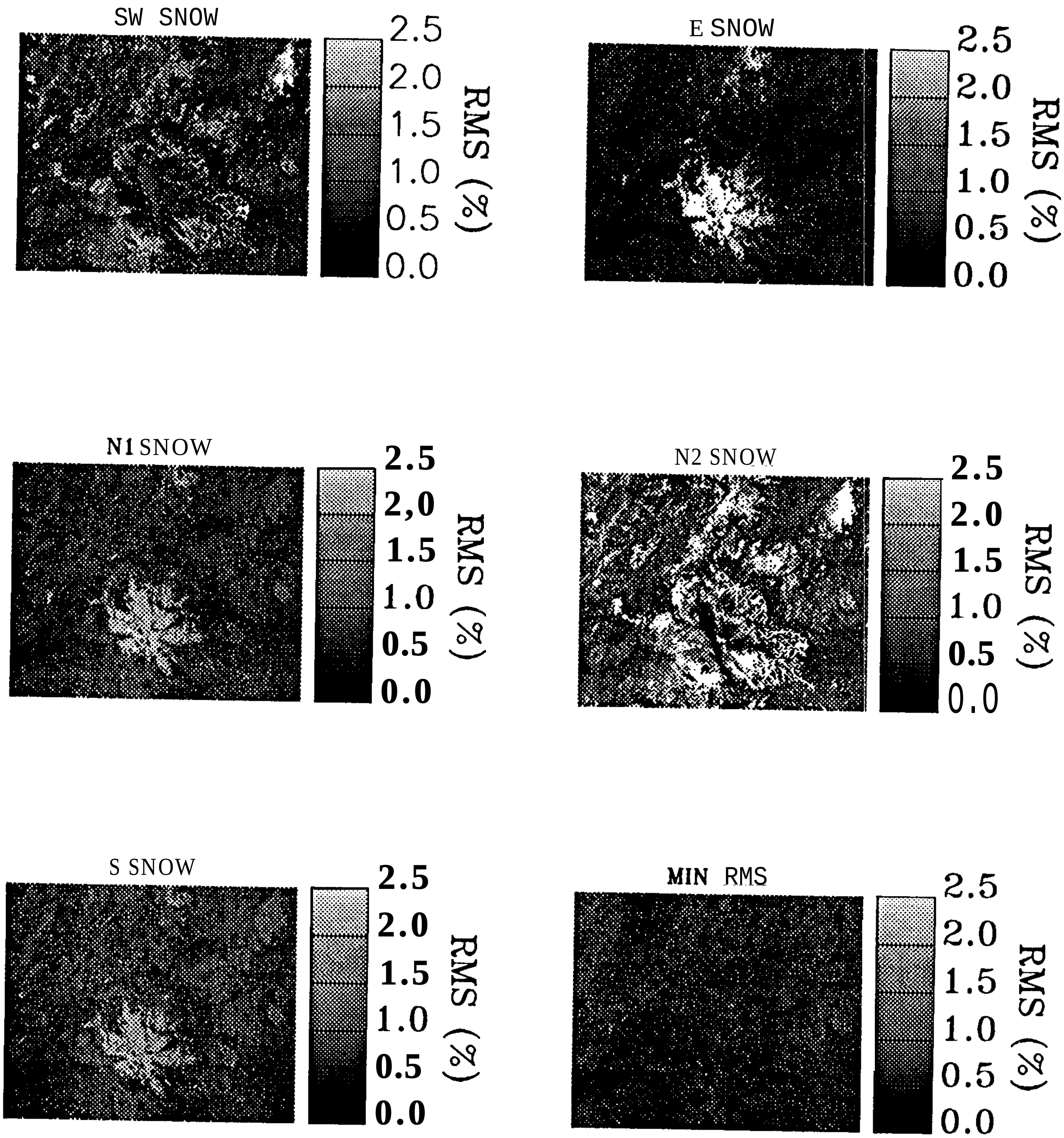

Figure 1. RMSE images for snow endmembers and minimum RMS image.