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SNOW REFLECTANCE FROM THEMATIC MAPPER

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SNOW REFLECTANCE FROM THEMATIC MAPPER

INTRODUCTION

In California 75% of the agricultural water supply comes from the melting Sierra Nevada snowpack. The California Cooperative Snow Survey uses measurements of snow water equivalent from snow courses, snow depth from aerial survey markers, and snowcovered area from satellite data to estimate the amount and the timing of the spring runoff.

Our work on snow reflectance from the TM should lead to improved use of satellites in snow hydrology.

1) Basin-wide albedo measurements from the TM could be used to better forecast the timing of the spring runoff, because these data can be combined with solar radiation calculations to estimate the net radiation budget. The TM is better-suited for this purpose than the MSS because of its larger dynamic range. Saturation still occurs in bands 1-4, but is only severe in band 1.
2) TM band 5 can discriminate clouds from snow.
3) Measurements of snowcovered area should be better with the TM, because the $30m$ spatial resolution can be used to estimate the contiguity of the snowcover above the snowline.

SPECTRAL ALBEDO OF SNOW

Calculations of snow reflectance in all 6 TM reflective bands (i.e. 1, 2, 3, 4, 5, and 7), using a delta-Eddington model[7], show that snow reflectance in bands 4, 5, and 7 is sensitive to grain size. An objective in our investigation is to interpret surface optical grain size of snow, for spectral extension of albedo. Our results so far are encouraging.

Table 1 and Figure 1 show calculations of integrated reflectance for snow over all reflective TM bands, and water and ice clouds with thickness of $1mm$ water equivalent over TM bands 5 and 7. In the blue and green bands (1-2) snow reflectance is not sensitive to grain size, so measurements in these wavelengths will show the extent to which snow albedo is degraded by contamination from atmospheric aerosols, dust, pine pollen, etc. In the red and near-infrared, snow reflectance is sensitive to grain size but not to contaminants, so grain size estimates in these wavelengths can be used to spectrally extend albedo measurements.

The reason that snow reflectance in bands 1 and 2 is not sensitive to grain size is that ice is so transparent in these wavelengths that increasing the size of a snow crystal does not significantly change the probability that a photon impinging on the crystal will be absorbed. Impurities are much more absorptive than ice in these wavelengths, however, so small amounts of contaminants will affect reflectance[6]. In the near-infrared, bands 3 and 4, ice is slightly absorptive, so an incident photon is more likely to be absorbed if the crystal is larger, and snow reflectance is therefore sensitive to grain size. Impurities are not so important in these wavelengths because their absorption coefficients are not much larger than those of ice.

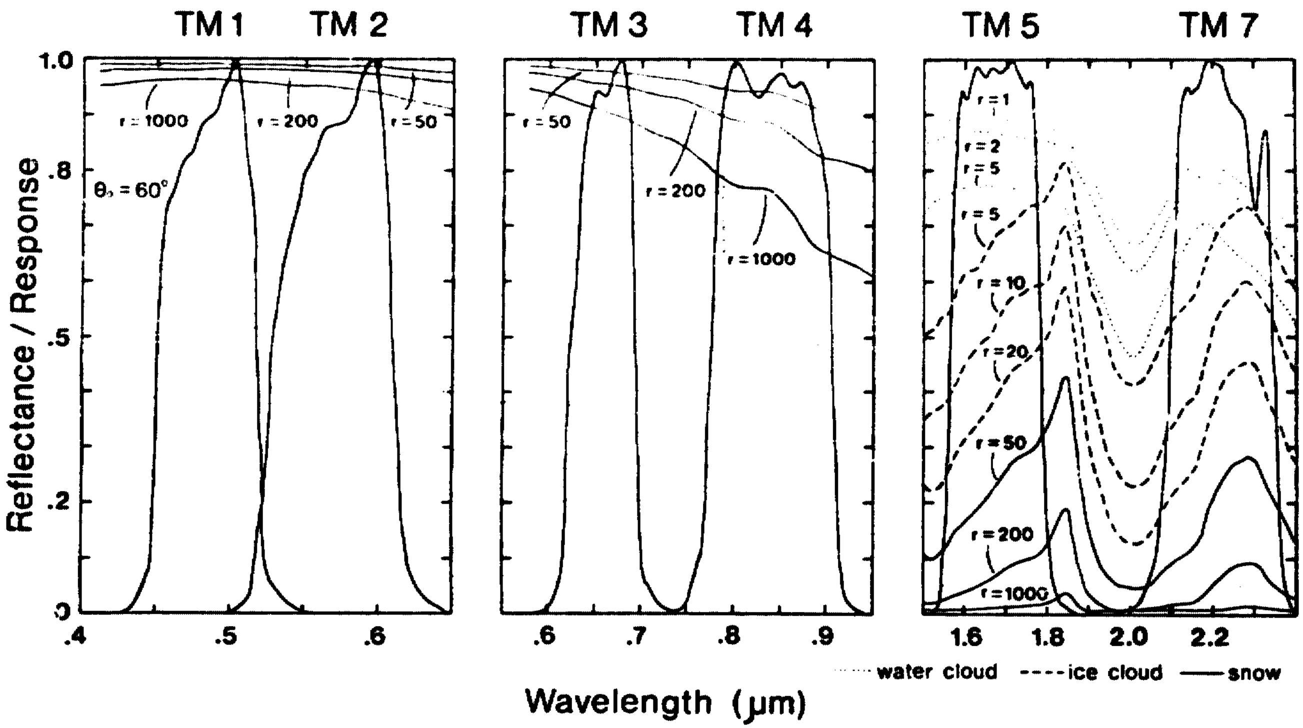

Figure 1. Sensor response functions and snow reflectance, at illumination angle ϑ_0=60° and grain radii r from 50 to 1000μm, for the reflective bands (1-5, 7) of the Landsat-4 Thematic Mapper.

Table 1

TM Integrated Reflectances*, ϑ_0=60°

band	*clean semi-infinite snow, optical grain radius (μm)* 50	100	200	500	1000
1	.992	.988	.983	.974	.963
2	.988	.983	.977	.964	.949
3	.978	.969	.957	.932	.906
4	.934	.909	.873	.809	.741
5	.223	.130	.067	.024	.011
7	.197	.106	.056	.019	.010
band	***water cloud, 1mm water, optical droplet radius (μm)*** *1*	*2*	*5*	*10*	*20*
5	.891	.866	.769	.661	.547
7	.784	.750	.650	.481	.345
band	***ice cloud, 1mm water equivalent, optical crystal radius (μm)*** *1*	*2*	*5*	*10*	*20*
5	.817	.780	.665	.513	.383
7	.765	.730	.642	.478	.341

* Integrated reflectance ρ is

$$\rho = \frac{\mu_0 \int_0^\infty \rho_\lambda \, \Phi_\lambda^{(j)} \, E_\lambda \, d\lambda}{\mu_0 \int_0^\infty \Phi_\lambda^{(j)} \, E_\lambda \, d\lambda}$$

where ρ_λ is direct-beam spectral snow reflectance at illumination angle $\vartheta_0=\cos^{-1}\mu_0$, E_λ is spectral solar constant, and $\Phi_\lambda^{(j)}$ is instrument response function for band j. (The μ_0's of course cancel.)

DYNAMIC RANGE

Table 2 gives characteristics of the Thematic Mapper, and, for background information, the Multispectral Scanner and NOAA Advanced Very High Resolution Radiometer. In the radiance columns of the table, the quantization errors and saturation radiances of the sensor bands are compared with the solar constant, integrated through the sensor response functions. Solar constant spectral distributions are from the NASA standard[5], adjusted to fit the integrated values measured from the Nimbus-7 cavity radiometer of the earth radiation budget experiment[2]. The last column in the table expresses the sensor saturation radiance as a percentage of the solar constant, integrated through the band response function.

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Table 2

TM, MSS, and AVHRR Spectral Characteristics
[spectral distribution of solar constant from Ref. 5]

band	wavelengths (50% ampl., μm)			radiances ($W\,m^{-2}\,\mu m^{-1}\,sr^{-1}$) NEΔL	sat.	solar	%
Thematic Mapper							
1	.452	-	.518	.63	161	621	25.9
2	.529	-	.610	1.24	316	540	58.5
3	.624	-	.693	.95	241	468	51.5
4	.776	-	.905	.92	234	320	73.1
5	1.568	-	1.784	.13	31.7	66.5	47.7
7	2.097	-	2.347	.067	16.9	24.4	69.3
6	10.422	-	11.661		(thermal band)		
Landsat-2 Multispectral Scanner							
4	.5	-	.6	4.0	259	574	45.1
5	.6	-	.7	2.8	179	491	36.5
6	.7	-	.8	2.3	149	401	37.2
7	.8	-	1.0	3.0	192	285	67.4
NOAA-7 Advanced Very High Resolution Radiometer							
1	.56	-	.72	.51	518	485	106.8
2	.71	-	.98	.33	341	364	93.7
3	3.53	-	3.94		(thermal bands)		
4	10.32	-	11.36				
5	11.45	-	12.42				

For the TM and AVHRR, the solar constant values were integrated over the sensor response functions. We do not have response function data for the MSS, so the sensor was assumed to have a square-wave response.

Snow will frequently saturate in band 1, but in bands 2, 3, and 4 the saturation problem is not nearly as severe as with the MSS, so the TM can be used to measure snow albedo and thus allow basin-wide energy budget snowmelt calculations. Bands 5 and 7 will not saturate over snow.

Snow *does* stretch the dynamic range of the TM, however. Figure 2 shows histograms of all 6 reflective bands for the the southern Sierra Nevada on 10 December 1982 (northwest portion of path 41, row 35) and Table 3 lists portions of the image that are saturated in all 7 bands. In band 1 fully 1/8 of the pixels are saturated, and the saturated portion would increase as sun elevations get higher in the spring.

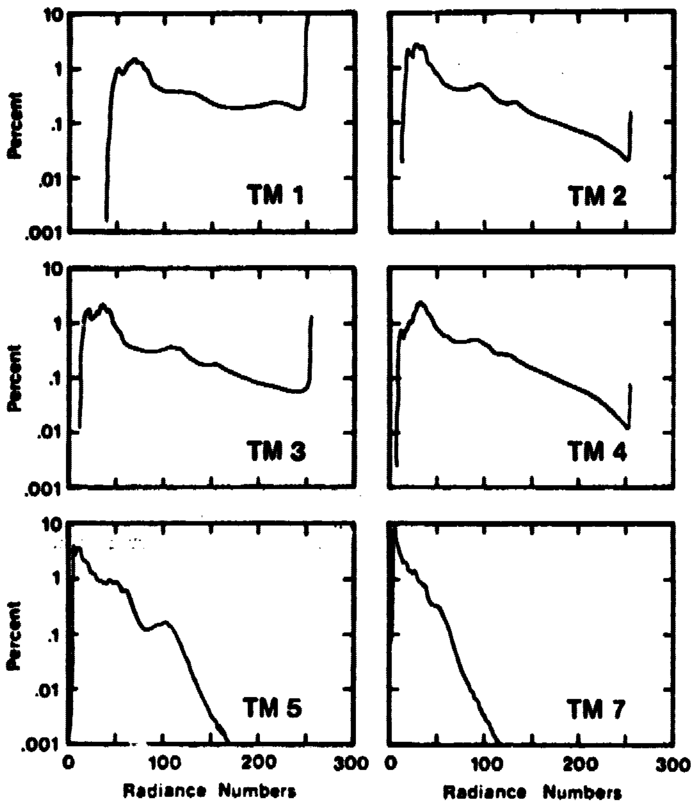

Figure 2. Histograms of digital radiance numbers for all reflective bands (1-5, 7) for the scene in Figure 2. The saturation percentages are in Table 3.

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Table 3

Sierra Nevada and White Mountains, 10 Dec 1982
Saturation, TM Reflective Bands

band	*percentage saturated*
1	12.25
2	0.15
3	1.40
4	0.07
5	0.00
7	0.00

SNOW/CLOUD DISCRIMINATION

Figure 3 shows TM bands 2 and 5 of the Sierra Nevada, Owens Valley, and the White Mountains on 10 December 1982 (northwest quarter of path 41, row 35). In band 2 both snow and clouds are bright, while in band 5 the clouds are bright but snow is dark.

Table 1 and Figure 1 also analyze reflectance of snow and ice clouds. In both "shortwave infrared" bands, 5 and 7, snow is much darker than clouds, and water clouds are brighter than ice clouds in band 5. In both of these bands ice is highly absorptive, and snow reflectance is low and sensitive to grain size for small sizes, which explains the higher reflectance of ice clouds than snow. In band 5 water is less absorptive than ice[1], so water clouds are more reflective than ice clouds.

EFFECT OF RESOLUTION ON SNOWCOVER MAPPING

The major operational use of satellite data in snow hydrology has been in mapping snowcovered area, as an index to the amount of snowmelt runoff[3,4]. In mountainous regions the usual approach has been to use the satellite data to identify the snowline (above which the ground is snowcovered, below which it is snowfree) and to then measure the area within the snowline as the snowcovered area.

Unfortunately the elevation of the snowline is not always a good index to the volume of snow (or snow water equivalence) in the watershed. Sometimes a cold storm deposits small amounts of snow over a wide area, whereas a warmer storm will deposit much more snow but over a smaller area. The finer spatial resolution of the Landsat 4 Thematic Mapper might make it possible to use textural information about the snowcovered area, and thereby to better use satellite data to estimate the volume of snow in a watershed. Even above the snowline, there are differences between years of large accumulation and normal or lean years. Rocks, bushes, trees, etc may or may not be covered. Ridges may or may not be blown clean. The *spatial contiguity* of the snow is also an index of its volume, and the TM should help us estimate this.

CONCLUSION

Landsat-4 Thematic Mapper data include spectral channels suitable for snow/cloud discrimination and for snow albedo measurements that can be extended throughout the solar spectrum. Except for band 1, the dynamic range is large enough that saturation occurs only occasionally. The finer spatial resolution gives much better detail on the snowcovered area.

SNOW/CLOUD DISCRIMINATION

SIERRA NEVADA and WHITE MOUNTAINS, 10 DEC 82

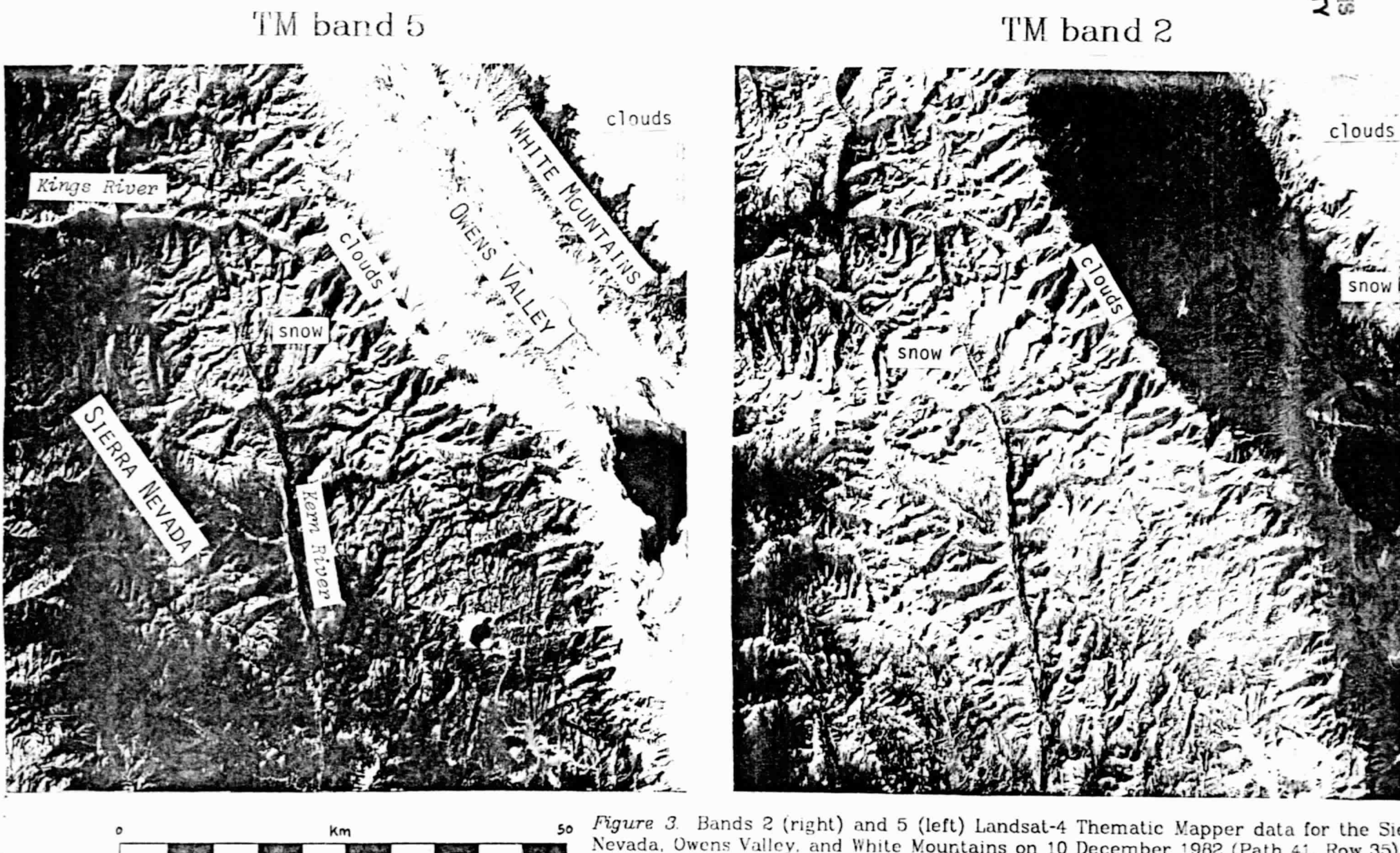

Figure 3. Bands 2 (right) and 5 (left) Landsat-4 Thematic Mapper data for the Sierra Nevada, Owens Valley, and White Mountains on 10 December 1982 (Path 41, Row 35). In band 2 both snow and clouds are bright, but in band 5 snow is dark and clouds are bright

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