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Quarterly Progress Report, Contract No. NAS5-27463

Landsat-D Investigations in Snow Hydrology

Reporting Period: November 17, 1982 to December 31, 1982*

Results to Date

We have received the sample Landsat-4 TM tape (7 bands) of NE Arkansas/ Tennessee area (centered on Blytheville, just north of Memphis) and are able to display TM data on our I^2S system. Documentation on LAS tape format supplied by GSFC was terse but marginally adequate.

We have simulated snow reflectance in all 6 TM reflective bands, i.e. 1, 2, 3, 4, 5, and 7, using Wiscombe and Warren's (1980) delta-Eddington model. Snow reflectance in bands 4, 5, and 7 appear sensitive to grain size. One of the objectives of our investigation is to interpret surface optical grain size of snow, for spectral extension of albedo. While we have not yet received TM data of our study area, our simulation results are encouraging.

It also appears that the TM filters resemble a "square-wave" closely enough that we can just assume a square-wave in our calculations. We calculated integrated band reflectance over the actual response functions, using sensor data supplied by Santa Barbara Research Center. Differences between integrating over the actual response functions and the equivalent square wave were negligible.

Let ρ_λ indicate spectral snow reflectance, as a function of grain size and illumination angle; μ_0 is cosine of illumination angle, E_λ is spectral solar constant, and $\Phi^{(j)}{}_\lambda$ is the instrument response function for band j. The filter-integrated reflectance is

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

(The μ_0's of course cancel.)

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*Not a full quarter, but this will get us on a quarterly schedule

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The equivalent reflectance, assuming the sensor is a square wave with half-amplitude band limits λ_1, λ_2 is

$$\rho = \frac{\mu_0 \int_{\lambda_1}^{\lambda_2} \rho_\lambda E_\lambda d\lambda}{\mu_0 \int_{\lambda_1}^{\lambda_2} E_\lambda d\lambda}$$

The second formula is much easier to use. Comparisons between the two are shown in the three tables below.

Table 1, for background information, gives characteristics of the Thematic Mapper, Multispectral Scanner, and 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 Thekaekara (1970), adjusted to fit the integrated values of Hickey et al. (1980). The last column in the table expresses the sensor saturation radiance as a percentage of the solar constant, integrated through the band response function.

Table 2 compares integrations through the sensor response function with integrations over the equivalent square wave, for the solar constant and for reflectance of snow of optical grain radius $r = 1000 \mu m$. The values are close, better than the uncertainty in the spectral distribution of the solar constant.

Table 3 shows calculations of integrated reflectance for snow over all reflective TM bands, and water and ice clouds with thickness of $1 mm$ water equivalent over TM bands 5 and 7. These calculations look encouraging for snow/cloud discrimination with TM bands 5 and 7.

Presentations

Oral paper presented at AGU fall meeting, San Francisco, "Remote Sensing of the Snow Surface Radiation Budget."

Recommendations

Documentation of LAS tape format was terse. Perhaps some features should be more precisely described, if other PI's are having difficulties. (If not, leave as is, as EROS format will be different anyway.)

References

Hickey, J.R., L.L. Stowe, H. Jacobowitz, P. Pellegrino, R.H. Maschoff, F. House, and T.H. VonderHaar, 1980, Initial solar irradiance determinations from Nimbus 7 cavity radiometer measurements, *Science*, **208**, 281-283.

Thekaekara, M.P., ed., 1970, The solar constant and the solar spectrum measured from a research aircraft, NASA TR-R-351.

Wiscombe, W.J., and S.G. Warren, 1980, A model for the spectral albedo of snow, 1, Pure snow, *Journal of the Atmospheric Sciences*, **37**, 2712-2733.

Table 1
TM, MSS, and AVHRR Spectral Characteristics
[Thekaekara (1970) spectral distribution of solar constant]

Thematic Mapper

	wavelengths			radiances ($W m^{-2} \mu m^{-1} sr^{-1}$)			
band	(50% ampl., μm)			*NEΔL*	sat.	solar	%
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				

Landsat-2 Multispectral Scanner

band	wavelengths			NEΔL	sat.	solar	%
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	3.0	192	285	67.4

NOAA-7 Advanced Very High Resolution Radiometer

band	wavelengths			NEΔL	sat.	solar	%
1	.56	-	.72	.51	518	485	106.8
2	.71	-	.98	.33	341	364	93.7
3	3.53	-	3.94				
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. For the MSS, the sensor was assumed to have a square-wave response.

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Table 2
Accuracy of Integration, TM 1-5 & 7 (for snow $r = 1000 \mu m$, $\vartheta_0 = 60°$)

band	filter limits	sq. wave	solar const		snow refl	
			filter	sqw.	filter	sqw.
1	.413 - .551	.452 - .517	621	625	.963	.963
2	.501 - .650	.529 - .609	540	542	.949	.949
3	.576 - .740	.625 - .693	468	468	.906	.906
4	.730 - .950	.777 - .905	320	319	.743	.741
5	1.501 - 1.880	1.568 - 1.784	66.5	66.7	.0114	.0112
7	1.951 - 2.409	2.097 - 2.347	24.4	24.1	.0094	.0097

Table 3
TM Integrated Reflectances, $\vartheta_0 = 60°$

	clean semi-infinite snow optical grain radius (μm)		
band	50	200	1000
1	.992	.983	.963
2	.988	.977	.949
3	.978	.957	.906
4	.934	.873	.741
5	.223	.067	.011
7	.197	.056	.010
	water cloud, $1mm$ water optical droplet radius (μm)		
band	1	2	5
5	.890	.866	.770
7	.772	.737	.651
	ice cloud, $1mm$ water equivalent optical crystal radius (μm)		
band	5	10	20
5	.665	.512	.382
7	.651	.492	.351