ESTIMATING SURFACE ALBEDO IN ALPINE TUNDRA USING THE LANDSAT THEMATIC MAPPER AND DIGITAL TERRAIN DATA

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ABSTRACT:

A method is developed to estimate surface albedo in alpine tundra using Landsat Thematic mapper data and a digital elevation model. The technique includes procedures for atmospheric and topographic correction and extrapolation from narrow-band satellite data to broad-band albedo. Application of the technique to two different TM scenes shows good agreement with albedos previously measured in-situ.

KEY WORDS: Landsat TM, DEM, Albedo, Alpine Tundra

1. INTRODUCTION

Surface albedo (hemispherical bidirectional reflectance integrated over the solar spectrum) is well documented as an important input to the calculation of the surface energy balance (Dickinson, 1983). However, because the factors affecting this optical property are variable in both a temporal and spatial context, it is difficult to parameterize albedo for energy balance simulations. Problems of measurement are further exacerbated in alpine terrain both because reflectances are more complex on steep, multiple slopes than on flat surfaces and because high elevations are associated with different atmospheric transmissivity characteristics than lower elevations.

Remote sensing from space, for example with Landsat Thematic Mapper (TM) data, provides an opportunity to characterize surface albedos over large geographic areas, bur measurement is complicated by two problems. First, the sensor has only limited off-nadir pointing capability, (±2.89°), and therefore cannot integrate the entire hemisphere. Second, the TM does not provide continuous sensitivity to the entire solar spectrum (Table 1). Nevertheless, some useful methods have been developed for estimating albedo using Landsat sensors (Brest and Goward, 1987).

2. PURPOSE

Our brief paper outlines a technique for estimating albedo in alpine tundra using Landsat TM data in conjunction with a digital elevation model (DEM). The method, which is intended to address the measurement difficulties introduced by alpine terrain, includes corrections for both topography and the atmosphere, and allows for extrapolation to broad-band albedo.

3. STUDY SITE

Niwot Ridge, an area of mid-latitude alpine tundra in the Indian Peaks area of the Colorado Front Range was selected as the study site. Niwot Ridge is located at 40° 3' N by 105° 36' W. Altitude varies from 3350 to 3650 meters above sea level.

4. DATA AND PROCESSING

Two cloud-free Landsat 5 TM images, acquired 29 July, 1984 and 19 June, 1986 were used to test our procedures. The study site was segmented from each of the larger data sets, and each of the images was separately georeferenced to the Universal Transverse Mercator (UTM) coordinate system. using standard first order nearest-neighbor techniques (Jensen, 1986). Similarly, the area of the study site was extracted from a 1:24000 scale DEM, and a slope data set created. Both the elevation and slope files were then registered to the image data.

4.1 Calculation of In-Band Reflectivity

The estimation of albedo required two steps: 1) calculation of in-band reflectivity; and 2) extrapolation of broad-band albedo from these in-band reflectivities. Using the method outlined here, the atmospheric correction procedure is an intrinsic part of the latter calculation.

Assuming a Lambertian surface with equal reflectance of direct and diffuse irradiance, surface reflectivity (ρ_λ) is given by:

$$\rho_\lambda = \pi(L_{s\lambda}-L_{p\lambda})/\tau_\lambda(E_{d\lambda}+\cos\theta_z E_{D\lambda}), \qquad (1)$$

where;

θ_z = solar zenith angle with respect to an arbitrarily inclined slope (Garnier and Ohmura, 1968),
τ_λ = atmospheric transmittance,
$E_{D\lambda}$ and $E_{d\lambda}$ = direct and diffuse beam irradiance at the surface (Iqbal, 1983),
$L_{P\lambda}$= path radiance,

and the radiance received at the satellite ($L_{s\lambda}$) is:

$$L_{s\lambda} = (DN_\lambda/DN_{max\lambda})(L_{max\lambda}-L_{min\lambda})+L_{min\lambda}, \quad (2)$$

where;
DN_λ = pixel digital value per band,
$DN_{max\,\lambda}$ = maximum digital value per band (255),
$L_{max\,\lambda}$ and $L_{min\,\lambda}$ = maximum and minimum radiance detectable by the sensor per band.

Path radiance ($L_{p\lambda}$) was evaluated using a clear oligotrophic lake as a calibration standard (Ahearn, 1977). In this study, Lake Isabelle, located immediately north of Niwot Ridge, was used as the reference standard.

Atmospheric transmittance (τ_λ), which is a function of ozone, precipitable water, and aerosol content, takes the form (Dozier and Frew, 1981):

$$\tau_\lambda = \exp[-2(k_{o\lambda}03_{z2}+k_{w\lambda}w_{z2}{}^{1/2} + (a/Re)\beta_{z2}\lambda^{-\alpha}/1+(a/Re) \quad (3)$$

where;
k_w and k_o = water vapor and ozone absorption coefficients,
03 = atmospheric ozone content (mm),
w = precipitable water (mm),
α = Ångstrom turbidity exponent,
β = Ångstrom aerosol coefficient,
a/Re = absorbtance/reflectance ratio for aerosols.

The subscript z2 indicates that scattering is occurring at atmospheric level $P_z/2$, where P_z is surface pressure. Equation (3) is evaluated on a pixel-by-pixel basis using path lengths and atmospheric levels determined from the digital elevation data.

4.2 Extrapolation of Broad-Band Albedo

Narrow-band reflectances were converted to broad-band albedo using a modification of the method of Brest and Goward (1987). This technique consists of dividing spectral reflectance curves for typical surfaces into segments of nearly-uniform reflectance, with each segment then represented by the appropriate spectral band of the satellite data. A weighting factor relative to the proportion of solar radiation within each uniform region is then multiplied by the reflectivity of the representative band. Coefficients for the weighting factors were determined by theoretical studies of atmospheric transmissivity for a clear summer day (Böer, 1977). Typical spectral reflectance curves for three cover types, vegetated, non-vegetated, and snow, were used. For snow-free pixels, a simple vegetation index consisting of the ratio of the red (TM3) and near infrared (TM4) spectral bands was used to discriminate vegetation from unvegetated areas. When the ratio was greater than 2, the surface was considered vegetated and broad-band albedo (α_g) was given by:

$$\alpha_g = 0.526(\rho_{TM2})+0.366(\rho_{TM4})+0.128(\rho_{TM7}), \quad (4)$$

otherwise:

$$\alpha_g = 0.526(\rho_{TM2})+0.481(\rho_{TM4}), \quad (5)$$

where;
ρ_{TMx} = reflectivity in TM band x.

Because of its dissimilarity with the other two cover types, snow had to be evaluated separately. An unsupervised classification technique was used to separate snow-covered from snow-free pixels. Albedo for snow-covered pixels was then calculated using:

$$\alpha_g = 0.526(\rho_{TM2})+0.232(\rho_{TM4}) +0.13[0.63(\rho_{TM4})]+0.112(\rho_{TM7}). \quad (6)$$

5. ACCURACY ASSESSMENT

Satellite estimated albedos were compared to those measured in-situ during July, 1987 using an Eppley-type albedometer. Details of the field collection program can be found in Goodin and Isard (1989).

To assess the statistical significance of the comparison, a sample of thirty snow and non-snow pixels were randomly collected from each image and compared to the in-situ data set using the Aspin-Welch test. Means and standard deviations for both the satellite and in-situ data sets are presented in table 2. P-values for each test appear in table 3. The results show that for both dates, the albedo estimates derived from Thematic Mapper data cannot be distinguished from those made in-situ at any statistically significant level.

6. DISCUSSION AND CONCLUSIONS

A simple method for estimating surface albedos using Landsat Thematic Mapper data was developed. The method includes procedures for atmospheric correction, topographic normalization, and extrapolation of broad-band albedo from narrow-band satellite measurements, but does not correct for the non-Lambertian reflection characteristics of the surface. Even so, the agreement between satellite-estimated and field measured albedo is good. Apparently, angle-of-illumination effects on reflectivity are not as pronounced in alpine tundra vegetation as they are in other vegetation canopy types such as agricultural crops. This could be attributed to the fact that tundra vegetation consists of sparse, low-lying canopies interspersed with bare ground. Canopies of this type do not seem to be subject to the factors such as internal shading and variable leaf orientation which produce the bidirectional reflectance typical of denser vegetation canopies. A comprehensive study of the bidirectional reflectance characteristics of alpine vegetation is recommended.

7. REFERENCES

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TABLE 1.

Band numbers and wavelengths of Landsat Thematic Mapper

BAND NUMBER	WAVELENGTH (µm)
1	0.45 - 0.52
2	0.52 - 0.60
3	0.63 - 0.69
4	0.76 - 0.90
5	1.55 - 1.75
7	2.08 - 2.35

TABLE 2.

Sample size, mean and standard deviation for Thematic Mapper and in-situ data sets

	NON-SNOW			SNOW		
DATA SET	n	$\bar{x}$	s	n	$\bar{x}$	s
TM (7/29/84)	30	.172	.019	30	.401	.046
TM (6/19/86)	30	.170	.021	30	.416	.039
IN-SITU	87	.167	.008	32	.426	.074

TABLE 3.

P-values of Aspin-Welch test comparisons between satellite estimated and in-situ data sets. Significant P-value for statistical separability in all cases = 0.025

	TM DATA SETS	
IN-SITU DATA	7/29/84	6/19/86
SNOW	.0838	.0548
NON-SNOW	.2206	.1736