MINNAERT TOPOGRAPHIC NORMALIZATION OF LANDSAT TM IMAGERY IN RUGGED FOREST AREAS

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ABSTRACT

Minnaert constants (*K*) were derived from non atmospherically corrected, high-sun elevation angle Landsat TM data (8 June 1996 and 13 July 1997) and DEMs at 30x30 m spatial resolution using the IDL procedure developed at Dartmouth College. *K* constants were calculated for two contiguous areas in northern Apennines, the former (366 ha) covered by beech (*Fagus Sylvatica*) forest and the latter (343 ha) by mixed deciduous forest (*Quercetalia pubescentis*). Calculated Minnaert *K* ranges for the two forest types and dates were 0.21-0.26, 0.49-0.55 and 0.58-0.63 for bands 3, 4 and 5 respectively, with an r significance level of the *K* values estimates between 0.77 and 0.91. The correlation factors between uncorrected TM bands 3, 4 and 5 and the cosine of solar illumination angle (*i*) ranged from 0.70 to 0.91, thus indicating that 49% to 83% of the variance of these bands in this rugged forested area is explained by the topographic effect. *K* regression significance as well as topographic dependence of TM data tended to increases from band 3 to band 5 for both dates and forest types. Minnaert normalization was effective at removing the topographic effect reducing the correlation coefficients of the three corrected bands with cos (*i*) within the range -0.07/+0.02.

1 INTRODUCTION

Remote sensing classification and biomass estimate of vegetation in rugged areas are hampered by topographic effects on spectral signatures. Several proposed algorithms use Digital Elevation Models as the basis for topographic correction. In particular, the non-lambertian Minnaert model (Smith et al., 1980) is reported as the most effective at reducing the topographic effect on spectral signatures of several forest types in a wide range of geographic locations (Justice et al., 1981; Baker et al., 1991; Colby, 1991; Costa-Posada and Devereux, 1995).

In spite of the reported effectiveness topographic normalization methods are used infrequently, probably as a consequence of the lack of high-resolution DEMs especially in areas of limited cartographic coverage. Studies have suggested that digital elevation data of a resolution comparable to the multispectral data being corrected should be used in the modeling process (Katawa et al., 1988). This constraint may be removed upon completion of the Shuttle Radar Topography Mission (SRTM) a cooperative effort between NASA, DLR, ASI and NIMA that will provide a huge SIR-C/X-SAR interferometric elevation data-set at a 30x30 m spatial resolution. Since X and C bands radar signals only partially penetrate through canopies, the interferometric DEMs produced will represent the terrain elevation plus a certain height depending on radar frequencies and canopy height and structure. Minnaert topographic normalization has been successfully applied both with DEM modeling the terrain elevation and with DEM modeling the canopy elevation as in the case of satellite stereo matching (Costa-Posada, 1998).

This paper describes the results of Minnaert topographic correction of Landsat TM data of rugged deciduous forest areas using DEMs at 30x30 m spatial resolution derived from topographic maps. The same procedure will be applied using SRTM DEM data when available.

2 METHODS

2.1 Study Site and data

Figure 1 is a composite (RGB Landsat ETM 29/09/1999 - bands 3, 4 and 5) of the study area in the northern Apennines (Italy). This mountainous area, located in the province of Piacenza, is predominantly covered by mixed deciduous oak forest (*Quercetalia pubescentis*), beech (*Fagus Sylvatica*) forest above 900 m of elevation and small retreating areas of chestnut forest (*Quercetalia robori-petraea*).

The dominant bedrock of the area is calcareous flysch and most frequent soils are, following the FAO classification, *calcaric cambisols* and *calcaric regosols*. Elevation ranges in the study area from about 650 m for the Boreca riverbed to 1620 m for the Alfeo mountain.

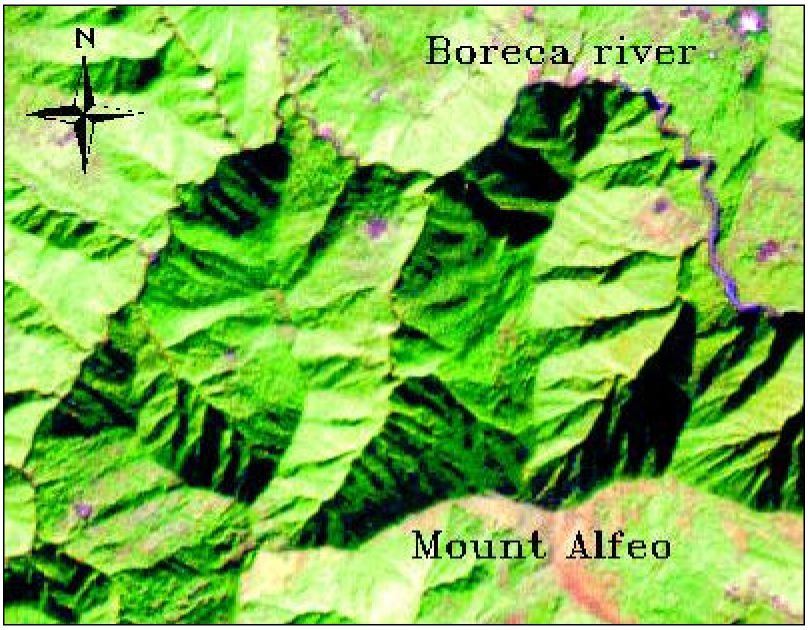

Figure 1. Landsat ETM 29/09/99 bands 3/4/5 RGB composite of the study area, IHS sharpening by panchromatic band 8 (area centre: 44°:38':40''N, 9°:15':40''E)

As shown in Figure 1 surfaces of this rugged forest area are characterized by a wide range of slopes and aspect angles and, as a consequence, by a wide range of values of the parameter regulating the topographic effect, the solar illumination angle (i), the angle between the solar vector and the vector normal to the surface. Two contiguous areas where chosen in the study site for topographic correction, the former (366 ha) covered by beech (*Fagus Sylvatica*) forest, roughly above 900 m of elevation, and the latter (343 ha), at lower elevations, by mixed deciduous forest (*Quercetalia pubescentis*).

The Landsat TM data chosen for this study were for 8 June 1996 and 13 July 1997, with a solar elevation angle of 56° and 57° respectively, and a sun azimuth of 120° and 125°. The Minnaert model has been reported to perform inconsistently from image to image (Gu and Gillespie, 1998). Although the biophysical properties governing the optical behaviour of vegetation, like leaf chlorophyll, water content and canopy structure undergo dramatic changes during the growing season, Minnaert *K*s are frequently reported with little concern about the phenological stage of the vegetation cover. The high-sun elevation angle images used in this study depict the period of maximum foliage, close to the summer solstice, when the topographic effect is at minimum.

The 30x30 m spatial resolution DEM used in the topographic correction was derived by linear interpolation of the contours from the 1:25.000 scale regional topographic map (digital database). The resulting DEM was smoothed by the application of a mean (low pass) 3x3 filter. The satellite images of the study site and the DEM were then co-registered by nearest neighbor resampling with twelve control points and a root mean square error of less than 0.5 pixels.

2.2 Minnaert topographic normalization

The Minnaert model (Smith et al., 1980) involves the calculation of empirical coefficients, *K* constants, for each band describing the bidirectional reflection distribution of the surface where *K*=1 represents the Lambertian model and decreasing *K* values indicate increasing anisotropic behaviours. The *K* constant is calculated obtaining the slope of the regression line:

$$\log(DN \cdot \cos e) = \log DN_m + K \cdot \log(\cos i \cdot \cos e) \quad (1)$$

Where: DN is the raw radiance (digital numbers), DN_m is the corrected radiance, *i* is the solar illumination angle between the solar vector and the vector normal to the surface and *e* is the exitance angle equal to the surface slope angle when the sensor is viewing at nadir.

Minnaert constants (*K*) were derived from non atmospherically corrected Landsat TM data using the IDL© procedure developed at Dartmouth College. Slope (*e*) and shaded relief (cos *i*) images of the study site were obtained from the DEM using ENVI© 3.1 image analysis software. TM data topographic dependence and the effectiveness of the model at removing the topographic dependence were evaluated by calculating the correlation coefficients between corrected and uncorrected TM bands 3, 4 and 5 and the cosine of solar illumination angle (cos *i*, the lambertian correction factor).

2.3 Modeling non-atmospherically corrected data

Although the diffuse light incident on a surface varies relatively little with slope and aspect it can represent a significant percentage of global irradiance for slopes with high solar illumination angles. The atmospheric correction of the data to be modeled for the topographic effect is not considered here on the basis of these previous findings and observations:

- under non-hazy, clear sky condition the diffuse light component is only a small portion of the total irradiance and has been ignored as insignificant in topographic normalization by most researchers (Colby, 1991);
- subtracting the diffuse skylight by the “dark object” method (Bentley et al. 1976) assumes an isotropic skylight distribution and a lambertian surface both of which are fallacious (Holben and Justice, 1981);
- according to Costa-Posada (1998) *K* values are smaller when modeling non-atmospherically corrected data, with a reduction proportional to the amount of atmospheric scattering for each band (minimum for TM band 4 and 5) and without noticeably increasing of the dispersion of the points in the *K* regression plot.

3 RESULTS

In Table 1 are reported calculated Minnaert *K* values, along with the significance of the *K* estimates and the topographic dependence on cos *i*, the lambertian correction factor, of corrected and uncorrected TM data, both expressed as r correlation coefficient.

Band	*Deciduous forest type*	*8 June 1996*				*13 July 1997*			
		K	r *K*	r cos *i*	r* cos *i*	*K*	r *K*	r cos *i*	r* cos *i*
TM3	Mixed	0.26	0.81	0.77	-0.07	0.25	0.81	0.78	-0.05
	Beech	0.21	0.77	0.73	-0.06	0.25	0.79	0.70	-0.01
TM4	Mixed	0.49	0.88	0.86	-0.06	0.55	0.90	0.88	-0.03
	Beech	0.50	0.83	0.82	-0.01	0.53	0.83	0.82	-0.02
TM5	Mixed	0.61	0.91	0.91	-0.02	0.63	0.91	0.90	0.00
	Beech	0.58	0.86	0.84	0.00	0.59	0.85	0.84	0.02

Table 1. Minnaert *K*s, r correlation coefficients of the *K* regression estimate (r *K*) and topographic dependence of TM data: r correlation coefficients against cos *i* of uncorrected (r cos *i*) and corrected TM data (r*cos *i*)

Minnaert model appears to have a consistent behaviour for the two high-sun elevation angle TM images with *K* values ranges for the two forest types and dates of 0.21-0.26, 0.49-0.55 and 0.58-0.63 for bands 3, 4 and 5 respectively. The similarity of *K* values for the two forest types suggests that local beech and mixed deciduous forest could be treated as a single vegetation cover during topographic normalization of remote sensing data collected close to the summer solstice when both forest type has reached maximum LAI and leaf chlorophyll content. NDVI calculation from the topographically corrected TM data confirmed the phenological stage similarity with a range of the mean NDVI values for the two dates and the two forest types of 0.74-0.76.

K regression significance as well as topographic dependence of TM data tend to increases from band 3 to band 5 for both dates and forest types. Increasing significance levels of the *K* value estimates and in particular the marked differences existing between band 3 and 4 are explained by the canopy absorption of the majority of the light in the red band allowing the atmosphere path radiance, maximum for band 3 and minimum for band 4 and 5, to dominate (Justice et al., 1981). Nonetheless, the significance of the *K* estimates for band 3 showed a minimum r value of 0.77 (beech forest, June 96).

The correlation factors between uncorrected TM bands 3, 4 and 5 and the cosine of solar illumination angle (*i*) ranged from 0.70 to 0.91, thus indicating that even in the period of minimum strength the topographic effect explains 49% (band 3) to 83% (band 5) of the variance of these bands in this rugged forested area. Minnaert normalization was effective at removing the topographic effect reducing the correlation coefficients of the three corrected bands with cos *i* within the range -0.07/+0.02. Figure 2 displays the strong topographic control of TM data in the study area as well as the effectiveness of the model even for band 3 where canopy absorbs the majority of light.

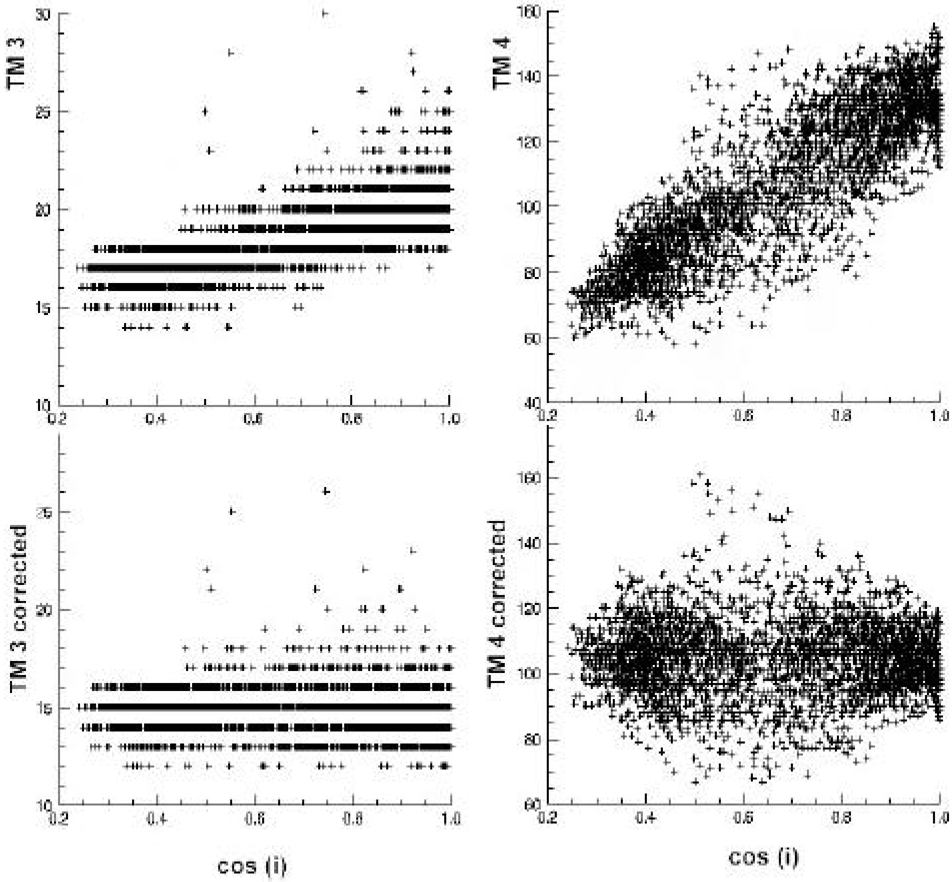

Figure 2. Scatterplots of corrected and uncorrected TM bands 3 and 4 vs. cos *i* for mixed deciduous forest, July 1997

The increasing TM data topographic dependence on cos *i* from band 3 to band 5, although most likely affected by the atmospheric effect, can possibly be also attributed to the increasing *K* values, i.e. increasing isotropic behaviors, leading to higher accordance with the lambertian model (cos *i*). Similarly, the effectiveness of the Minnaert model at removing the topographic effect, although presumably affected by the significance level of the *K* estimate, is evaluated here as residual correlation of the corrected data with the lambertian model leading to better results for bands with higher *K* values.

4 CONCLUSIONS

Minnaert topographic correction model appears to have a consistent behaviour for Landsat TM data of rugged mixed deciduous and beech forests collected close to the summer solstice in the northern Apennines, when both forest type has reached maximum foliage and leaf chlorophyll content. It is questionable that differences in the Minnaert *K* constant values obtained in dissimilar periods of the growing season can be reported as inconsistencies of the model (Gu and Gillespie, 1998).

Most likely, the seasonal changes of the biophysical properties governing the optical behaviour of vegetation, as well as different seasonal combination of canopy and sub-canopy radiances of the deciduous forest, are reflected in the bidirectional reflection distribution of the vegetation surface leading to specific Minnaert *K* constants for each phenological stage.

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