RELIEF EFFECT CORRECTION ON LANDSAT IMAGERY FOR FOREST APPLICATIONS USING DIGITAL TERRAIN MODELS

Luiz Alberto Vieira Dias - Researcher
Eni Alvim de Oliveira - Researcher
Flávio Jorge Ponzoni - Researcher

Instituto de Pesquisas Espaciais-INPE
P.O. Box 515
12201 - São José dos Campos - SP - Brazil

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ABSTRACT

Many times forest are planted on mountainous terrain. In this case the remotely sensed radiation at the LANDSAT sensor is highly dependent on the terrain slope, rendering difficult an accurate classification of the multispectral data. With a slope map derived from a digital terrain model (DTM), and information about the position of the sun, and the satellite sensor, it is possible to correct the image for the relief effect, by means of an illumination model. This work studies quantitatively the effect of this correction on the image classification, for an Eucalyptus ssp. forest near Jambeiro, SP, Brazil.

INTRODUCTION

The basic assumption underlying the use of TM imagery for forest inventory is the terrain flatness. Many times, however the forests are located on mountainous regions. If one has topographical information about the region under study a DTM can be prepared. With a DTM, acquired from geographical charts or aerial photographs, a slope map can be obtained, with the position of the surface normal, and the slope. This information, combined with the location of the sun, the position of the sensor at the time of the satellite passage, and an illumination model, allows one to correct the image for relief effects.

The need for the topographic effect correction has been determined at least since 1974 (Hofner, 1974). Smith, Lin and Ranson (1980) found the Lambertian illumination model valid for slopes of less than 25 degrees and effective illumination angles of less than 45 degrees for mid-latitude ponderosa pine forests. It was asserted by Holben and Justice (1980), that one cover type could be associated to a wide range of pixel values, due to variations in slope angle and aspect. Hugli and Frei (1981) found the radiometrical correction limited, due to the practical difficulty of exactly determining all reflection properties in a mountainous environment. Justice, Wharton, and Holben (1981) asserted that the Lambertian, and the modified Lambertian models actually increased the topographic effect, while a non-Lambertian model reduced it. Good results were reported by Kawata, Ueno, and Kusaka (1986) by means of an atmospheric correction combined with a Lambertian illumination model, for a forest near Kanazawa city, Japan. Karin Hall-Konyves (1987) found only a weak relationship between LANDSAT (MSS and TM) response variation, and gentle undulating parameters within cultivated fields and forests, in Sweden. As it is seen, from this incomplete survey, there is no consensus on the role of radiometric correction for the topographic effect, on image classification of forests.

This work adds new data to the problem, since it was tested for a forest located at the tropics (23 degrees South), on undulating terrain, with a thick uniform vegetal cover (Eucalyptus ssp.)

THE TEST AREA

Taking advantage of existing recent aerial photographs, an 1:25.000 geographical chart, and easy access roads (for field trip verification), a reforested region near Jambeiro, São Paulo State, Brazil, was selected as test area. A LANDSAT TM image taken on December 9th, 1985 was used for analysis purposes. This image was taken on Summer on the Southern Hemisphere, with a sun elevation of 56 degrees and azimuth of 97 degrees. The forest size is roughly 30 squares kilometers. The TM channels used were 3, 4 and 5, proper for forest studies. Figure 1 shows a TM image in near real color composition of the region under study. North is up, the forest being seen in green. A different color composition in false color is presented in Figure 2.

CORRECTION PROCEDURE

The idea behind the correction procedure is to obtain a terrain mathematical model, and for each pixel of the original image correct the illumination, getting a correct pixel value.

Starting from the region aerial photographs, a contour map was obtained, on an 1:20.000 scale. From this map, using the INPE developed Digital Terrain Model program (Felgueiras, Dias, and Erthal, 1987), a region Digital Elevation Model (DEM) was produced. Figure 3 presents a perspective view of this model, that was obtained from nearly 10.000 samples from the contour map, being the observer with an elevation of 30 degrees and an azimuth of 150 degrees. Another program, using the DEM as input, calculates the surface normal. This normal was used on the illumination model program to correct the pixel values. An interpolation was performed in such manner that each image pixel matches the DEM horizontal plane grid quadrangles.

The original LANDSAT TM channels (3, 4 and 5) were then classified by means of a maximum likelihood algorithm. In a mountainous region it is expected that even a region with an uniform vegetal cover will present different classes, yielding a difficult automatic classification, due to the relief effect. For the present case a field trip to the test area confirmed the site vegetal cover uniformity.

As far as the illumination model, the Lambertian was chosen, in spite of its intrinsic limitations (for near grazing angles), and the problems pointed out by Justice, Wharton, and Holben (1981), like overcorrection. However, since the system used was microcomputer based, and one of the goals was to reduce the computational complexity, it was decided to check first the potentialities of this illumination model. Of course, it is planned, in the near future, to add more sophisticated illumination schemes as Minnaert (1941), Gouraud (1971), Phong Bui-Tuong (1975), and Torrance-Sparrow (1987). In addition Kawata, Ueno, and Kusaka (1986), and Smith, Lin and Ranson (1980), reported good results with a Lambertian model.

The LANDSAT scene radiance, for a given wavelength λ, and incidence and exitance angles i and e, is according to Smith, Lin, and Ranson (1980):

$$L(\lambda, e, i) = \frac{\rho(\lambda, e, i)}{\pi\, C(\lambda)\, E_0(\lambda)\, T(\lambda)} \cos i$$

where π is the constant 3.1415925...,
$C(\lambda)$ is the LANDSAT scanner calibration factor,
$E_0(\lambda)$ is the solar irradiance,
$T(\lambda)$ is the atmospheric transmittance,
$\rho(\lambda,e,i)$ is the surface (target) reflectance.

For a Lambertian surface $\rho(\lambda,e,i) = \rho(\lambda)$, i.e, the reflectance is independent of the incidence and exitance angles. Since C, E and π are known constants, and T can be considered approximately constant for a limited bandwidth centered around a given λ, then

$$L(\lambda) = \frac{\rho(\lambda)}{C(\lambda)E_0(\lambda)T(\lambda)} \cos i$$

or

$$L(\lambda) = L_n(\lambda)\cos i$$

The incidence and exitance angles can be computed from the scene geometry:

$$\cos i = \cos\theta_s \cos\theta_n + \sin\theta_s \sin\theta_n \cos(\phi_s - \phi_n)$$

and

$$\cos e = \cos\theta_n \text{ (for a nadir pointing sensors)}$$

where θ_s is the solar zenith angle,
θ_n is the surface normal zenith angle,
ϕ_s is solar azimuth angle, and
ϕ_n is the surface azimuth, or aspect angle.

For a Lambertian model to be used it is only needed to know the terrain normal, and the solar position. For more sophisticated models it is also necessary to compute the

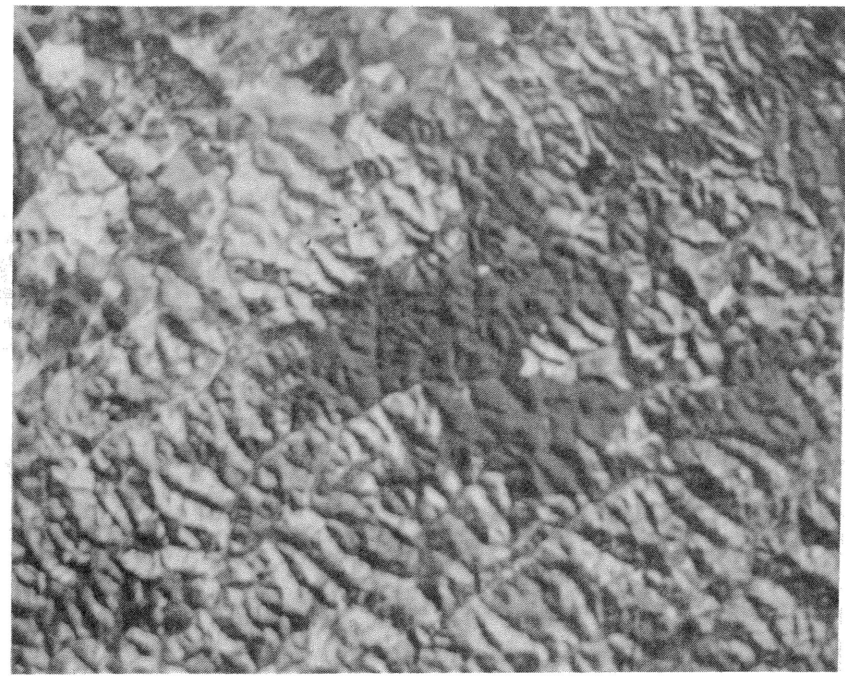

Fig. 1 - Thematic Mapper (TM) near real color composition image of the test area. North is up.

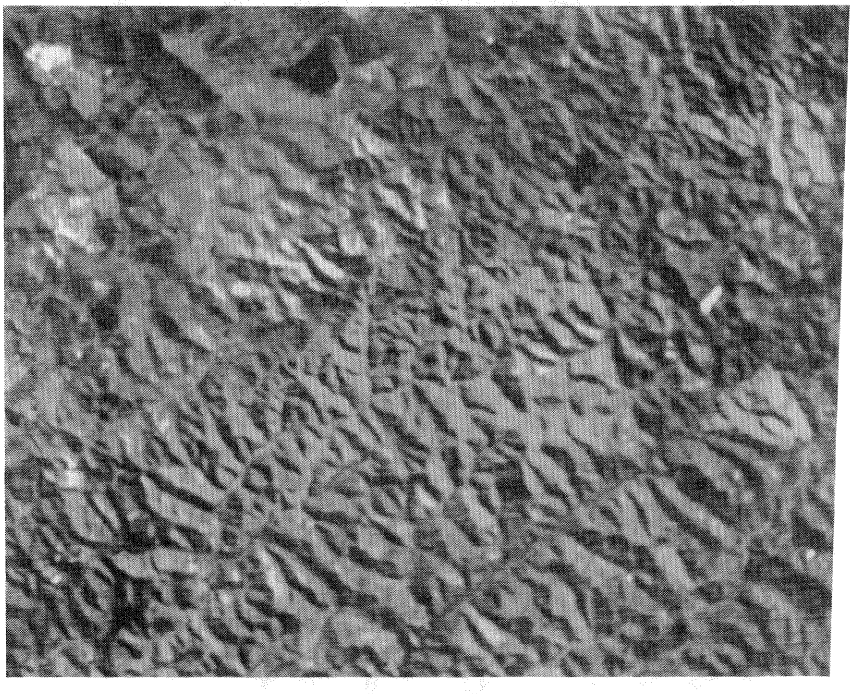

Fig. 2 - TM false color image of the test area. The Eucalyptus ssp. reforested area is the red patch at the image center.

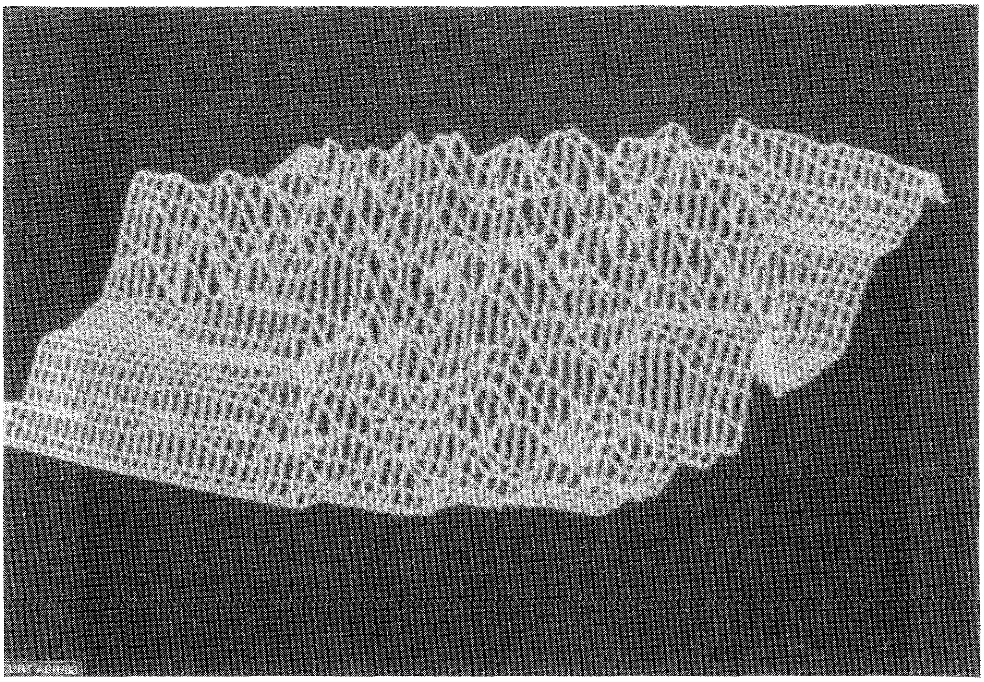

Fig. 3 - Digital Elevation Model of the test area. Observer position: elevation 30 degrees, azimuth 150 degrees. Vertical scale exaggerated for clarity.

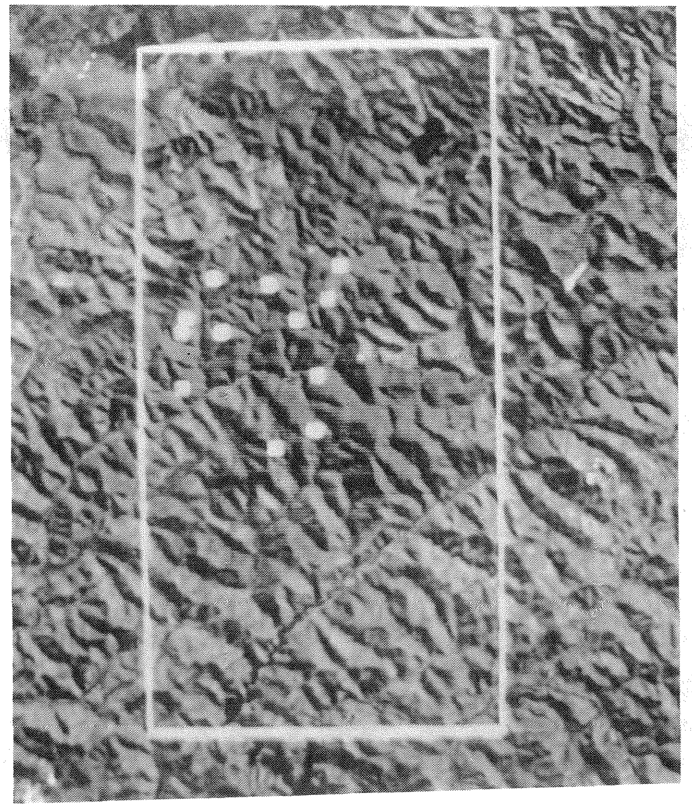

Fig. 4 - False color TM image with a cursor indicating the region where the correction was performed and the sample points for the maximum likelihood classification (3 classes, 4 samples for each class).

position of the sensor with respect to the terrain normal (exitance angle). In this study the satellite images were acquired under the supposition of nadir looking sensors, in spite of the fact that for illumination correction the exitance angle was not used.

Another distortion produced by the topography is the geometric distortion, described by Guindon, Goodenough, and Teillet (1982), and expressed as:

$$\Delta g = h \tan\theta$$

where θ is the sensor looking angle,
h is the elevation above the ground reference, and
Δg is the ground range error.

For the present test area θ is smaller than 4 degrees and $h<1000$ m, rendering the ground range error to the subpixel level.

RESULTS AND CONCLUSIONS

In order to assess the relief effect correction on the image classification, the maximum likelihood classifications were compared before and after the correction. Figure 4 shows the sample positions used on both classifications, as well as the interest region adopted (inside the cursor area). The classification on the original scene identified three classes, mainly on the forest limits, as seen from Figure 5. It was painted blue the darkest class (class 1), pink the medium shaded class (class 2), and white the clearest class (class 3), on the reforested area, seen in red in Figure 2.

The corrected image is presented channel by channel on Figure 6, and as a color composition on Figure 7. Note the difference between this last Figure, and Figure 1. The image degradation is supposed to be due to the linear interpolation on the DEM, and the Lambertian illumination model.

The classification of the corrected scene (channels 3, 4 and 5) is presented on Figure 8. Table 1 shows the areas of each class. The same sample positions were used, taken from the corrected image after being registered to the original image, and the same class names were given. The classified image is painted with the same colors as the original image.

TABLE 1

AREAS FOR EACH CLASS

CLASSES	ORIGINAL	CORRECTED
1 (BLUE)	3.953 km	4.568 km
2 (PINK)	8.397 km	7.252 km
3 (WHITE)	4.548 km	19.349 km

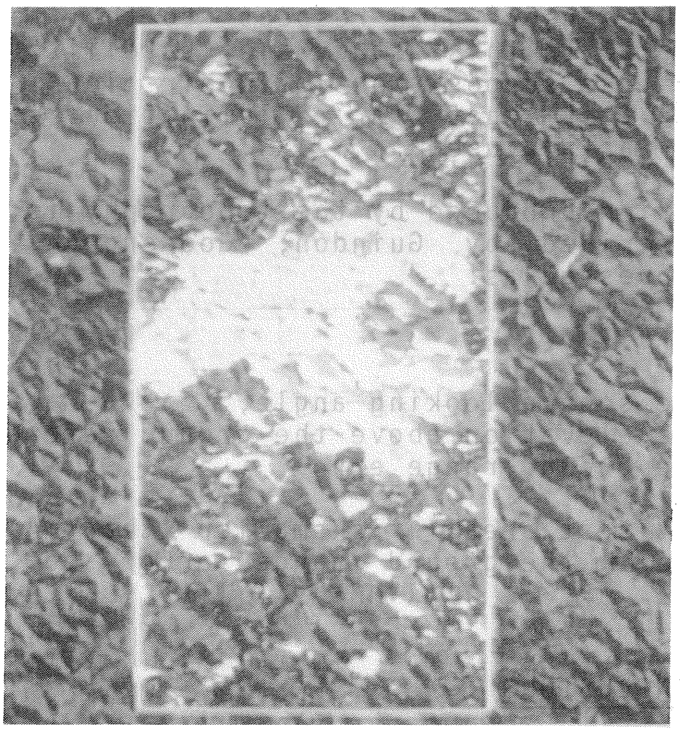

Fig. 5 - Original image classified with a maximum likelihood algorithm with the sample locations showm on Figure 4. Three classes, 4 samples each.

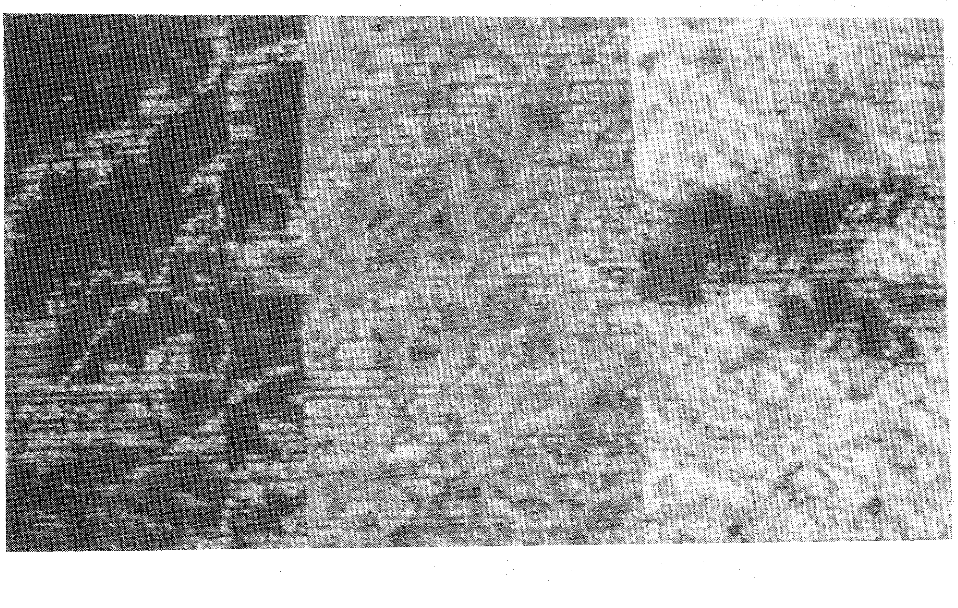

Fig. 6 - The 3 channels of the scene corrected for the relief effect.

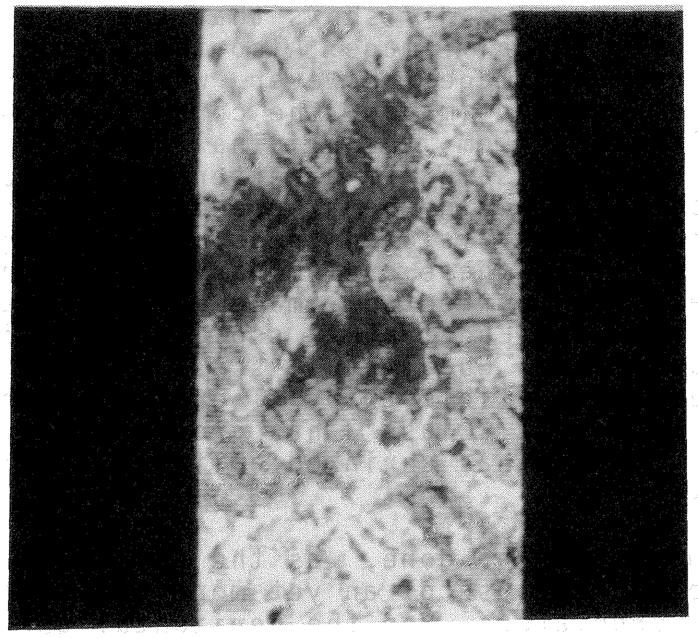

Fig. 7 - Corrected image. Color composition.

Fig. 8 - Corrected image. Classified with maximum likelihood algorithm. Sample location seen in Figure 4. Three classes, 4 samples each.

A comparison of Figures 1 and 7 shows that the forest is more homogeneous on the original image. Also there is an striking difference between these images. However, when a comparison is made between the classified images, the corrected image is not visually very different from the original one. The forest contours are nearly the same. If a better classification was expected, an indication would be a predominance of a class (plane area) over the other (sloped areas). According to Table 1 this has occured, but these preliminary results have to be viewed with care. The corrected image classification has picked a larger area of Eucalyptus ssp., some of it outside the forest. Those were Eucalyptus ssp. planted on flat terrain, confirmed by a field trip. There is almost no flat terrain inside the forest. Class 3 has grown from 4.548 sq.km to 19.349 sp.km. Class 2 has shrinked a little, while Class 1 has grown sligtly.

Further work remains to be done, as the inclusion of better illumination models, the use of an yet more accurate DEM, the use of better interpolators for the horizontal grid (nearest neighbours were used), and for refining it on the DEM, the determination of more accurate reflection parammeters for the species under study. This work shows that using a simple model, on a microcomputer based system, the classification can be improved. For future work it is recommended the use of Summer and Winter images and a better selection of samples for the classification algorithms.

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