EVALUATION OF THE TOPOGRAPHIC NORMALIZATION METHODS FOR A MEDITERRANEAN FOREST AREA

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ABSTRACT

Various radiometric correction methods have been developed for reducing errors, due to topography, on remotely sensed images. Among them the Cosine method, which assumes Lambertian surfaces, the two semiempirical methods (the Minnaert and the C correction method), and the Statistical-Empirical method are the most widely known. Although the Cosine method is included in most remote sensing software, it presents disadvantages because it does not take into account diffuse skylight and light from surrounding sides. Semiempirical methods generally, use constants to modify dependence on the cosine of the incidence angle, and Statistical-Empirical methods are class-specific.

In the preprocessing chain, correction methods for topographic effects are strongly recommended for forestry applications where vegetation classes on mountainous areas have to be studied.

This paper investigates the response of SPOT XS data to the specific topography of a typical Mediterranean forest area in Attica, Greece and the possibility of improving the classification results for such mountainous areas by applying the most efficient correction method for topographic effects.

Three SPOT XS scenes were used, one of them captured after a big fire. Raw data were ortho-rectified and geo-referenced to the Hellenic Georeference System and the four aforementioned radiometric correction methods were implemented. Their results served as input in a supervised classification procedure. The evaluation of the classification results showed that of the four radiometric correction methods, only the Minnaert method marginally improves classification results. As the method's effectiveness was found to be affected by atmospheric conditions, the involvement of an atmospheric model in the Minnaert reflectance model is considered important for the correction of remotely sensed images of Mediterranean forest areas.

1 INTRODUCTION

Various radiometric correction methods have been proposed to reduce topographic effects on remotely sensed images. These could refer to:

1. The reflectance part of a general atmospheric correction model.
2. Topographic slope-aspect correction methods.

In the first case, methods use knowledge of the observation and illumination conditions at the time of the satellite overpass, and usually rely on the Lambertian assumption. Ideally, the atmospheric model which is involved should be able to take into account the effects of elevation variations in mountain valleys on atmospheric parameters (Woodham and Lee, 1985), as well as the effects of adjacent slopes on diffuse irradiance and path radiance (Kimes and Kincher, 1981). Actually, several simplifications and assumptions have been made on both the reflectance and atmospheric part of the model, causing its inherent drawbacks. Kawata et al. (1988) proposed a radiometric correction method, which can remove both the atmospheric and topographic effects from LANDSAT MSS data over a rugged terrain. The values of relevant atmospheric parameters such as optical thickness, the single scattering albedo and the turbidity factor of the atmosphere were adopted from either an Elterman's model atmosphere or a model atmosphere given by Lowtran 5 code. No allowance for the bidirectional reflectance law of the ground surface in flat terrain and the adjacent effects due to the background targets in rugged terrain was taken into account. Conese et al. (1993) used Hay's atmospheric model (Hay, 1979) which takes into account an anisotropic distribution of diffuse radiation. Transfer radiation parameters, such as beam transmittance and diffuse light were provided by the atmospheric model considerations.

In the second case, topographic slope-aspect correction methods normalize image values according to mathematical and/or empirical models, and are characterized by the lack of consideration of the components of diffuse light and light reflected from surrounding areas. Teillet et al. (1982), in their relevant study, described four such correction methods: the Lambertian cosine correction, the Minnaert, a statistical-empirical correction, and the C correction. Each method marginally meets success criteria (Teillet et al. 1982), because it presents weaknesses in the full parameterization and reliable adjustment of the model parameters, which are valid for large-scale applications. Specifically:

Based on the simplifying assumption that the surfaces of interest are Lambertian, the Lambertian cosine model was applied on several studies. Kawata et al. (1988) found that it considerably reduces topographic effect when smoothed terrain data are used, but it tends to overestimate ground albedos for small angle i, which is defined as the angle between the solar incident direction and the local surface normal. Additionally, the Lambertian assumption becomes very weak when the insolation angle falls below a critical value. The lack of modeling of the downwelling atmospheric irradiance in the Lambertian method mainly accounts for the above drawbacks. To improve method performance for forest canopy, Gu et al. (1998) proposed the Lambertian correction at subpixel scale, normalizing only the sunlit area of the forest canopy.
The Minnaert correction method (Smith et al., 1980) adopts the bi-directional reflectance principles. In this correction, a measure of how close a surface is to the ideal diffuse reflector is introduced by the Minnaert constant. Ekstrand (1996) found that the Minnaert constant changes with the cosine of the incidence angle. As resulted from several studies (e.g. Meyer et al., 1993, Ekstand, 1996), the Minnaert correction produces fewer residuals than the Lambertian cosine correction, but also lacks a parameterization of the skylight irradiance.

For forest canopies, statistically significant correlations have been found between image values and topographic parameters such as incident illumination angle relative to the surface normal. Civco (1989) determined an empirically-derived calibration coefficient by comparing the spectral responses from large samples of an equal number of pixels falling on northern and southern slopes with the overall mean spectral response for the deciduous forest category. However, the class specific nature of statistical methods makes it difficult to formulate image correction functions of general applicability (Teillet, 1986). Teillet et al. (1982) proposed a C correction model based on the observed empirical linear correlation between radiance and the cosine of the incidence illumination angle. Although the C coefficient, calculated by the slope and aspect of the regression line and introduced in the Lambertian cosine method, tends to compensate for skylight effects, its value is so large in some images, that the c-correction method clearly lacks an exact physical explanation (Gu et al., 1998).

This study focuses on the evaluation of the four traditional topographic slope-aspect correction methods in a typical Mediterranean forest area. The latter was selected for this specific research as Mediterranean forest environments are - due to marginal climatic conditions, human activities, proximity to the sea and high fire incidence – characterized by selective degradation, lack of homogeneity and coexistence with other land uses, particularly peri-urban and agricultural land (Thornes, 1999). The four topographic slope-aspect correction methods proposed by Teillet et al. (1982) (Chapter 2), have been applied (Chapter 3) and evaluated (Chapter 4) on three remotely sensed images, captured on various dates, which show a forest area, in Attica, Greece. Emphasis has been placed on the empirical definition of the optimal value of the Minnaert constant, which explains surfaces' reflectance behavior in the study area (Chapter 4). Results were not the optimum ones. One of the images, captured a week after a big fire, accentuated the methods' weaknesses and the necessity of involvement of an atmospheric model in the radiometric correction pre-processing procedure (Chapter 5).

2 BASIC METHODS OF RADIOMETRIC CORRECTION FOR TOPOGRAPHIC EFFECTS

2.1 The Lambertian cosine correction method

This correction assumes that surfaces are Lambertian i.e. the radiance (L) of light transmitted downward through the atmosphere and reflected on the surfaces presents an isotropic spatial distribution. In this way, radiance observed on a tilted surface (L_T) is given by that observed on a horizontal surface (L_H) corrected by a geometrical configuration factor, which is the cosine of the incidence angle (i). The last is defined as the angle between the vector of the incident sunlight and the vector normal to the surface, and can be calculated from the following equation:

$$\cos i = \cos\theta_s \cos\alpha + \sin\theta_s \sin\alpha \cos(\varphi_s - \varphi_\alpha) \quad (1)$$

where θ_s is the sun's zenith angle, α is the terrain's slope angle, and φ_s and φ_α are the sun's azimuth angle and the terrain's aspect angle respectively. Consequently, the Lambertian cosine correction of the remote sensing data is a simple topographic slope-aspect correction, summarized by the following equation:

$$L_H = L_T \cos\theta_s / \cos i \qquad (2)$$

Because of the lack of consideration of the components of diffuse light and light reflected from surrounding areas, the Lambertian cosine correction method usually underestimates the reflectance of sun-facing slopes and overestimates the reflectance of slopes facing away from the sun.

2.2 The Minnaert correction method

The "backwards Minnaert correction" allows the surface to favor certain directions of scattering over others, unlike the perfectly diffuse reflector assumed by the Lambertian correction. The equation for this correction is given below:

$$L_H = L_T (\cos\theta_s / \cos i)^{k} \qquad (3)$$

where k is the Minnaert constant, which varies between 0 and 1. If k = 1, the surface is Lambertian, and the Lambertian cosine correction method is, in effect, applied.

2.3 The C correction method

Empirical – statistical methods are based on the assumption that a linear correlation between the observed radiance L and the cos i exists. The slope m and offset α of the regression line are calculated. Teillet at al. (1982) proposed the C correction method where the term $c = \alpha/m$, is introduced in the cosine equation.

$$L_H = L_T \ (\cos\theta_s + c) / (\cos i + c) \qquad (4)$$

Effects from diffuse light, as well as light reflected from surrounding areas, are expected to be reduced by the introduction of the c coefficient. Unfortunately, this method is scene and band specific.

2.4 The statistical-empirical method

Values of slope and offset calculated from the regression line may be included in a proper statistical – empirical method. According to the latter, radiance on a horizontal surface (L_H) is related to that on a tilted surface (L_T) by the following equation:

$$L_H = L_T - \cos(i)\, m - \alpha + \overline{L_T} \qquad (5)$$

where $\overline{L_T}$ is the average of the radiance values L_T for tilted and horizontal surfaces of known land use (usually forest). This method, like the previous one, is scene and band specific.

3 CASE STUDY

3.1 Study area and satellite data

The study area is a mountainous forest area in the north-east of the Athens agglomeration, which covers a surface of about 30 km^2. It is a typical Mediterranean forest area where forest pines alternate with shrubs, rock-outcrops and bare soil. The Geographical coordinates (Lat/Long) of its centre are $\varphi = 38^\circ$ 04' and $\lambda = 23^\circ$ 54'. Vegetation in this area consists mainly of pinus halepensis, quercus coccifera, and pistacia lentiscus. The area has intensive topographic relief with elevations ranging from 10 to 1104 meters. Pine forest and bushes are found on elevations higher than 375 meters. Most of the pine forest is encountered at 550 meters height. 23.40% of the terrain of the study area has smooth slopes (0-10%), 56.86% has gently rugged slopes (11-20%), 15.86% has a rugged slope (20-30%) and 3.88% has highly rugged slopes (>30). 77.2% of the area is illuminated during SPOT overpasses. Several fires have erupted at this site. One took place on 27/7/1992, i.e. a week before the capture of the image of 5/8/1992, and burned 113 hectares, which amount to approximately a third of the study area.

Three SPOT XS images were used for this application. Two of them were taken in the same season at different years. Illumination conditions could be considered similar on the dates these images were taken,, but this is not the case with the optical thickness of the atmosphere, which presents a high presence of smoke, dust and other aerosol particles after the fire of 27/7/1992. Images have the following scene parameters:

Scene Parameters			
K-J identification	092-274	092-274	092-274
Date	86/05/16	87/08/01	92/08/05
Azimuth angle (degrees)	148.1	137.8	138.7
Elevation angle (degrees)	064.3	065.6	064.3

Table 1. SPOT XS parameters

Images were ortho-rectified. For this purpose, the production of the Digital Elevation Model (DEM) of the area and the selection of control and check points were required. Seven topographic maps, scale 1: 5000, provided by the Army Map Service of Greece were used for the DEM production. These maps were compiled by means of vertical aerial stereopairs of 1945, scale 1:42000, and were photogrammetrically updated in 1972. The DEM was constructed by digitizing the 4-m contour lines of these maps. The ARC-INFO 7.0.3 software was used to construct the 2-m resolution grid DEM. The projection of the DEM is the Greek National Geodetic System (EGSA 1987).

The SPOT Orthorectification Module of the IMAGINE software was applied to rectify SPOT images. Twenty eight Ground Control Points were selected for each image, and Polynomial equations for a 2-order transformation were calculated. The Nearest Neighbor resampling method was applied.

For each image, Ground Control Points present the following Root Mean Square (RMS) Error:

SPOT 86/05/16 image RMS Error X = 0.4301 RMS Error Y = 0.4350 RMS total Error = 0.5903
SPOT 87/08/01 image RMS Error X = 0.4407 RMS Error Y = 0.3729 RMS total Error = 0.5773
SPOT 92/08/05 image RMS Error X = 0.4272 RMS Error Y = 0.4420 RMS total Error = 0.6152

The accuracy of each output image was examined by the use of a set of 14 check points:

SPOT 86/05/16 image Error X = 7.92 Error Y = 8.83 Total Error = 12.05
SPOT 87/08/01 image Error X = 9.57 Error Y = 7.94 Total Error = 12.42
SPOT 92/08/05 image Error X = 5,99 Error Y = 9,13 Total Error = 10.92

3.2 Implementation of the correction methods

The four topographic slope-aspect correction methods were implemented in ER Mapper software environment and performed on each remote sensing data set. For this purpose, slope and aspect images were generated from the DEM, and the angle (i) was calculated for every pixel of the study area. Each correction method generated three new bands for each of the three remote sensing data sets, containing data with corrected radiance.

The application of the Minnaert correction method required a value for the k constant. This was defined as follows: the method was applied 9 times for each remote sensing data set, each time with different value of the k constant, ranging from

0.10 to 0.90 and increasing by a step of 0.10. Results were input in the classification procedure. By the evaluation of the classification results, the most suitable value of the k constant, corresponding to the optimum results, was defined.
Coefficient c of the C correction method was calculated using five different training sites of known forest stands covered by pine. Study area particularities, due its Mediterranean character, impeded the collection of more training sites. The five training sites were selected using photo- interpretation methods and techniques on relevant air – photographs taken in 1988 and 1991. Photo-interpretation was supported by ancillary data collected in situ, which concern 23 training and test sites for the vegetation types present in the study area during September 1999. The training sites are small homogeneous plots of about 1.4 ha surface and present an average slope of 13%, 17%, 18%, 20%, 24%, and an average aspect of 265, 245, 315, 190 and 120, respectively. Changes of land cover types during the 1988-1991 period were checked and taken into consideration.

This set of training sites was also used during the implementation of the statistical-empirical method.

3.3 Classifications with uncorrected and radiometrically corrected data

The Maximum Likelihood classification algorithm was applied on both radiometrically corrected and uncorrected image data, in order to evaluate topographic slope-aspect correction methods performance. Images containing data with corrected radiance were expected to improve classification results, which should present higher accuracy. This could be a measure of the effectiveness of each topographic correction method. Towards this direction, 39 supervised classifications were performed, 13 for each date, classifying the land cover of the study area into 6 categories: burned areas; quarries; rock outcrops; bare soil; bush; pine.

For this purpose, a set of 11 training sites was used, selected by a procedure similar to that of the set used in the C correction method. Four of them belong to the forest pine category. For each date, the produced classification images are the following:

- one image based on the not radiometrically corrected data,
- three images based on the radiometrically corrected images resulting from the Lambertian cosine, the C method, and empirical-statistical method respectively, and
- nine images based on the radiometrically corrected images resulting from the application of the Minnaert method 9 times, each time with different k value.

The validation of the classification images was performed using a different set of 14 test sites, selected through a procedure similar to that used in the C correction method. Seven of the test sites belong to the pine category but have different topographic characteristics (slope and aspect).

4 EVALUATION OF THE RESULTS

4.1 The determination of the optimum value of the Minnaert constant

The Minnaert constant explains the reflectance behavior of surfaces. According to the Minnaert assumption, the terrain reflects equal amounts of light in all directions, forshortening in the direction of observation which is taken into account (Teillet, 1986). For the study area, the optimum Minnaert constant was determined empirically, by analyzing the results of the classifications applied on the 9 data sets, generated by the adjustment of the k value. This value should be the same for the three different dates, since time does not affect the reflectance properties of the surfaces, and land use changes have been taken into consideration during the training and test sites' selection.

Figure 2 presents overall classification accuracy for each value assigned to the Minnaert constant and for each remote sensing scene. Although the forest class is usually used to evaluate such methods, in our case all land cover types, found in the study area have been considered. This is due to the particularities that Mediterranean forest environment presents.

Figure 2. Relation between Minnaert constant and overall classification accuracy

We observe that the value 0.90 gives the highest accuracy for the scenes captured in 1987 and 1986. On the contrary, the value 0.10 gives the highest classification accuracy for the scene taken in 1992. The dramatic decrease of the Minnaert constant for the study area, during the 1987 – 1992 period could not be explained based on surface reflectance properties. The fire of 27/7/92 affected the optical thickness of the atmosphere, increasing diffused skylight. It is evident that the lack of a parameter describing diffuse skylight in the model, makes it weak in correcting remote sensing data for topographic effects, particularly if these data are captured under specific atmospheric conditions, like those present after a fire.

4.2 Evaluation of the four topographic normalization methods

By considering particularities of the Mediterranean forest environment, a quantitative test, based on the statistical discrimination of the six land cover types of the study area, was used to evaluate the performance of each topographic normalization method.

The overall accuracy and the kappa statistical coefficient were calculated for each of the classification results and presented graphically. The Minnaert correction presented in figures 3 and 4, is the one with the optimum Minnaert constant.

We observe that:

- Lines delineating the overall accuracy and kappa coefficient are similar for different dates.
- The four applied topographic correction methods do not improve the classification results for the image captured in 1992. Even data generated using the Minnaert correction method which present the best classification results, produce the same classification accuracy (75.10) as the raw data. This reinforces conclusions about the lack of effectiveness of the Minnaert correction method, for data strongly illuminated by diffuse skylight. This conclusion could be generalized for all the methods applied in this study.
- The Cosine correction method produced data which when classified, decreased the classification accuracy for each remote sensing scene. The Lambertian assumption was not adequately reliable for the study case, where six different land uses were taken into consideration. The decrease in classification accuracy was particularly high (10%) for the scene of 1992. The other scenes presented a decrease of approximately 2%.
- The classification based on the images generated by the Minnaert correction presented the highest overall accuracy and kappa coefficient for all scenes. Improvements were in the range of 2.6% and 0.30% for the scene of 1987 and 1986 respectively.

- The C correction method gives the second most satisfactory results after the Minnaert correction, but improvements made by it are not considerable. For the scene of 1992, a decrease of 2.80% is presented although the statistical parameter c, pine forest class specific, is introduced in this model.
- The statistical –empirical correction, although based on the pine forest class statistics of the study area, does not yield suitable results. This happens because classes other than the pine forest class, which are not affected by the topography of the relief in a similar way, are also present on the study area. Moreover, pine forest samples, although representative of 5 different orientations (cosi) ranging from 0.47 to 0.68, cannot be considered as a statistically strong sample. Besides, Mediterranean forest canopy presents observable variations regarding terrain orientation.

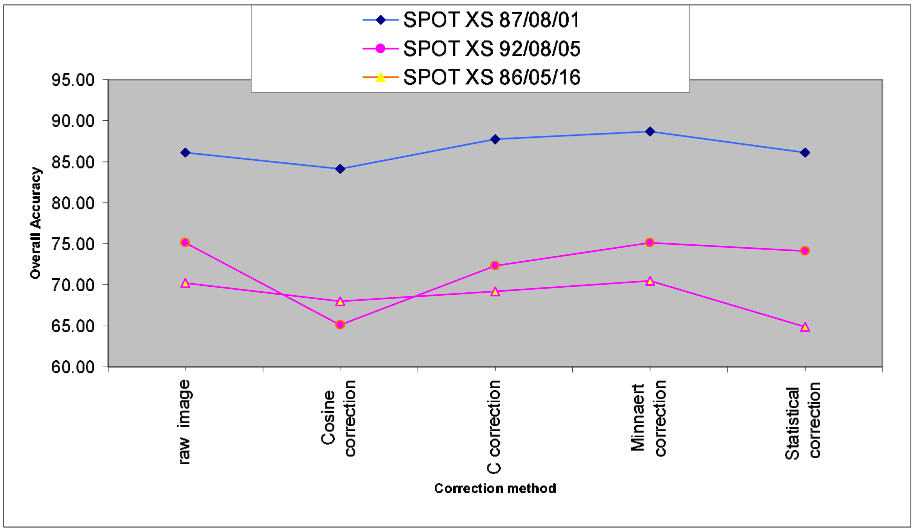

Figure 3. Topographic normalization methods and classifications overall accuracy

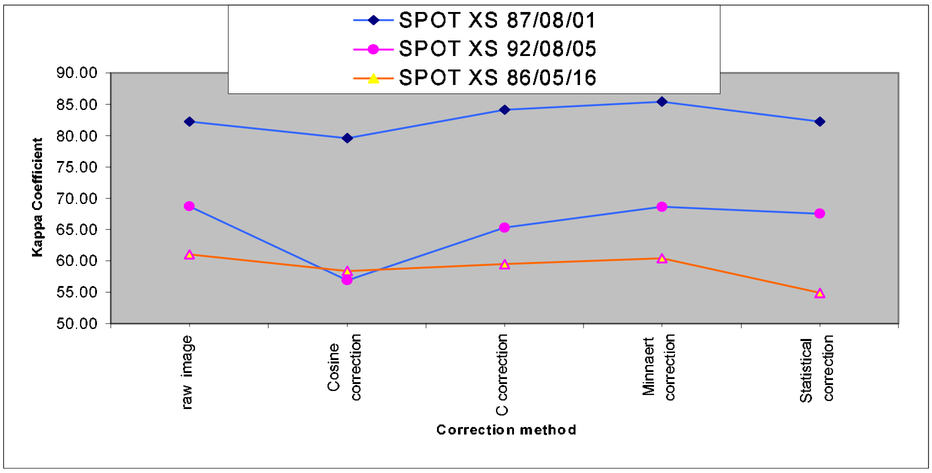

Figure 4. Topographic normalization methods and classifications kappa statistics

5 CONCLUSIONS

The four radiometric corrections for topographic effects do not improve classification results in the study area. Moreover, they are affected by the impact of fire on atmospheric conditions. Only the Minnaert correction method presents marginal success. The Lambertian assumption included in the cosine correction model does not meet surfaces' reflectance behavior in the study area and reduces classification accuracy when data corrected by this model are involved in a classification procedure. The Minnaert correction model better fits the reflectance behavior of the surfaces, presenting the best improved classification results. Unfortunately, the lack of the parameter of diffuse skylight in the model reduces its effectiveness. Statistical-empirical methods are class specific and depend on the sampling of the forest areas. Consequently, they are strongly affected by degradation, heterogeneity and low participation of the forest class in the study area, parameters which are strongly pronounced in Mediterranean forest environments and prevent statistical methods from yielding adequate results. The C correction method presents the same drawbacks as statistical methods. Although the model included preserves classification accuracy, it cannot be considered as an effective one for reducing topographic effect.

Based on the above conclusions, the development of a method for the involvement of an atmospheric model in the Minnaert reflectance model is considered important, especially for the correction of remotely sensed images of Mediterranean forest areas. This will be the object of further research.

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