International Journal of Applied Earth Observation and Geoinformation 18 (2012) 436–450

Contents lists available at SciVerse ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Evaluation and parameterization of ATCOR3 topographic correction method for forest cover mapping in mountain areas

Vincent Balthazar[a,*], Veerle Vanacker[a], Eric F. Lambin[a,b]

[a] Georges Lemaître Centre for Earth and Climate Research, Earth and Life Institute, University of Louvain, Belgium
[b] School of Earth Sciences and Woods Institute for the Environment, Stanford University, Stanford, California, United States

ARTICLE INFO

Article history:
Received 10 November 2011
Accepted 26 March 2012

Keywords:
Topographic correction
Mountains
Remote sensing
Forest
Landsat
ATCOR

ABSTRACT

A topographic correction of optical remote sensing data is necessary to improve the quality of quantitative forest cover change analyses in mountainous terrain. The implementation of semi-empirical correction methods requires the calibration of model parameters that are empirically defined. This study develops a method to improve the performance of topographic corrections for forest cover change detection in mountainous terrain through an iterative tuning method of model parameters based on a systematic evaluation of the performance of the correction. The latter was based on: (i) the general matching of reflectances between sunlit and shaded slopes and (ii) the occurrence of abnormal reflectance values, qualified as statistical outliers, in very low illuminated areas. The method was tested on Landsat ETM+ data for rough (Ecuadorian Andes) and very rough mountainous terrain (Bhutan Himalayas). Compared to a reference level (no topographic correction), the ATCOR3 semi-empirical correction method resulted in a considerable reduction of dissimilarities between reflectance values of forested sites in different topographic orientations. Our results indicate that optimal parameter combinations are depending on the site, sun elevation and azimuth and spectral conditions. We demonstrate that the results of relatively simple topographic correction methods can be greatly improved through a feedback loop between parameter tuning and evaluation of the performance of the correction model.

1. Introduction

Mountain environments are particularly sensitive to natural perturbations and human activities (Gerrard, 1990; Milliman and Kao, 2005; Vanacker and Govers, 2007). Steep slopes and sharp altitudinal gradients give rise to strong variations in biophysical and ecological conditions over relatively short distances, leading to highly diverse anthropogenic and natural ecosystems. Mountainous ecosystems are characterized by complex land-cover histories, including major changes in forest cover. Monitoring these shifts in forest cover across time is important for adaptive ecosystem management (Turner et al., 1990; Lambin and Meyfroidt, 2011). While forest cover changes may initially consist in forest clearing of primary vegetation for agricultural expansion, later stages often imply mosaic deforestation and degradation (World Bank, 2008). In some countries, forest recovery is observed with net increases in forest cover by spontaneous regeneration, active planting, or both (Rudel et al., 2005). Natural regeneration of forests or tree plantations most often takes place on abandoned land in mountain areas as they are marginal regions of low value for intensive agriculture (Lambin and Meyfroidt, 2010; Vanacker et al., 2003). Given the fragmented and highly dynamic characters of forested landscapes in human-disturbed mountain areas, there is a need for accurate forest cover mapping and monitoring.

Assessing the rate and spatial pattern of forest cover change is challenging given the ruggedness and the inaccessibility of mountain areas. Remote sensing techniques are a privileged tool, even if they suffer from methodological challenges that have to be resolved by appropriate and advanced pre-processing techniques. Radiometric correction techniques are a necessary step for change detection analysis to obtain homogeneous time series of satellite data. This procedure should include sensor calibration, atmospheric and topographic corrections, and relative radiometric normalization (Vicente-Serrano et al., 2008). Topographic effects have long been recognized as a problem for multispectral and multi-temporal vegetation classification in steep terrain as topography can bias the signal recorded by spaceborne optical sensors (Lu et al., 2008; Riaño et al., 2003; Richter et al., 2009a). Shadowing effects cause variations in land surface reflectance values due to the position of the sun. For the same land surface characteristics, slopes oriented away

---

[*] Corresponding author at: Georges Lemaître Centre for Earth and Climate Research, Earth and Life Institute, University of Louvain, Place L. Pasteur 3, B-1348 Louvain-la-Neuve, Belgium. Tel.: +32 10 479182.

E-mail address: vincent.balthazar@uclouvain.be (V. Balthazar).

0303-2434/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jag.2012.03.010

from (or in the direction of) the sun will appear darker (or brighter) compared to a planar surface (Richter and Schläpfer, 2011).

Accurate forest cover monitoring in steep terrain is clearly compromised by terrain effects. When analysing time-series and/or multi-sensor images, apparent reflectance values can vary largely because of the position of the sensor, the sun zenith and azimuth angles that are all scene-specific. It may be difficult to distinguish forest cover changes from topographic bias (Huang et al., 2008). Although topographic disturbances have to be considered for an effective correction (Kobayashi and Sanga-Ngoie, 2008), a large majority of remote sensing studies that are based on the retrieval of reflectance values in 3D conditions are assuming flat surfaces.

Different correction techniques have been developed for optical remote sensing data. They can be categorized into three types based on their degree of complexity and data requirements.

The first group consists of simple empirical methods, such as band ratioing, that do not require additional non-spectral auxiliary data (Holben and Justice, 1981; Civco, 1989; Ekstrand, 1996). These procedures assume that variations in reflectance values between spectral bands caused by shadowing are proportional so that a band ratio will remove the topographic effects. While this technique is easily implemented, its output does not have a physical meaning (Blesius and Weirich, 2005).

Secondly, semi-empirical approaches, such as the Cosine correction (Teillet et al., 1982), C-correction (Meyer et al., 1993; Jensen, 1996) and Minnaert models (Smith et al., 1980), integrate a Digital Elevation Model (DEM) to reconstruct differences in illumination according to the terrain relief and sun position. These methods correct topographic effects to some extent but only consider direct solar irradiance (Kobayashi and Sanga-Ngoie, 2008). Various empirical or physically-based adjustments were proposed to improve the conversion from at-satellite radiance to flat surface true radiance (Wen et al., 2009), and to approximate other radiative components, such as the sky diffuse irradiance, terrain reflected irradiance and bi-directional reflectance distribution (BRDF) of the ground objects (Gu and Gillespie, 1998; Richter and Schläpfer, 2002; Dymond and Shepherd, 1999; Lu et al., 2008; Wen et al., 2009). Some semi-empirical methods have additional correction algorithms that are developed for the specific geometric attributes of particular surface cover types such as trees. The SCS (Gu and Gillespie, 1998) and SCS + C (Soenen et al., 2005) approaches were developed for forested terrain, and they directly take the interaction between the sun, forest canopy and sensor into account. Compared to other semi-empirical correction methods, the efficiency of the SCS and SCS + C models is still a subject of debate. While several studies reported adequate results after the topographic correction (Kobayashi and Sanga-Ngoie, 2009), others were far more sceptical (Gao and Zhang, 2009). Moreover, the SCS and SCS + C models require information on the forest structure (density, crown structure, and tree height) at the sub-pixel scale. Although this information can be retrieved from coarse modelling (Soenen et al., 2005) or LIDAR data (Kane et al., 2008), it requires additional computational costs and input data.

The third category of topographic correction includes physically based approaches, such as the integrated radiometric correction (Kobayashi and Sanga-Ngoie, 2008) that models the full pathway of radiance through the atmosphere on the target object and backwards. A thorough modelling of the radiance components on a physical basis is expected to give the best results but has important data requirements (e.g., C-factor, transmittance functions including sea-level atmospheric pressure, ambient atmospheric pressure, relative air-mass, precipitable water vapor, water-vapor absorption coefficients).

Despite the availability of multiple procedures for correcting topographic effects, there is still no standard and generally accepted model that would be universally applicable on rugged terrain (Riaño et al., 2003). While much effort has been dedicated to the refinement of topographic correction methods, two issues related to their implementation have received little attention so far: (i) the tuning of the topographic model parameters and (ii) the evaluation of the performance of the correction. Most semi-empirical methods imply the computation of empirical parameters whose values need to be defined for a specific scene (Gao and Zhang, 2009). The quality of the semi-empirical correction is likely to be sensitive to these parameter values. Visualization of areas with and without deshadowing for sunshade and sunlit areas provides a first indication of the performance of a topographic correction. Nevertheless, it is imperative to evaluate quantitatively the results to select the best correction procedure and the best set of parameter values. Previous studies have used different techniques that compare several metrics before and after corrections: (i) spectral statistics for the entire image or for selected objects – i.e., mean, standard deviation, coefficient of variation, correlation coefficients, or spectral reflectance curves (Gu and Gillespie, 1998; Bishop and Colby, 2002; Huang et al., 2008; Richter et al., 2009a; Wen et al., 2009; Hantson and Chuvieco, 2011); (ii) correlation metrics between the reflectance values and the illumination angles, which are expected to be low for an effective correction (Ekstrand, 1996; Huang et al., 2008; Kobayashi and Sanga-Ngoie, 2008; Wen et al., 2009); and (iii) classification accuracies for individual land-cover classes or for the entire image (e.g., Meyer et al., 1993; Blesius and Weirich, 2005; Huang et al., 2008). There exists a clear need for a robust method to evaluate the performance of topographic correction techniques in rough terrain. Such an evaluation method should: (1) maximize the similarity of reflectances corresponding to a same land-cover type located on differently illuminated slopes, and (2) minimize undesirable noise or artefacts due to the propensity of existing topographic correction methods to miscorrect pixels in low illuminated areas.

While previous work mainly focused on the comparison of existing or newly developed topographic correction methods (with similar or higher complexity levels), the main objective of this study is atypical. It aims to improve the performance of topographic corrections for forest cover change detection in mountainous terrain through an iterative tuning method of model parameters based on a systematic evaluation of the performance of the correction. Our hypothesis is that the result of relatively simple semi-empirical topographic correction methods can be greatly improved through a feedback loop between the evaluation of the performance of a given correction model and the tuning of its model parameters. We selected the semi-empirical ATCOR3 procedure developed by Richter and Schläpfer (2011) for several reasons. First, this approach is part of the second type of models, making a compromise between computational simplicity, input data requirements and physical-structural basis. Secondly, its semi-empirical nature makes the model sensitive to tuning parameters, which is adequate for the purpose of this paper. Thirdly, the ATCOR3 algorithm is considered to be widely used as it is implemented in commercial image analysis software such as PCI Geomatics and ERDAS Imagine. Compared to other semi-empirical approaches, the ATCOR3 procedure is reported to perform well for a wide variety of satellite sensors, terrains, land-cover and illumination conditions (Richter et al., 2009a; Hantson and Chuvieco, 2011).

In this study, the performance of the topographic correction with a given set of model parameters is evaluated based on the statistical similarity of forest cover reflectance values between sunlit and shaded slopes and on the minimization of abnormal reflectance values caused by under- or overcorrection (Fig. 1). The method is tested on two mountain sites with rough (Ecuadorian Andes) and very rough (Bhutan Himalayas) terrain.