EFFECTS OF TOPOGRAPHIC CORRECTION ON NATURAL FOREST REFLECTANCE IN A MOUNTAINOUS REGION OF SOUTHERN BRAZIL

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ABSTRACT

Rugged terrain may be a major source of distortions on signals recorded by imaging sensors, compromising a series of remote sensing applications. To compensate for these distortions, Topographic Corrections (TC) methods have been developed. Although some methods are discussed and recommended by the literature, their usage is hampered by the lack of implementation on geospatial and remote sensing software. Alternatives would be open source applications and programming languages. This paper provides an overview on TC methods readily available in the R package “landsat”. We evaluated the effects of seven algorithms on the reflectance of natural forest remnants recorded by the OLI sensor (Landsat 8). Among all evaluated methods the C-Correction presented the best performance, reducing terrain influence and spectral variability. Several methods failed to compensate for terrain influence on reflectance. The results highlight the potential of TC methods and instigate further investigation on this topic.

***Key words* —** Topographic Corrections, R, Landsat.

1. INTRODUCTION

Rugged terrain imposes challenges for remote sensing applications, especially when we consider areas under low solar elevation conditions [1],[2]. These areas present higher percentages of shaded surfaces, increasing the reflectance variability for similar features under distinct terrain conditions [3]. High variability may compromise the characterization of land cover classes and even biophysical modelling efforts [2]. To tackle this issue, pre-processing techniques known as Topographic Corrections (TC) aim to remove terrain influence on radiances recorded by imaging sensors.

Although several TC methods are discussed by the literature [3],[4],[5], their usage is hampered by the lack of implementation on Remote Sensing (RS) software and Geographical Information Systems (GIS) [6]. Alternatives would be open source applications and programming languages such as R, Python and C++. In recent years, lots of geospatial packages became available for the R environment. These packages extend the functionality of the language, making advanced Digital Image Processing (DIP) techniques more accessible for RS data users without programming background.

In this sense, this paper provides an overview on the performance of TC methods readily available in the “landsat” R package. To achieve this goal, we investigated the effects of the corrections on spectral patterns of natural forest formations found in mountainous regions of southern Brazil. The evaluation process followed a multi-criteria approach, scoring points for each criteria and indicating the best methods through a ranking scheme.

2. MATERIAL AND METHODS

2.1. Study Area

Located in southern Brazil, the study area covers 2 500 km² of complex landscapes. The area comprises the transition of the Serra Geral formation and lowland coastal regions in the southern states of Santa Catarina and Rio Grande do Sul. An escarpment divides two different geomorphological regions with elevations ranging from 0-100 (costal lowlands) to 1,000 -1,200 (uplands) meters above sea level (Figure 1).

The land coverage is dominated by paddy rice fields in the lowland and by pastures and natural grasslands in the uplands. Commercial tree plantations, such as *Pinus* spp. and *Eucalyptus* spp. stands, are found throughout the region. Natural forest formations occupy mainly the steep hillsides of the escarpment, which are not suitable for agricultural activities.

2.2. Data acquisition and processing

Our investigation is based on a 2500 km² square-shaped subset of a Landsat 8/OLI scene (220/080). The image is part of the “High-Level” Landsat products, delivering on-demand surface reflectance images [7]. Acquired on late August 2014 (2014/08/26) , the image presents Sun Azimuth Angle (θ) of 42.84 and Sun Elevation Angle (φ) of 40.18. We evaluated OLI bands 2 (Blue), 3 (Green), 4 (Red), 5 (NIR), 6 (SWIR I) and 7 (SWIR II). The selection criteria considered cloud coverage and date compatibility with RapidEye imagery available from the Brazilian Ministry of the Environment (MMA - geocatalogo.mma.gov.br). The compatibility allowed the use of higher resolution imagery for derivation of reference points. In total, 7173 pixels

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representing natural forest formations were used as reference data.

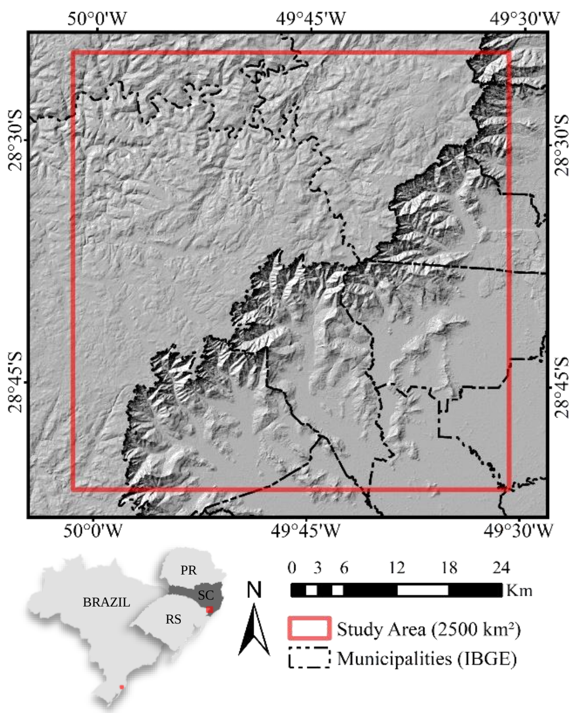

Figure 1 – Study area with detailed terrain. PR = Paraná State; SC = Santa Catarina State; RS = Rio Grande do Sul State.

Elevation data, necessary for TC methods, was acquired through the Earthdata platform (earthdata.nasa.gov) as a Digital Elevation Model (DEM). This data, derived from the SRTM mission [8], has a spatial resolution (30 m) that matches Landsat 8/OLI bands.

The algorithms tested were C-Correction (CC) [5], Cosine (COS) [5], Gamma (GM) [9], Improved Cosine (IMC) [3], Minnaert (MNT) [10], Minnaert with slope (MNS) [3] and Sun-Canopy-Sensor (SCS) [11]. Uncorrected data (NC) was considered as control group. All methods are readily available in the “landsat” R package.

2.3. Evaluation strategies

To evaluate the TC methods applied, we selected strategies that explore the spectral variability and stability within land cover classes [1],[3]. We also quantified the terrain influence on reflectance through the correlation between the Illumination Condition (IC) (Eq. 1) on each pixel and its respective reflectance. Combined, these variables indicate diverse aspects of TC methods giving insights on which are the best methodologies to compensate for topographic effects under the given terrain/illumination conditions.

$$IC = \cos\beta\cos(\pi - \varphi) + \sin\beta\sin(\pi - \varphi)\cos(\Phi - \theta) \quad (Eq. 1)$$

Where β is the slope angle, φ the solar elevation angle, θ the sun azimuth angle and Φ the aspect angle.

We investigated the spectral variability of the data through the Standard Deviation (SD) of each band and TC method. The spectral stability of the corrected data was assessed through the Relative Difference of Median Radiance (RDMR) index (Eq. 2).

$$RDMR = \frac{(\bar{L}_{corr} - \bar{L}) * 100}{\bar{L}} \quad (Eq. 2)$$

Where $\bar{L}$ is the median radiance of uncorrected data and $\bar{L}_{corr}$ is the median radiance of corrected data. Herein we adapted the equation for the use of surface reflectance instead of radiance levels.

The RDMR index allows the detection of possible biases introduced on corrected radiances. Higher RDMR values indicate low stability of land cover median radiance, while values close to zero are ideal [1]. The influence of IC on the reflectance was determined through Pearson’s correlation coefficient (R). Ideally, the correction procedure should remove any relations and drop coefficients to near-zero levels.

Finally, a ranking scheme was designed to contemplate all criteria and define the algorithm with the best performance. TC methods were ranked within each criteria, receiving scores that matched their respective position. This way, methods with lower scores yielded better performances. Afterwards the scores obtained for each criteria were added up to a single overall index, indicating the most consistent methods.

3. RESULTS AND DISCUSSION

Our results indicate that some TC methods decreased the variability of the data and maintained a relatively stable level of reflectance (Figures 2 and 3). On both cases, the CC algorithm performed the best and COS/SCS the weakest. The results agree with the literature [1],[3], indicating the poor performance of lambertian methods such as COS and SCS.

All TC methods decreased terrain influence on reflectance significantly (Figures 4 and 5). GM, followed by CC, presented the best performances. However, in multiple cases the correlation coefficient presented inverted signal, possibly indicating overcorrections. Through visual evaluation of processed images, one can notice several overcorrected pixels. These issues occur mainly with poorly illuminated ones, located on hilly south-facing terrain. Some authors suggest the exclusion of such pixels from the calculations of TC parameters [1], while others indicate slope smoothing as a way to reduce overcorrection [3]. These strategies could improve the results, especially when we consider the use of algorithms that fit linear models to derive parameters, as the CC and MNT methods.

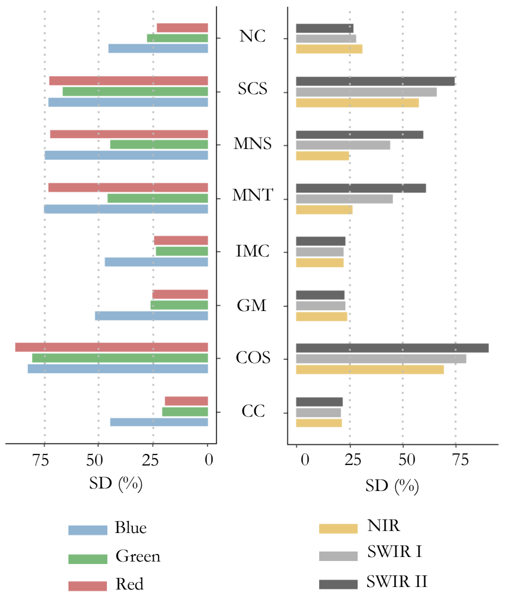

Figure 2 – Spectral variability of the data following the application of TC methods. SD (%) = Standard deviation relative to the mean reflectance; NC = Uncorrected data.

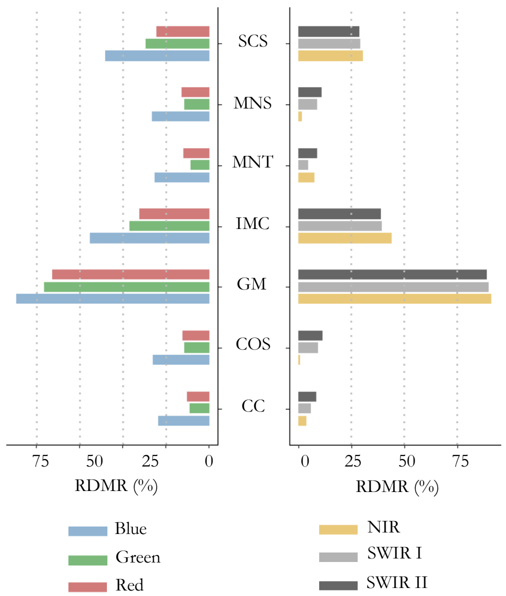

Figure 3 – Spectral stability of the data following the application of TC methods. RDMR (%) = Relative Difference of Median Radiance.

To provide evaluation metrics that contemplate all criteria, a raking scheme was designed. We evaluated the performance of TC methods on each band (Tables 1 and 2). CC method had the best performance in spectral variability (SD) and stability (RDMR) criteria (excluding NC data from the latter). GM had the best performance according to the correlation criteria (COEF), being closely followed by CC. Within the COEF criteria, methods that presented statistically identical values for R had their scores summed and equally divided.

Therefore, the CC method had the best overall performance followed by MNT and NC. Several methods (COS, GM, IMC, MNS and SCS) proved to introduce biases and/or distortions (e.g. overcorrections) on the NC data and their usage should be avoided.

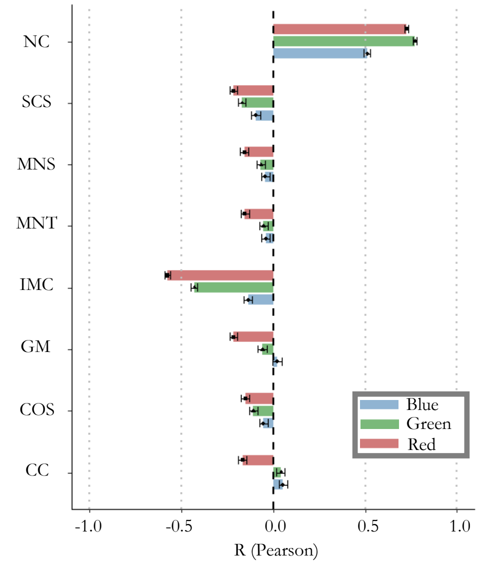

Figure 4 – Pearson's correlation coefficients between reflectance of natural forest formations and Illumination Condition (IC) for bands of the visible domain. Confidence intervals with significance level of α = 0.05.

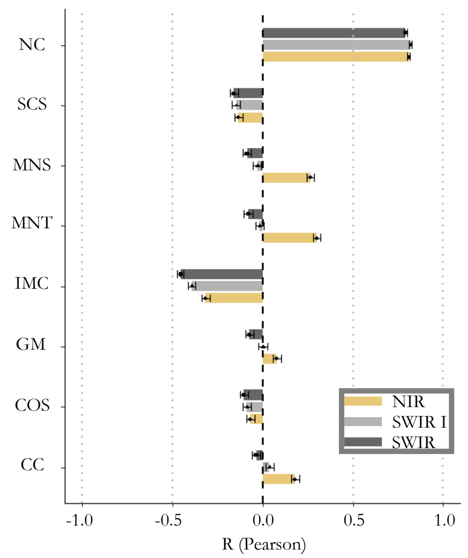

Figure 5 – Pearson's correlation coefficients between reflectance of natural forest formations and Illumination Condition (IC) for bands of the infrared domain. Confidence intervals with significance level of α = 0.05.

Criteria	TC	B2	B3	B4	B5	B6	B7	∑
SD (%)								
	CC	1	1	1	1	1	1	6
	COS	8	8	8	8	8	8	48
	GM	4	3	4	3	3	2	19
	IMC	3	2	3	2	2	3	15
	MNT	7	6	7	5	6	6	37
	MNS	6	5	5	4	5	5	30
	SCS	5	7	6	7	7	7	39
	NC	2	4	2	6	4	4	22
RDMR								
	CC	2	3	2	4	3	2	16
	COS	4	4	4	2	5	5	24
	GM	8	8	8	8	8	8	48
	IMC	7	7	7	7	7	7	42
	MNT	3	2	3	5	2	3	18
	MNS	5	5	5	3	4	4	26
	SCS	6	6	6	6	6	6	36
	NC	1	1	1	1	1	1	6
COEF								
	CC	4.5	2	2.5	4	2.5	1	16.5
	COS	4.5	5	2.5	1.5	5	4.5	23
	GM	2	2	5.5	1.5	2.5	2.5	16
	IMC	6.5	7	7	7	7	7	41.5
	MNT	2	2	2.5	6	2.5	2.5	17.5
	MNS	2	4	2.5	5	2.5	4.5	20.5
	SCS	6.5	6	5.5	3	6	6	33
	NC	8	8	8	8	8	8	48

Table 1 – Ranking scheme for multi-criteria evaluation, by TC method and Landsat OLI bands.

TC	SD (%)	RDMR	COEF	Overall Index	Overall Ranking
CC	1	2	2	38.50	1
COS	8	4	5	95.00	6
GM	3	8	1	83.00	5
IMC	2	7	7	98.50	7
MNT	6	3	3	72.50	2
MNS	5	5	4	76.50	4
SCS	7	6	6	108.00	8
NC	4	1	8	76.00	3

Table 2 –Multi-criteria evaluation results.

4. CONCLUSIONS

The CC method had the best overall performance followed by MNT and NC. Several methods (COS, GM, IMC, MNS and SCS) failed to compensate for terrain influence on reflectance, introducing biases and/or distortions on the data. In follow-up experiments, we recommend the evaluation of smoothing methodologies for slope calculation [3] and testing of other non-lambertian TC methods such as SCS+C [4] and Statistical Empirical [5]. We also suggest the investigation of effects on map accuracy, area estimation of land cover classes and derivation of biophysical parameters.

5. REFERENCES

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