Vegetation Cover Method Emissivity Dependencies on Atmosphere and Multispectral Vegetation Index

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ABSTRACT - *This work studies the effect caused on land surface emissivity (LSE) by the lack of atmospheric correction of the optical images used to calculate a multispectral vegetation index. Previous works of the authors pointed out that improved thermal emissivity is calculated with the Vegetation Cover Method (VCM) by means of atmospherically corrected optical images. Now, the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) radiative transfer code is used to simulate common atmospheric situations. Atmosphere type, aerosol model and total load, illumination and observation geometries and spectral range are taken into account. The described atmosphere simulation data are applied to a set of spectral configurations from AVHRR, MODIS and MERIS satellite sensors. In addition, vegetation and soil samples from ASTER spectral library version 2.0 are used to compute the effect of the atmosphere on the estimation of the vegetation cover, using the Normalized Difference Vegetation Index (NDVI) and the thermal emissivity, when top of the atmosphere (TOA) reflectances are used in relation to bottom of the atmosphere (BOA) reflectances. For a pure landscape the thermal (8-13 μm) emissivity error varies between -0.0009 and +0.0014 (which represents a systematic error of approximately -0.05K to +0.07K). The results for a mixed landscape show the combined effect of the spectral mixing of soils along with the atmosphere effect. The impacts of both vegetation cover and thermal emissivity are then larger than previously. In this case, the thermal emissivity error varies between -0.02 and +0.05 (which represents a systematic error of approximately -1.0K to +2.5K).*

1 INTRODUCTION

Land surface temperature (LST) is a key parameter for most Earth environmental models. Many sensors on board satellites provide the radiance emitted from the surface at local, regional or even global scales. However, this radiance is affected by three main effects which must be compensated in order to obtain the temperature: atmospheric, emissivity and angular effects. The planet atmosphere disturbs the radiation emitted from the surface to the sensor acting as an emitting and absorbing body. Emissivity is the physical property which defines the capacity of a body to emit radiation at a given temperature in relation to the perfect emitter with emissivity equal to 1. Land surfaces are not perfect emitters, their emissivity must be known. Due to the directional nature of radiance measurements on heterogeneous and rough surfaces, we also must account for the angular effects.

Land surface emissivity (LSE) measurement by remote sensing has the drawback that the temperature and the emissivity cannot be simultaneously calculated because the number of unknown variables is always higher than the number of measurements. Several methods have been proposed in order to obtain the LSE from space. The vegetation cover method (VCM) algorithm developed by Valor and Caselles (1996) relates the data taken in the solar spectrum to the thermal infrared region through the vegetation cover of the surface. The solar radiation data is related to vegetation cover by means of the normalized difference vegetation index (NDVI) described by Rouse et al. (1973). Therefore, the methodology relates vegetation index to emissivity estimations. It is based on the relationship between emissivity in the thermal infrared and the NDVI suggested by Van de Griend and Owe (1993). As a consequence, it is expected that the determination of thermal emissivity may be affected to a certain extent by the interaction of the atmosphere with the solar radiation (Martinez et al., 2008), which is the subject of this work.

The atmospheric effect in the solar spectrum is sometimes not significant (Song et al., 2001), but this is not the general case. Vegetation indexes decrease the influence induced by the atmosphere, but the scattering effects from atmospheric aerosols still can affect the top of the atmosphere (TOA) reflectances (Kaufman and Tanre, 1992). There are many procedures described in the literature for obtaining bottom of the atmosphere (BOA) reflectances on multispectral satellite sensors. The most accurate are those based on the use of a radiative transfer code (Bolle and Langer, 1991). One of the most popular codes is the Second Simulation of the Satellite Signal in the Solar Spectrum (6S), described by Vermote et al. (1997).

The aim of this study is to measure the influence of the atmospheric correction on the estimate of thermal emissivity with the VCM. First, the 6S code is used to compute a radiative transfer database at high spectral resolution. Next, this database is applied to a set of mixed ground-vegetation spectra and then vegetation cover is computed from them to AVHRR, MODIS and MERIS channels by using NDVI. Then, thermal emissivity values for the 8-13μm region are computed and compared with the original ones. Finally, temperature differences are estimated when TOA reflectances are used instead of BOA reflectances with the VCM.

2 METHODOLOGY

2.1 Vegetation Cover Method

The vegetation cover method is a model for calculating the LSE of a pixel that provides the effective emissivity of an heterogeneous and rough surface for a given *i*th band, ε_i, as:

$$\varepsilon_i = \varepsilon_{iv} \cdot P_v + \varepsilon_{ig} \cdot (1 - P_v) + 4 \cdot \langle d\varepsilon_i \rangle \cdot P_v \cdot (1 - P_v) \qquad (1)$$

where ε_{iv} represents vegetation emissivity in the *i*th band, P_v is the fractional vegetation cover, ε_{ig} is bare soil emissivity in the *i*th band, and $<d\varepsilon_i>$ is the cavity term for the same band related to the radiance indirectly emitted through internal reflections occurring between vegetation walls and the ground (Valor and Caselles, 1996). Emissivity values for vegetation and bare soil are obtained from Salisbury and D'Aria (1992) database. The cavity term is a mean cavity term for several kinds of vegetation types (Table 1).

Emissivity values for the 8-13 μm region	
ε_{iv}	0.985±0.005
ε_{ig}	0.93±0.03
$<d\varepsilon_i>$	0.03±0.02

Table 1 Values for the VCM coefficients in the 8-13μm region.

The determination of the fractional vegetation cover is calculated using the NDVI, with the following expression (Valor and Caselles, 1996):

$$P_v = \frac{\left(1 - \dfrac{NDVI}{NDVI_g}\right)}{\left(1 - \dfrac{NDVI}{NDVI_g}\right) - K \cdot \left(1 - \dfrac{NDVI}{NDVI_v}\right)} \qquad (2)$$

where $NDVI_g$ and $NDVI_v$ represent the minimal and maximum values of the NDVI image respectively, which, provided that the area is large enough, will correspond with areas with no vegetation (bare soil) and with full vegetation coverage.

The K parameter for a multispectral set of bands is calculated as (Valor and Caselles, 1996):

$$K = \frac{\rho_{nir\_v} - \rho_{red\_v}}{\rho_{nir\_g} - \rho_{red\_g}} \qquad (3)$$

where ρ_{nir_v} and ρ_{red_v} are the reflectances in the near infrared (AVHRR band 2, MODIS band 2, MERIS band 13) and in the red (AVHRR band 1, MODIS band 1, MERIS band 8) for the area with full vegetation cover, ρ_{nir_g} and ρ_{red_g} the reflectances in the near infrared and in the red for the area without vegetation (bare soil).

2.2 Mixed pixels

A mixed pixel reflectance without considering neither internal reflections occurring inside the rough surface, nor the effect of shadows is expressed as

$$\rho_i = \rho_{iv} P_v + \rho_{ig} (1 - P_v) \qquad (4)$$

where ρ_i is the pixel reflectance measured in the *i*th band, and ρ_{iv} and ρ_{ig} are the vegetation and bare soil reflectances for the same band. P_v is the fractional vegetation cover that ranges from 0 to 1 in order to represent all the possible mixed vegetated landscapes.

2.3 Atmospheric simulations database

Considering the interaction phenomena described in Staenz and Williams (1997), it is possible to express the TOA radiance L_i^*, when observing an horizontal surface, for a given *i*th band, as

$$L_i^* = A_i \frac{\rho_i}{(1 - \langle \rho_{ie} \rangle S_i)} + B_i \frac{\langle \rho_i \rangle}{(1 - \langle \rho_{ie} \rangle S_i)} + L_{ia} \qquad (5)$$

where ρ_i is the BOA reflectance of the surface, $<\rho_{ie}>$ is the BOA reflectance of the neighbourhood, S_i is the atmospheric albedo, L_{ia} is the radiance backscattered to the sensor, and A_i and B_i are coefficients related to the direct and diffuse radiance (all for the *i*th band).

The parameters A_i, B_i, S_i and L_{ia} characterize both observation and illumination geometries and the atmospheric conditions for the *i*th band. Their values depend neither on the observed surface reflectance, nor on the neighbourhood's. Thus, they are calculated from the magnitude L_{ig}, which is the radiance entering the sensor from the observed surface, and the magnitude L_{ip}, which is the radiance entering the sensor from the neighbourhood of the observed surface and backscattered by the atmosphere towards the sensor. If the surface has a uniform reflectance, those magnitudes for the *i*th band are:

$$L_{ig} = A_i \frac{\rho_i}{1-\rho_i S_i} \qquad L_{ip} = B_i \frac{\rho_i}{(1-\rho_i S_i)} + L_{ia} \tag{5}$$

Both L_{ig} and L_{ip} are obtained by means of the 6S radiative transfer code working on direct form. The values of A_i, B_i, S_i and L_{ia} are directly obtained by solving the corresponding equations systems. The radiative transfer simulations are performed using the atmospheric and geometric data in Table 2 at 6S maximum spectral resolution (2.5nm of spectral sampling between 250 and 4000nm). A Look Up Table system is calculated and stored in a database. Consequently, atmospheric simulation is possible on the spectra by using equation 5 with the adequate set of A_i, B_i, S_i and L_{ia} parameters and the hypothesis of a uniform reflectance environment, so that in equation 5 $<\rho_{ie}>$ is be equal to ρ_{ic}.

6S Radiative Transfer Parameters Values	
Atmospheric model	US standard 62, Tropical, Mid-latitude winter, Mid-latitude summer, Sub-arctic summer & Sub-arctic winter
Aerosol model	Continental, maritime & urban
Aerosol concentration (meteorological vis km)	7.5, 15, 30, 60 & 120
Solar zenith angle (zenith=0º)	0, 30, 45, 60 & 75
Sensor zenith angle (zenith=0º)	0, 15, 30, 45 & 60
Azimuth difference	0, 45, 90, 135, 180, 225, 270 & 315

Table 2 Geometric and atmospheric values for the 6S radiative transfer simulations (total 18,000).

3 DATASET

The Second Simulation of the Satellite Signal in the Solar Spectrum radiative transfer code is used to simulate the atmosphere. Atmosphere type, aerosol model and total load, illumination and observation geometries, and spectral range are taken into account when computing simulations. The described atmosphere simulation database is applied to a set of spectral configurations from different satellite sensors (AVHRR, MODIS and MERIS) by means of their red and near infrared spectral sensitivities.

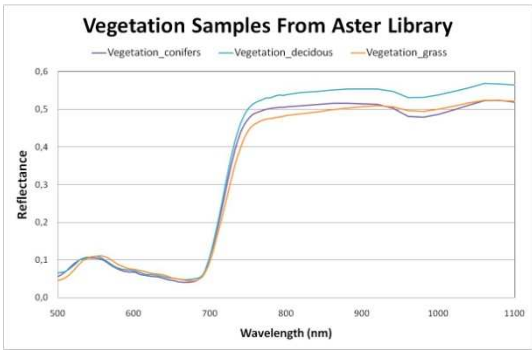

Figure 1 Vegetation samples from Aster spectral library used to characterize the vegetation covers.

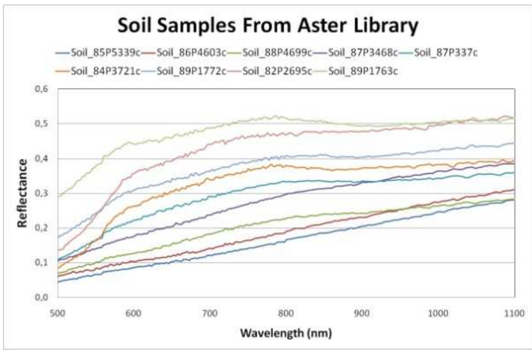

Figure 2 Soil samples from Aster spectral library used to characterize the soil covers.

Three vegetation samples (Figure 1) and nine soil samples (Figure 2) from ASTER spectral library version 2.0 (Baldridge et al., 2009) are combined by using the Equation 4 with several P_v values to compute up to 1,200 different mixed vegetation-soil samples. Each reflectance sample and the atmospheric simulation are also computed at 2.5nm of spectral sampling between 250 and 4000nm.

4 RESULTS

Differences are computed in two ways: pure landscape and mixed landscape. When all 1,200 different mixed vegetation-soil samples are taken into account, the results are representative of a mixed landscape. Then a single spectrum is chosen as pure soil, and another one, as pure vegetation. Otherwise, a pure landscape is represented if only the mixed spectra coming from a pure ground sample and a pure vegetation sample are considered each time to find the pure soil and the pure vegetation.

First, the results for a pure landscape (Table 3) show that the atmosphere effect only slightly impacts the estimation of the vegetation cover. In this case, the vegetation cover error ΔP_v varies between -0.010 and +0.016. Furthermore, the thermal (8-13 μm) emissivity error $\Delta\varepsilon$ varies between -0.009 and +0.0015 (which, according to Becker (1987), represents a systematic error of approximately -0.05K to +0.08K) when TOA reflectances are used instead of BOA reflectances.

Pure landscape and atmosphere			
	AVHRR	**MODIS**	**MERIS**
ΔP_v mean	0.002	0.002	0.002
ΔP_v max	0.016	0.016	0.016
ΔP_v min	-0.010	-0.010	-0.009
$\Delta\varepsilon$ mean	0.0001	0.0001	0.0001
$\Delta\varepsilon$ max	0.0014	0.0014	0.0014
$\Delta\varepsilon$ min	-0.0009	-0.0009	-0.0008

Table 3 Differences in fractional vegetation cover P_v and thermal emissivity ε (8-13μm) for a pure landscape and atmosphere (Results are TOA values minus BOA values).

Mixed landscape and atmosphere			
	AVHRR	**MODIS**	**MERIS**
ΔP_v mean	0.112	0.112	0.117
ΔP_v max	0.438	0.442	0.427
ΔP_v min	-0.247	-0.248	-0.212
$\Delta\varepsilon$ mean	0.0074	0.0073	0.0071
$\Delta\varepsilon$ max	0.0502	0.0501	0.0493
$\Delta\varepsilon$ min	-0.0199	-0.0198	-0.0171

Table 4 Differences in fractional vegetation cover P_v and thermal emissivity ε (8-13μm) for a mixed landscape and atmosphere (Results are TOA values minus BOA values).

Mixed landscape without atmosphere			
	AVHRR	**MODIS**	**MERIS**
ΔP_v mean	0.170	0.161	0.150
ΔP_v max	0.509	0.486	0.457
ΔP_v min	-0.022	-0.023	-0.011
$\Delta\varepsilon$ mean	0.0089	0.0086	0.0079
$\Delta\varepsilon$ max	0.0567	0.0546	0.0518
$\Delta\varepsilon$ min	-0.0056	-0.0055	-0.0052

Table 5 Differences in fractional vegetation cover P_v and thermal emissivity ε (8-13μm) for a mixed landscape without atmosphere (Results are TOA values minus BOA values).

Next, the results for a mixed landscape (Table 4) show the combined effect of the spectral mixing of several soils along with the atmosphere effect. The impacts on both vegetation cover and thermal emissivity ε are then larger than previously. Now, the vegetation cover P_v error varies between -0.25 and +0.44. Besides, the thermal emissivity error varies between -0.02 and +0.05 (which, according to Becker (1987), represents a systematic error of approximately -1.0K to +2.6K) when TOA reflectances are used in instead of BOA reflectances.

Thus, previous results on Tables 3 and 4 indicate that there is an important dependence of the final emissivity values on the soil type. This fact is related to the sensitivity of the NDVI to the soil brightness. This hypothesis is confirmed by the results of Table 5, where only the pure original vegetation and soil samples are analyzed without considering atmospheric effects. The results show that even without the influence of the atmosphere there is an important impact of the soil on both the vegetation cover P_v and the thermal emissivity (the same order of magnitude than for a mixed landscape and atmosphere). The vegetation cover P_v error varies between -0.023 and +0.51. Besides, the thermal emissivity error varies between -0.006 and +0.06 (which, according to Becker (1987), represents a systematic error of approximately -0.3K to +3.0K).

Next, the variations in vegetation index and fractional vegetation cover show a decrease when using MERIS sensor compared to MODIS (which, in turn, are smaller than in AVHRR results). This behavior seems to be correlated to the bandwidth of the sensors in such a way that, the narrower the bandwidth is, the less error is produced in vegetation index and fractional vegetation cover.

Finally, it should be considered that other vegetation indexes different from NDVI could yield smaller differences in the emissivity with the VCM.

5 CONCLUSIONS AND FUTURE WORK

This work studies the influence of the atmosphere (simulated with 6S over a mixed ground-vegetation set of spectra) on the estimate of thermal emissivity (8-13μm region) with the VCM for AVHRR, MODIS and MERIS.

The vegetation proportion shows a substantial increase when using BOA reflectances instead of TOA reflectances. The spectral mixing of several soils increases this systematic error due to NDVI sensitivity to background soil brightness. Nonetheless, the atmosphere effect impacts only a few tenths of Kelvin on the measurement of the temperature. However, the spectral mixing of several soils increases this systematic error to a few Kelvin.

Future work will focus on multispectral vegetation indexes that are less sensitive to the background soil. Additionally, these emissivity and temperature results would be compared to real data.

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