Campaign for Vicarious Calibration of SumbandilaSat in Argentina

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Abstract. The importance of calibrating satellite imagers has been explained in literature such as K Arai (2007) and K J Thome (2001). Calibration of satellite sensors (imagers) is crucial for data consistency, reliability and comparability. To perform a meaningful analysis of a satellite image, the Digital Numbers (DNs) of the image are first converted to absolute radiance by using the sensor-specific radiometric calibration coefficients. Satellite imagers are calibrated pre-launch and for continuous assessment, they are also calibrated post-launch. Various post-launch techniques exist including cross-sensor, solar, lunar and vicarious calibration. Vicarious calibration relies on *in-situ* measurements of surface reflectance and atmospheric transmittance to estimate Top-Of-Atmosphere (TOA) spectral radiance. A vicarious calibration field campaign was executed in Argentina to support monitoring of the radiometric response of the multispectral imager aboard SumbandilaSat. Results obtained using two Radiative Transfer Codes (RTCs) MODTRAN and 6SV are presented.

1. Introduction

Satellite images are key to most earth observation studies. The importance of a satellite sensor calibration has been explained in literature such as K Arai (2007) and K J Thome (2001). In gist, calibration of a satellite sensor is crucial for data consistency, reliability and comparability. To perform meaningful analysis of a satellite image, the Digital Numbers (DNs) of the image are first converted to absolute radiance by using the sensor specific radiometric calibration coefficients [3]. The derived radiance is expected to be comparable to the radiances derived with alternate and similarly specified sensors.

Satellite sensors are calibrated before launch to determine pre-flight radiometric calibration coefficients. However, the process of launching is accompanied by extreme vibrations and thermal fluctuations which may change the characteristics of the sensor. In addition, the characteristics of the sensor may change while the sensor is on-orbit. This change may be due to detector out-gassing and the deterioration of electronic components. This means that there is a need for continuous calibration while the sensor is on-orbit. There are various methods of on-orbit calibration, including cross sensor calibration, the use of on-board calibration instruments, vicarious calibration and lunar calibration [4].

SumbandilaSat does not have any on-board calibration instruments. In addition, after launch SumbandilaSat experienced a failure of some components, which compromised the functionality of its attitude control system. This means that it would be difficult and risky to perform lunar calibration. Currently, the only options available for continuous calibration of SumbandilaSat are the cross sensor calibration method and the vicarious calibration method. In this paper, the focus is on vicarious calibration. Vicarious calibration is a calibration method that is independent of the pre-launch calibrations [5].

The first step of any vicarious calibration campaign is the selection of a calibration site. Calibration sites are characterized using reference information such as reflectance data and atmospheric conditions during the calibration campaign. Scott *et. al.* (1996) gives a summary of the criteria for selecting a radiometric calibration site. A calibration site must be suitably large, homogenous and cloud-free to allow fine ground characterization [6]. Once a suitable site is chosen, reflectance and atmospheric properties of the site are measured at the time of satellite overpass. The measured data are used as inputs into a Radiative Transfer Code (RTC) to estimate the at Top-Of-Atmosphere (TOA) spectral radiance. The average DNs of the calibration site are then computed from the satellite image acquired during the satellite overpass. Depending on the DN-to-radiance conversion model of the sensor, the calibration coefficients are then calculated. The simplest sensor model for converting DN to radiance is shown in equation (1).

$$L_\lambda = CC_\lambda \times DN_\lambda - O_\lambda \qquad (1)$$

where CC_λ is the calibration coefficient, DN_λ is the average digital count of the sample site on the satellite image, L_λ is the TOA radiance and O_λ is the offset or dark signal of the band situated at wavelength λ. O_λ can be obtained using various methods, including observing deep space, using camera shutters or from onboard calibrators [5].

The aim of this study is to compute the TOA spectral radiance using two different RTCs. The surface spectral reflectance and atmospheric characteristics used as inputs were measured at two sites with relatively homogeneous ground reflectance targets in Argentina during near coincident SumbandilaSat overpasses.

2. Radiative Transfer Codes

Optical remote sensing sensors measure spectral radiance reflected from the surface of the earth. The source of the radiance in the shortwave spectrum is the sun. The strength and characteristics of this reflected energy depends on the characteristics of the surface reflectance, however, it is also affected by the gaseous absorption and the scattering by molecules and aerosols in the atmosphere.

RTCs are used to compute the scattering and absorption effects of the atmosphere as well as the TOA spectral radiance. There are a number RTCs available but the focus in this study will be on the **MOD**erate resolution atmospheric **TRAN**smittance (MODTRAN) code and the Second Simulation of a Satellite Signal in the Solar Spectrum Vector code (6SV). These two RTCs are the most commonly used codes within the Committee on Earth Observation Satellite (CEOS)-Working Group on Calibration and Validation (WGCV).

MODTRAN was developed by the Geophysics Division of the Air Force Research Laboratory (AFRL) and their partners. It was developed in the late 1980s using the FORTRAN computer language. Currently the latest version is MODTRAN 5, but MODTRAN 4 is still widely used and has been available to the public since January 2000. 6S was developed in 1997 and is an improved version of 5S (Simulation of the Satellite Signal in the Solar Spectrum), developed by the Laboratoire d'Optique Atmosphérique [7]. 6SV is a vector version of the 6S RTC for the clear sky Earth atmosphere under the plane parallel assumption. 6SV is a vector code, as opposed to a scalar code such as the current MODTRAN generation and takes full account of the polarization state of the Electro-Magnetic radiation field.

Polarization turns out to be an important consideration when Rayleigh scattering dominates or when retrieving TOA reflectance, particularly for low reflectance targets such as ocean or dark vegetation. For vicarious calibration of land imagers one is usually dealing with a high reflectance target with viewing angles near nadir and relatively high Solar Zenith Angle (SZA). In these circumstances, the difference between a scalar and a vector code should be minimal. However, it is always good practice to use at least two RTCs and to compare the results. MODTRAN and 6SV differ greatly in the nature and format of their inputs, their capabilities and their outputs as well as availability and licensing.

3. Methodology

Field campaigns were held on the 19th and the 24th of October, 2010. The campaigns were executed at Barreal Blanco playa and Salar de Arizaro in Argentina. *In-situ* surface reflectance and atmospheric characteristic were measured in close to the times of the SumbandilaSat overpasses. The spectral reflectance at the two sites is plotted in Figure 1. These plots show that the two sites have relatively uniform (flat) spectral reflectance in the wavelength region of 600 nm to 900 nm.

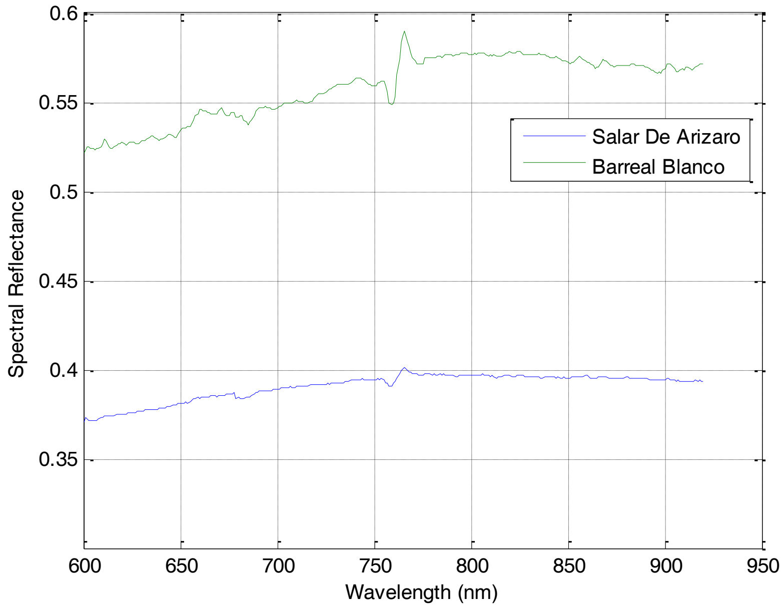

Figure 1. Surface Spectral Reflectance of Salar de Arizaro and Barreal Blanco.

Pre-processed *in-situ* measurements were used as inputs into MODTRAN and 6SV in order to compute the TOA spectral radiance. The computed TOA radiances for the two sites are given in the plots in Figure 2. The equivalent TOA spectral radiances are computed as shown in equation (2).

$$L_{spectralj} = \frac{\int_{\lambda_1}^{\lambda_2} S_j(\lambda) L_{TOA}(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} S_j(\lambda) d\lambda} \tag{2}$$

Where $S_j(\lambda)$ is the spectral response function or sensitivity of band j, L_{TOA} is the TOA spectral radiance and λ_1 and λ_2 are the spectral range of band j. The results of this computation are shown in Figure 1.

4. Results and Discussions

It can be observed in Figure 1 that the surface spectral reflectance values of the two sites are different. Any differences between the TOA radiance values over the two sites may be attributed to the difference in surface spectral reflectance, differences in atmospheric conditions or SZA at the time of overpass.

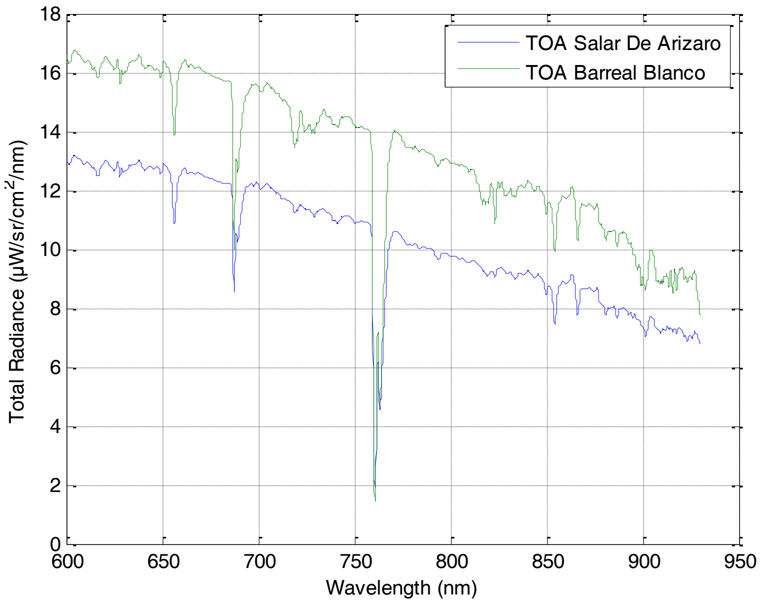

Figure 2. Top of Atmosphere Radiance for Salar De Arizaro and Barreal Blanco.

It can be observed in Table 1 that 6SV and MODTRAN results are consistent with each other for the respective sites. The TOA spectral radiance values shown in Table 1 have units of $Wm^{-2}sr^{-1}\mu m^{-1}$. The percent difference of the results shown in Table 2 yielded from MODTRAN and 6SV range between 0.14 % and 2.3 %. These results are not in agreement with the value of 0.5 % as discussed in Thome (2004).

Table 1. Top of Atmosphere Spectral Radiance in $Wm^{-2}sr^{-1}\mu m^{-1}$.

	Salar De Arizaro		Barreal Blanco	
Red	6SV	MODTRAN	6SV	MODTRAN
Red	122.571	123.819	157.711	157.933
Red Edge	114.021	116.646	146.552	147.986
NIR	95.644	97.168	125.490	126.246

A likely cause of not achieving the expected 0.5 % agreement in results is the difference in aerosol models between the two codes. Refinement of the inputs to the two codes which control aerosol spectral characteristics is expected to improve the agreement. MODTRAN and 6SV permit detailed control of aerosol characteristics with user-defined aerosol options. Usually there is insufficient measurement data to completely specify the aerosols and assumptions have to be made.

Table 2. Percent Difference of 6SV and MODTRAN Results.

Band	Salar De Arizaro (%)	Barreal Blanco (%)
Red	1.013	0.141
Red Edge	2.276	0.974
NIR	1.581	0.601

5. Conclusions

There is an expectation that the calibration coefficients for the SumbandilaSat imager would have changed after launch, due to the effects of launch and due to the extreme nature of the space environment. For quality assurance, the results obtained from this Argentina campaign need to be verified. One method of verification is 'cross-sensor calibration'. A cross-sensor calibration refers to comparing two images, of the same target, acquired almost simultaneously with the uncalibrated, and a well calibrated sensor. One critical point to consider during cross-sensor calibration is the difference in spectral response of the two sensors as discussed in Thome (2004).

In terms of the vicarious calibration campaign in Argentina, the surface spectral reflectance measurements that were taken over the ground targets did not extend over all spectral bands in the SumbadilaSat imager. This shortfall had to be compensated for by extrapolation of the surface reflectance values in order to run the RTCs. This extrapolation may have introduced an uncertainty, which could not be quantified. It is therefore recommended that surface reflectance should always be measured in wavelength ranges that fully encompass the spectral response functions of the satellite's imager.

At the time of writing this paper, the bias or dark current of SumbandilaSat's sensor was not yet known. The dark current, once determined, must be subtracted from the average DNs before making any comparison.

The recommendation is that the results shown in this report be verified during the second calibration campaign, to be held in the second or third quarter of 2011. The protocol for the forthcoming campaigns will be similar to the protocol followed in CEOS-WGCV intercomparison campaigns that were held in Turkey in 2009 and 2010.

The first iteration of calibrating SumbandilaSat imager was a learning exercise. The lessons learned in this exercise will be highly valuable during the subsequent iterations.

The methodology employed in this study was adequate to obtain consistent results between MODTRAN and 6SV to within a few percent. In order to achieve best agreement between multiple RTCs it is necessary to pay detailed attention to the inputs, in particular the inputs that control aerosol characteristics. Forthcoming campaigns will make use of more detailed atmospheric measurements and hence better quality RTC inputs.

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