Desert test site uniformity analysis

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ABSTRACT

Desert test sites such as Railroad Valley (RRV) Nevada, Egypt-1, and Libya-4 are commonly targeted to assess the on-orbit radiometric performance of sensors. Railroad Valley is used for vicarious calibration experiments, where a field-team makes ground measurements to produce accurate estimates of top-of-atmosphere (TOA) radiances. The Sahara desert test sites are not instrumented, but provide a stable target that can be used for sensor cross-comparisons, or for stability monitoring of a single sensor. These sites are of interest to NASA's Atmospheric Carbon Observation from Space (ACOS) and JAXA's Greenhouse Gas Observation SATellite (GOSAT) programs. This study assesses the utility of these three test sites to the ACOS and GOSAT calibration teams. To simulate errors in sensor-measured radiance with pointing errors, simulated data have been created using MODIS Aqua data. MODIS data are further utilized to validate the campaign data acquired from June 22 through July 5, 2009. The first GOSAT vicarious calibration experiment was conducted during this timeframe.

Keywords: ACOS, GOSAT, MODIS, vicarious calibration

1. INTRODUCTION

NASA's ACOS has teamed with the Japanese Greenhouse gases Observing SATellite (GOSAT) [1,2] to provide calibration support. GOSAT was successfully launched on January 23, 2009 to make global measurements of atmospheric carbon dioxide and methane from space. The ACOS team supported NASA's Orbiting Carbon Observatory (OCO), which was also designed to make carbon dioxide measurements from space[3]. Unfortunately, the satellite did not reach orbit on February 24, 2009, due to the failure of its launch system. Both the OCO spectrometer and the shortwave channel of the GOSAT TANSO Fourier Transform Spectrometer (TANSO-FTS) were designed to measure the absorption of sunlight by molecular oxygen (O_2) within the 762 nm O_2 A-band, and CO_2 within the weak and strong CO_2 bands at 1610 and 2060 nm. However, there were several differences in the observing strategy. For example, OCO used an imaging spectrometer designed to collect 12-24 moderately high resolution (<1.29 km by 2.25 km at nadir) soundings each second along a narrow (<10 km) ground track[3]. The GOSAT TANSO-FTS collects one sounding every 4 seconds within a larger (10.5 km diameter at nadir) circular footprint[2]. Because of the common measurement products and science objectives, the two projects developed plans to cross calibrate and validate each other's scientific results. The first of these collaborations were conducted prelaunch, and have been described elsewhere[4]. Post launch cross-calibration plans include measurement comparisons over the Sahara Desert, as well as vicarious calibration field campaigns at Railroad Valley, Nevada[5]. This paper assesses the utility of three desert test sites for OCO and GOSAT radiometric analyses. The Committee on Earth Observation Satellites (CEOS) is an international organization charged with coordinating the calibration of civil spaceborne Earth observing missions. Committee members work with partners around the world to endorse globally distributed reference standard test sites for the post-launch calibration of space-based optical sensors. At present, eight instrumented sites and six pseudo-invariant test sites are identified by the visible/ near-infrared sub-group (IVOS). These sites include Railroad Valley, Nevada [38.49703 N, 115.69013 W] Egypt-1 [27.12 N, 26.1 E], and the Libya-4 test site [28.55 N, 23.39 E]. Based on the CEOS recommendations, the preferred uninstrumented site is Libya-4, located in the Saharan desert, although Egypt-1 is also on their list of 6. Railroad Valley is a preferred test site for taking ground measurement in support of on-orbit calibrations, known as vicarious calibrations. These CEOS-endorsed sites have been selected for the on-orbit calibration study presented here.

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2. PROCEDURE FOR ASCERTAINING SITE REFLECTANCE UNIFORMITY

2.1 Acquisition of MODIS Aqua data

The Moderate Resolution Imaging Spectroradiometer (MODIS) was launched on the NASA Aqua satellite in April 2002, and has been imaging the entire globe approximately every 2 days since June 24, 2002. Measurements from this instrument were adopted as the reference standard in this study because well calibrated observations of the CEOS sites are available at regular intervals, and the spatial resolution of the MODIS measurements (pixels as small as 250 m x 250 m) is adequate to resolve spatial variability within the larger surface footprints of OCO and GOSAT. Calibrated, geolocated, spectral radiance measurements (L1B data) from MODIS Aqua are stored in Hierarchical Data Format (HDF) files. The L1B HDF datasets for 2008 and 2009 containing clear-sky measurements over RRV, Egypt-1, and Libya-4 have been downloaded from The GSFC website at: http://ladsweb.nascom.nasa.gov/data/ . As an example, a browse image depicting the full 2300-km swath for June 20, 2009 is presented in Figure 1.

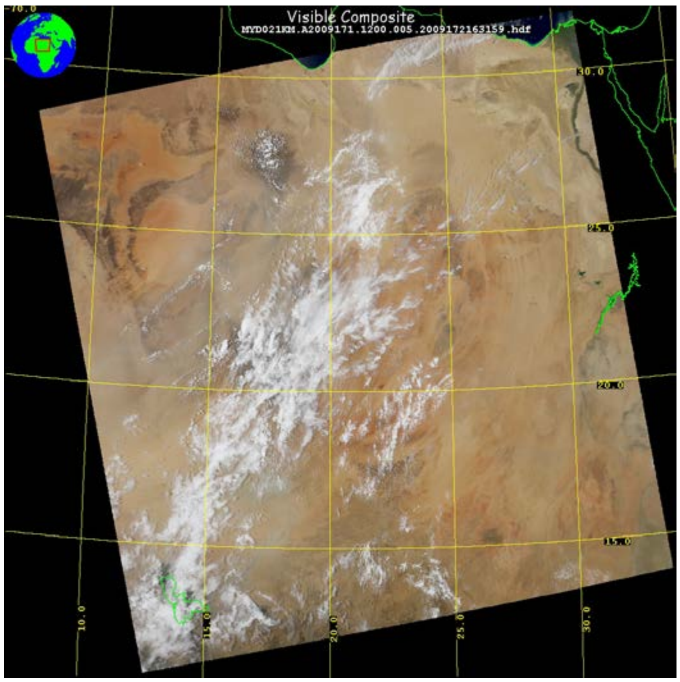

Figure 1. MODIS Aqua overpass of North Africa on June 20, 2009, showing the full 2300 x2300 km granule. Egypt-1 is at the top right, and is uniform over hundreds of kilometers.

2.2 Analysis approach

This study uses MODIS Band 1 ("red" 620-670 nm) and Band 2 ("near infrared," or "NIR" 841-876 nm). These two MODIS channels were chosen because they straddle the wavelength range of the 762 nm O_2 A-band channels used by OCO and GOSAT and because they provide the highest possible spatial resolution. MODIS data in these channels are reported at 250 m spatial sampling. This pixel size is maintained irrespective of view angle by re-sampling during the geolocation operation. A large number of pixels are averaged to generate simulated samples each the size of a OCO or GOSAT footprint. The first step in the analysis process is to read the HDF file and extract TOA radiances surrounding the target area. Next the analysis code bins the pixels into a 3x3 array of virtual OCO or GOSAT samples, with the user-supplied coordinate at the center. The 3x3 samples will allow us to investigate the deviation in TOA radiance as a function of sensor pointing error. Summaries of the mean per-footprint TOA radiance, mean TOA reflectance, and standard deviations for these large-area samples are then computed and reported. These values are presented in the figures below. In the discussion that follows "pixel" is used to refer to the original MODIS data elements, whereas "sample" is used to refer average of MODIS pixels, used to create the simulated 3x3 arrays of GOSAT or OCO soundings.

3. RESULTS

The results of the analysis are shown in Figs. 2-7. In the left panel of Figs. 2, 4, and 6, the simulated GOSAT reflectances are shown for nine samples. These are computed from the mean of the underlying MODIS pixels. The numbers in red are derived from the MODIS Band 1 (Red) product; the numbers in black are from the Band 2 (NIR) product. The right panels depict two different ways to report departures in test-site uniformity using these data. The solid lines show results from the first algorithm. These are the standard deviation, in percent, of the MODIS pixels within a given simulated GOSAT footprint, plotted for each of the nine GOSAT simulated samples. A standard deviation of less than 5% is typically observed for smaller footprint sensors. Results presented here suggest that, for the Railroad Valley site and GOSAT-scale footprints, the ground measurements are not representative of the footprint average, in that they measure only a fraction of the area observed in the footprint. It is for this reason that the vicarious calibration campaign at RRV will make ground measurements to characterize the site on MODIS spatial scales. MODIS data, scaled by the ground measurements, will then be used to characterize the entire site within a GOSAT sample.

The dashed lines show results from the second algorithm. Here the deviation, in percent, is given between the reflectance of any of the outer GOSAT samples, as compared to the reflectance associated with the center GOSAT sample. This deviation represents the error that would result from an error in GOSAT pointing. For example, if a GOSAT radiance value is thought to have come from Footprint 5 (the target site), but the sensor was actually looking at the location represented by Footprint 1, there would be 30% departure in radiance, as compared to the radiance reported at the Railroad Valley test site.

GOSAT data products have a 5% accuracy requirement. Nevertheless, an uncertainty of 10% or less is sought for the first campaign. This "vicarious-calibration" campaign has been conducted at Railroad Valley, Nevada. A ground team has measure surfaced and atmospheric properties, and computed the at-sensor TOA radiances using these ground measurements. These radiances will be compared to the GOSAT radiances reported for the test site coordinate, and hence the level of agreement can be determined. If there is a geolocation error, there will be a corresponding error in the radiance reported for the test site. We see, from Figure 2, that the pointing error must be within 1 km in order to maintain the validation to within 10% uncertainty.

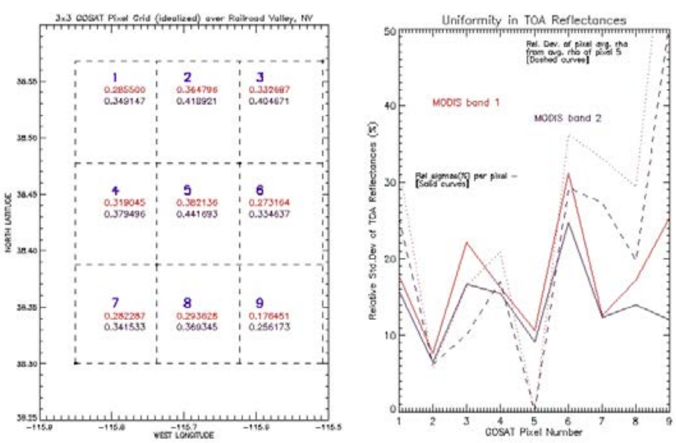

Figure 2. Results from the analysis of simulated GOSAT 3x3 footprint over Railroad Valley analysis. Left panel) Reflectances for simulated GOSAT samples, as constructed from MODIS Band 1 (Red) and Band 2 (NIR) data products. Right panel, solid line) Relative standard deviation among the MODIS pixels used to construct the simulated GOSAT footprint. Right panel; dashed lines) departure in radiances as GOSAT points in the direction of Footprints 1-9, as compared to the center footprint reading (Footprint 5).

Figures 3 (left), 5, and 7 provide an image of the 3 test sites, as reported by MODIS Aqua. The area of the image shown here illustrates the size of the simulated GOSAT 3x3 array. An image overlay also shows the site location (diamond) and the bounding area (asterisks) used to simulate a 3x3 array of OCO radiance measurements. Figure 3 (right) shows the results of the uniformity study at Railroad Valley, when OCO sized footprints are considered. We see that the maximum error is 4%, which is an order of magnitude smaller that in Figure 2. This reduction is due to the smaller footprint.

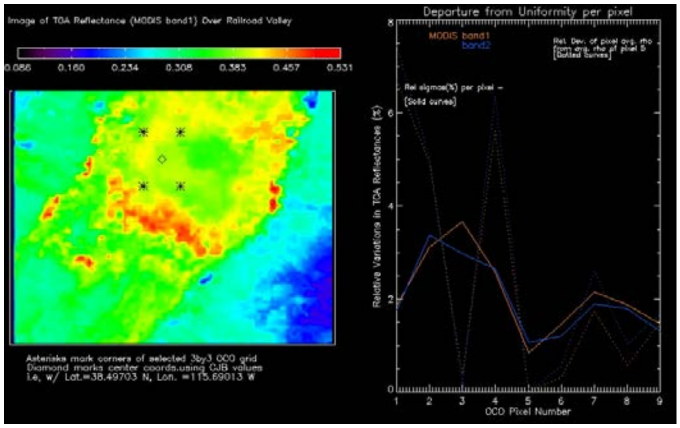

Figure 3. Left panel) MODIS Band 1 reflectance image for the area used to simulate a 3x3 array of GOSAT measurements. An overlay shows the bounding box used to create the 3x3 OCO array. Right panel, solid line) Relative standard deviation among the MODIS pixels used to construct the simulated OCO measurements. Right panel; dashed lines) departure in radiances as OCO points in the direction of one of the 8 simulated footprints, as compared to the center footprint reading.

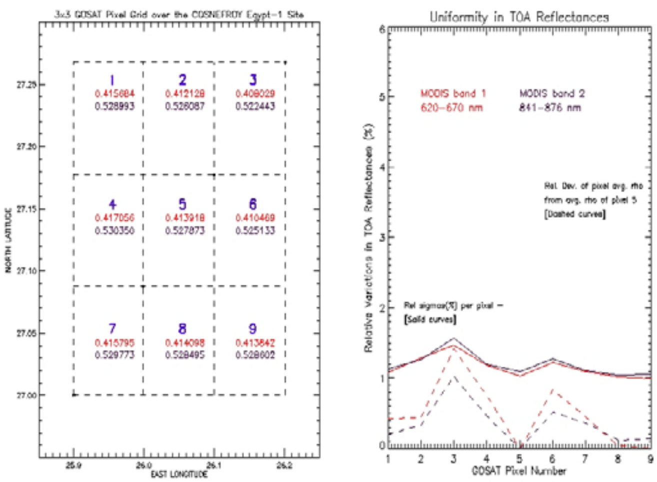

Figure 4. Results for simulated GOSAT pixels over the Cosnefroy et al.[6] Egypt-1 site.

Figure 5. MODIS Band 1 reflectance image for the area associated with the simulated 3x3 array of GOSAT measurements. An overlay shows the bounding box used to create the 3x3 OCO array.

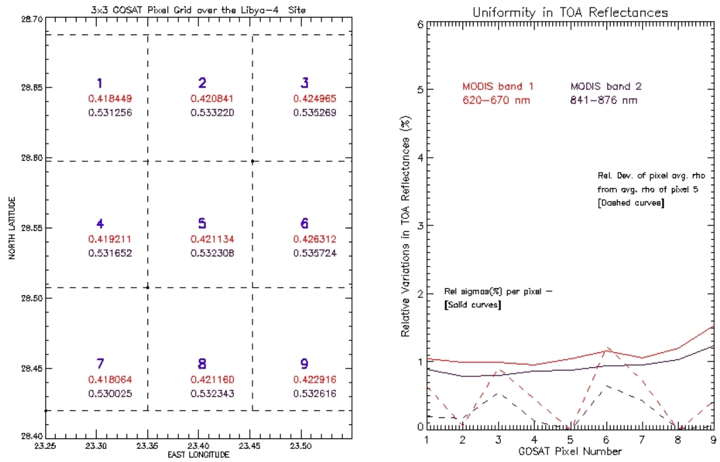

Figure 6. Results for simulated GOSAT pixels over the Libya-4 site.

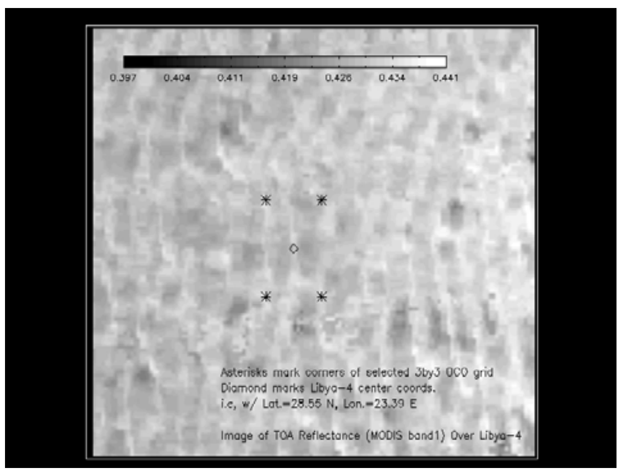

Figure 7. MODIS Band 1 reflectance image for the area associated with simulated 3x3 array of GOSAT footprints for the Libya-4 site. An overlay shows the bounding box used to create the 3x3 OCO array. The test site location is marked with a diamond.

Continuing now with the example of Libya-4, shown next in Figure 8 is the resultant uniformity analysis associated with the OCO simulation. It is clearly seen how homogeneous the Libya-4 site is, with relative percentage departures from perfect uniformity of about 1% or less. We therefore conclude that Libya-4 is a uniform test site and that sensor pointing errors even as large as a single pixel will not induce radiometric errors for either GOSAT or OCO.

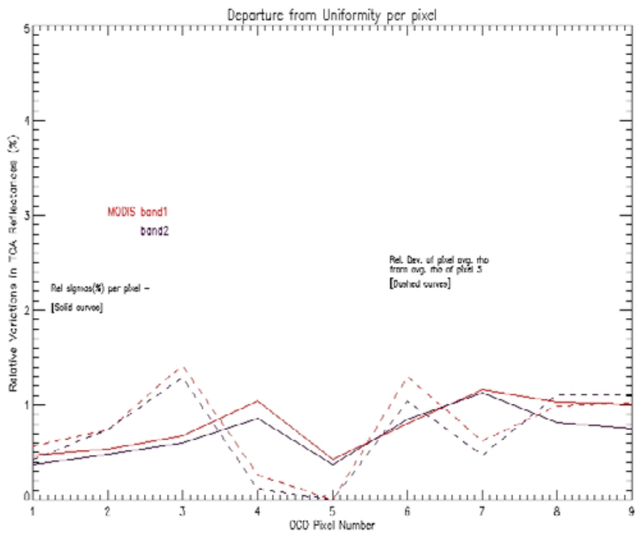

Figure 8. Results for simulated OCO footprints over the Libya-4 site.

4. VALIDATION OF RRV SURFACE REFLECTANCE MEASUREMENTS

In addition to the uniformity studies summarized above, an effort to accomplish the first vicarious calibration of GOSAT was just completed. Moreover, in the aftermath of an intensive field campaign by Bruegge, et al. at RRV, preliminary radiative transfer modeling making use of RRV atmospheric and surface measurements, coupled with coincident MODIS Aqua overpass observations, is helping to provide evidence of the continuing stable radiometric performance of MODIS as well as corroborating the accuracy of the RRV suite of surface reflectance measurements. Specifically, post-campaign analysis is aimed at validating the detailed Analytic Spectral Devices (ASD) spectrometer data collected at RRV on several different days throughout the 2 week long campaign.

As the final segment of this paper, we present an example of our ability to make accurate inter-comparisons between satellite sensor observations and radiative transfer module (RTM) calculations. The resultant TOA Visible-near-IR (VNIR) and short-wave IR (SWIR) modeled spectrum, as obtained via MODTRAN execution using RRV-specific surface reflectivity data, is shown in Figure 9. An over-plot shows the MODIS L1B radiances. The ASD characterization of the surface was made by the RRV field campaign team personnel, whereby the perimeter and interior of a 500 m by 500 m "low" reflectance ground target designated as "L06" [center cords. = 38.46478 N, 115.70095 W] was measured.

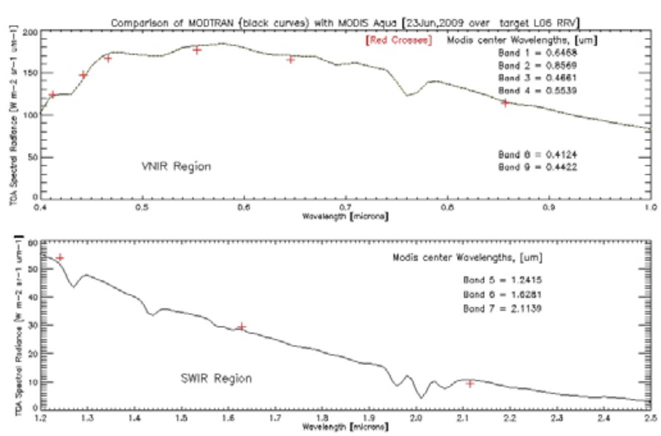

Figure 9. Comparison of MODIS Aqua TOA observed radiances with the results generated by execution of MODTRAN using ASD RRV surface spectral reflectances taken across ground target L06. The VC analysis was carried out for June 23, 2009, at a satellite RRV overpass time of approximately 20:50 UTC. The sensor view angle was 6.6° [aft direction].

Table 1 provides a summary of the good agreement between the MODIS observations and our model. The MODIS center wavelengths are given in microns for MODIS bands 8, 9, 3, 4, 1, 2, 5, 6, and 7 [listed in that order]. The TOA radiances are expressed in W m^{-2} sr^{-1} um^{-1}, while the relative percent differences are taken as: {MODTRAN-MODIS/MODIS}*100.

Table 1. MODIS measured radiances compared to those provided by the campaign data.

MODIS λ, μm	MODIS Band	ASD reflectance	MODIS Rad	MODTRAN Rad	% rel. diff
0.4124	8	0.198	123.8	122.0	-1.5
0.4422	9	0.238	147.2	146.8	-0.31
0.4661	3	0.266	166.8	171.3	2.7
0.5539	4	0.354	176.5	181.8	3.0
0.6458	1	0.386	165.4	169.8	2.7
0.8569	2	0.414	113.8	115.5	1.5
1.241	5	0.401	54.02	51.47	-4.7
1.628	6	0.426	29.52	28.59	-3.2
2.114	7	0.396	9.390	10.72	14.

5. CONCLUSIONS

As a result of comparisons between the Egypt-1 and Libya-4 Saharan desert test sites, both exhibit uniformity to better than 1%, even with a 10 km displacement. The Libya-4 site is therefore recommended, in that it is the CEOS-preferred site. For an instrumented test site, Railroad Valley playa is suitable for the vicarious calibration of 2 km class sensors. Larger footprint sensors, such as GOSAT, can be calibrated with the aid of a transfer sensor, such as MODIS. For uncertainties below 10%, pointing knowledge to better than 1 km is required.

5.1 Acknowledgement

The field campaign at Railroad Valley was made possible to the efforts of many individuals. From JAXA these include Akihiko Kuze, who provided the experiment plan, Shuji Kawakami who was responsible for the JAXA field equipment and ASD data acquisition, and Kei Shiomi who defined the test sites. Also present to support were Mr. Urabe, Ms, Kataoka, Mr. Ohyama, and Mr. Yotsumoto. Mr. Matsunaga from NEIS also participated as part of the Japanese team. On the American team, Mark Helmlinger, Northrop Grumman Space Technology, was responsible for the field equipment and quick-look data processing code. Staff from JPL/ Caltech included Benjamin Cherian, Randy Pollock, Ralph Basilio, Howard Tan, and Lars Chapsky. Jason Day participated representing Colorado State University. Jack Xiong, NASA Goddard Space Flight Center (GSFC) is also thanked for providing information on MODIS data acquisition. The research described in this paper was carried out at the, Jet Propulsion Laboratory, California Institute of Technology, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

REFERENCES

[1] Hamazaki, T., Y. Kaneko, a. Kuze, and K. Kondo, "Fourier transform spectrometer for Greenhouse Gases Observing Satellite (GOSAT)," Proc. of SPIE, 5659, doi: 10.1117/12.581198, (2005).

[2] Shiomi, K., S. Kawakami, T. Kina, Y. Mitomi, M. Yoshida, N. Sekio, F. Kataoka, and R Higuchi, "GOSAT Level 1 processing and in-orbit calibration plan," Proc. of SPIE, 7106, doi: 10.1117/12.800278, (2007).

[3] Crisp, D., D. C. E. Miller, P. L. DeCola, "NASA Orbiting Carbon Observatory: measuring the column averaged carbon dioxide mole fraction from space," J. Appl. Remote Sens., *2,* 023508; DOI:10.1117/1.2898457 (2008).

[4] Sakuma, F., C. Bruegge, D. Rider, D. Brown, S. Geier, S. Kawakami, and A. Kuze, "OCO/ GOSAT preflight cross-calibration experiment," IEEE Trans. Geosci. and Remote Sensing, 47(4), 1244-1255 (2009).

[5] Shiomi, K., S. Kawakami, T. Kina, Y. Mitomi, M. Yoshida, N. Sekio, F. Kataoka, and R Higuchi, "Calibration plan of GOSAT sensors," Proc. of SPIE, 6744, doi: 10.1117/12.738206 (2007).

[6] Cosnefroy, H., M. Leroy, and Xavier Briottet, "Selection and characterization of Saharan and Arabian desert sites for the calibration of optical satellite sensors," Remote Sensing of Environment, 58, 101-114 (1996).