Final Report

"Radiometric Calibration and Spatial Characterization of the Advanced Land Imager and Hyperion sensors"

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The purpose of our investigation was to evaluate the radiometric calibration of ALI and Hyperion using vicarious calibration and to evaluate the spatial performance of ALI. Our work relies on field work at selected sites, image analysis, and modeling. This report will divide the work into two sections as they are fairly independent and do not rely on the same sensor data. The vicarious calibration was normally done at spatially uniform high reflectance ground targets while the spatial analysis relied on scenes with distinct, linear, high-contrast edges.

Radiometric calibration

This work was done over most of the period of the investigation. Ideally, vicarious calibration of a sensor should start immediately after the sensor is turned on in a normal imaging mode and continue on some sort of schedule until the sensor is turned off or calibration is no longer necessary. In this investigation we built on previous experience with other sensors of similar spatial resolution such as the Thematic Mapper, SPOT, and ASTER. Prior to starting this project, we had developed our reflectance-based method to make use of reflectance measured with portable spectrometers. Therefore we were already prepared to work with the entire spectral region covered by ALI and Hyperion.

Our basic method is to measure the ground reflectance of a topographically flat, high reflectance ground site during overpass of the sensor to be calibrated. Figure 1 shows a photo of Barreal Blanco, a typical playa site. We also measure the atmospheric extinction along the slant path to the sun. We use a 10-band solar radiometer that automatically tracks the sun to get extinction data between about 380 nm and 1040 nm. This data is processed to find the component parts of the extinction such as molecular, aerosol, and absorption due to ozone and water vapor. The spectral behavior of the aerosol extinction allows us to estimate a particle size distribution for the aerosol particles which is then used to compute the aerosol contribution at other wavelengths. In a similar way, the amount of ozone and water vapor can be estimated from the solar radiometer data and then used for transmittance computations. A radiative transfer code based on Mie scattering by the aerosols is used to estimate the radiance at the top of the atmosphere given the measured ground reflectance and the atmospheric parameters.

Once the transmittance along the path from the Sun to the site and then back to the sensor and the radiance at the top of the atmosphere from the radiative transfer code are known, the radiance at the sensor entrance pupil can be computed. This radiance as computed by the code is a relative radiance for an input of one unit of irradiance at the top of the atmosphere. To convert to an absolute radiance, we use measured solar irradiance spectrum which is band-averaged over the pass band of the sensor being calibrated. In this work we have used the Chance data base as tabulated in the MODTRAN 4 code as that is the irradiance spectrum used for Landsat ETM+. One of the goals of this study was to compare ALI to ETM+ and using a consistent solar spectrum was essential. However, one must note that there are differences in the various published measurements of the solar spectrum and in some cases the differences in certain sensor bands is larger than the combined estimated uncertainties. If a consistent spectrum is used to similar spectral bands of different sensors, the bias between the sensors can be determined even if the absolute radiance values are different. Another reason for using the MODTRAN spectrum is that the AVIRIS team uses MODTRAN for the calibration of AVIRIS. As AVIRIS was

Figure 1. Barreal Blanco Playa, Argentina

available during some of the vicarious calibration experiments, it is advantageous to use the MODTRAN irradiance values. Again, by using MODTRAN with AVIRIS and ALI and Hyperion, relative biases can be accurately determined even if the absolute radiance values might be different if we used a different solar irradiance such as that reported by Thuillier.

During our vicarious calibration experiments, we mark some of the corners of the rectangular area on the ground that we measure. For this work for ETM+ we normally measure an area of 64 30-m pixels which is 120 meters wide (cross track) and 480 meters long (along track). For pushbroom sensors like ALI and Hyperion, we measure a rectangular area aligned such that the long axis is crosstrack to maximize the number of detectors calibrated. One corner of the ETM+ site is also a corner of the ALI/Hyperion site so a number of 30-m pixels are common. The corners are marked with large blue tarpaulins that change the reflectance of one or more pixels enough to be seen in the ETM+ or ALI image. The tarpaulins can usually be seen in Hyperion but has proven to be more difficult, probably due to the lower SNR. An example from RRV follows as Figure 2.

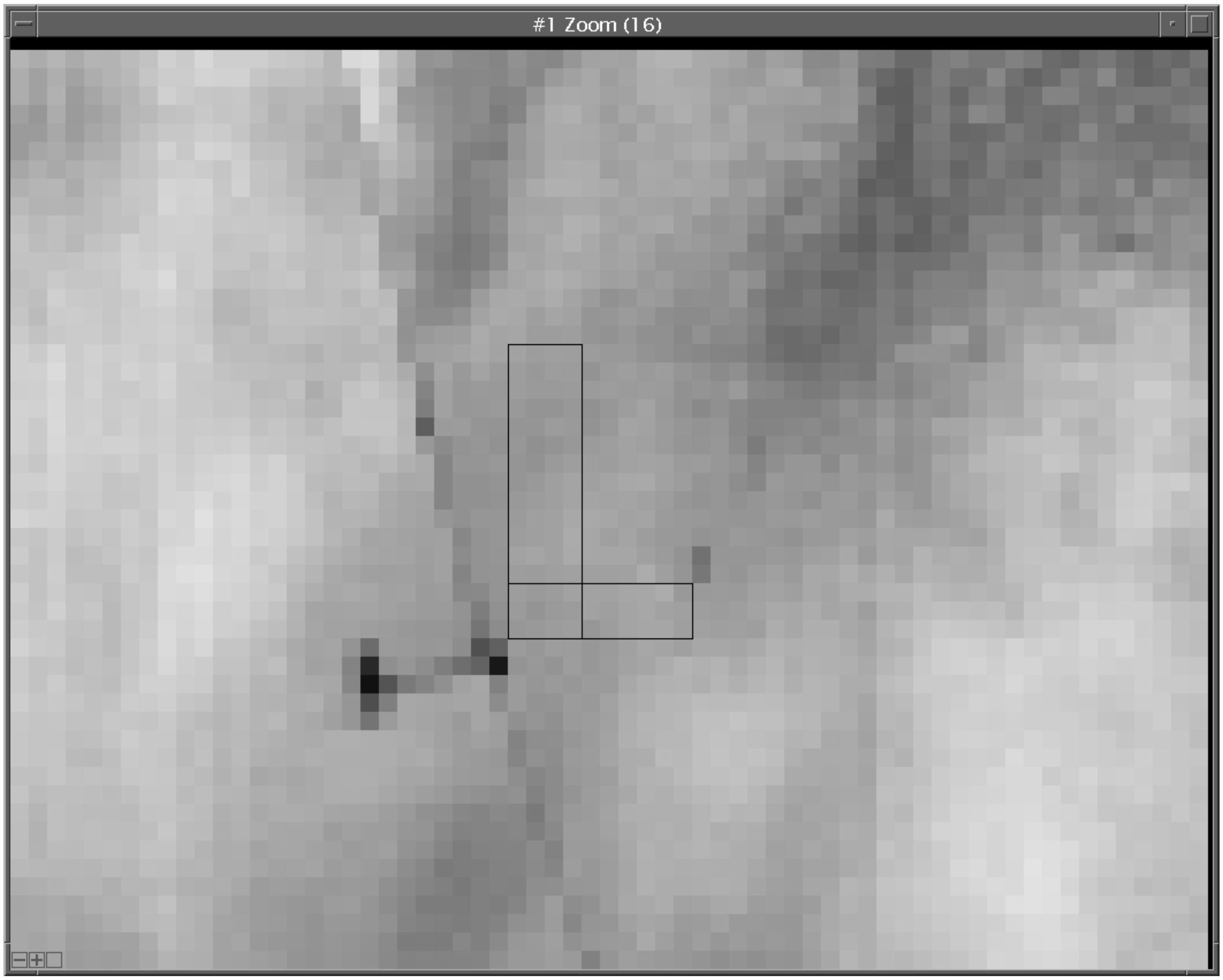

Figure 2. Image of Railroad Valley showing area measured

We use the ENVI program from RSI to extract the average digital count for each band in the marked area in the image. This digital count average is then divided by the computed radiance value to get a calibration coefficient in counts per unit radiance. We then compare this calibration to that determined by either preflight or on-board calibration sources. We attempt this vicarious calibration many times over the life of the sensor. A number of consistent calibrations gives us confidence in the results, especially when we have a large number at sites where we have extensive experience. For ALI and Hyperion, we have used a number of sites including Railroad Playa in Nevada, Ivanpah Playa in California, the alkali flats of "Chuck Site"at White Sands Missile Range, Barreal Blanco Playa in Argentina, and the asphalt parking lot at the Pima County Fairgrounds near Tucson Arizona. All of these sites except for Barreal Blanco had been used for other sensors before ALI and Hyperion. The playa sites are better than White Sands for measurements in the SWIR as White Sands has various strong absorption bands in the SWIR resulting in low signals and consequently much larger uncertainties. A plot showing nominal reflectance values from the sites used is shown as Figure 3.

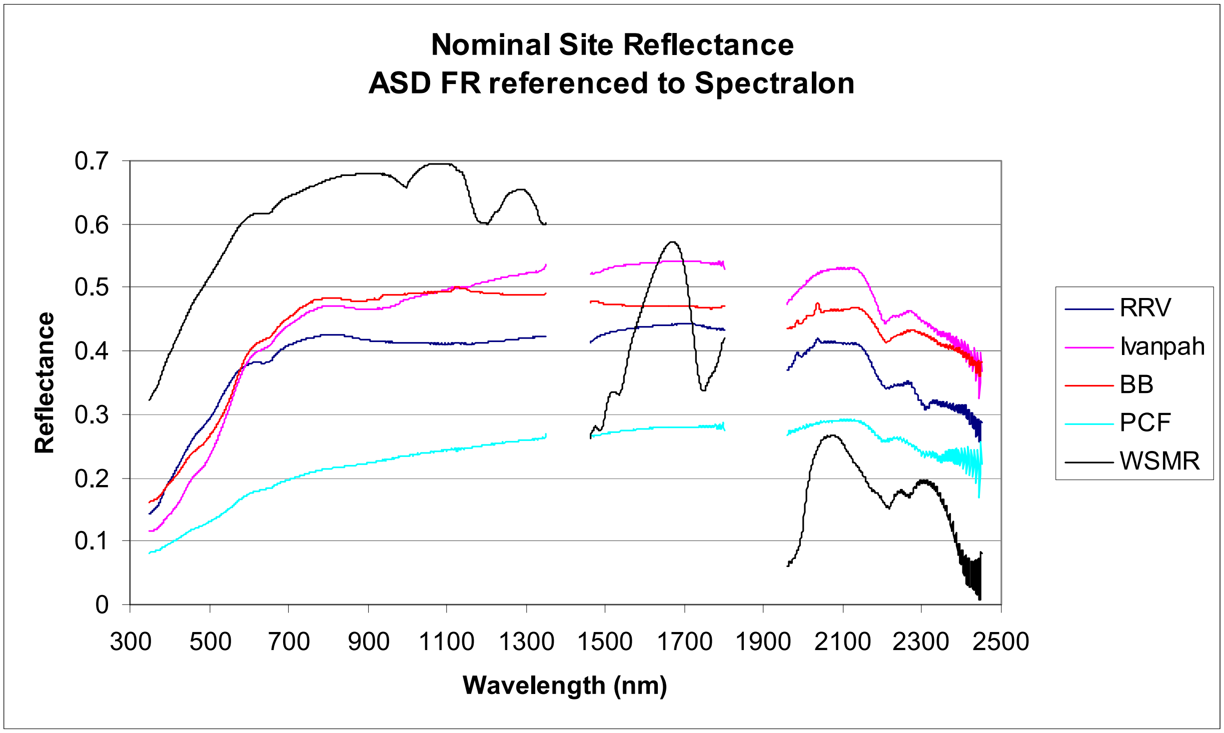

Figure 3. Typical reflectance of sites used for vicarious calibration

For both ALI and Hyperion, we have made numerous attempts at calibration. Only a small subset of the attempts made resulted in good results. Images were not always collected when we were in the field making measurements. We had equipment problems on a few occasions. On many occasions there were too many clouds present to allow a calibration. On our first experiment for EO-1, ALI was contaminated and Hyperion was not at the correct operating temperature. A graph showing a comparison of the radiance measured by ALI (using the pre-flight calibration) to the experimental, predicted radiance is given as Figure 4. There is an unexpected large difference in the shortest wavelength band. This vicarious result is consistent with results derived from the on-board solar calibrator. We do not understand the result in the SWIR band at 1.65 micrometers. These results are also consistent with cross calibrations with ETM+ and with lunar calibrations. Therefore, the ALI Instrument team decided to adjust the calibration of ALI in December of 2001. A comparison of our vicarious results to the newly calibrated ALI instrument is given in Figure 5.

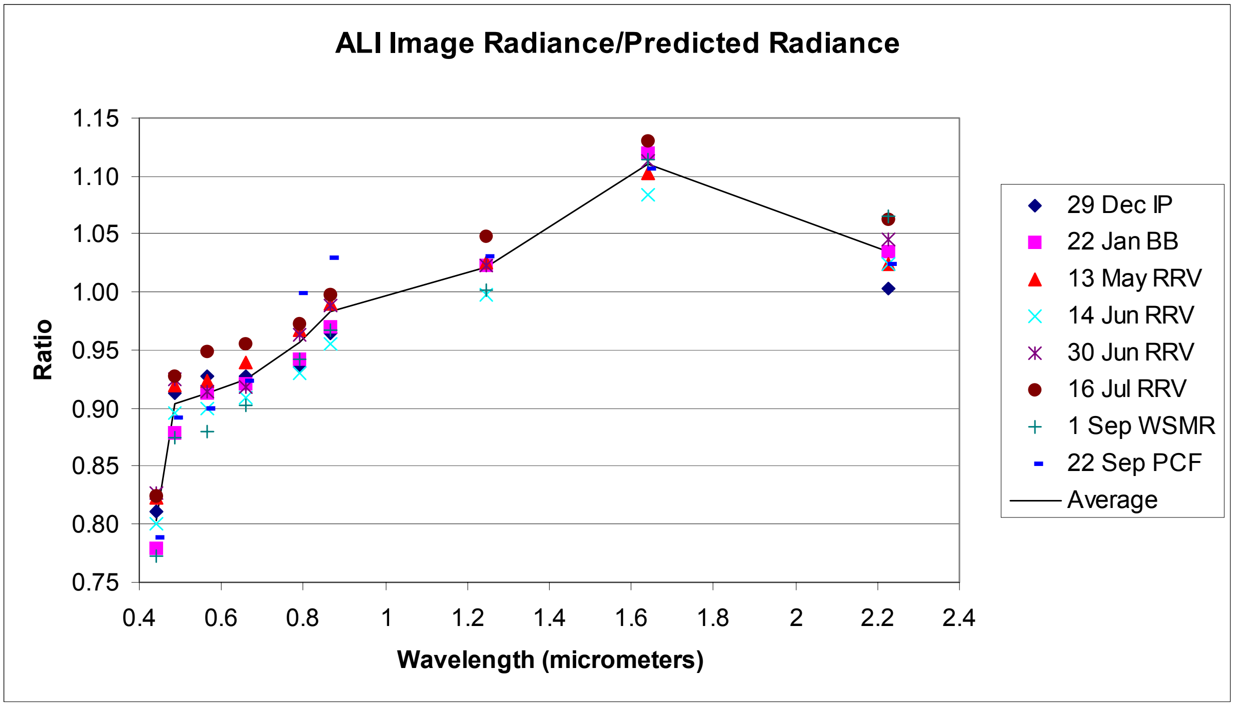

Figure 4. Radiance ratio (preflight derived/vicarious calibration)

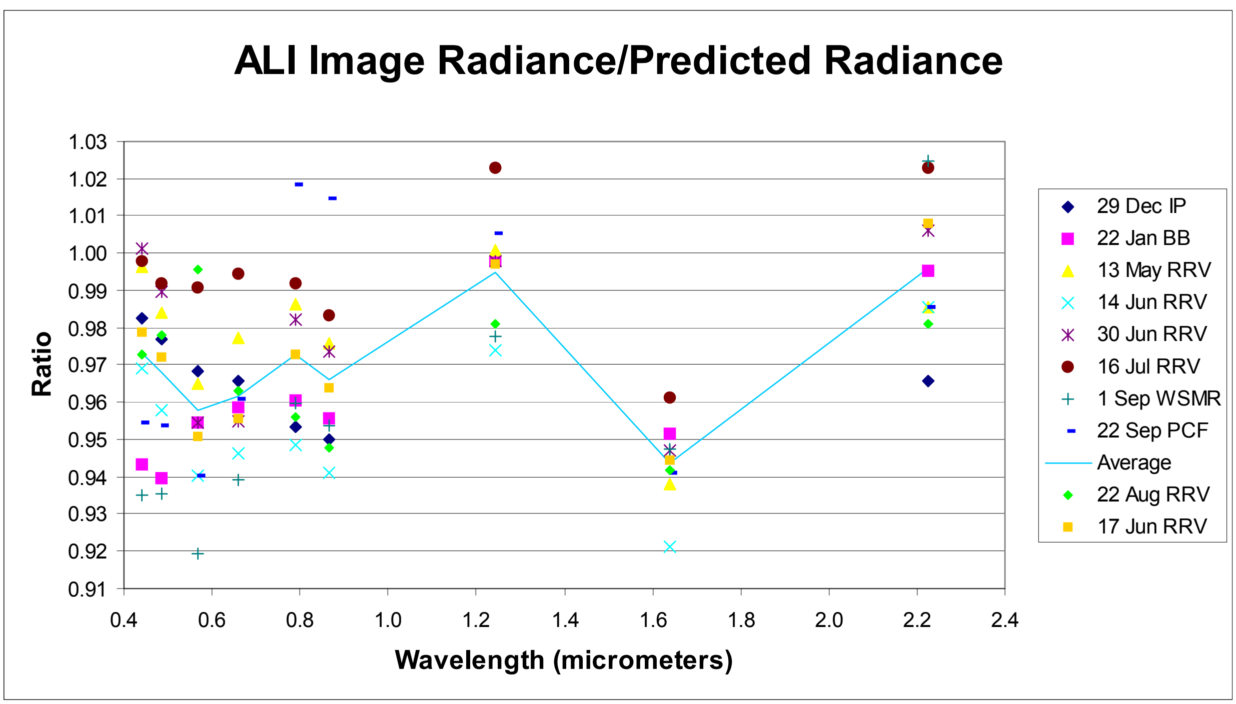

Figure 5. Radiance Ratios after December 2001 calibration adjustment

A table presenting our results at all sites and Railroad valley only is given as Figure 6. As can be seen from the table, our results are fairly consistent as indicated by the relatively low standard deviation. Our results are biased slightly from the revised calibration coefficients but the difference in the average is less than 5% except for the 1.64 micrometer band (band 5).

Band	λ	Avg (all 10)	Std dev (all 10)	Avg (RRV)	Std dev (RRV)
1p	0.442	0.973	2.36	0.986	1.42
1	0.485	0.968	2.08	0.979	1.29
2	0.567	0.958	2.42	0.966	2.32
3	0.660	0.962	1.62	0.965	1.83
4	0.790	0.973	2.25	0.973	1.79
4p	0.866	0.966	2.27	0.964	1.74
5p	1.244	0.995	1.54	0.996	1.72
5	1.640	0.944	1.15	0.942	1.38
7	2.226	0.996	1.91	0.998	1.67

Figure 6. Calibration results after adjustment in December 2001.

We have done the same basic work for Hyperion on days where we have good Hyperion data. In some cases, ALI imaged our site but Hyperion did not due to pointing problems. On other days, the SWIR data were not usable (usually temperature related). The Hyperion data are much less consistent. However, the basic trend is that vicarious calibration of Hyperion showed a consistent bias from preflight values. Figure 7 is a plot showing our results for five dates . The average difference between our results and preflight in the VNIR are about 9% for the bands between 448 and 916 nm with a standard deviation of about 4%. In the SWIR, the differences are between 12 to 20% with a larger standard deviation of up to 10%. Based on consistent differences found in AVIRIS underflight calibrations and our results, the preflight calibration of Hyperion was also adjusted in December 2001 by 8 and 18% in the VNIR and SWIR.

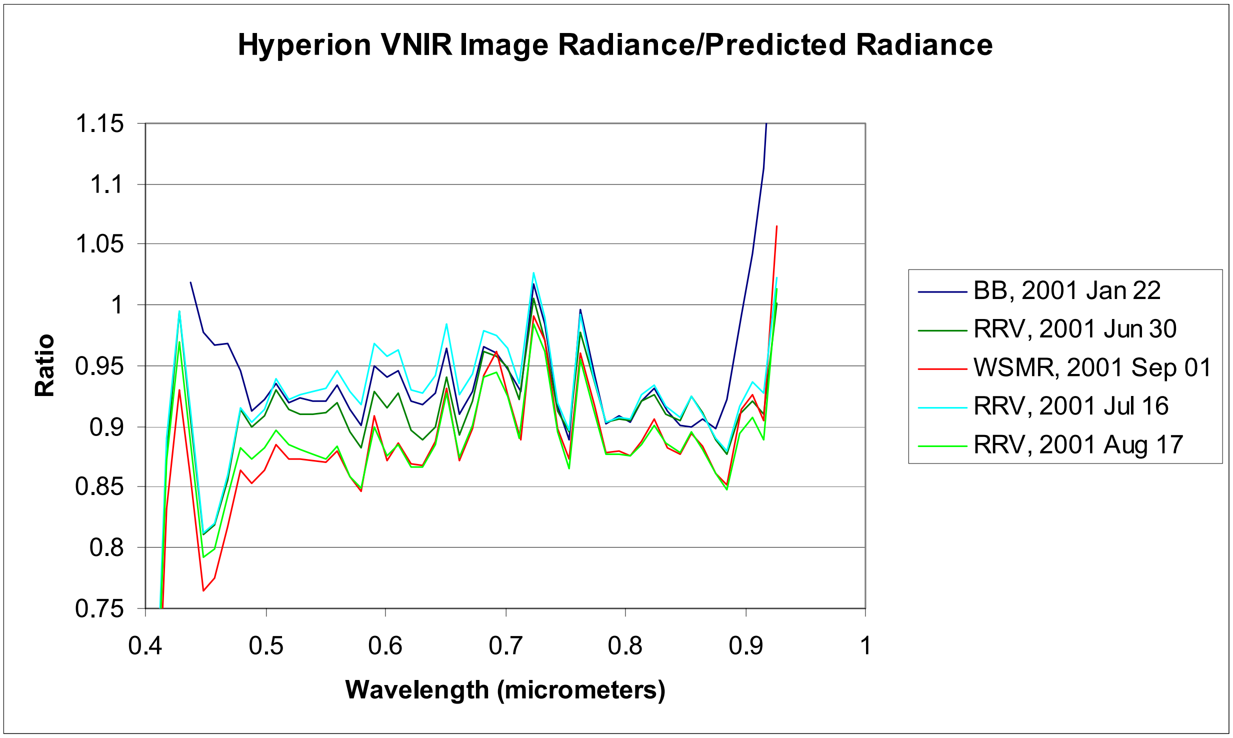

Figure 7. Radiance Ratios (preflight to vicarious) before adjustment

The vicarious calibration experiments have shown that the ALI and Hyperion sensors work as designed. The performance of ALI is stable and the SNR is high. The calibration of both instruments appears to have shifted from that determined prior to launch. ALI shifted significantly in the blue and less at longer wavelengths. Hyperion appears to have shifted more in the SWIR than in the VNIR. Adjustments to the calibration of both instruments has removed the bias between preflight and in-flight calibrations. Users needing consistent and accurate radiometric calibration should use the calibration coefficients adopted in December 2001.

Spatial Characterization

This section describes the effort to characterize the spatial response of the EO-1 Advanced Land Imager (ALI) multispectral and panchromatic bands using datasets derived from two different geographic areas. The cross-track and in-track performance of the ALI 30-meter multispectral bands was evaluated using agricultural berms between fields at the Maricopa Agricultural Center (MAC), Arizona (Figure 8) This dataset was acquired on July 27, 2001. IKONOS data acquired on July 26, 2001, were used for target validation purposes. The cross-track performance of the ALI 10-meter panchromatic band was analyzed using the Lake Pontchartrain Causeway, Louisiana (Figure 9). The ALI data used for this analysis were acquired on September 20, 2001. The results of this analysis were compared to published results for the Landsat 7 ETM+, which also used the Causeway. The in-track performance of the ALI 10-meter panchromatic band was analyzed using the same Maricopa data used for the multispectral bands.

Figure 8. Maricopa Agriculture Center was used to characterize performance of ALI multispectral and pan (in-track) bands. IKONOS was used for target validation

Figure 9. Lake Pontchartrain Causeway was used to analyze the ALI 10-meter panchromatic band in the cross-track direction. These results were compared to the spatial response of ETM+.

The agricultural fields at Maricopa are oriented in a north-south and east-west pattern and formed angles of 13.08° with the ALI in-track and cross-track directions. This inclination of the fields to the EO-1 orbit provided sub-pixel sampling across the target. Results indicated that there was a 20% broader spatial response in-track compared to cross-track for ALI's multispectral bands. This is probably due to integration time smear in-track.

The Louisiana causeway target used to evaluate ALI's panchromatic band consists of a double-span bridge, each 10 meters wide and with a center-to-center separation of 24.4 meters. This separation was large enough to allow two separate spatial response measurements. The angle between the causeway and the ALI data was 4.1949°, resulting in a sub-pixel cross-track sample increment of 0.0733 ALI pixels. The in-track analysis of the panchromatic band was done using the east-west berms at Maricopa.

Results indicated that the measured cross-track on-orbit MTF was about 0.1 higher at the Nyquist frequency (0.5 cycles/pixel) than pre-launch data for sensor chip assembly (SCA) 4. The cross-track spatial response Full Width Half Maximum (FWHM) value was found to be 1.3 pixels (13-m) and the cross-track MTF at 0.5 cycles/pixel, corrected for the target, was found to be 0.31. These values compare to 1.28 pixels (19.2-m) and 0.28, respectively, for ETM+ as reported by J. Storey in an earlier analysis.

A comparison of in-track and cross-track ALI spatial response calibration showed an expected lower on-orbit performance in-track. The panchromatic band in-track, on-orbit MTF was measured to be about 50% lower than the cross-track MTF at the Nyquist frequency. As in the case of the multispectral bands, this is consistent with in-track integration time smear. Results from this on-orbit characterization of the ALI multispectral and pan bands are somewhat different from pre-launch measurements and models developed by Lincoln Lab, but are consistent in terms of lower response in-track compared to cross-track.

Miscellaneous

The Arizona members of the EO-1 Science Validation Team hosted the first team meeting after launch. The meeting was held at the Westward Look in Tucson in May 2001. Initial results for the vicarious calibration were presented there. Discussions with the instrument teams confirmed that the initial in-flight calibration results from Barreal Blanco had shown shifts as compared to preflight results.

Papers Published:

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Schowengerdt, R. A., "Spatial Response of the EO-1 Advanced Land Imager (ALI)," Proc. Int. Geoscience and Remote Sensing Symposium (IGARSS '02), Vol. VI, pp3121-3123, Toronto, June 24-28, 2002.

Biggar, S. F., Thome, K. J., and Wisniewski, W., “Vicarious Radiometric Calibration of EO-1 Sensors by Reference to High-Reflectance Ground Targets,” IEEE TGRS, Vol 41, Num 6., pp 1174-1179, June 2003.

Thome, K. J., Biggar, S. F., Wisniewski, W., “Cross Comparison of EO-1 Sensors and Other Earth Resources Sensors to Landsat-7 ETM+ Using Railroad Valley Playa,” IEEE TGRS, Vol 41, Num 6., pp 1180-1188, June 2003.

Bryant, R., Moran, M. S., McElroy, S. A., Holifield, C. D., Thome, K. J., Miura, T., and Biggar, S. F., “Data Continuity of Earth Observing 1 (EO-1) Advanced Land Imager (ALI) and Landsat TM and ETM+,”, IEEE TGRS, Vol 41, Num 6., pp 1204-1214, June 2003