Radiometric Calibration Stability of the EO-1 Advanced Land Imager: 5 Years On-Orbit

Brian L Markham*[a], Lawrence Ong[b], Julia A. Barsi[b], Jeffrey A. Mendenhall[c], Donald E. Lencioni[c], Dennis L. Helder[d], Douglas M. Hollaren[e], and Ron Morfitt[e]
[a]Biospheric Sciences Branch, Code 614.4, NASA/Goddard Space Flight Center (GSFC), Greenbelt, MD, USA 20771
[b]Science Systems and Applications, Inc., Code 614.4, NASA/GSFC, Greenbelt, MD USA 20771
[c] Massachusetts Institute of Technology – Lincoln Laboratory, 244 Wood Street, Lexington, MA USA 02420-9185
[d] Electrical Engineering and Computer Science Department, South Dakota State University, Brookings, SD USA 57007
[e] Science Applications International Corporation (SAIC), Contractor to U.S. Geological Survey (USGS), Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD USA 57198

ABSTRACT

The Advanced Land Imager (ALI) was developed as a prototype sensor for follow on missions to Landsat-7. It was launched in November 2000 on the Earth Observing One (EO-1) satellite as a nominal one-year technology demonstration mission. As of this writing, the sensor has continued to operate in excess of 5 years. Six of the ALI's nine multi-spectral (MS) bands and the panchromatic band have similar spectral coverage as those on the Landsat-7 ETM+. In addition to on-board lamps, which have been significantly more stable than the lamps on ETM+, the ALI has a solar diffuser and has imaged the moon monthly since launch. This combined calibration dataset allows understanding of the radiometric stability of the ALI system, its calibrators and some differentiation of the sources of the changes with time. The solar dataset is limited as the mechanism controlling the aperture to the solar diffuser failed approximately 18 months after launch. Results over 5 years indicate that: the shortest wavelength band (443 nm) has degraded in response about 2%; the 482 nm and 565 nm bands decreased in response about 1%; the 660 nm, 790 nm and 868 nm bands each degraded about 5%; the 1250 nm and 1650 nm bands did not change significantly and the 2215 nm band increased in response about 2%.

Keywords: Advanced Land Imager, ALI, radiometry, calibration

1. INTRODUCTION

The Advanced Land imager on board the EO-1 spacecraft was developed as a prototype for future moderate resolution land imaging sensors. EO-1 was inserted to a 705 km orbit and navigated so that it trails one minute behind Landsat-7. This close formation flying minimizes atmospheric and geometrical changes between the Landsat and ALI imaging opportunities thus allowing easier cross-comparison of simultaneously acquired data. There are a total of 9 multi-spectral bands on the ALI. Six of these are similar to those on Landsat-7. The spectral coverage of three other bands was designed to complement those on Landsat-7. Salient spectral and spatial characteristics of the ALI instrument are presented in Table 1. The numbering of the ALI bands is so as to correspond with the Landsat ETM+ spectral bands. The bands not present on the ETM+ are given the "p" or prime designation.

The ALI is a pushbroom instrument, imaging the full 15° Landsat swath with fixed wide field reflective optics, as opposed to the scanning mirror of ETM+. As a technology demonstrator, 3° out of the 15° was populated with detectors. A complete ALI focal plane would require approximately 6200 detectors to cover the 15° at 30 meter ground sample distance for the multispectral bands and 3 times this number for the 10 meter panchromatic band. The focal plane is composed of multiple Sensor Chip Assemblies (SCA); 4 SCA's were used in ALI to cover 3° field of view. Each SCA had 320 detector elements for the 30 meter bands and 960 for the panchromatic band. The populated portion of the focal plane corresponds to the eastern most portion of the corresponding Landsat-7 scene when the ALI is nadir pointing in the daytime descending portion of the orbit. SCA 1 is the eastern-most.

* Brian.L.Markham@nasa.gov; phone 1 301 614-6608; fax 1 301 614-6695; www.nasa.gov

Sensors, Systems, and Next-Generation Satellites X, edited by Roland Meynart, Steven P. Neeck, Haruhisa Shimoda,
Proc. of SPIE Vol. 6361, 63610U, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.690058

Table 1. EO-1 Advanced Land Imager spectral bands

Band	Bandpass (nm)	Ground Sample Distance (m)
Pan	480-690	10
1p	433-453	30
1	450-515	30
2	525-605	30
3	630-690	30
4	775-805	30
4p	845-890	30
5p	1200-1300	30
5	1550-1750	30
7	2080-2350	30

The ALI has two on-board radiometric calibration devices: a lamp based system and a solar diffuser based system plus an aperture door. The lamp system[2] has 3 gas filled lamps in an integrating sphere. A lens images the output of this sphere onto the focal plane after reflection off the last mirror in the optical train (a flat mirror). This system thus does not monitor the 3 main mirrors in the ALI telescope. The lamps are operated at constant current.

The solar calibration system consists of a Spectralon™ panel that is deployable in front of and in the light path of the secondary mirror and a set of openings in the ALI aperture door that is normally covered by a sliding door. During a solar calibration sequence, with the aperture door closed and the instrument pointed to the sun, the sliding door is operated so as to sequentially uncover the openings and thereby provide a total of 7 solar illumination levels on to the sensors.

The ALI instrument was extensively characterized and calibrated prior to launch[3]. On-orbit radiometric stability results have been presented for the first year on-orbit[3] and through 2.5 years on-orbit[4]. These stability results were based on lamps and solar calibrators described above, and, in addition, lunar and vicarious calibrations. The key results of the stability analysis showed: (1) contamination affects the response of the focal plane, though this contamination can be removed by heating the focal plane to 260K, i.e., a bakeout, as was done nominally every 15 days during the mission; (2) this contamination effect has decreased significantly after the first year on orbit; (3) the solar, lunar and lamp results were generally consistent leading to clear indications as to the stability of the ALI; (4) bands 1p, 1, 2, 5p, 5, 7 and pan showed excellent stability with average response changes of less than 1% per year and (5) bands 3, 4 and 4p showed changes of 2-3% per year.

Beginning in 2004 an Image Assessment System was built for the ALI (ALIAS). This ALIAS was designed to characterize and track the radiometric, spatial and geometric performance of the ALI over its lifetime[5]; algorithms were included to characterize the radiometric response to the dark shutter, internal lamps, solar calibrator and lunar observations[6]. As of July 2006, all the lamp, shutter, solar and lunar data collected through December 2005 had been processed through ALIAS. The paper is based primarily on the results generated by ALIAS on the ALI radiometric stability over time as indicated by its on-board calibrators and lunar observations and serves to update previous analyses to cover the first 5+ years on orbit. In addition, the observed degradations are attributed to various components of the system to the extent possible and equations for the lifetime calibration of the instrument are proposed. This paper treats the overall trends in response at the SCA level; changes at the detector-by-detector level are being studied and will be reported on in future papers.

6. SUMMARY/CONCLUSIONS

All of the multiple calibration methods available on the ALI are well behaved in terms of providing consistent results on the ALI instrument response. Even the lamps, which have been problematic on other sensors such as Landsat-7 ETM+, show changes of less than 1%/year in the shortest wavelength band. The lunar results appear most valuable, in that they trend the full instrument performance. The instrument itself is likewise well behaved and stable, with changes in the response being less than 2% per year even early in the mission and averaging at most slightly more than 1% per year over the full mission. The observed inconsistencies between the results of the different calibrators, though present, and not readily explained, are small compared to other missions, i.e., in general there would only be a percent or two difference in degradation of the instrument indicated between techniques over the first five years of the mission. For example, using the lamps and assuming they were stable in band 1 would indicate a 3% response change over the mission life, whereas the lunar measurements would indicate about a 1% change. Having these multiple well-behaved techniques has allowed narrowing down the changes in the ALI calibration to around 1% over its first five years on-orbit.