EO-1 HYPERION ONBOARD PERFORMANCE OVER EIGHT YEARS: HYPERION CALIBRATION

S.G. Ungar, E.M. Middleton, L. Ong, P.K.E. Campbell, NASA Goddard Space Flight Center, Mail Code 614.4, Greenbelt, MD 20771, USA

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ABSTRACT:

The Hyperion instrument onboard NASA's Earth Observing-One (EO-1) satellite is a pioneering imaging spectrometer that has been used to explore technologies and to develop applications for space-based hyperspectral observations of the Earth's land and coastal regions. The EO-I mission was launched in November 2000 to a 705km polar orbit with an equatorial crossing time of about 10am. The initial one-year technology validation mission was subsequently extended to the present. EO-1's birth as an Earth orbiting technology test-bed has endowed this mission with extraordinary spacecraft agility, onboard intelligent processing, a variety of highly reliable advanced support technologies, and unique passive optical observing capabilities. At the successful culmination of its technology mission, EO-1's unique assets were put to use in addressing a variety of NASA Earth science program questions. The eight years of Hyperion data acquisitions from a Low Earth Orbit have provided unique opportunities to study the long-term performance in a space environment of the imaging instruments and other technologies. Complementing the onboard lamps, the Hyperion instrument has the additional capability to conduct solar calibrations and collect images of the moon to monitor changes in the instrument characteristics. This paper presents results from these calibration/engineering data sets, which have been regularly collected throughout the mission's eight year duration. These calibrations methods should be useful for other hyperspectral missions under development. EO-1 is well poised to serve as a unique tool for developing and validating observing strategies and algorithms for the future NASA HyspIRI mission called for in the NAS/NRC Decadal Survey.

1. INTRODUCTION

1.1 Background

The Earth Observing One (EO-1) satellite was launched in November of 2000 as part of NASA's New Millennium Program (NMP) technology path-finding activities to enable more effective (and less costly) hardware and strategies for meeting Earth science mission needs in the 21st century. The EO-1 Mission was designed to provide sufficient information to allow for a thorough evaluation of the performance of its mission technologies and operations strategies from an engineering perspective. Fortunately, it was recognized, from project inception, that the ultimate metric for measuring science performance is the impact of these technologies and strategies on our ability to characterize terrestrial surface state and processes. To this end, a Science Validation Team (SVT) was competitively selected to ascertain how well the technologies and strategies employed served in enhancing the extraction of scientifically interesting information for a variety of scenarios. The selected SVT team members ended up representing a variety of ecological interests including forestry, agriculture, invasive species, desertification, land-use, vulcanization and natural disasters. There were several international team members, with the Southern Hemisphere well represented. The one common thread for all team member proposals was the use of remotely sensed data as an essential contributor within each research area. The data gathering phase of the mission was designated to last one year, leading to a hardwire design lifetime of 18 months. The SVT was funded for an additional year of analysis to permit a thorough science validation of the technology candidates for future missions. EO-1 was placed in an orbit which allowed it to pass over the same piece of real estate as Landsat-7 exactly one minute later. This was done to develop and test a "formation flying" technology as well as to facilitate the validation of EO-1 instruments through direct inter-comparison with observations from a known satellite system. The objective of gathering two hundred paired Landsat/EO-1 scenes during the first year was far exceeded. Furthermore, the SVT members' analyses were published, less than six months after completion of the analysis phase, in the June 2003 special issue of IEEE TGARS. Since EO-1 was launched in late November, the project proposed **the Accelerated Mission**, consisting of Intensive Southern Hemisphere Field Campaigns, in order to ensure assembling a validation database of well illuminated vegetated scenes early in the mission.

The Extended Mission started in February of 2002 when science data acquisition, ground reception and processing functions were transferred to USGS EROS. Although the operational phase of the EO-1 data gathering activity had been successfully concluded, it was widely recognized that the data being collected was a great interest to the community at large. EROS serves as the public archive and distribution center for all data collected prior and subsequent to the transition. Furthermore EROS continued to supply "fill-in" data to SVT members in order to allow them to incorporate complete growing cycles into their analyses. During this phase of the mission EO-1 made itself available for tasking related to various homeland security and natural disaster tasking as directed by NASA headquarters. We developed a "bulk customer" constituency among US federal agencies. Additionally, great strides were made in developing an on board autonomous planning system which greatly reduce operational costs of EO-1. When the EO-1 science team was disbanded at the end of 2002, those members engaged in NASA related science projects continued to receive data through a subsidy arrangement the Mission Science Office negotiated with the bulk customers. By the end of 2003 several hundred articles, papers and presentations had appeared. During this period of time, the Advanced Land Imager (ALI) became the reference frame for generating the performance specifications for the Landsat Data Continuity Mission (LDCM).

1.2 Recent Activities

Since 2005, the EO-1 mission has been addressing several pressing needs for NASA. The LDCM activity was, and is, drawing heavily on ALI to help refine specifications, operating strategies, and processing algorithms for LDCM. NASA investigators engaged in the LBA, North American Carbon, and other terrestrial ecology programs were starting to productively use the EO-1 Hyperion imaging spectrometer, achieving results with accuracies far exceeding those available with the existing spaceborne fleet of multispectral scanners. Since NASA has dictated a de-orbited maneuver at the end of EO-1 spacecraft life, the mission started lowering the EO-1 orbit to be in compliance. Slightly lowering of the orbit at a slow rate has several beneficial effects. Firstly, it breaks formation with Landsat-7, allowing for coincident observations with other satellites in standard EOS Sun synchronous orbits. This has proven extremely useful in employing EO-1's strong calibration/characterization heritage to provide cross calibration for a variety of instruments on EOS platforms. Secondly, the series of miniscule reductions in orbit altitude allows for maintaining an equatorial crossing time (> 10am) ensuring adequate solar illumination with minimum fuel expenditure. Lastly, EO-1 is less susceptible to worrying about collision avoidance maneuvers. Currently EO-1 has enough fuel on board to continue observing through 2012. During the whole history of the mission there has been only one anomaly with implications for the science evaluation. This involved a failure of a mechanism designed to provide a variable level for ALI solar calibration. This occurred well after the formal end of the mission and subsequent to the full technological and science evaluation of this strategy. Furthermore, the cause of the failure is well understood and can be avoided on any future mission choosing to adapt this calibration strategy. The ALI continues to be well calibrated through the use of lunar calibration, onboard lamp sources, well characterized instrumented ground sites, and inter-comparisons with other sensor systems (including Hyperion).

1.3 Current and Future Activities

The gaps that have developed in Landsat-7 scan coverage have made it less than ideal for that mission to provide necessary coral reef and atoll acquisitions for NASA's mid-Decadal Study. EO-1 is currently supplying 90% of the collects of these areas for this important study and should continue to do so. LDCM continues to rely on ALI as a testbed for mission concepts and expects to use ALI to resolve many questions that may arise, during and after contract award, regarding instrument and platform performance as well as calibration strategies. However, the continued exploratory investigations being performed with the Hyperion imaging spectrometer are of most interest scientifically. Hyperion is the first, and currently the only, imaging spectrometer acquiring data from space. There are no plans to launch an imaging spectrometer with anywhere near the coverage pattern of Hyperion within the next several years. The NAS/NRC Decadal Survey commissioned by NASA calls for an imaging spectrometer as part of the HyspIRI Mission. NASA is currently incorporating a JPL led imaging spectrometer Mission Concept Study into their future plans. This concept study has relied heavily on Hyperion and any future mission will benefit substantially from experience gained through continued operation of this absolutely unique resource. Lastly, EO-1 has come full circle and is once again acting as a technology test-bed for developing enabling technologies and strategies for lowering the costs and raising the quality and utility for measurements needed to address global problems. EO-1 is serving as the prototypical space platform for experiments involving autonomous operation, onboard processing of data (e.g. cloud screening), development of sensor webs which trigger targeted satellite acquisitions through anomalies reported autonomously by ground sensor systems, and making data available to emergency responders and policymakers through the Internet.

2. SAMPLE APPLICATIONS

The figures 1 through 3 appearing below are illustrative of the capabilities of EO-1 ALI as described in the preceding sections. The captions are self-explanatory.

Figure 1 ALI Pan-Enhanced (10m) RGB color composite

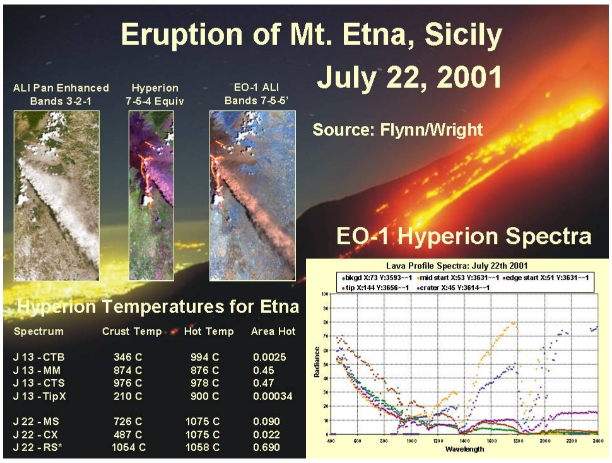

Figure 2 Determining Lava Thermal Viscosity

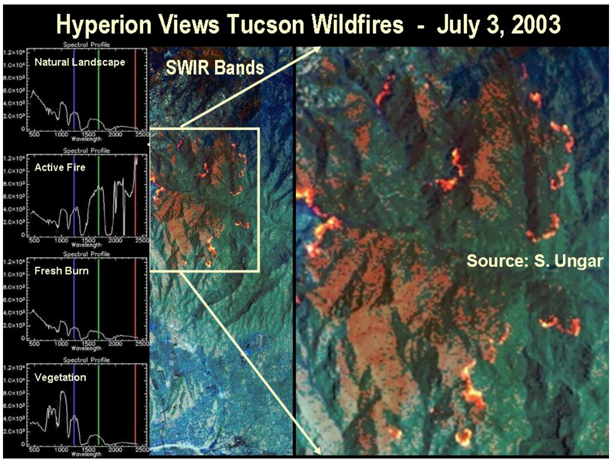

Figure 3 Mapping Active Wildfires with Hyperion

3. HYPERION ON-ORBIT CALIBRATION

The Hyperion on-orbit calibration strategies fell into four general categories: solar; lunar, lamp-based, and opportunistic. Currently, solar calibrations are performed every two weeks. As EO-1 passes beyond the North Pole in its orbit, the spacecraft is maneuvered to point the solar baffle aperture at the sun. The internal lamps are exercised as part of this calibration procedure.

3.1 Solar Calibration

Daily to weekly solar looks were used for radiometric and, when viewed through the atmosphere, spectral calibration. Figure 4 describes the solar diffuser mechanism. The inside of the Hyperion telescope aperture cover is coated with a special paint whose spectral-radiometric properties have been well characterized. The aperture is closed between acquisitions and during dark current or internal lamp based calibrations.

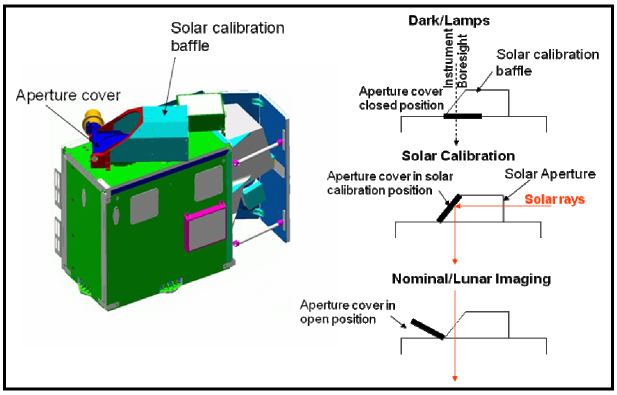

Figure 4 Hyperion Imaging Modes

Spectra of the solar diffuser panel show large degradation in the shorter wavelengths over the 8 years of operation as seen in figure 5. (Note: 2001047 means day 47 of 2001)

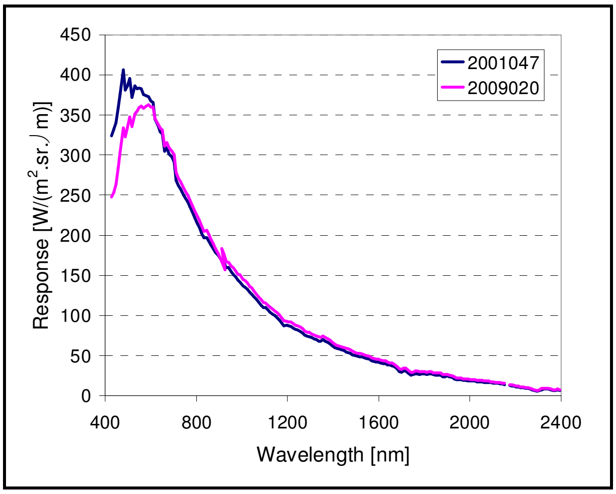

Figure 5 Solar Panel Spectra

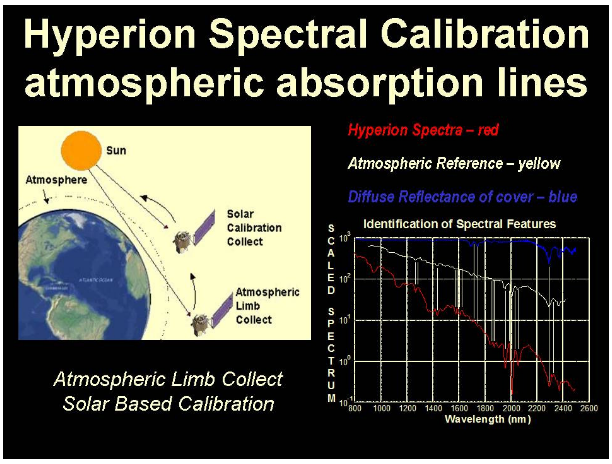

Figure 6 Hyperion Solar Calibration Geometry

Figure 6 shows the viewing geometry which allows for the exploitation of atmospheric absorption features to track the stability of Hyperion's spectral calibration.

3.2 Lunar Calibration

EO-1 has acquired approximately 100 lunar looks over its lifetime. Observations are collected monthly at a specified phase angle, just past full-moon, coincident with collections by SeaWiFS and ASTER. Figure 7 shows an image of the moon, constructed from ALI band-pan sensor observations, accompanied by sample lunar spectra acquired by Hyperion. The spectra were used as a reference source for adjusting the sensor system spectral response for NASA's state-of-the-art imaging spectrometer, the Moon Mineralogy Mapper (M3), which was launched onboard the Chandrayaan-1 Indian satellite on October 22, 2008. M3 provides substantial heritage for the HyspIRI imaging spectrometer design.

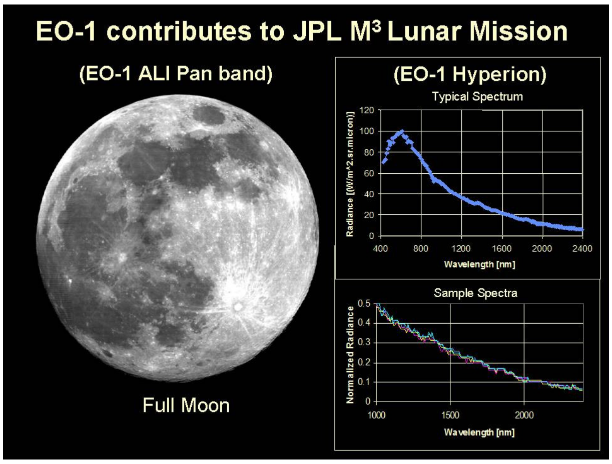

Figure 7 ALI lunar image and Hyperion spectra

3.3 Lamp-based Calibration

Lamps intensity shows some degradation over the entire spectral range over the 8 years of operation (see Figure 8). Although lamps are currently only exercised before and after solar calibration, the lamps were used more frequently during the first three years of the mission. Lamp measurements are always made with the aperture cover closed and both preceded and followed by dark current measurements.

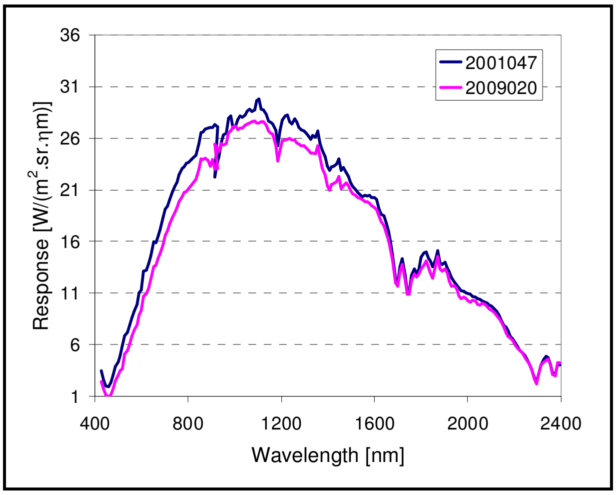

Figure 8 Hyperion Lamp Spectra

3.4 Opportunistic Calibration

Much emphasis has been placed on developing calibration strategies that could be used by future missions, including those that have sparse calibration resources. These include use of instrumented and/or well characterized globally distributed validation sites, unusual targets of opportunity (e.g. natural gas flares in Mumba, Australia; Las Vegas nightlights; planet Venus; bright stars). Traditional techniques for flat fielding individual detectors within the same spectral channel involve either observing suitably sized homogeneous ground targets or statistically trending individual detector responses over many orbits. EO-1's spacecraft agility allows for a 90 degree yaw of the detector array which permits each detector in a given channel to observe the same piece of real estate under identical viewing and illumination geometries.

3.5 Trending of Calibration Results

Figure 9 shows a significant initial decrease in lamp output during the first year of operation. The lower wavelength channels (< 500 nm) exhibited the largest change. The SWIR channels responses have decreased by less than 10 % over the mission life. For most bands the lamps appears to achieve some stability after year 4. All this is consistent with a modest diminishment of lamp filament temperature during the early stages of the mission.

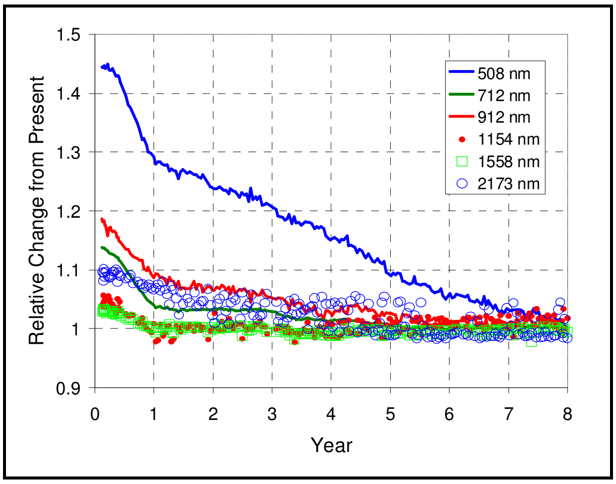

Figure 9 Hyperion Lamp Trends

Changes in the solar panel on orbit are most pronounced during the first 3 years. Most of the variations are within +/- 5% except for the longer wavelengths. For most bands the lamps appears to achieve some stability after year 4 (see Figure 10).

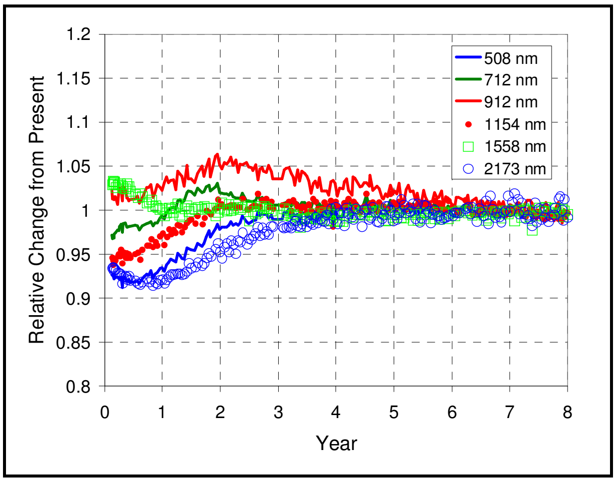

Figure 10 Hyperion Solar Trends

Although inconsistent during early mission life, the solar and lamp trends agree well after 4 years in orbit as shown by figure 11.

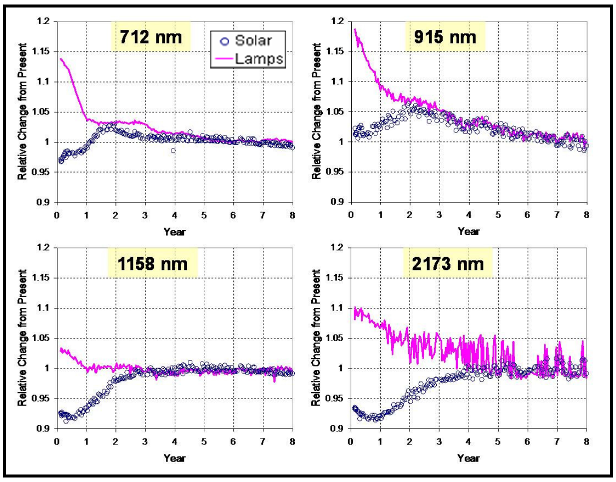

Figure 11 Comparing Lamp and Solar Trends

4. CONCLUSIONS

Lamp and solar diffuser panel observations have drifted during the first 3 years on orbit, but appear to have stabilized afterwards. Since lunar calibration ,when compare with the Rolo model, shows that Hyperion is stable to within 5% we can attribute much of the drift to changes in the lamp characteristics and spectral-radiometric properties of the solar diffuser. Most likely suspects are a degradation of the lamp filaments, resulting in a lower operating temperature and an oblation of the surface of the solar diffuser (telescope-cover surface) by the solar wind.

5. REFERENCES

An extensive list of references relating to the calibration and history of EO-1 and Hyperion may be found at:
http://eo1.gsfc.nasa.gov/new/SeniorReviewMaterial_References.doc