Semi-annual EOS Contract Report

Period: July 1 - December 31, 2002

Remote Sensing Group (RSG), Optical Sciences Center (OSC) at the University of Arizona

Principal Investigator: K. Thome

Contract Number: NAS5-31717

Summary: During this six-month period, Remote Sensing Group personnel attended meetings related to MODIS and ASTER, including the ASTER and MODIS Science Team meetings. Initial field campaigns were held for the Aqua MODIS sensor showing differences between the Terra and Aqua MODIS sensors in excess of the expected uncertainties but still under investigation. Continued work with the MODIS and ASTER sensors on Terra showed similar results to past reporting periods. The ASTER sensor continues to show large differences from predicted values in the VNIR due to probable calibration changes in orbit and in the SWIR due to the optical crosstalk effect. Results from MODIS on Terra show that the calibration of this sensor is well understood and any changes in sensor response are taken into account in the Level 1B processing. Both results have been verified through comparisons with ETM+. Laboratory work has also been done in support of the field work showing that RSG is now capable of resurfacing field reference panels to return them to their original characteristics. In addition, the accuracy of the group's spectral response measurements has been improved through the addition of an optical wedge.

Introduction: This report contains four sections. The first three sections present different aspects of work performed under our contract: 1) Science team support activities; 2) Calibration laboratory; and 3) Field experiments and equipment. The fourth section contains information related to faculty, staff, and students.

Science Team Support Activities: This section refers to all work performed in support of MODIS and ASTER team activities as well as work performed for other sensor teams. Over the past six months this included the attendance at team and other related meetings and completing assigned action items. In MODIS-related activities, S. Biggar participated in a large fraction of the weekly teleconference calls coordinated by the MODIS Characterization and Support Team. Biggar and K. Thome attended the MODIS Science Team meeting held July 23-24 in Greenbelt where Thome presented results of the vicarious calibration of MODIS on both Terra and Aqua. Biggar and Thome also attended the related MCST, Land Discipline, and Ocean Discipline meetings held in conjunction with the MODIS Science Team meeting.

ASTER-related activities consisted of attendance by Biggar, Thome, and E. Zalewski at a US ASTER Calibration Team (ACT) Meeting in Flagstaff, Arizona July 17-18 where Thome presented the University of Arizona’s results on the radiometric calibration of ASTER reflective bands. This meeting also served as preparation for the larger joint ACT meeting held July 30-31 and attended by Thome who presented similar material at that meeting. Biggar, C. Cattrall, and Thome attended the ASTER Science Team Meeting held in Palm Springs, California from December 2-5 as well as the US ASTER Science Team Meeting held December 1. Biggar presented recent results related to the SWIR crosstalk effect at both meetings and Thome presented the vicarious calibration results of ASTER as well. In addition, Thome chaired the Atmospheric Correction Working Group Meeting where he presented a sensitivity of the reflective bands to water vapor absorption, improvements to the atmospheric correction to reduce artifacts due to input conditions. Cattrall presented plans for the implementation of a new MISR aerosol model into the correction of ASTER.

In related activities, Biggar attended the Annual SPIE meeting in San Diego where he presented the results of a study to evaluate the feasibility of resurfacing field reflectance standards. Biggar also chaired a session on Earth Observing Sensors. Thome attended the 34th COSPAR Scientific Assembly - The Second World Space Congress in Houston, Texas and presented a talk entitled “Radiance validation of MODIS in the solar reflective.” A similar talk was given by Thome to the Optical Sciences Center at the University of Arizona and at the International Symposium for Photogrammetry and Remote Sensing held in Denver, Colorado.

Calibration Laboratory: This section describes the laboratory work used to ensure that the results from the field measurements are consistent with each other and to NIST-standards. To this end, the RSG relies on a set of cross-calibration radiometers (CCRs) that cover the wavelength region from 400 to 2500 nm and are ultrastable with respect to temperature and time. These radiometers were used to provide an independent calibration and cross-calibration of the calibration facilities used for the preflight calibration of EOS sensors. In addition, the RSG has developed a calibration laboratory that includes the capability of absolute radiometric calibration using NIST primary standards of spectral irradiance, a 40-inch spherical integrating source, a collimator for field of view measurements, and a double-pass monochromator for spectral characterization.

Work during this period related with our laboratory activities included a study to improve the accuracy of measurements of the spectral transmittance. The approach to this is the addition of an optical "wedge" into the double-pass monochromator. This device prevents stray light reflected in the system from causing a bias in the transmittance characterization. C. Burkhart and B. Garland implemented a wedge insert to the monochromator and tested the effect of the device. Garland found that the wedge has significant impact on the measurement of interference filters (as predicted) but no effect on absorption filters (again as predicted). Figure 1 shows an example of the difference seen between the wedge in and wedge out. The results for the interference filter centered at 667 nm are clearly larger than the difference seen for the broader absorption filter that is a NIST reference. The approximately 0.5% difference seen for the absorption filter is within the uncertainty of the measurement device. The 4-8% difference seen in the interference filter far exceeds the measurement uncertainty. Preliminary investigation by Biggar on the effects of the wedge-based results on the calibration of the VNIR cross-calibration radiometer

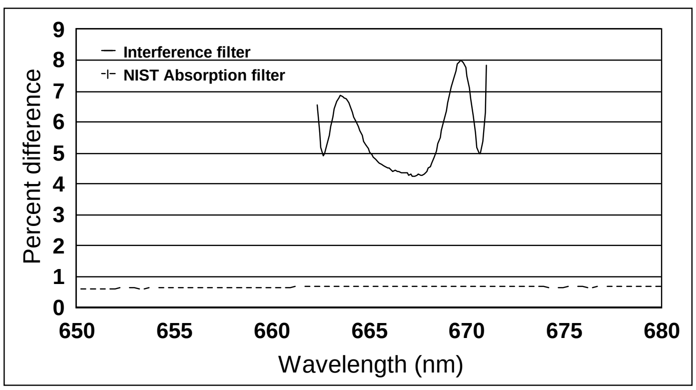
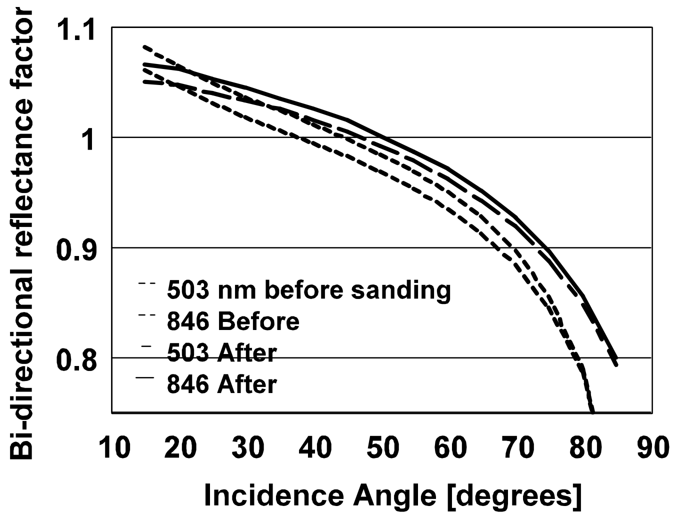


Figure 1 Percent difference in measured spectral transmittance of two spectral filters with and without a wedge insert in the RSG monochromator.



indicate that the agreement with NIST-based comparisons should improve.

A second area of work during the period was completion of a study to examine the feasibility of resurfacing older field reference standards of reflectance. Work by the RSG relies heavily upon the knowledge of the reflectance of Spectralon-based field references. These panels are characterized in the RSG's blacklab to obtain the panels reflection as a function of incident irradiance angle. Several of the references that have been used by the RSG have been in use for an excess of 10 years and have suffered definite degradation, becoming yellower and less lambertian. N. Anderson and Burkhart developed techniques and equipment to sand these references to roughen the surface (making it more lambertian) and to remove the layer of yellowed material. A sample of the results is shown in Figure 2. Four lines are shown on the graph two for the wavelength 503 nm and two for 846 nm. The two lines for each wavelength represent the bi-directional reflectance factor of the panel before and after sanding. A perfectly lambertian panel would have a value of unity at all angles for the reflectance factor. From the figure, it is clear that sanding has made the panel more lambertian (lines at both wavelengths are flatter after sanding). In addition, the separation between the two wavelengths decreases after sanding implying that the wavelength dependence (yellowing) is smaller. The next step in this work will be to examine whether the resurfacing will make the panel similar to the original characteristics when first purchased. This would allow field researchers to improve their results without requiring time consuming laboratory measurements.

Other work in the laboratory consisted of measurements of the spectral and spatial quality of the ASD FieldSpec FRs used to measure the surface reflectance in the field. Results from the vicarious calibration of both MODIS and ETM+ show a small bias in the blue and green portion of the spectrum. Two postulated sources of this bias are out-of-band sources of light and out-of-field response. The out-of-band error would imply that light from one portion of the spectrum is scattered into another while the stray light implies that the field of view is actually larger than specified. Initial measurements of the field of view of the system indicated problems with the laboratory set up due to the design of the FieldSpec. These are planned to be redone in the next reporting period. The spectral out-of-band measurements relied on using colored LEDs as sources as well as a secondary measurement using interference filters to isolate a specified portion of the spectrum and determine whether energy manifests itself at other wavelengths. These approaches were selected because of the low-cost aspect to the test and negated the need for expensive tunable lidars. Preliminary results of the spectral characterization show no stray light in the FieldSpec FRs.

Field Experiments and Equipment: The objectives of the field experiments are to test new equipment, determine needed improvements, develop and test retrieval algorithms and code, and monitor existing satellite. Numerous field campaigns were undertaken during the reporting period related to both ASTER and MODIS, as well as several additional campaigns which were supported through the group's Landsat and EO-1 funding. A total of six field experiments took place during the reporting period. Of these, the most disappointing trip was December 28-30 to Railroad Valley for maintenance of the RSG's meteorological equipment and Cimel sunphotometer deployed at the site. Unfortunately, a breakdown of the vehicle used to make the trip prevented Thome from getting to the site.

Other campaigns during the period were more successful. The initial calibration activity for Aqua MODIS took place July 11-15 with Garland, M. Mavko, and Thome participating. The dates of primary interest to this project were July 13 for a nadir overpass of Aqua MODIS and a July 12 overpass of Terra MODIS with a 12-degree view. Less favorable views by Aqua MODIS on the 11th and 15th were also attempted. Unfortunately, poor weather prevented usable data from being collected on July 11, 12 and 15, but clear skies prevailed on July 13 and these results are shown in Figure 3 and discussed in more detail below.

An extensive campaign to Railroad Valley and Ivanpah took place August 10-22. A total of five personnel from RSG participated in portions of this work (K. Canham, Cattrall, M. Kuester, Mavko, and Thome). In addition, L. Ong from the EO-1 project at Goddard Space Flight Center participated in the campaign from August 12-14. The plans for the campaign were overpasses of Aqua MODIS at Railroad Valley on Aug. 12 (26 degrees), Aug. 14 (4 degrees), Aug. 16 (20 degrees), and Aug. 19 (35 degrees), where the angles in parentheses are the view angles of the sensor on that day. Terra MODIS overpasses occurred on Aug. 11 (12 degrees), Aug. 15 (32 degrees), Aug. 18 (20 degrees), and Aug. 20 (2 degrees). The Aug. 20 date for MODIS was also used for ASTER (as well as ETM+, ALI, and Hyperion) and in addition the group collected data on Aug. 13 at Ivanpah Playa for ASTER, ETM+, ALI, and Hyperion. Successful data collections were made on all dates except for Aug. 19 which suffered from strong winds and clouds. Another key result of this campaign was that the group collected data at both Lunar Lake and Railroad Valley on Aug. 20 for both ASTER and ETM+. Results from all dates are discussed in more detail below.

A follow-up campaign to this trip was made one month later from Sept. 21-22 for a nadir view of the Terra platform and ETM+ at Railroad Valley on the Sept. 21 and a 14-degree view by Aqua MODIS on Sept. 22. This trip consisted of Kuester, Mavko, and Thome and had successful data collections on both dates leading to the results discussed below. A similar campaign took place Nov. 1-2 to Ivanpah Playa and Railroad Valley with a collection at Ivanpah for a nadir view by ASTER and ETM+ and then Railroad Valley for a nadir view by Aqua MODIS on November 2. J. Czapala-Myers, Mavko, and Thome participated in this campaign and successful data were collected on both dates. This November trip was mimicked identically on Dec. 3-4 by Czapala-Myers, Mavko, Thome, and W. Wisnieski. The group was also joined by ASTER scientists from Japan on Dec. 3 and by a group representing the Japanese sensor, GLI, on both dates. Unfortunately, wet conditions on the Ivanpah Playa on Dec. 3 forced the RSG to cancel the data collection on this date while good data were collected on Dec. 4 at Railroad Valley.

The results of the above work for ASTER are summarized in Figure 3. There are no results for August 13 because ASTER imagery have not yet been located in the data archive and this is also the case for the November 2 date as well. One key conclusion that can be drawn from this figure are that the VNIR bands (1-3) have all degraded since early in the lifetime of the sensor (June 2000) with band 2 showing the largest change. Also noticeable is the noticeable difference between the Lunar Lake and Railroad Valley results from August 20. In the VNIR this difference ranges from 5-7% that is larger than would be expected. Further investigation of these data are underway. Figure 4 shows a similar graph to Figure 1 except for Landsat-7 ETM+ results for the same date except scaled to June 11, 2000 (June 4, 2000 results show similar values except Band 3 of ETM+ was saturated). Of note in Figure 4 is the smaller variation with date, band, and from early in the mission. Thus, the Lunar Lake data for ASTER could be indicative of an anomalous behavior at the edge of the scene or with smaller test sites.

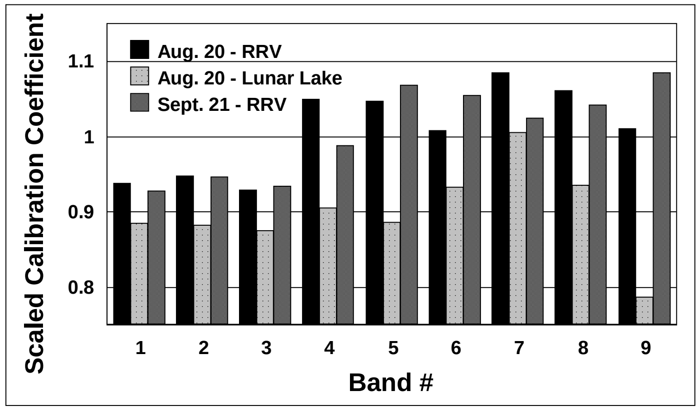


Figure 3 Summary of ASTER results from data sets collected during the 6-month reporting period. Values shown are scaled calibration relative to results from June 4, 2000.

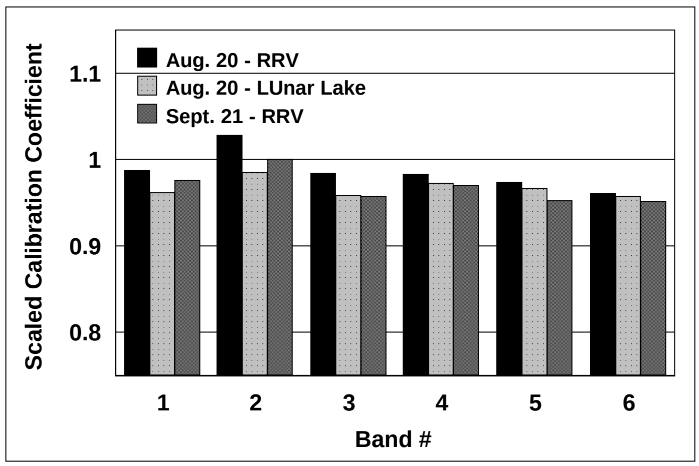


Figure 4 Summary of ETM+ results from data sets that coincide with ASTER data shown in Figure 3. These values are scaled to June 11, 2000.

The effect of smaller test sites on the results is clearly evident in the SWIR bands of ASTER where the known SWIR crosstalk effect plays a role. In band 9, the large amount of energy leaking from band 4 into band 9 for an extended site such as Railroad Valley is no longer present in the smaller test site of Lunar Lake. Thus, there is a distinct difference in the results of these bands, where band 4 shows the "bias" present in the VNIR bands. The ratios also indicate that there is likely very little change in the radiometric calibration of ASTER in the SWIR bands.

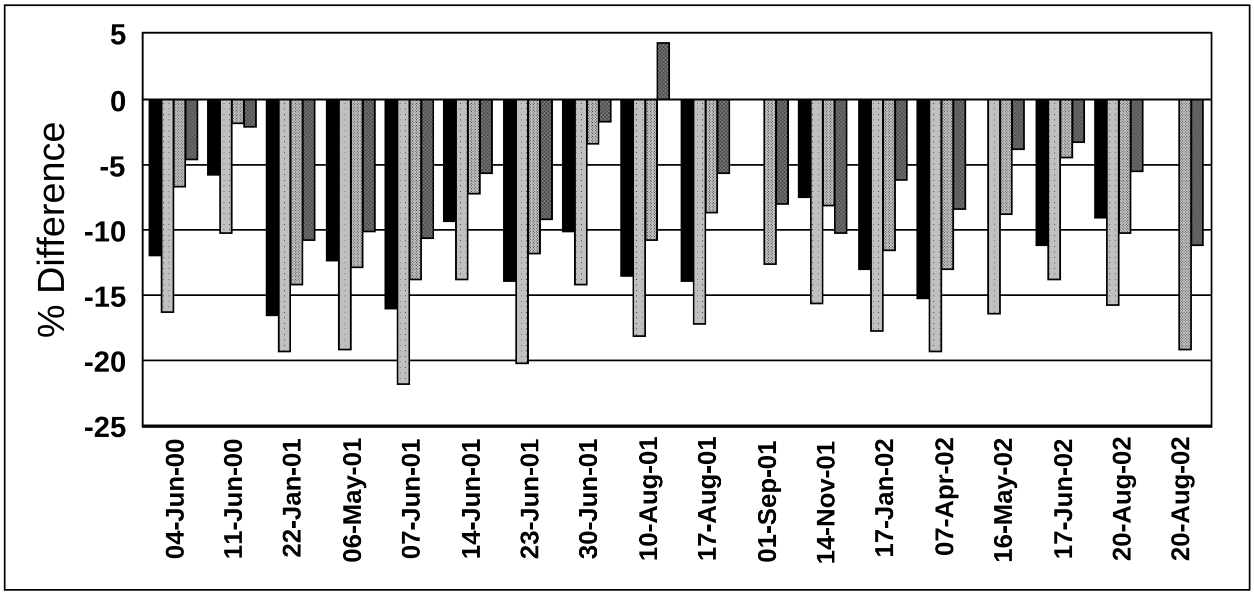


Figure 5 Percent difference between reported Level 1B ASTER radiances for all dates and sites and bands 1-4. Missing data for bands 1 and 2 are due to saturation.

Figure 5 puts all of the ASTER data from bands 1-4 for the Level 1B product of ASTER. There are fewer results for Level 1B than 1A due to saturation of bands 1 and 2 of the 1B product and several missing scenes. The graph shows the percent difference between the predicted radiance based on the vicarious calibration data and the reported Level 1B radiance from ASTER. In this figure, a negative value indicates that the vicarious predictions exceeds that of the reported radiance. Clear in this figure is the apparent bias between bands 1-3 and the field measurements. This bias varies with time but there is little to no temporal trend.

Averaging these data and comparing with results from ETM+ over the same period and dates is shown in Figure 6. That is, Figure 6 shows how the vicarious predictions and sensor output compare for

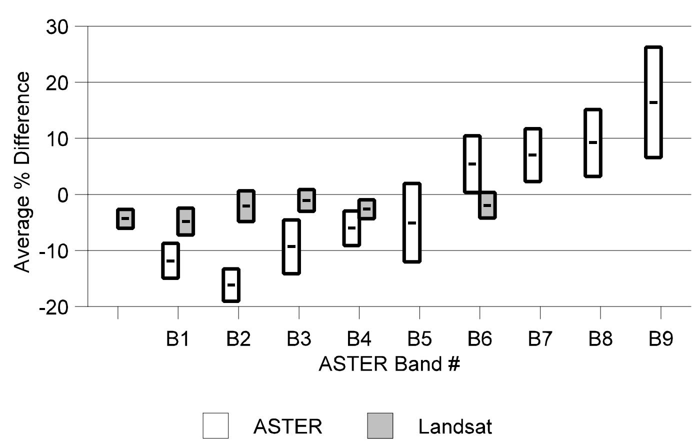


Figure 6 Comparison of average percent difference between vicarious predictions and reported radiance for ASTER and ETM+ bands.

ETM+ and ASTER using coincident dates for which data exists for both sensors during the period from June 2000 to September 2002. The bands listed in the figure are for those of ASTER and the ETM+ data are displayed with the nearest spectral band from ASTER (except band 1 of ETM+ for which there is no corresponding band). Focusing on Bands 1-3, it is clear that there is a bias with no overlap with ETM+. In addition, the standard deviations for ASTER are much larger than those of ASTER indicating a degradation in ASTER that is not corrected in the Level 1B processing. Band 4 shows reasonable agreement with ETM+ but with a larger standard deviation. This could be indicative of an unknown sensor artifact since temporal studies of the data do not show a degradation with time. The cross-talk effect is also clearly evident in all bands except band 5 of ASTER. This is of interest because band 5 should have a significant effect and the “good” agreement with the vicarious results for this data set could be due to the use of WRC solar model for ASTER and the MODTRAN4 solar model for ETM+.

Figure 7 summarizes the results during the reporting for MODIS on the Terra platform. These results are consistent with past work for the Terra MODIS sensor and results for both dates shown are reasonably consistent with each other and ETM+. Results for the 858 nm bands of the two sensors are larger than would be expected for the August dates and these are under investigation. All other results are well within the expected uncertainties of the reflectance-based approach as applied to the larger footprint of MODIS. Data from August 20 are not shown in this figure due to the fact that an equipment malfunction prevented surface reflectance collections of the MODIS site at Railroad Valley. Other dates are still under review at this time.

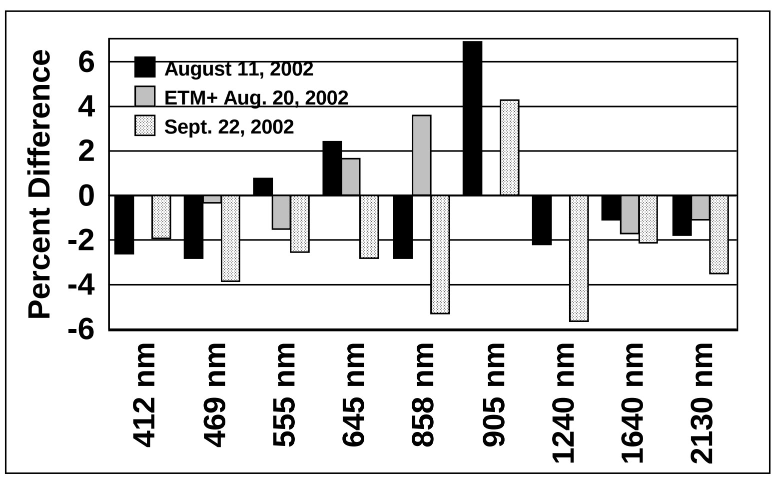


Figure 7 Summary of current reporting period results for Terra MODIS showing percent difference between the reported Level 1B radiance and the vicarious results. Also shown for reference are the results for ETM+ reflective bands on August 20, 2002

Figure 8 shows a similar graph to Figure 6 except comparing the ETM+ and Terra MODIS results from all coincident dates. This figure consists of results from a total of six dates. The encouraging fact is that all coincident bands of the two sensors overlap with the largest differences being only 3% in the red and NIR bands. Also clear from these results are the fact that the 905 nm results are less accurate than other bands. This is most likely due to contamination by water vapor in the surface reflectance measurements. In addition, it should be noted that the standard deviations of the two data sets are also comparable with the blue bands of MODIS having larger standard deviations than the ETM+ and the red and NIR bands of ETM+ being larger. Further work to perform direct cross-comparisons between ETM+ and MODIS are underway.

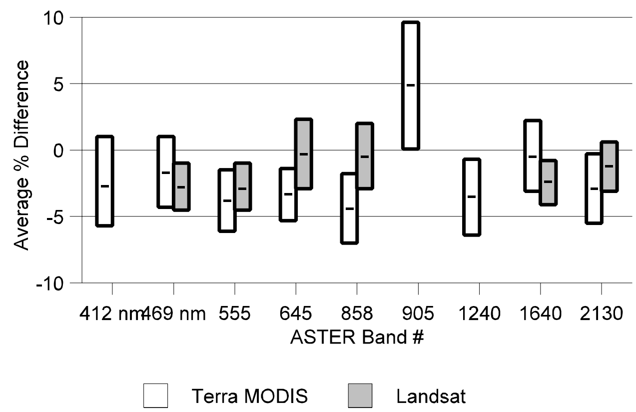


Figure 8 Comparison of average percent difference between vicarious predictions and reported radiance for MODIS and ETM+ bands for identical dates

The final set of results that were completed during the reporting period were those from the Aqua MODIS sensor. This represents the initial results for Aqua and a total of five data sets have been processed at this point. The results of all dates processed to this point are shown in Figure 9 as well

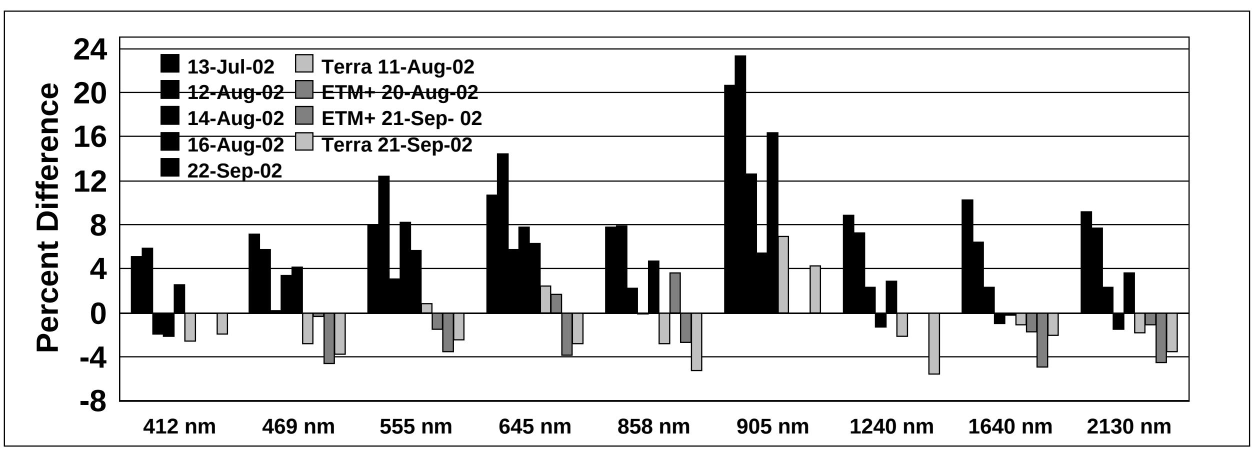


Figure 9 Summary of percent difference between reported Level 1B radiance from Aqua MODIS and those predicted by the vicarious resuls.

as results from ETM+ and Terra MODIS for near-coincident dates in August and September. Of the data sets shown, the July 13 and August 14 data sets represent nadir looks by the Aqua sensor. The view angles on the other two August dates were 26 and 20 degrees respectively. The view angle for the September 22 date was 14 degrees. Past work with Terra MODIS has shown that the results are not sensitive to BRDF effects within these range of view angles. Thus, it is surprising to see the level of disagreement between the Aqua and Terra MODIS sensors. This disagreement is in excess of the uncertainties of the approach and further work is underway to understand this possible difference.

Faculty, staff, and students: The personnel associated with the RSG during the reporting period and receiving some level of funding from the RSG's EOS contract were as follows: Faculty: S. Biggar, C. Cattrall, K. Thome, and E. Zalewski. Staff: C. Burkhart, R. Kingston, R. Pylman, and S. Recker. Students: N. Anderson (undergrad), K. Canham (undergrad), T. Chen (Ph. D.), J. Czapala-Myers (Ph. D.), B. Garland (Ph. D.), M. Kuester (MS), M. Mavko (undergrad), J. Pina (undergrad). Of this list of personnel, Cattrall joined the group in August as an Assistant Research Scientist to assist with the atmospheric correction of ASTER and to further formalize the RSG's processing software and Chen joined as a graduate research assistant in October. Pina joined the group as an undergraduate intern for the Fall 2002 scholastic semester and graduated in December along with Anderson, who was also named the Optical Engineering Departments Outstanding Graduate. Mavko completed his bachelor's degree in Physics and left the group in December. Czapala-Myers successfully passed his written and oral preliminary examinations for the PhD during the reporting period and Kuester successfully defended her MS thesis on a new approach for analyzing solar radiometer data for calibration of the instrument.

Papers and publications

The list of publications below are those which were published during the reporting period containing research results funded through the RSG's EOS contract.

Anderson, N., S. Biggar, C. Burkhart, K. Thome, M. Mavko, "Bi-directional calibration results for the cleaning of Spectralon reference panels," *Proc. of SPIE Conf. #4814,* Seattle, pp. 201-210, 2002.

Biggar, S. F., K. J. Thome, W. T. Wisnieski, "In-flight radiometric calibration of the Advanced Land Imager and Hyperion sensors on the EO-1 platform and comparisons with other earth observing sensor, *Proc. of SPIE Conf. #4814,* Seattle, pp. 289-295, 2002.

Teillet, P. M., K. J. Thome, N. P. Fox, J. T. Morisette, "Earth observation sensor calibration using a global instrumented and automated network of test sites (GIANTS), *Proc. SPIE Vol #4540*, Crete, Greece, 2002.

K. Thome, R. Barnes, G. Feldman, "Intercomparison of ETM+, MODIS, and SeaWiFS using a land test site," *Proc. SPIE Conf. #4881,* Crete, Greece, 2002.

K. Thome, M. Kuester, and J. Reagan, "Cirrus spectral optical depths retrieved from solar transmittance measurements," *International Geoscience and Remote Sensing Symposium*, Toronto, Canada, 2002

K. Thome, "Ground-look radiometric calibration approaches for remote sensing imagers in the solar reflective," *Proc. ISPRS*, Denver, 2002.