Semi-annual EOS Contract Report

Period: January 1 -June 30, 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. 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+.

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, K. Thome attended the launch and briefing of the Aqua platform the first week of May. Biggar participated in a large fraction of the weekly teleconference calls coordinated by the MODIS Characterization and Support Team.

In ASTER-related activities, Biggar and Thome attended the ASTER Science Team Meeting held in Pasadena from January 15-18 as well as the US ASTER Science Team Meeting held January 14. Thome presented the vicarious calibration results of ASTER and chaired the Atmospheric Correction Working Group Meeting where he presented the validation of the VNIR/SWIR reflectance retrieval. The two also attended the ASTER Science team meeting held in Tokyo from May 21-23 as well as the US ASTER Science Team Meeting held May 20 and the ASTER Workshop held May 24. 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 plans for the implementation of a new MISR aerosol model into the correction of ASTER and effects of assumed solar irradiance models on the retrieval of surface reflectance. Biggar and Thome also attended an ASTER ACT Meeting held in Tokyo February 26-27 where Thome presented the RSG's results for the vicarious calibration of ASTER.

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 beginning a study to improve the accuracy of measurements of the spectral transmittance. Past work indicated that significant differences existed between the predicted spectral irradiance from a NIST standard and measured values with the VNIR CCR. Much of the difference was traced to uncertainties in the knowledge of the spectral transmittance of the interference filters used in the instrument. These filters are measured by the RSG using the group's double pass monochromator and the transfer radiometer was then calibrated with a set of standards of spectral irradiance (FEL type, calibrated, quartz-halogen, 1KW lamps). The calibration was also calculated but the calibration based on measuring a known lamp did not agree well with the computed calibration, being between about 2 and 12 percent different, depending on the band. As the estimated uncertainty of the measured calibration is less than 2.5% and the computed calibration should be even better, the difference was troubling.

We procured NIST standard reference material (SRM) filters to check the calibration of the Optronic used for filter transmittance measurements. The measurement of the NIST SRM filters was well within the expected uncertainty. However, the NIST SRM filters are absorbing glass filters rather than interference filters as used in the transfer radiometers. After using the transfer radiometers to make window transmittance measurements on a multiple pane window assembly which is now in the International Space Station laboratory module, E. Zalewski realized that the filter transmittance accessory design was possibly allowing “enhanced forward transmittance” to make the measurements of interference filters incorrect. If “enhanced forward transmittance” was effecting the measurements, the measured transmittance of interference filters would be too high. The computed calibration of a filter radiometer would then give a calibration too high. Figure 1 presents the difference in calibration (calculated - measured) for the transfer radiometer based on four different measurements in late 1995 and early 1996 showing that the radiometer calibration was repeatable, but the differences are larger than expected. Note that the error is positive in all bands as predicted by theory. In order to reduce the errors in the measurement of interference filters, a glass wedge design was begun. 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 designed a wedge insert to the monochromator

A second area of work during the period was the start 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 designed and implemented an approach to sand these references to roughen the surface (making it more lambertian) and to remove the layer of yellowed material. Work will continue on this study to evaluate whether the reference panels can be returned to their original state via sanding.

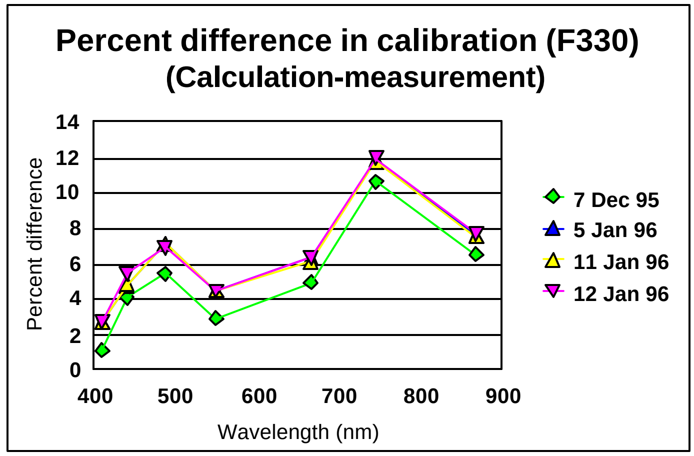

Figure 1 Percent difference between calculated and measured calibration of transfer radiometer

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 seven field experiments took place during the reporting period. This included attempts to collect data for overpasses of Terra at Railroad Valley Playa on February 9, March 13, May 14, May 16, June 15, and June 17. Overpasses for the calibration of ASTER at Ivanpah Playa during this period took place on January 1, January 17, March 22, April 7, June 10. Of these, the weather on January 1 and March 22 at Ivanpah, and March 13 at Railroad Valley prevented any data from being collected. In addition, the calibration attempt on June 10 at Ivanpah for ASTER was unsuccessful due to an error in scheduling the sensor.

Other campaigns during the period were more successful. The work at Ivanpah Playa on January 17 was held in combination with the ASTER Science Team Meeting in Pasadena to allow participation of members of the Japanese Science Team. The weather for this overpass was clear and the data collection was successful. The results from this work are included in the discussion below. Similarly good results were obtained for the overpasses at Railroad Valley on February 9, May 14, May 16, June 15, and June 17. The collection at RRV Playa on May 14 was done only for MODIS and that of June 15 included an off-nadir view of 23 degrees by ASTER (and likewise MODIS).

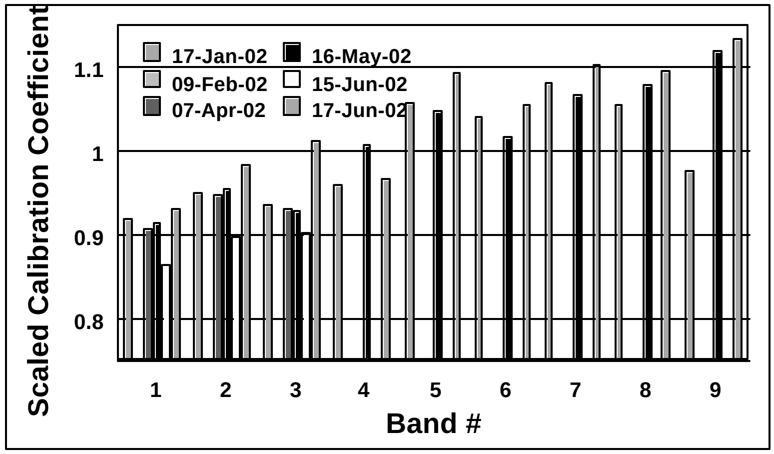

Figure 2. Summary of ASTER results from data sets collected during the 6-month reporting period. Values shown are scaled calibration relative to results from June 4, 2000.

The results of the above work for ASTER are summarized in Figure 2. 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. Missing data in the SWIR bands are due to off-nadir views by ASTER which do not include SWIR collections and data from February 9, 2002 are not available in Level-1A format. Figure 3 shows a similar graph to Figure 2 except for Landsat-7 ETM+ results for the same dates except scaled to June 11, 2000 (June 4, 2000 results show similar values except Band 3 of ETM+ was saturated). Of note in Figure 3 is the smaller variation with date and band, for ETM+ from early in the mission. Also note that several of the dates show similar trends for both ETM+ and ASTER indicating possible biases in the ground-based measurements. These results will be used to understand better the vicarious approach with the hope of reducing uncertainties in the data sets.

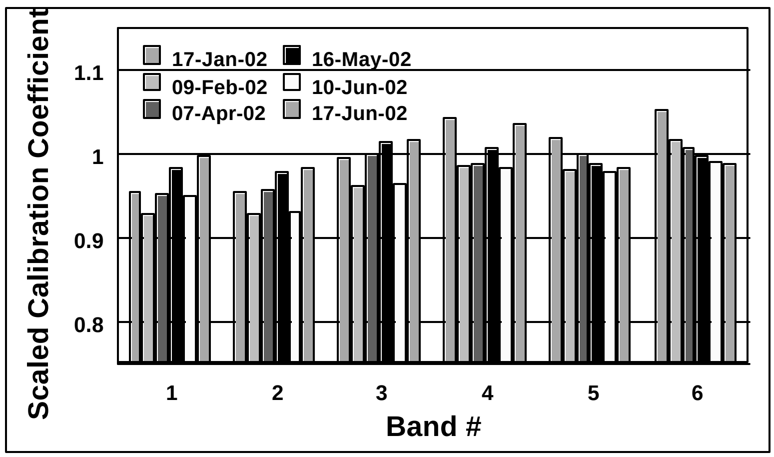

Figure 3. Summary of ETM+ results from coincident data sets shown for ASTER in Figure 1. Values shown are scaled calibration relative to results from June 11, 2000.

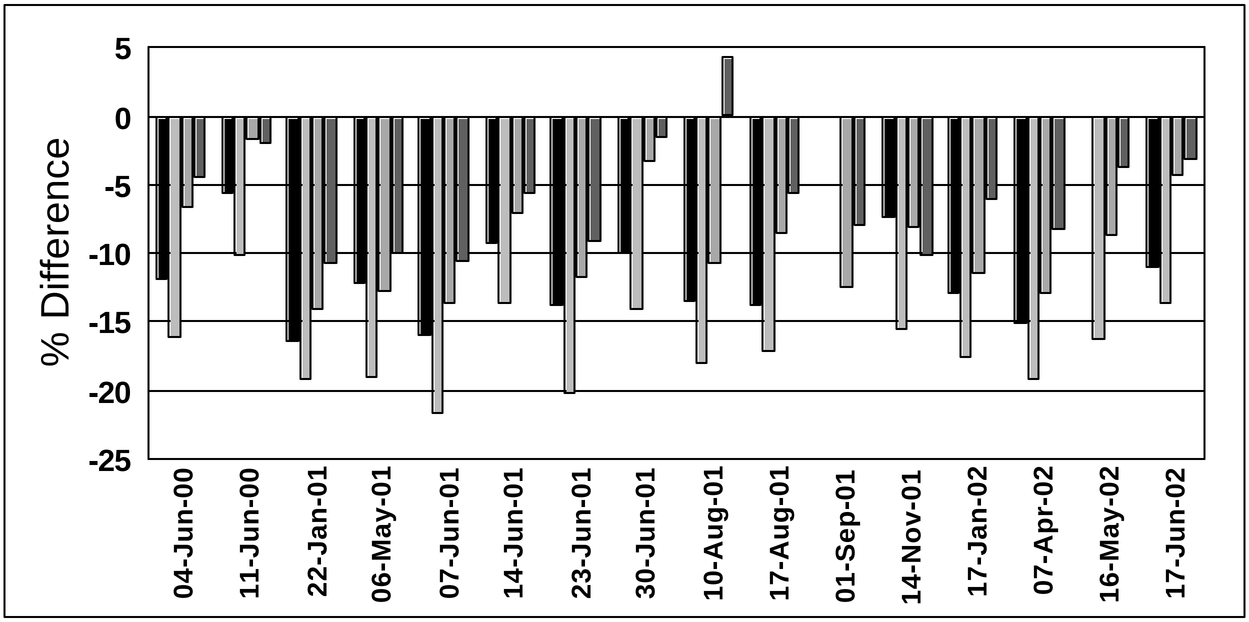

Figure 4. Percent difference between reported Level 1B ASTER radiances for all dates and sites and bands 1-4. Missing data for bands 1 and 2 are due to saturation

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 4 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 5. That is, Figure 5 shows how the vicarious predictions and sensor output compare for ETM+ and ASTER using coincident dates for which data exists for both sensors during the period from June 2000 to June 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 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 SWIR bands except bands 4 and 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+.

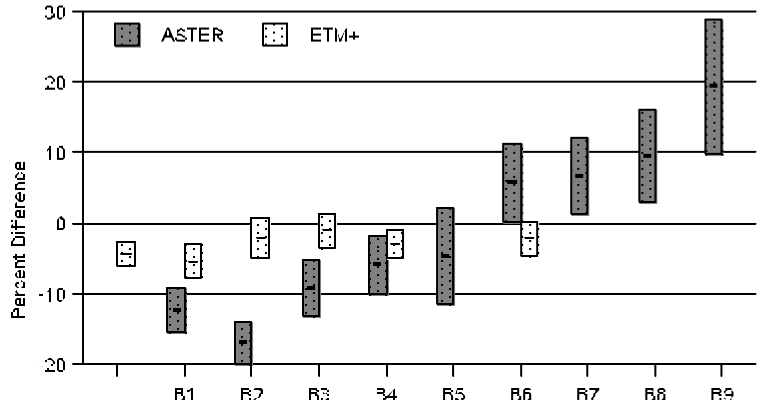

Figure 5. Comparison of average percent difference between vicarious predictions and reported radiance for ASTER and ETM+ bands.

Figure 6 shows a more detailed comparison between the vicarious predictions and those from ASTER for the June 30, 2001 collection at Railroad Valley. There are three sets of results are shown for each of the nine ASTER

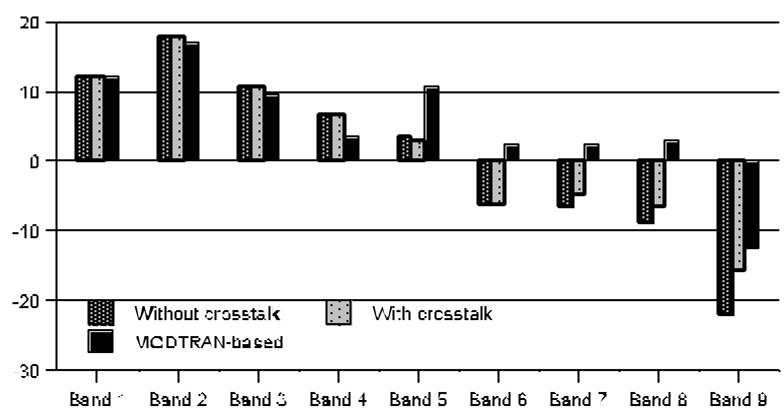

Figure 6. Comparison between ASTER and vicarious data collected on June 30, 2001 at Railroad Valley Playa.

spectral bands in the VNIR and SWIR. All results show the percent difference between ASTER and the predicted at-sensor radiance from the ground-based data. The first set of results are the comparison where no crosstalk correction has been applied. The second includes a crosstalk correction to bands 5-9 based on software supplied by ERSDAC. The final set of results is the same as the uncorrected Level-1B except that the MODTRAN-based solar irradiance is used as opposed to the WRC. Of note is that the crosstalk software does improve the comparison with the vicarious but not enough to account for the entire difference between the vicarious and sensor-based results. The use of the MODTRAN solar irradiance has a significant impact on the results due to the large difference between the WRC model and MODTRAN solar irradiances in the SWIR. In this case, all bands except band 5 are improved in the comparison.

A comparison between AVIRIS and ASTER on June 30, 2001 is shown in Figure 7. The AVIRIS data in this case have been corrected for the small amount of atmosphere above the ER-2 flight altitude as well as the two-minute difference in overpass time between ASTER and AVIRIS. The AVIRIS data were also band-averaged to the ASTER spectral responses except for band 9 of ASTER which is omitted due to the lack of AVIRIS bands in this spectral region. Clear in this figure is the bias in the VNIR bands as well as significant differences in the SWIR. Further analysis of these data is underway to better understand the SWIR results. Unfortunately, MODIS was not operating on this date so no similar comparison is available.

A summary of the MODIS results is given in Figure 8. These results are consistent with past work for the Terra MODIS sensor. Of interest is that the percent difference is larger for the two off-nadir dates than for the nadir views. BRDF measurements of the surface do not indicate that such a difference should exist, thus further work is being done to determine the cause of this difference. Results for the

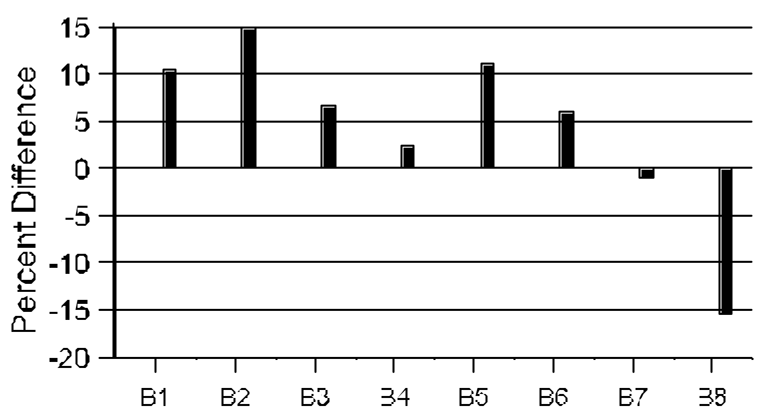

Figure 7. Percent difference between AVIRIS and ASTER on June 30, 2001 at Railroad Valley Playa.

nadir-view dates compare well with ETM+ results indicating that the reflectance-based approach works well for both the large and the small footprint case.

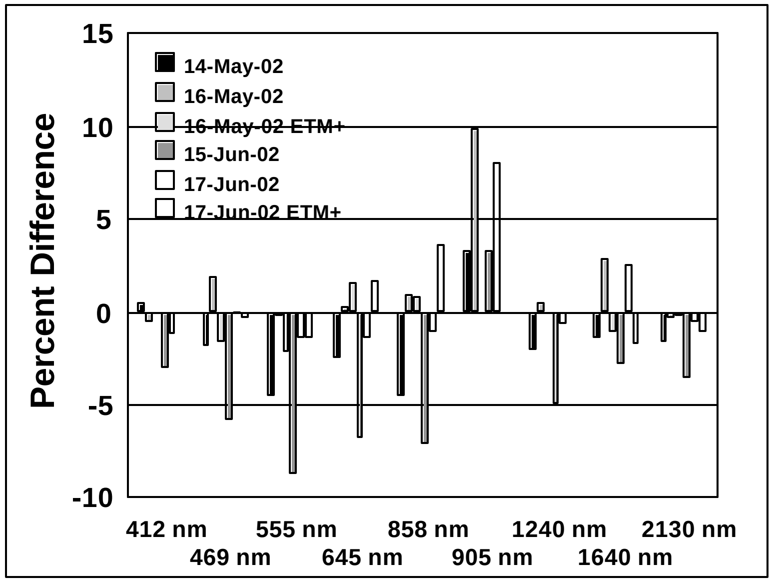

Figure 8. Summary of current reporting period results for Terra MODIS showing percent difference between the reported Level 1B radiance and the vicarious results. Also shown for reference are the results for ETM+ reflective bands on August 20, 2002

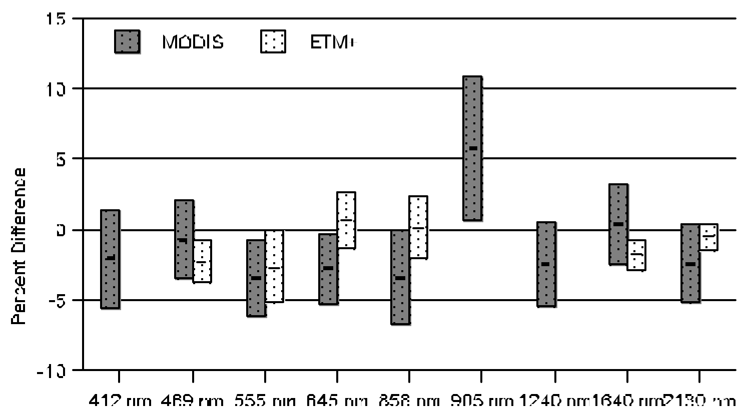

Figure 9. Comparison of average percent difference between vicarious predictions and reported radiance for MODIS and ETM+ bands for identical dates

Figure 9 shows a similar graph to Figure 7 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.

<u>Faculty, staff, and students</u>: 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, K. Thome, and E. Zalewski. Staff: C. Burkhart, R. Kingston, R. Pylman, and S. Recker. Students: N. Anderson (undergrad), K. Canham (undergrad), J. Czapala-Myers (Ph. D.), W. Garland (Ph. D.), M. Kuester, M. Mavko (undergrad), N. Smith (PhD). Of this list of personnel, W. Garland joined the group during the reporting period and Smith left the group at the end of the reporting period.