Semi-annual EOS Contract Report -- Report #72

Period: July 1 - December 31, 1997

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

Principal Investigator: P. Slater

Contract Number: NAS5-31717

Report compiled by: K. Thome

Summary: Processing of data from the joint vicarious calibration that took place the latter half of June in the last reporting period occupied much of the group's efforts during this six-month reporting period. Results from the field portion of the campaign were sent to the EOS Calibration Scientist two weeks after the campaign ended. Updated results, based on reference panel calibrations supplied by the RSG, were sent in by groups that used the measurements from the RSG and agreement is better than 7% for most bands and better than 4% between results of the RSG and the JPL group from MISR. Other work during the past six months consisted of Science Team support activities including the attendance at meetings related to MODIS and ASTER. In addition, K. Scott continued work on the cross-calibration software package by completing a beta version of the package. The group sent six members to the San Diego SPIE meeting where five papers from the group were presented and S. Biggar chaired a session on EOS calibration. E. Zalewski organized the Newrad '97 Conference where P. Slater chaired a session on solar irradiance characterization and Biggar and K. Thome presented papers on the VNIR CCR calibration and 1996 Lunar Lake campaign respectively. Evaluation of the diffuse-to-global instrument continued as did work on the BRDF camera. Data were collected to examine the accuracy of three methods for calibrating the VNIR CCR and field campaigns were made to White Sands Missile Range and Railroad Valley Playa.

Introduction: This report contains eight sections. The first seven sections present different aspects of work performed under our contract. If appropriate, each section covers five areas; task objective, work accomplished, data/analysis/interpretations, anticipated future actions, and problems/corrective actions. The first seven sections are: 1) Science team support activities; 2) Cross-calibration radiometers; 3) Bi-directional reflectance distribution function (BRDF) meter;

4) Diffuse-to-global meter; 5) Calibration laboratory; 6) Algorithm and code development; and 7) Field experiments and equipment. The eighth 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.

ASTER Activities:

K. Thome met in Pasadena with B. Eng on September 18 to discuss work on the code development of the atmospheric correction of ASTER. Thome attended the WAVES meeting October 20-21 in Hampton, Virginia where he presented the validation plans for ASTER. S. Biggar, J. LaMarr, and Thome attended the US ASTER Science Team Meeting in Tokyo on December 8 where Thome presented the results of the 1997 Joint Vicarious Calibration Campaign. Biggar and Thome attended the Joint ASTER Science Team Meeting December 9-12. Biggar co-chaired the Radiometric Calibration Working Group Meeting and presented work the RSG has done with their cross-calibration radiometers. Thome presented the status of the calibration plan for ASTER and the special-issue paper on ASTER calibration. Thome co-chaired the Atmospheric Correction Working Group Meeting and presented the current status of the VNIR/SWIR atmospheric correction, results of the joint Lunar Lake campaign, and the previous week’s SWAMP Land Validation Meeting.

MODIS Activities:

K. Thome attended a meeting in Madison, Wisconsin September 11 and 12 where MCST described their work related to the TIR bands of MODIS. N. Che, H. Montgomery and B. Guenther of MCST traveled to Tucson on September 17 to meet with Biggar, Thome, and Zalewski and they described the results of the algorithm development and characterization of the SRCA of MODIS. B. Schowengerdt, PI of a recently selected MTPE Validation proposal for evaluating MTF effects of MODIS, also attended the briefing. Biggar and Thome attended the MODIS Science Team Meeting in College Park, Maryland that was held October 22-24.

Other EOS Related Activities:

In September, P. Slater attended the IGARSS'97 meeting in Singapore where he co-chaired, with MODIS Science Team Leader, V. Salomonson, a session titled "High Resolution Sensors". He gave a talk titled "Solar-Radiation-Based Calibration" to CSIRO and University of Curtin members in Perth, Western Australia. In the same month, Slater also chaired a session on "Sensor Calibration" at the EUROPTO meeting in London. S. Biggar, B. Crowther, J. LaMarr, R. Parada, P. Spyak, and E. Zalewski attended the SPIE conference in San Diego the week of July 28. Biggar chaired a session of the conference related to EOS calibration. Crowther presented a paper on the cosine collector of the diffuse-to-global meter, and LaMarr presented his work on the autotracking solar radiometer. Because M. Sicard was unable to attend, Spyak described the work he and Sicard did with the Cimel TIR radiometer. Spyak also presented a paper on modeling laboratory transmittance in the SWIR, and Parada gave a talk on calibrating the MMR in the laboratory and field.

Thome met with the MISR Validation Team on September 19 to discuss the results of the Lunar Lake campaign. Biggar prepared data from the VNIR cross-calibration radiometer (CCR) for a poster presentation at the Newrad Conference organized by E. Zalewski and held in Tucson at the end of October. Biggar also presented an additional paper on the CCR for the conference and Thome presented the results of the 1996 Lunar Lake campaign. Slater chaired a session of the Newrad Conference related to solar irradiance determination. Based upon discussions at the Newrad meeting on the results of the preflight calibration of Landsat-7 ETM+, Biggar sent a memo about the VNIR/SWIR calibration of MODIS using the SIS to R. Murphy recommending procedures to account for drift of the SIS during calibration. The day after the Newrad meeting was used to hold a discussion of the 1997 Lunar Lake results that included representatives from JPL from MISR, CCRS, South Dakota State University, CNES, CERT, and NIST. Thome attended the SWAMP Land Validation in College Park held Dec. 3-5.

Cross-Calibration Radiometers: This section describes work related to a set of preflight cross-calibration radiometers (CCRs) that cover the wavelength region from 400 to 2500 nm. We have constructed two radiometers to accomplish this with each radiometer optimized for a specific portion of the spectrum. Both use interference filters for spectral selection and have low stray light and polarization responses, exhibit sharp, and well-defined fields of view and spectral response profiles. The radiometers are ultrastable with respect to temperature and time and have been used to provide an important independent calibration and cross-calibration of the calibration facilities used by the Phase C/D contractors. The VNIR CCR covers the 400- to 900-nm spectral range and is compared directly to NIST-calibrated and NIST-traceable standards of spectral irradiance. Biggar designed the radiometer with three silicon detectors in a "trap" configuration and two precision apertures determine the field of view. Heating the detector assembly, filters, apertures, and amplifier to a temperature a few degrees above ambient provides thermal control of the system. The SWIR CCR operates in the 1000- to 2500-nm spectral range. This radiometer is compared to NIST-calibrated and NIST-traceable standards of spectral irradiance and pressed PTFE (Algoflon) targets. The system is designed around an InSb detector. and the field of view is defined by a cryogenically-cooled baffle system. A chopper is used to optimize the signal-to-noise ratio and absorption filters provide additional out-of-band rejection.

Biggar modified the original SWIR CCR code to add error checking and forced configuration of the amplifier. Biggar collected data with the VNIR CCR viewing a Spectralon panel illuminated by a NIST primary source. A similar setup was used by Zalewski to calibrate the SWIR CCR and by LaMarr for an Exotech calibration. The SWIR measurements also included complementary data from the ASD. In addition, Biggar calibrated the VNIR CCR in irradiance mode using an FEL lamp and, at the same time, made measurements to evaluate the inverse-square law assumption applied to FEL lamps for adjusting irradiance for distance. This was done for three lamps, each at 2 wavelengths. Biggar found that a modified inverse-square law is required to accurately account for the distances different than the specified 50 cm.

In addition to the radiance and irradiance calibrations of the VNIR CCR, Biggar collected data for a solar-radiation-based calibration (SRBC) to check the results of the other two approaches. This SRBC included calculations based on updated solar irradiance data from G. Thuillier. These new solar irradiance values improved the comparison between the SRBC results and those from the laboratory at both the shortest and longest VNIR radiometer wavelengths. Biggar processed CCR data collected in October of the RSG's 40-inch spherical integrating source (SIS) and sent the radiance values to B. Kindel of the University of Colorado who had made concurrent measurements with their ASD FieldSpec FR used by ASD for absolute radiometric calibrations. Biggar also processed ASD FieldSpec FR data collected during the joint laboratory work last June for comparison with data from NIST.

Biggar and E. Zalewski traveled to GSFC November 17-20 to make measurements of GSFC's 42-inch SIS with the RSG's VNIR and SWIR CCRs for comparison with measurements made by groups from NIST and Ames. This SIS has been well characterized by NIST for uniformity and radiometric output and was used to evaluate the accuracy of calibration techniques used by the Ames group for radiometric calibration of aircraft-based sensors. Biggar and Zalewski also used the trip as an opportunity to make VNIR measurements of NRL's 40-inch SIS measurements. These measurements show that the output of the SIS increased by 2% at 412 nm during the one hour period after 6 of the 10 lamps were turned off. A similar effect was seen at the other wavelengths of the CCR, but with smaller changes. Biggar sent these results to J. Young of SRBS as well as comments about linearity measurements of the A/D converters in MODIS.

C. Burkhart developed a method for aligning the SWIR CCR to the 40-inch SIS that is repeatable to within 0.062 inches. He also designed an accessory shelf for the tripod of the SWIR CCR that allows the electronics boxes for the radiometer to be moved more easily and to keep wiring from becoming loose during moving the radiometer.

BRDF Meter: The objective for this task is to design and construct a device, and develop software for measuring the directional reflectance and inferring the bi-directional reflectance distribution function of the ground. The basic design incorporates a fisheye lens, a CCD-array detector, and interference filters for spectral selection.

P. Nandy determined the blocking-filter requirements for the operation of the BRF camera the aperture fully open (F/2.8) to eliminate spot-formation on the image plane as a result of the nearly-telecentric optical path of the system. Nandy relied on data collected with the 40-inch SIS to determine the requirements. He also used data collected over a barium sulfate panel illuminated by the sun. Nandy determined that a 2-mm, NG9 filter would fulfill most of the system requirements and he ordered and received an image-quality filter from Custom Scientific. Nandy measured the spectral transmittance of the magnesium-fluoride and uncoated BG-34 filters and the new NG-9 in the Optronic monochromator. Use of the two BG-34s also allowed measurement of the effectiveness of the anti-reflection coating. Surface figure and roughness were determined for all three filters using a WYKO interferometer setup. Nandy installed the filters and tested the system outside. Signal levels were close to predicted for the exposures used and a two-second exposure can be used without saturation while viewing a lambertian surface of unity reflectance during the summer at our test sites.

Nandy began calibrating the camera system using the 40-inch SIS and a precision 60-inch linear stage. C. Burkhart and Nandy discussed methods to mount the camera for calibration to allow repeatable alignment with the SIS. Biggar, Burkhart, and Nandy developed a method to attach the BRF camera to the linear stage and Burkhart machined the assembly. Biggar and Nandy also investigated methods to rotate the camera head while viewing the SIS. Data were collected with the camera system at multiple f-stop settings to compare data taken before and after installation of the new filter system. Multiple linear stage positions were used to obtain full illumination of the CCD array. Additional data were collected with the array rotated by 90 degrees to determine sphere uniformity. Nandy developed software to decouple the pixel-to-pixel variability of the CCD-array from the SIS non-uniformity using the linear and rotational translations. Preliminary results of the calibration show known defect regions in the CCD array and scanning artifacts.

Nandy began to evaluate the angular mapping of the BRF camera by mounting the camera head over a uniform grid of squares and taking multiple images at various elevations to determine focal plane offsets. He conducted tests to determine the best focus position for the camera lens. Nandy also designed and implemented graphical interface routines for the BRF data-processing programs. He began work on a polar deconvolution routine to produce results based on both constant-angular integration and constant-area integration. Dark current extraction routines were also included. A defective lens mounting bracket was replaced on the camera head. At the end of October, the BRF camera system was used as part of a White-Sands experiment. The camera was operated with the tripod at full elevation on the bed of the RSG's truck to increase the spatial sampling and the data are currently under evaluation.

<u>Diffuse-to-global meter:</u> The objective of this task was to design and build an instrument to collect diffuse-to-global irradiance data. By comparing the diffuse downwelling irradiance to the global (direct plus diffuse), an improvement to the atmospheric correction may be made which reduces the uncertainty of the reflectance-based method. Currently, global irradiance data are collected using a radiometer viewing a reflectance panel and diffuse data are collected by manually positioning a parasol to shade the panel. The diffuse-to-global meter will collect these data automatically and more repeatably.

J. Smith developed software to process the diffuse-to-global data. She used several shell scripts to handle the main "file housekeeping" and Excel spreadsheets to produce early results. The methods used in this preliminary processing were used to develop the main IDL program to process the raw diffuse-to-global data. This code interpolates the diffuse count to the time of the global measurement to correct for the 45-second difference between the two measurements. Smith wrote a module allowing the user to view each scan and an ephemeris module based on the calculations from Duffet-Smith to calculate the airmass and solar zenith angle. Smith added a correction for temperature variation of the Licor Spectrometer and sphere response. A graphical user interface is currently being developed to allow simple access to the processing routines.

While testing the diffuse-to-global instrument in preparation for field work, Smith found that the azimuth stage was unable to smoothly rotate the altitude assembly and determined that the stage did not operating to specification. B. Crowther and Smith contacted the manufacturer to remedy this situation and discovered that the manufacturer had made an error in the specification sheets for the current requirements of the azimuthal motor. The necessary modifications have been made and the motor now operates smoothly. This has allowed the automated stages to work properly and the instrument can now automatically track the sun and take measurements at predetermined time intervals.

Smith processed the diffuse-to-global-meter data from the Lunar Lake campaign. Data from all bands were processed using the Langley method to determine spectral optical depths and evaluate the performance of the system. Top-of-the-atmosphere counts for the direct solar signal and atmospheric optical depths were calculated for data collected on June 23, 24 (morning and afternoon), and 25. The optical depth results agree to within 0.003 in optical depth at short wavelengths and 0.015 at longer wavelengths with results from the RSG's 10-band solar radiometer for the same days. Smith also determined diffuse/global (D/G) ratios from the data and used these results to interpolate the D/G ratio to an airmass of 1 to be used in the irradiance-based calibration. Data from the White Sands made at the end of October have been processed and also show good agreement with the solar radiometer data. Smith tested the effect of obstructions within a 10-ft radius of the instrument. Preliminary inspection of the results show that there is a strong effect in the diffuse measurement from a strongly reflecting object that is 180 degrees from the solar azimuth.

Calibration Laboratory: The objective of this project is to develop a calibration laboratory that will provide the necessary high-radiometric-accuracy standards and characterization set-ups for 1) the cross-calibration radiometers and 2) the field and aircraft radiometers needed for preflight algorithm and code validation and the actual in-flight calibration of the EOS multispectral imaging sensors beyond 1998.

The major effort in the calibration laboratory was the aftermath of laboratory measurements made prior to the joint campaign to Lunar Lake. A total of 10 panels were characterized in both the VNIR and SWIR over a period of eight days for the campaign. Using software developed by Biggar, J. McCalmont reduced these data and sent the results to the campaign's participants. In addition to the BRF measurements in the RSG's blacklab, the 40-inch SIS was used to evaluate the field radiometers used by each group for surface reflectance retrievals. Processing of these data by the groups show that care must be taken to ensure that the radiometers have stabilized prior to their use and that use of these field radiometers in an absolute sense needs further study. These conclusions are especially true for the spectrometers that are being used in the SWIR.

At Biggar's direction, Z. Rouf made extensive measurements of our Algoflon samples. He collected several sets of data from -85 degree to +85 degree at 5-degree intervals to check the uniformity of the sample. These measurements were done for all of the bands in the VNIR with the radiometer fixed and the panel rotating and also for the panel fixed with the radiometer rotating. Rouf collected several data sets at 1-degree intervals at a few selected wavelengths. The entire procedure was repeated with the Algoflon sample rotated 90 degrees clockwise from its normal orientation. Finally Rouf measured the directional reflectance of our two field Spectralon panels and of the NIST panel. The NIST panel measurements were made with normal orientation and with a 90-degree, clockwise rotation. Biggar and Burkhart developed shims for the NIST panel measurements to ensure that it was properly aligned. Biggar processed the data from these measurements as well as those of the BRDF round-robin measurements and sent the results to C. Johnson of NIST. Biggar and J. Walker investigated the use of the Hapke model to predict the BRF of Spectralon and early results look favorable.

LaMarr and Rouf reassembled the Optronic OL750 monochromatic after the group's move. LaMarr trained M. Mienko and Rouf on the operation of the monochromator and the two started working with the monochromator to measure the transmittance of filters from our field radiometers. Mienko also began to characterize the SWIR filters being used by H. Kieffer of the ASTER Science Team to measure the lunar radiance. A. Ahmad, Biggar and Rouf began developing software to operate the Optronic monochromator in conjunction with a linear translation stage using a GPIB interface. Rouf established the GPIB connection for the Unidex 100 along with the stage with the host computer of the OL750. This stage will be used to change and hold the filters for the monochromator for transmittance measurement. Burkhart and E. Nelson made initial drawings for incorporating the linear stage as part of the OL750.

Algorithm and Code Development: Currently, several algorithms exist to perform our calibration work. The RSG has applied these algorithms as FORTRAN programs which are neither user friendly nor efficiently linked together into a single package. The task objective is to convert these existing codes into ANSI standard C in a user-friendly package with rules-based decision making in the package. The group is now also involved in the atmospheric correction of ASTER data in the solar-reflective portion of the spectrum

K. Scott continued work on the cross-calibration software. She modified the existing software to make it compatible with Silicon Graphics workstations and to upgrade the software to IDL 5.0. These changes will make the software more robust and portable, as well as eliminate some of the minor problems seen on the Sun workstations. She also removed commands that have become obsolete in the upgrade.

Scott installed the new version of the 6S (version 4.1) radiative transfer code and comparisons of results from the new and old versions agree well. More importantly, several key problems of the older version have been corrected. Specifically, TM band 1 can now be called and the format error in the apparent reflectance function has been corrected. Scott completed the pixel matching program that matches pixels between two images and calculates the error given the misregistration by the user. The site selection module finds a set of calibration sites within an image based on criteria given by the user. The selected sites are displayed so the user can review them and select the sites they wish to pass on to the calibration portion of the program. If too few or too many sites are found, the user redefines the site parameters and the procedure is repeated. Scott also included the calibration module that calls the 6S radiative transfer program and calculates the calibration coefficients for test image pixels. An error module will be developed that allows the variation of all important parameters that can introduce error into the calibration coefficient calculations.

Field Experiments and Equipment: The objectives of the field experiments are to test new equipment, determine needed improvements, test retrieval algorithms and code, and monitor existing satellites in much the same way as we shall for EOS sensors.

Thome processed the Lunar Lake data from 1800 UTC on June 24 to predict radiances

Table 1.
Normalized radiance results (W/m^2-sr-µm) from fast processing of June 24 data set at Lunar Lake Nevada submitted July 11 to the EOS Calibration Scientist

Band (nm)	CCRS	GSJ	MISR	Saga	SDSU	RSG
480	0.0972	0.0898	0.0901	0.0952	0.0866	0.0942
560	0.1150	0.1094	0.1077	0.1167	0.1059	0.1180
810	0.1441	0.1388	0.1404	0.1466	0.1425	0.1453
1690	0.1442				0.1452	0.1452
2220	0.1344				0.1277	0.1261

at the top of the atmosphere and sent the results to the other five groups. All of the groups submitted their predictions for top-of-the-atmosphere radiance to Thome who then compiled a report and submitted this to EOS calibration scientist, Jim Butler on July 11. The results of this early processing are summarized in Table 1 and show differences of less than 11% for the triangular bands used. The blank entries in the table are due to groups either not having data for the SWIR portion of the spectrum (Saga and GSJ) or not having the capability to determine atmospheric transmittance in the SWIR (MISR). Because of the rapid processing required for these early results, it was not possible for the groups to use the RSG's blacklab measurements. Subsequent processing of the remaining data and reprocessing of the June 24 data set included these data. All data were processed by each group prior to the October 30 meeting in Tucson and were submitted to Thome who is in the process of compiling the results and preparing an overall report on the results. Included in this report will be a reprocessing of each group's raw data with the RSG's software and panel to examine the effects of methodology on the retrieved reflectance.

Examples of the results of the reprocessed data are shown in Figures 1-4. The first two figures show retrieved surface reflectance for several ASTER bands for a dark 8%

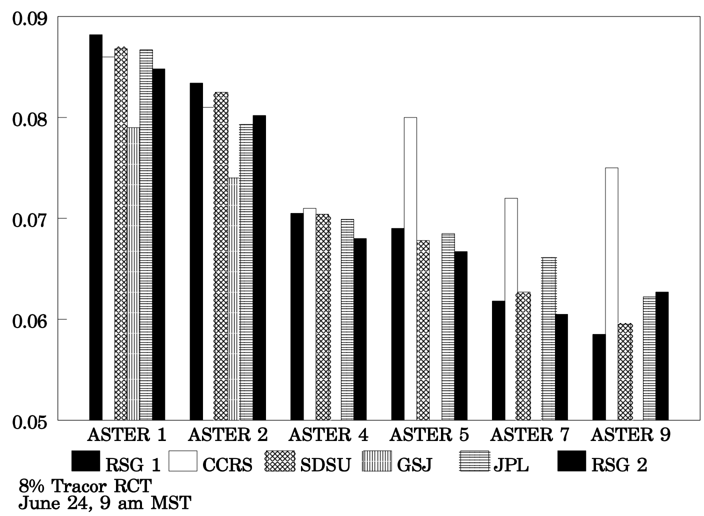

Figure 1 Retrieved reflectances from 8% reflectance calibration target.

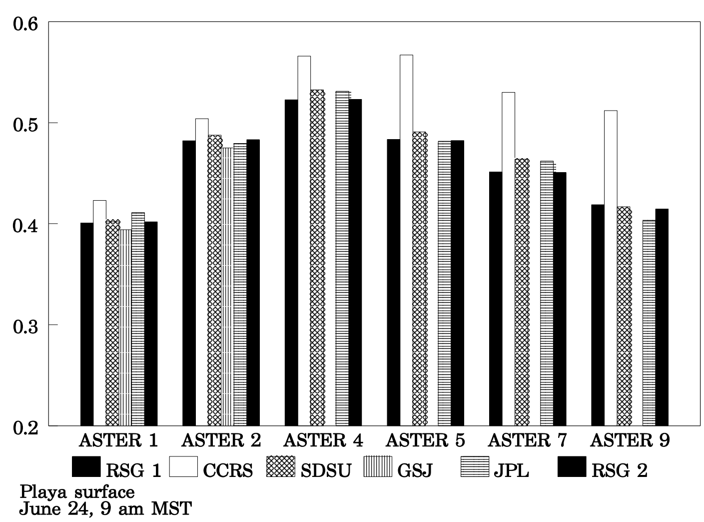

Figure 2 Retrieved reflectances from playa target.

reflectance target and the Lunar Lake Playa. As can be seen, the agreement is quite good except for the CCRS data in the SWIR bands. This is from a problem with the GER spectrometer that the group used. Also, data in the SWIR for the GSJ group are missing due to a malfunction of their instrumentation. At the high reflectance level, the difference between the maximum and minimum in reflectance is less than 0.012 (approximately 2%) and less than 0.003 in reflectance (approximately 4%) if the CCRS results are ignored. In addition to the ASTER bands shown, results were found for all four MISR bands, the SPOT HRV bands, three ETM+ bands and the original five triangle filters. Figure 3 shows the radiance results from 24 June for several VNIR bands and Figure 4 shows the results in terms of percent difference from the RSG results. Investigations are currently underway to determine the large percent difference between the GSJ results and the others, but the good agreement with the JPL results and RSG is quite encouraging.

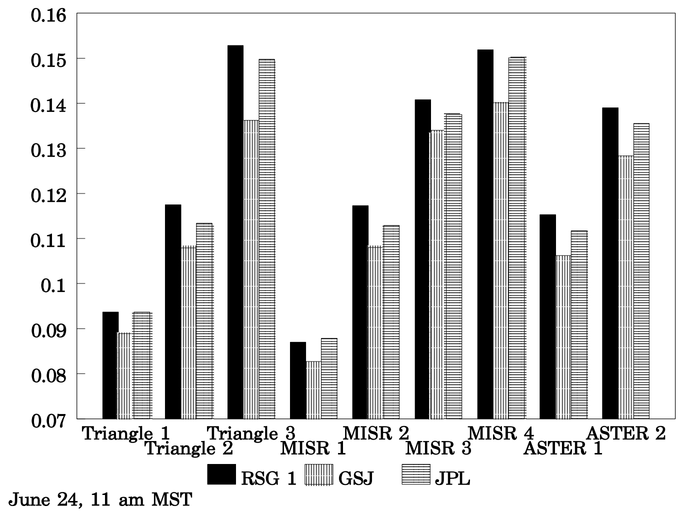

Figure 3 Normalized radiances for June 24 simulated overpass

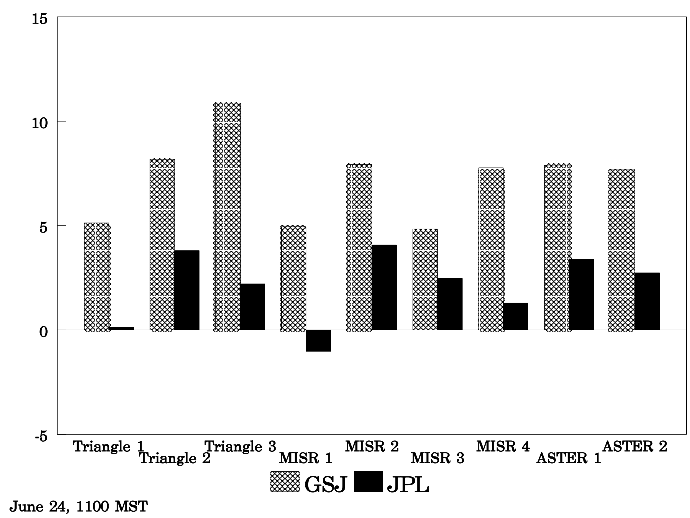

Figure 4 Percent difference between RSG and other group's predicted radiances

The AVIRIS image from Lunar Lake was received the first week of December and LaMarr determined the average radiances for each of 224 bands of the AVIRIS data of the test site at Lunar Lake site from June 23 of the joint campaign. Figure 5 shows a comparison between the results from the AVIRIS sensor and those of the RSG predicted from the reflectance-

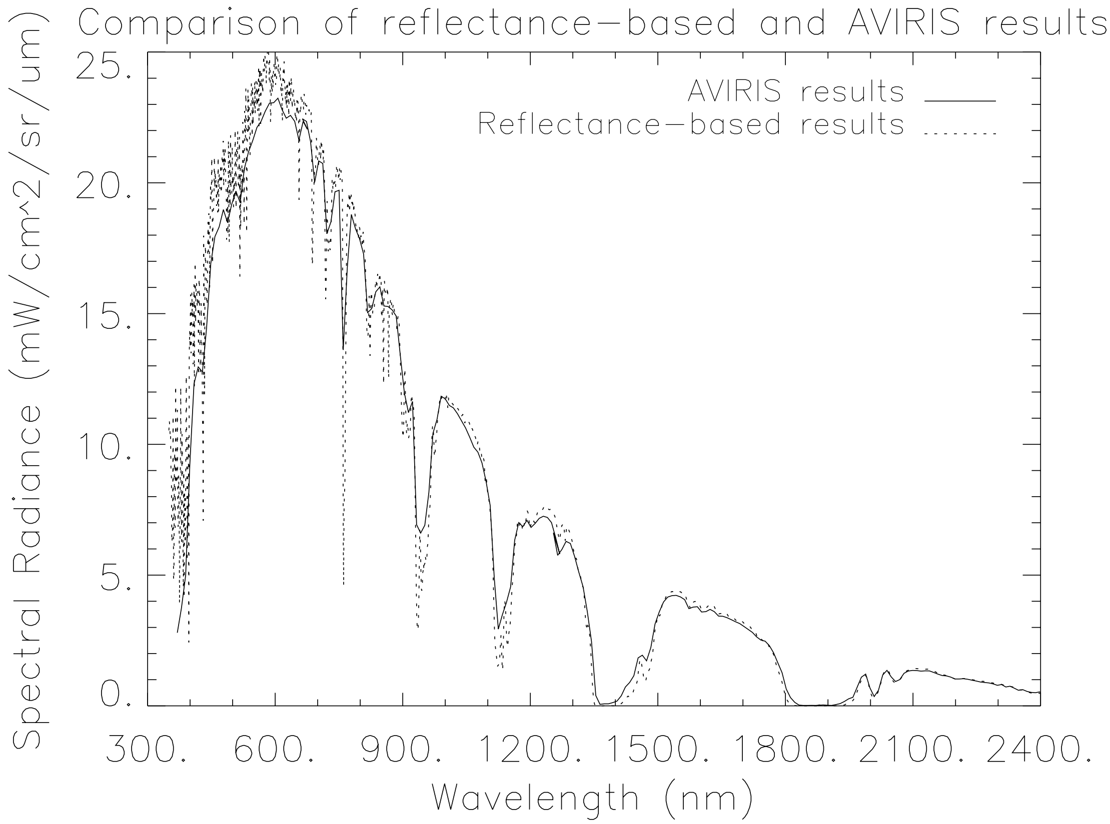

Figure 5 AVIRIS- and reflectance-based results for June 23 overflight of Lunar Lake

based method. This preliminary comparisons show that the agreement is quite good, but our results need to be resampled to the AVIRIS bands to perform a true comparison.

The group made several field trips during the reporting period. Ahmad calibrated our Spectralon panels in preparation for the group's trip to White Sands at the end of October. W. Barber, B. Magi, Nandy, Smith, and Thome participated in the experiment to White Sands from October 30 to November 2. The campaign's primary purpose was to collect data for a vicarious calibration of Landsat-5 TM. In addition, good weather conditions on all three days allowed two diffuse-to-global data sets to be collected along with BRF camera data. Data from the campaign will also be used to attempt a cross-calibration of SeaWiFS using TM and a direct reflectance-based calibration of SeaWiFS. J. LaMarr and Zalewski organized a field experiment to Lake Tahoe November 7-10 to attempt a calibration of SeaWiFS and to also help develop our methods that will be used for MODIS. LaMarr, M. Mienko, E. Nelson, and Zalewski made the trip to Lake Tahoe, but unfortunately, the weather was not favorable so no usable data were collected. Barber, Nandy, Nelson, and Thome traveled to Railroad Valley from November 20-23 to attempt calibrations of SPOT HRV. Poor weather hampered the actual data collections, but the trip was still useful for learning information needed for using this site for EOS-AM1 sensors.

LaMarr made plans for a joint field experiment in Tsukuba, Japan planned for December 13-14. This campaign was a joint campaign with Saga University, the Geological Survey of Japan, Kanazawa Institute of Technology, and the Meteorological Research Institute of Japan. The purpose of the campaign was to evaluate the level of agreement of surface reflectance retrievals over grass and asphalt targets similar to those that will be used for the validation of the atmospheric correction of ASTER. Multiple data collections were made of two surface types on December 13 and 14. LaMarr also collected additional surface reflectance data earlier in the week at the Meteorological Research Institute. Unfortunately, weather was not good enough on December 10 to attempt a calibration of Landsat-5 TM. The campaign also provided an additional opportunity for comparisons of reflectance-based results. Thome is currently processing the data from the campaign.

LaMarr and Thome processed the TM and SPOT data from the May White Sands campaign. Thome processed the surface reflectance data from the Jornada PROVE and submitted the results to F. Rahman of the Soil and Water Sciences Department at the University of Arizona. Thome also submitted the TM image for this campaign, along with radiometric calibration coefficients, to J. Privette of GSFC and sent optical thickness results to A. Hyman of Boston University. LaMarr developed software for our UNIX-based system to determine the Junge parameter for the aerosol size distribution and columnar ozone from solar radiometer data. LaMarr also investigated the possibility of rewriting some of the algorithm using mathematical inversion techniques. LaMarr histogrammed TM band 5 data to determine probable radiance values expected for the SWIR band that will be on the SPOT-5 HRV.

LaMarr, assisted by M. Zaheedul and Smith collected Langley plot data on the mornings of July 1 and 2 with the manual solar radiometer and the autotracking radiometer. LaMarr and Thome reduced these data for both instruments. The two also used the spectral-filter transmittances for the autotracker's filters along with MODTRAN3 output to simulate bandaveraged transmittances for a variety of solar angles and atmospheric conditions. All of the above data were used as part of a paper presented by LaMarr at the SPIE conference mentioned above. LaMarr and Zaheedul tested the I/O board from the autotracker and determined that the board works and the cause of problems with the board are due to interrupt problems with the computer. Zaheedul developed software to move the Autotracker as desired and began work on software to track the sun continuously. He will begin work to incorporate the lead-sulfide detectors as well as automating the filter wheels.

W. Barber began developing a new yoke for field measurements with the ASD FR. Barber and Burkhart designed a boom and fixture. Burkhart machined the mounting block and carrier tubes for the head based on these designs. The block is designed to mount the fiber optic for the spectrometer, the field-of-view optics, a laser pointer, and a clinometer for pointing knowledge during data collection. The laser targeting system will help align the ASD on the reference panel and the clinometer helps the operator maintain the same view angle as that of the satellite at overpass. Barber and R. Kingston began fitting the Exotech/MMR yokes with a similar laser targeting system and simplifying the data collection with these yokes. Barber began developing new stands for the yokes to make it easier for one person to use the yokes.

Biggar and Nandy sent the ASD-FR for maintenance and upgrade. Nandy tested the ASD FieldSpec FR after receiving the system back from servicing/retrofitting. Measurements with the spectrometer of the group's 40-inch SIS were made to test the improved the system. Data from the spectrometer were collected every 30 seconds from two minutes after startup for two hours after allowing the SIS to warm up for two hours. Preliminary results show a constant, uniform decrease in responsivity with time and no evidence of stabilization. Further studies are underway to better understand this problem.

Burkhart completed designs of modifications to the field-reference stand. The modifications include using tripod legs for the stand and changing the location of the legs. Burkhart completed a second panel stand based on these modifications for our other Spectralon panel. The parts for this second stand were sent out to be anodized. Burkhart assembled the second Spectralon panel case and stand.

Nelson constructed a transimpedance amplifier and packaged and mounted it to the back of the line-of-sight radiometer. He designed a post amplifier for the radiometer using batteries installed in the post amplifier housing and began establishing standard connectors for each voltage level of our various power sources. He replaced slip on power connectors with solder joints and also began developing battery chargers with these standard connectors. Burkhart machined pieces to improve accessibility to the external electrical outlets of the mobile laboratory.

Nandy began preliminary work on an aircraft-based system designed to fly in a variety of commercially-available, stabilized camera mounts over our calibration sites. Field-of-view considerations were examined, along with basic instrument requirements. Nandy contacted several vendors on the requirements for using a standard RC-30 mount. A Phoenix-based aerial-surveying company, Landiscor, was contacted about using their Zeiss-K, custom-built, manually-stabilized mount compatible with the latest Zeiss, high-performance, gyro-stabilized camera mount. Leica and Zeiss were contacted about their respective mounting/stabilization systems and specifics were requested. Nandy also arranged for an aircraft to fly our four-band Exotech radiometers during a January campaign to Railroad Valley using a mount used by MODIS Science Team Member, A. Huete.

Faculty, staff, and students: The personnel presently associated with the RSG are as follows: Faculty: Biggar, Slater, Thome, and Zalewski. Staff: Barber, Burkhart, Dancer, Kingston, Nelson, and Recker. Students: Ahmad (MS), C. Gustafson (MS), LaMarr* (Ph.D.), Magi, Mienko (MS), McCalmont (Ph.D.), Nandy (Ph.D.), Scott* (Ph.D.), Smith (MS), A. Sparks, and Walker* (Ph.D.). Those with an asterisk following their names have passed the Ph.D. Preliminary Examination and are mainly working on their Ph.D. research. Magi and Sparks are undergraduates and Gustafson, McCalmont, Scott, and Walker are independently funded. The rest are supported by this and other contracts. Z. Murshalin and Z. Rouf left the group in September to complete their degrees in the Electrical and Computer Engineering Department. Ahmad and Mienko joined the group in September.

Papers and publications

One peer-reviewed paper was published during the six-month period. This was "Radiometric calibration of Landsat" by K. Thome, B. Markham, J. Barker, P. Slater, and S. Biggar. The abstract of this paper is:

> The radiometric calibration of the sensors on the Landsat-series of satellites is a contributing factor to the success of the Landsat data set. The calibration of these sensors has relied on the preflight, laboratory work as well as inflight techniques using on-board calibrators and vicarious techniques. Descriptions of these methods and systems are presented. Results of the on-board calibrators and reflectance-based, ground reference calibrations of Landsat-5 Thematic Mapper are presented that indicate the absolute radiometric calibration of bands 1-4 should have an uncertainty of less than 5.0 percent. Bands 5 and 7 have slightly higher uncertainties, but should be less than 10 percent. The results also show that the on-board calibrators are of higher precision than the vicarious calibration but that the vicarious calibration results should have higher accuracy.

Five papers were presented by the group at the SPIE meeting in San Diego. The titles and authors are:

"Radiometer calibrations using solar radiation,"
R. J. Parada, K. J. Thome, S. F. Biggar, R. P. Santer, and J. LaMarr

"Characterization of a thermal-infrared field radiometer,"
M. Sicard and P. Spyak

"Internally-baffled integrating sphere cosine collector,"
B. G. Crowther, K. J. Thome, S. F. Biggar, and C. J. Burkhart

"Verification and characterization of an autotracking solar radiometer,"
J. H. LaMarr, K. J. Thome, P. R. Spyak

"Errors in laboratory measurements resulting from atmospheric absorption near 1380 nm,"
P. R. Spyak, J. H. LaMarr, and K. J. Thome

Two papers were submitted by the group to *Metrologia* based on the papers presented at the Newrad Conference. Two additional papers were submitted for the special issue of *IEEE Transactions of Geosciences and Remote Sensing* on the EOS AM-1 platform. The first is on the atmospheric correction of ASTER and the second is on the calibration of ASTER. In addition, a paper on the irradiance-based calibration using the new diffuse-to-global instrument has been accepted for publication in the *Canadian Journal of Remote Sensing.*