Semi-annual EOS Contract Report
Period: January 1 - June 30, 1998
Remote Sensing Group (RSG), Optical Sciences Center (OSC) at the University of Arizona
Principal Investigator: K. Thome
Contract Number: NAS5-31717

Summary: Preparations for a joint vicarious calibration that took place in the middle of June occupied much of the group's efforts during this six-month reporting period. 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, work continued on the cross-calibration software package by completing a beta version of the package. 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.

S. Biggar attended a MODIS Emissive Workshop at the University of Miami from February 2-3. On April 30 to May 1, S. Biggar traveled to the Algones Dunes near Yuma with B. Schowengerdt of the University of Arizona to examine the area for MTF studies of MODIS as part of Schowengerdt's EOS Validation grant. This included providing Schowengerdt with reflectance results based on measurements from the RSG's new ASD FieldSpec FR. Biggar and E. Zalewski attended the MODIS Science Team meeting from June 23-26, including the Calibration Meeting held on June 23 by MCST.

K. Thome attended the US and Joint ASTER Science Team Meetings in Tokyo held June 23-26. At the plenary session of the joint meting, Thome presented preliminary results of the Railroad Valley Campaign held the previous week in Nevada. Thome co-chaired the Atmospheric Correction Working Group meeting and presented the status of the atmospheric correction algorithm for the VNIR and SWIR. The at-launch version of the LUT for a power-law based aerosol distribution was completed and delivered to JPL.

Thome attended the JPL Airborne Workshop January 12-14 where he presented a paper on the use of dark and bright targets for the vicarious calibration of AVIRIS. The bright-target results were based upon AVIRIS data collected over Lunar Lake during the June 1997 joint campaign. J. LaMarr and E. Zalewski attended a one-day remote-sensing conference in Tucson on April 15 that covered the uses of remote sensing and problems such as the cost of data and the amount of time necessary to obtain data.

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 prepared the VNIR radiometer for a cross-calibration round-robin of the SIS-100 at SBRS used in the calibration of MODIS. He calibrated the VNIR radiometer using a NIST FEL and an Optronic FEL. Results from the NIST FEL repeated to no worse than 0.2% from a September 1997 calibration and those from the Optronic lamp were no worse than 0.4%. Calibrations from the two lamps differ by less than 1.1% and this is within the estimated uncertainties of the lamps. Biggar checked the stability of the VNIR radiometer/6" SIS combination over a four-day period found the results to be repeatable to better than 0.6%. In preparation for the measurements at SBRS, C. Burkhart machined alignment rods on the SWIR CCR’s tripod mount for better repeatability of the measurements.

Biggar and Zalewski traveled to SBRS May 11-15 to participate in the round-robin measurement at SBRS. Both the VNIR and SWIR CCR were used to measure the output of the SIS various levels, and the SWIR CCR monitored the SIS during level changes. Questions about the SBRS calibration of the SIS remain as do questions about how to compare SBRS values to our results. For example, Figure 1 shows the spline fit used by SBRS to fit the 11 measurements made by SBRS to

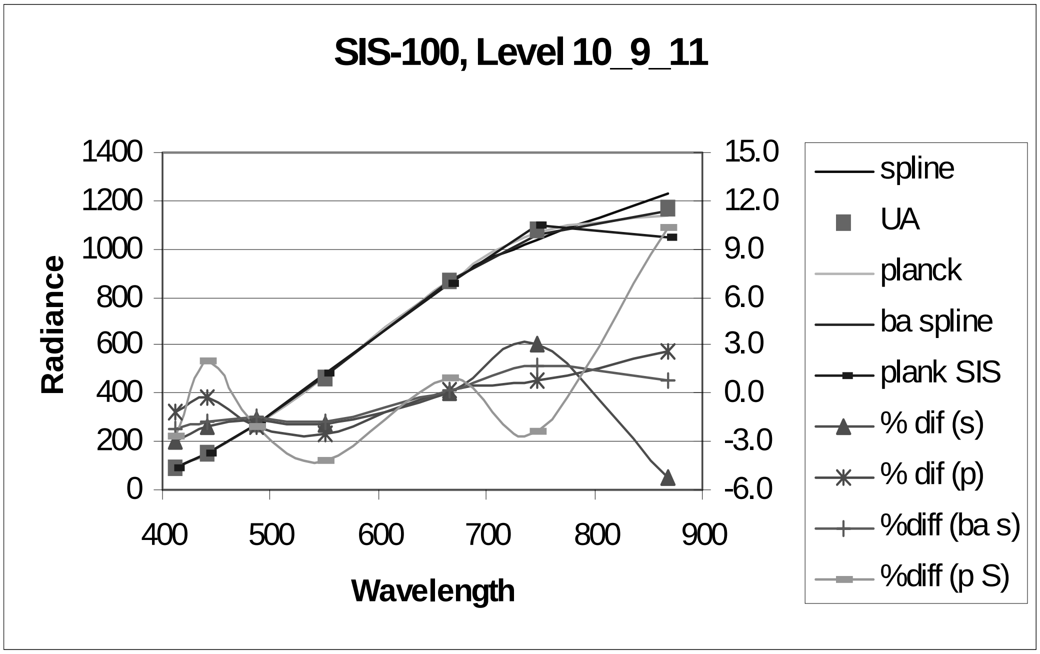


Figure 1. Comparison of measured and fitted SIS-100 output from recent SBRS round-robin experiment.

characterize the MODIS source in the VNIR. This spline fit is used by SBRS to determine the source output in bands not measured when calibrating the source. Also shown are the seven measurements made of the sphere by Biggar using the RSG's VNIR CCR. In addition to the spline fit used by SBRS, Biggar also computed three other curve fits and these are shown in addition to the spline fit used by SBRS. The bottom curves show the percent difference between the measurements from the VNIR CCR and the computed source output based on the curve fits. These percent differences are typically in the ±3% range, for bands near 900 nm, the results of the spline fit differ by nearly 10% from the CCR measurement. This is because the band is wide enough that a portion of the band integration requires extrapolation of the spline fit which is typically not recommended for spline fits. Further evaluation of these results is currently under way and Biggar has sent the results of the round-robin measurements to R. Barnes of GSFC.

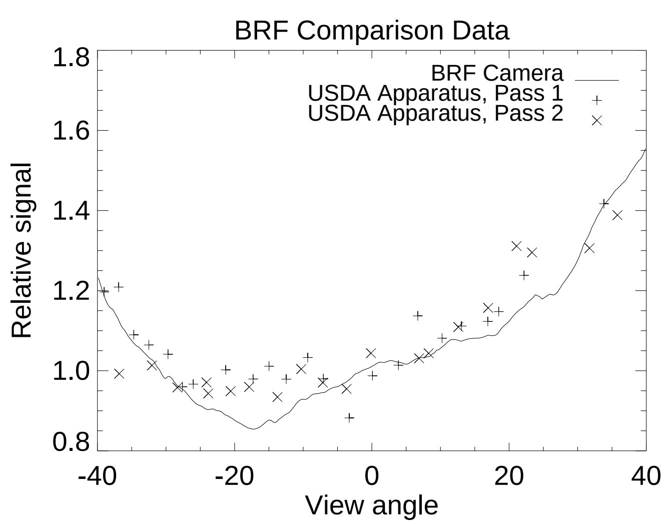
To further characterize the accuracy of the SWIR CCR, Zalewski received several sets of the custom-made ion-assisted deposition filters from Barr. These filters are similar to three of the

MODIS filters in the NIR region and are in a spectral region where the responsivities of the silicon detector of the VNIR CCR and InSb detector of the SWIR CCR overlap. This will enable direct comparison of the two instruments. Zalewski began measurements to characterize both the in-band and out-of-band transmission of the Barr filters.

Biggar tested the temperature stability of a second VNIR CCR. Biggar and E. Nelson discussed methods for implementing the second VNIR CCR head in a more portable version of the CCR for possible use in the field or traveling. The plan is to use this instrument for field measurements to further evaluate the solar-radiation-based calibration and to evaluate biases between absolute solar irradiance values and national laboratory calibrations of laboratory sources.

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.

The BRF camera was used by P. Nandy on a field campaign to Railroad Valley, Nevada in January, and data were collected to understand the instrument's behavior in extreme cold conditions (-10 degrees C). Nandy also used the instrument in March as part of a data collection at the USDA ARS facility in Tucson organized by Landsat-7 Science Team Member, M. S. Moran. Nandy collected BRF camera data at the same time as the USDA's BRF instrument over four different reflectance tarpaulins. A similar experiment was done the second week in March at Ivanpah Playa. Data were collected over the playa surface as well as over an 8%



reflectance calibration target. A portion of the results from the 8% target are shown in Figure 2. The figure shows a comparison between the two instruments for a single time and wavelength. While the qualitative agreement between the two systems is good, there are larger than expected variations in the Exotech data, and this is still being investigated. Unfortunately, a malfunction in the data collection method of our use of the USDA's instrument prevented any playa data from being logged. Plans are to repeat the experiment again during the next six months when the USDA's equipment becomes available.

Nandy adapted ephemeris code to compute the solar zenith and azimuth angles for the diffuse-to-global instrument to allow BRF data to be viewed in terms of scattering angle. Nandy began to investigate radiative transfer codes and BRDF models for processing of the camera data. He also developed software to average multiple images from the camera system of the 40-inch SIS. The standard deviation of averages of multiple CCD images is less than 0.5% for all detectors when no angular averaging of the CCD pixels is done. Averaging individual images over 2-degree intervals prior to computing the standard deviation reduces the value to less than 0.2%. Data from a SIS calibration were used to generate noise estimates for the camera system.

Nandy also developed software to produce a calibration for the entire BRDF system by applying a fourth-order polynomial to a single image of the center of the 40-inch SIS. The polynomial fit is better than 1% within the fitted region but gives nonphysical results towards the edge of the array. A method requiring five independent measurements of the SIS to calibrate the responsivity of all CCD-camera pixels was designed for the BRDF camera system, based on the assumption that each element of the CCD array can be treated independently. An experiment was devised by Biggar and Nandy to move the BRDF camera system and VNIR CCR across the SIS to calibrate the camera and measure the spatial uniformity of the SIS.

Diffuse-to-global meter: The objective of this task is 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. The diffuse-to-global meter will collect these data automatically and more repeatable than in the past.

Smith completed a first version of processing software for the diffuse-to-global processing. The package includes a graphical user interface to enter satellite and sensor data as well as interactive selection of ground reflectance and diffuse-to-global data. Output from the package includes predicted at-sensor radiance for all bands of the Licor LI-1800 using both optical depths derived from solar radiometer data and optical depths from the diffuse-to-global measurements. In addition, optical depths, exo-atmospheric intercepts, and diffuse-to-global ratios are reported along with summary results for comparison with solar radiometer results. The software includes general purpose procedures to produce files necessary to run the 6S radiative transfer code, to read reflectance results, and to band-average the results for a selected instrument or a single center wavelength and bandwidth.

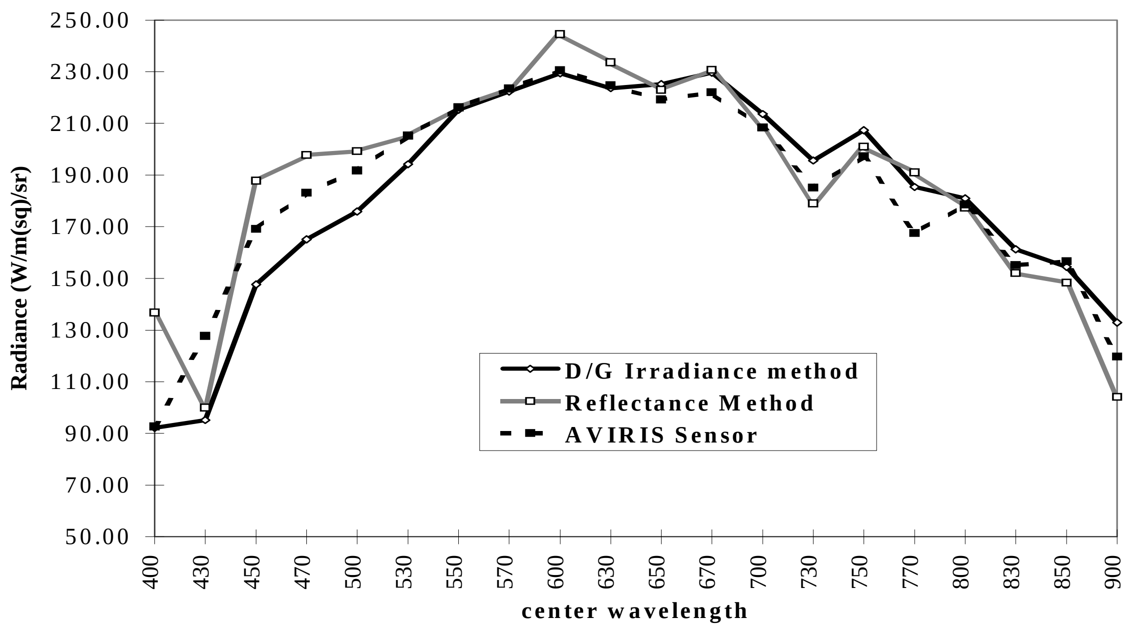
Smith continued characterization of the diffuse-to-global instrument using the Langley method on 13 days of data and found that the computed intercepts agreed to better than 1% for all wavelengths. Smith compared diffuse-to-global instantaneous optical depths to values obtained by our manual solar radiometer. For days where the vertical optical depths are stable, the comparisons are quite good with agreement to better than 0.002 between 400 and 900 nm. Poorer agreement is found at shorter wavelengths but the solar radiometer is known to have poorer signal-to-noise in these bands. While performing these comparisons, Smith found non-linearities in the Langley plots from the diffuse-to-global instrument in the 610 to 930 nm spectral range that appear to be from an incorrect sphere-response correction. She is investigating a new method for combining theoretical, lab and field tests to determine a better response curve.

The D/G meter was operated at Ivanpah Playa during a campaign in March to collect data for an irradiance-based calibration of Landsat-5 TM. Smith also tested the diffuse-to-global instrument in an automated mode during the recent joint campaign to Railroad Valley. While the set-up time is longer than in manual mode, due to the necessity of precise alignment needed to track the sun effectively, the benefit is that the user is no longer required to align manually the occulting disk for each measurement and this should give results that are user independent.

Smith collected diffuse-to-global data with S. Schiller from South Dakota State University March 3-11 at Pinal Air Park, approximately 20 miles north of Tucson. The two collected coincident data using Schiller's nine multi-filter, rotating shadowband radiometers (MFRSRs) and the RSG's diffuse-to-global instrument. Schiller provided a copy of his data along with processing software and Smith began processing both types of data for comparison. Smith has compared optical depths from these instruments and the diffuse-to-global for one of the days and found one MFRSR gives comparable results in optical depth. This one MFRSR also had good agreement with our diffuse-to-global instrument when comparing the diffuse-to-global ratios, although the data from the MFRSR were noisier. One cause of the greater noise in the MFRSR data could be EM interference at the site that is more noticeable in the low diffuse-light cases found in Arizona.

Smith performed an experiment to identify the effect of objects near the instrument on the diffuse irradiance measurements. The data were collected as part of the Ivanpah Playa experiment in March. This was accomplished by using a 0.8- by 1.0-m piece of cardboard held at approximately 2 m above the ground. Measurements were taken for three different azimuthal angles and at distances from 1.5 to 8 m from the instrument at approximately 1.5 m increments. For this experiment, we used a white object and a black object and two sun angles. Preliminary results show that there is no noticeable effect for objects greater than 5 m from the instrument. Objects nearer than 5 m can have a noticeable effect and this is most significant for a white object at an azimuth angle near 180 degrees from the sun. This result has prompted us to create a buffer zone around the instrument on the order of 5 m so as to reduce the influence of personnel walking near the instrument during measurements in automated mode.

Measurements from the Lunar Lake trip in June 1997 were used in an irradiance-based scheme to predict the at-sensor radiance for the AVIRIS overpass on June 23. The values were compared to AVIRIS and also to those obtained from the reflectance-based approach and are shown in Figure 4.



The differences are <11% for the 500 to 900-nm spectral range. As can be seen from the figure, there are no systematic differences between the methods. A similar analysis is planned for MAS data from the same date. A. Lopez has began analyzing the MAS data using software provided by L. Gumley from the University of Wisconsin.

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.

S. Biggar made modifications to our 40" SIS examining the warm up/cool down behavior in an attempt to explain results from measurements made at NRL last November. These modifications were based on the results of measurements of the current supplied to the lamps indicate that the Labsphere power supplies run in a quasi-constant current mode but the output from the supplies decreases several tenths of a percent over two hours after start up. Also, if the thermal environment of the SIS changes, the voltage required to maintain the output changes, however, the power supply current also changes which it should not do. If we power one lamp with a precise, constant current power supply, the voltage required to maintain that current goes up several tenths of a percent when additional lamps are lit. When the SIS is stable with 10 lamps lit, the optical output of the single, precisely-powered lamp changes for up to an hour after the other 9 are turned off. Turning off power supplies affects the output of a single lamp even though the other lamps are off. These results all have implications in how we characterize our cross-calibration radiometers (CCRs) and other equipment. We also need to carefully evaluate the use of any Labsphere SIS for instrument radiometric calibration purposes.

Biggar continued developing software for the blacklab and modifying our various codes for consistent use with GPIB, unidex, and HP subroutines. Testing of the software with the HP34970A showed problems so another GPIB connection was added to control the automated filter wheel, shutter, and chopper. Biggar developed software to control the lamp current and installed a new amplifier with electronic setting of gain and tested the improved performance. Modifications were made to the Y-axis stage of our goniometer, including a motor "home" sensor for improved accuracy and repeatability of positioning. A. Ahmad, Biggar, and M. Mienko began developing software to implement equipment that will automate our blacklab measurements. Biggar and Mienko began implementing an automated filter wheel and they are able to move the wheel using computer control. The three wrote the software to use a GPIB interface rather than serial so we can operate the blacklab from either our Sun network or PC. Burkhart aligned our blacklab stages and laser and installed nonskid pads on the floor to prevent the tables from moving. He realigned the stages in the lab, and he designed and began construction of a mount for the automated filter wheel. Biggar and E. Nelson tested a new amplifier for radiometers used in the laboratory and early results show that the amplifier works well and it will be implemented.

As part of preparations for the joint vicarious calibration campaign to Nevada in June, the RSG measured panels from the campaign’s participants the last two weeks of May. Also included in the measurements was a panel calibrated and provided by NIST as well as three panels from the USDA that are part of larger effort to evaluate the use of these reflectance standards in field data collections. Biggar oversaw the setup of the blacklab for these BRF measurements, debugged software problems that were encountered and reduced a portion of the data. LaMarr, E. Whittington, Ahmad, Zalewski, Biggar, M. Mienko, and J. McCalmont all helped to make these measurements. Biggar modified the processing software to incorporate IDL programs to graphically examine the data. Results of the measurements were sent to all of the campaign participants by June 9. Follow-up measurements were made by Chowdhury and Whittington to further examine these measurements. Plans have also been made to further evaluate the BRDF of the NIST-supplied reference to and compare the results from the RSG measurements with those of NIST. As part of last year’s laboratory comparisons, Biggar forwarded ASD data from last June’s measurements of the 40-inch spherical integrating source to Steve Brown at NIST after converting the data to radiance.

Ahmad, Biggar, R. Kingston, Mienko worked to find/fix a problem with the Optronic monochromator and found that the system's computer was failing due to both GPIB and serial problems. Kingston configured a new computer with the existing GPIB, video, HD, and ethernet to allow both GPIB and serial communication to be used with the monochromator. Burkhart sealed light leaks in the calibration laboratory and under doors leading between the laboratories in order to reduce stray light problems. Nelson and Kingston modified the wiring and connections for the monochromator to give more repeatable and reliable power to both the quartz halogen lamp and the glower (IR). Biggar implemented a new HP34970A to study the stability of the monochromator's source and found it to be stable in electrical power to about 1 part in 2000. The software developed by Biggar to operate this DVM is modular in nature so as to allow its use in the blacklab, calibration laboratory. While working with ASTER team member H. Kieffer's filters from his lunar characterization work, Biggar determined that the InSb detector in the monochromator needs to run for three hours once the dewar and detector have been cooled before beginning measurements.

Biggar developed plans for characterizing spectroradiometers from MODIS Science Team member, K. Carder's group at the University of South Florida. Burkhart machined a mount for this radiometer to measure its FOV. Biggar worked with R. Stewart and C. Cattral from Carder's group to characterize several of the spectroradiometers they use for their ocean-color work with MODIS. FOV measurements were made in March using our calibration laboratory's collimator and radiometric calibration and linearity measurements were done using the 40" SIS. Results were sent to Stewart shortly after the measurements were completed.

Chowdhury and Zalewski developed electronics for feedback-stabilized incandescent sources based on designs by Zalewski. Tests of an HP power supply control of our 6-inch spherical integrating source were used for preliminary determination of the electronic parameters. Chowdhury tested a preliminary feedback control circuit, designed by Zalewski, and Chowdhury also set up of a test source and detector system also based on designs from Zalewski and using diode and lamp holders machined by Burkhart. Zalewski is also creating a detailed plan to implement feedback control of our 6-inch, and then 40-inch, sources.

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 development of the cross-calibration program. The code that performs the search for suitable calibration sites was improved to increase the fidelity of the estimated inhomogeneity of the identified sites. Scott reviewed work of other investigators of the cross-calibration technique in preparation for the final data runs. She also collected data on the uncertainties in the cross-calibration technique when using different types of calibration targets. This information will be used in the design of the error module for the cross-calibration program to ensure that all important sources of uncertainty can be studied. The error module is being constructed that will allow users to run a statistical analysis of uncertainties for each cross-calibration performed.

Scott also modified the registration program to allow for user input registration errors to determine its effect on calibration. Median and standard deviation calculations for each possible test site have been added as well. A new module was created that allows the user to enter a reference gain coefficient and displays the minimum and maximum reference image digital counts for all of the sites selected. The user then selects a range of DC values as input to the radiative transfer code 6S to derive two linear equations that encompass these values. One equation calculates atmospherically-corrected reflectance from the reference image DCs, and the other calculates at-satellite radiance for the test satellite from the atmospherically-corrected reflectances. From the two linear equations, all of the test satellite radiance values are calculated with the DCs of the reference satellite rather than running the radiative transfer code each time. This method is much faster than running the code for each possible DC value and the loss in accuracy is small compared to other uncertainties. A display module has also been created that allows the user to look at all of the sites and the corresponding gain coefficient. The average gain coefficient for all sites and the standard deviation is also shown.

LaMarr obtained a copy of the 6S code being used by G. Wen of GSFC to atmospherically correct Landsat TM data. The code will be used to study possible ASTER atmospheric correction schemes. LaMarr also contacted B. Markham of GSFC regarding BOREAS data for pre-launch validation of atmospheric correction schemes. LaMarr continued background research on adjacency effects, both accounting and correcting for the effect. Preliminary indications are that the algorithm developed for MODIS is the easiest to adapt for ASTER. LaMarr contacted E. Vermote of GSFC about the possibility of using his MODIS code and adapting it for use with ASTER.

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.

The RSG obtained an automated solar radiometer from J. Reagan's group at the University of Arizona. Lopez learned the operation of the system and tested it during the diffuse-to-global comparison data collection at Pinal Air Park. The radiometer was also used during both the Railroad Valley and Ivanpah Playa campaigns held in March. Preliminary comparisons between the automated and manual solar radiometers show excellent agreement. Lopez began developing IDL software to simplify the processing of these data.

Zalewski completed a preliminary design for a new airborne radiometer and presented this design at an informal review on February 18. The system's construction and initial use are for SeaWiFS, but the system is planned to be used for calibration of the ocean-color bands of MODIS. The principal components are a telescope, fiber optics, filters, detectors, amplifiers and data acquisition system. The conceptual design for the telescope mounting system uses a Zeiss-type camera mount based on availability of aircraft. Burkhart designed and machined a mount for the system. The mount and a prototype of the radiometer were tested during the Railroad Valley campaign in June.

Nandy obtained a mounting bracket from MODIS team member, A. Huete, to hold an Exotech radiometer in a light aircraft. Nandy modified this mount to include a clinometer, video camera, and magnetometer and the mount and radiometer were flown on January 6 and 7 at Railroad Valley Playa. Data were collected along 11, 12-km long flight lines in the along-track direction of Landsat-5. The flight lines were approximately 500 m apart and the data were to be used to test techniques for calibrating large-footprint systems like MODIS. Unfortunately, poor weather on both days prevented the aircraft data from being used for calibration purposes, but B. Magi and Nandy developed software to generate a rasterized image from the data and the results qualitatively match those from a recent HRV image of the area. J. LaMarr collected a similar data set during the June campaign and these data are currently being processed for both reflectance and radiance and will be used for a calibration of the recently launched Vegetation sensor on the SPOT-4 platform.

A field campaign to Railroad Valley was made January 4-10 for calibration of Landsat-5 TM and SPOTs-1 and -2 HRV. Ahmad, W. Barber, Magi, Nandy, and Thome participated in the campaign.

Snow covered the site for the January 5 overpass of TM and it was decided not to collect data since the snow did not provide high reflectance in the SWIR and the goal of the data collection was to evaluate the playa surface for calibration purposes in the SWIR. Weather on the other dates was cloudy so no data were collected for calibration purposes.

LaMarr organized a field campaign to Railroad Valley Playa for the first week of March and to Ivanpah Playa for the second week. The plans were to calibrate Landsat-5 TM twice and SeaWiFS twice as well as to test new equipment and data collection methods. Zalewski arranged for the SeaWiFS sensor to view the site with a nadir view. On the trips, we successfully collected data for Landsat-5 TM at Ivanpah and Railroad Valley, but the weather was somewhat marginal at Railroad Valley. Poor weather, prevented us from collecting data for SeaWiFS calibrations. The data are currently being processed from this campaign. LaMarr and J. McCalmont participated in a field data collection in Tucson on April 1 that was a joint campaign with Positive Systems, Pima County, and A. Huete's group. LaMarr and McCalmont collected solar radiometer data for the experiment and the results have been provided to SAIC in Tucson.

Barber, Lopez, Magi, Nandy, Smith, and Thome participated in a field campaign to White Sands Missile Range from April 20-25, primarily for the calibration of SPOT-4 Vegetation and HRVIR. Data during the White Sands trip included collection of BRF camera data and diffuse-to-global meter data. Data from the BRF system were processed using calibration data from October 1997 and results included ratios between radiance at the sensor look angle and nadir radiance. The results agreed qualitatively with past results for White Sands. The trip was also used to test methods for calibrating large footprint sensors such as MODIS and to better evaluate accuracies in the SWIR. LaMarr made arrangements for a field campaign to Railroad Valley Playa from May 6 - 12. Kingston, LaMarr, Mienko, and Thome participated in this campaign that had similar goals as those of the White Sands trip in April but in addition. Weather conditions were not favorable for the campaign, with only one day of the trip providing clear skies. However, the trip still served as an excellent training exercise for the joint vicarious calibration campaign held in June.

Smith made arrangements for the Joint Vicarious Calibration Campaign to Railroad Valley Playa in June with help from S. Recker who arranged for an RV to be rented in Las Vegas for the trip and assisted in hotel arrangements for the RSG and Japanese ASTER team members. The campaign took place from June 13-18 and included representatives from the Japanese ASTER Science Team, JPL (representing ASTER), Canada Centre for Remote Sensing, Schiller from South Dakota State University, and the RSG. Both solar reflective and TIR work was done at Railroad Valley as well as TIR work at Cold Springs Reservoir. Poor weather hampered the early part of the campaign with very wet conditions. A successful overflight of AVIRIS and MAS took place on June 17 under partly cloudy skies. The French agency CNES also arranged for data collections by sensors on the SPOT-1, -2, and -4 platforms.

J. LaMarr began searching Landsat-5 TM data of the Tucson area in an attempt to find a local calibration site. This work is primarily for use with Landsat-7 ETM+, but will also be adapted for ASTER. A search of sites that are 4x16, 3x3 and 5x5 pixels based on a minimum, average apparent reflectance of 0.20 in all bands and a maximum percent standard deviation of 1-2% showed several possible candidates at the Asarco Mine complex south of Tucson. LaMarr sent a letter to the general manager of the site explaining our work and asking permission to make measurements at the mines.

Faculty, staff, and students: The personnel presently associated with the RSG are as follows: Faculty: Biggar, Slater, Thome, and Zalewski. Staff: Barber, Burkhart, Clemens, Dancer, Kingston, Nelson, and Recker. Students: Ahmad (MS), Andersen, Chowdhury, LaMarr* (Ph.D.), Lopez (MS), Magi, Mienko (MS), McCalmont (Ph.D.), Nandy (Ph.D.), Scott* (Ph.D.), Smith (MS), and Walker* (Ph.D.), Whittington (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. Andersen is a recently-graduated high school student who will enroll in the Optical Engineering program at the University of Arizona in the fall, Magi is an undergraduate and McCalmont, Scott, and Walker are independently funded. The rest are supported by this and other contracts.

Papers and publications

Three papers appeared in peer-reviewed journals and one paper was presented at a conference related to activities funded by this contract during the six-month reporting period. These are listed below along with their abstracts. The paper by M. Sicard was based on work done while with the RSG as is the paper by B. Schmid. The paper by Thome appeared in a special issue on calibration and validation and shows the first results from the diffuse-to-global meter. Reprints of these papers are available by contacting the RSG.

Sicard, M. K. J. Thome, B. G. Crowther, M. W. Smith, "Shortwave infrared spectroradiometer for atmospheric transmittance measurements," *J. of Atmos. and Oceanic Tech.*, **15**, pp. 174-183, 1998.

Abstract: The use of a shortwave infrared spectroradiometer as a solar radiometer is presented. The radiometer collects 1024 channels of data over the spectral range of 1.1 to 2.5 µm. The system was tested by applying the Langley method to data collected at a high altitude site on two consecutive days. Data processed for the 1.15 - 1.32 µm and 1.47 - 1.75 µm spectral intervals show temporal results similar to those obtained with a well-understood, visible and near-infrared radiometer having 10 channels in the 0.38 - 1.03 µm spectral range. A modified-Langley method was used for spectral regions where strong water vapor absorption invalidates the Langley method. It is estimated that the exo-atmospheric intercept of the spectroradiometer was determined to better than 4% in non-absorption regions between 1.15 and 1.75 µm and to better than 5% for a large portion of the 1.38 µm-absorption band. These results, in addition to the agreement between the shortwave, and the visible and near-infrared radiometers, imply that the SWIR system operates well as a solar radiometer. The spectral optical depths from one day were used to determine a power-law aerosol size distribution using data from both the visible and near infrared, and the shortwave infrared. The exponent derived for this power-law differed from that obtained by using only the visible and near infrared by 6%. Aerosol optical depths in the shortwave infrared derived from the visible and near infrared results differed from the measured values by 0.005 at an optical depth of 0.016 and wavelength of 1.66 µm.

Schmid, B., P. R. Spyak, S. F. Biggar, C. Wehrli, J. Sekler, T. Ingold, C. Matzler, and N. Kampfer, "Evaluation of the applicability of solar and lamp radiometric calibrations of a precision Sun photometer operating between 300 and 1025 nm," *Applied Optics*, **37**, pp. 3923-3941, 1998

Abstract: Over a period of 3 years a precision Sun photometer (SPM) operating between 300 and 1025 nm was calibrated four times at three different high-mountain sites in Switzerland, Germany, and the United States by means of the Langley-plot technique. We found that for atmospheric window wavelengths the total error (2 - statistical plus systematic errors) of the calibration constants V_0( ) the SPM voltage in the absence of any attenuating atmosphere, can be kept below 1.6% in the UV-A and blue, 0.9% in the mid-visible, and 0.6% in the near-infrared spectral region. For SPM channels within strong water-vapor or ozone absorption bands a modified Langley-plot technique was used to determine V_0( ) with a

lower accuracy. Within the same period of time, we calibrated the SPM five times using irradiance standard lamps in the optical labs of the Physikalisch-Meteorologisches Observatorium Davos and World Radiation Center, Switzerland, and of the Remote Sensing Group of the Optical Sciences Center, University of Arizona, Tucson, Arizona. The lab calibration method requires knowledge of the extraterrestrial solar irradiance spectrum, they agree with the Langley results within 2% at 6 of 13 SPM wavelengths. The largest disagreement (4.4%) is found for the channel centered at 610 nm. The results of these intercomparisons change significantly when the lamp results are referred to two different extraterrestrial solar irradiance spectra that have become recently available.

Thome, K. J., B. G. Crowther, S. F. Biggar, "Reflectance- and irradiance-based calibration of Landsat-5 Thematic Mapper, *Canadian Journal of Remote Sensing*, **23**, pp. 309-317, 1997

Abstract: The reflectance- and irradiance-based methods are used to determine an absolute, radiometric calibration of Landsat-5 Thematic Mapper for the solar reflective portion of the spectrum for data using the National Landsat Archive Production System format. Results are given for a calibration campaign at White Sands Missile Range in New Mexico in December 1996. The results of the two methods agree to better than 6% and comparisons with predicted, at-sensor radiances based on the gains and biases supplied with the data tape were found to differ by 1% to 31%. The results are also presented with reference to previously determined results from different processing techniques. The large differences between these results and the current values indicate the importance of consistent use of calibration for remotely-sensed data.

Thome, K., R. Parada, S. Schiller, J. Conel, J. LaMarr, "Evaluation of the use of dark and bright targets for the in-flight calibration of AVIRIS," *Proceedings of the Seventh Annual JPL Airborne Earth Science Workshop*, Pasadena, Calif., 1998.

Abstract: During a field campaign at Lake Tahoe on June 22, 1995, calibrations of AVIRIS were attempted using both the reflectance-based and radiance-based methods. This experiment shows that the use of dark, water targets to calibrate radiometric sensors can result in meaningful sensor characterization. In particular, the reflectance-based method shows promise towards meeting the desired 2-3% uncertainty levels for ocean color sensors since experimental agreement of better than 1.5% is found for the Lake Tahoe AVIRIS experiment. Similarly promising results were found from reflectance-based calibrations at Lunar Lake with large portions of the spectrum having less than a 5% difference between the reflectance-based predictions and the measured AVIRIS radiances. These results are still in the preliminary stage and it is likely that further study of this data set will lead to even better agreement. The results of the radiance-based calibration at Lake Tahoe are quite good at the shorter wavelengths where atmospheric scattering leads to larger signals and smaller effects of specularly reflected solar energy. The results also showed the sensitivity to radiometer pointing when using water targets for vicarious calibration.