

Semi-annual EOS Contract Report -- Report #66

Period: January 1 - June 30, 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:** Three major tasks occupied the group's efforts during this six months. The first was measuring the bidirectional reflectance properties of four reflectance samples provided by NIST. S. Biggar and P. Spyak made these measurements in both the VNIR and SWIR. The second major task was the group's move to a new facility in March. This required that our calibration laboratory and blacklab be disassembled and reassembled in addition to moving offices and other equipment. The third task was the joint vicarious calibration that took place the latter half of June. This campaign included two weeks of laboratory measurements by the RSG and nine days in the field. 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 developing a graphical interface to 6S, an uncertainty analysis code, and an image registration module. M. Sicard used a trip to Cimel in France to change the Cimel TIR radiometer's field of view and then characterized this new field of view. Z. Rouf and Z. Murshalin processed radiance-based data from last summer's Lunar Lake campaign.

**Introduction:** This report contains nine sections. The first eight 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 eight 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) TIR field radiometer; 6) Calibration laboratory; 7) Algorithm and code development; and 8) Field experiments and equipment. The ninth section contains information related to faculty, staff, and students.

On an administrative note, Edward Zalewski resigned as head of the Remote Sensing Group for health reasons. He remains a senior research member of the group but without administrative duties. Kurtis Thome accepted the position of permanent head of the Group effective May 9, 1997.

**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:**

Thome and Zalewski met with B. Eng, A. Kahle, A. Murray, M. Pniel, and A. Schwarz at JPL on March 20 to discuss modifications to the ASTER atmospheric correction in the VNIR and SWIR. Thome and Zalewski also travelled to Sioux Falls, South Dakota from May 19-23 for the Joint ASTER Science Team Meeting. Thome presented changes in the look-up table for the ASTER atmospheric correction at the US Science Team meeting and the Atmospheric Correction Working Group. He also presented plans for the joint calibration campaign at Lunar Lake, Nevada that took place from June 23-28.

**MODIS Activities:**

P. Slater attended the MODIS Consent to Ship Review May 12-13 at SBRS. S. Biggar attended the MODIS Science Team Meeting in College Park, Maryland from May 13-16 where he obtained a draft of Version 2.0 of the Level 1B Algorithm Theoretical Basis Document authored by Bruce Guenther and other members of MCST. Biggar combined comments on the document made by Slater, Thome, and Zalewski with his own and a 14 page list of comments was faxed to Guenther followed by a two-hour telephone conversation. There was agreement on most all issues, although some suggested additions will be omitted because of page limitations for ATBDs. Many of the points discussed related to new performance data, and their impact on calibration, recently made available at the pre-ship review at SBRS.

K. Thome attended the JORNEX96 meeting in Las Cruces on January 13-15 where he described ASTER's plans for validation and how the Jornada Experimental Test Range could be used. While at the meeting, Thome also met with J. Privette, W. van Leeuwen, and F. Raman of MODIS and J. Conel of MISR to discuss the possibility of an EOS AM-1 validation campaign at Jornada in May.

*Other EOS Related Activities:*

Slater reviewed two proposals submitted in response to the NASA Research Announcement titled "Satellite Remote sensing Measurement Accuracy, Variability, and Validation Studies". P. Spyak presented a paper on "A shortwave-infrared, calibration-transfer radiometer: design, characterization, and application" to the Council on Radiation Measurements 97 Conference held in Washington, D. C. April 26 to May 1. Sicard attended the 7th International Symposium on Physical Measurements and Signatures in Remote Sensing in Courchevel, France where he presented a poster showing the repeatability, reliability and stability of the CIMEL thermal-infrared radiometer.

**Cross-Calibration Radiometers:** This section describes work to design, fabricate, test, and calibrate a set of preflight cross-calibration radiometers (CCRs). These radiometers are to cover the wavelength region from 400 to 2500 nm. To accomplish this, two radiometers have been constructed, each optimized for a specific portion of the spectrum. They have very low stray light and polarization responses, exhibit sharp, well-defined fields of view and spectral response profiles, and be ultrastable with respect to temperature and time. The radiometers have been used to provide an important independent calibration and cross-calibration of the calibration facilities used by the Phase C/D contractors.

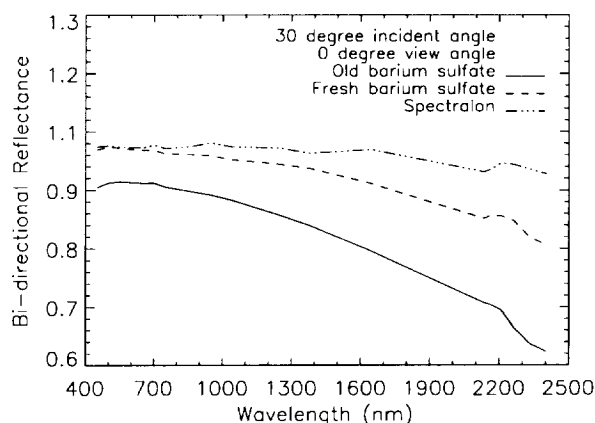
The objective of the VNIR portion of the project was to design and build a 400- to 900-nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. This radiometer is compared directly to NIST-calibrated and NIST-traceable standards of spectral irradiance. Biggar designed the radiometer with three silicon detectors in a "trap" configuration. Spectral selection is through interference filters, and two precision apertures determine the field of view. Heating the detector assembly, filters, apertures, and amplifier to

a stabilized temperature, a few degrees above ambient, provides thermal control of the system. The system uses a high accuracy voltmeter connected via GPIB to digitize the amplifier output. A commercial datalogger digitizes ancillary information such as detector temperature, and controls the amplifier gain through digital output ports. This datalogger sends the serial digital data to an MS-DOS compatible computer.

The objective of the SWIR portion of the project was to design and build a 1000- to 2500-nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. 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. Spectral selection is through interference and absorption filters, and the field of view is defined by a cryogenically-cooled baffle system. A chopper is used to optimize the signal-to-noise ratio.

Spyak and J. LaMarr used the SWIR CCR to make measurements of our field reflectance panels in the SWIR. Figure 1 shows the results of these measurements for a Spectralon and two barium sulfate panels. The figure also shows the results of measurements made in the VNIR using our usual blacklab radiometer. These SWIR measurements were critical in determining the cause of some of the differences in the retrieved reflectances in the 1.0-2.5  $\mu\text{m}$  spectral range seen in last year's Lunar Lake calibration campaign. In processing the data from last year, we assumed a spectral reflectance in the SWIR for our barium sulfate panel that more closely resembled that of a fresh panel. The actual panel that was used was the old panel. From the figure, it should be clear that this would cause a substantial difference in the retrieved reflectance. This point is discussed in further detail in the section on field campaigns.

Prior to the field portion of this year's joint Lunar Lake campaign, there were two weeks worth of laboratory measurements. These laboratory measurements included measurements using



**Figure 1.** Bidirectional reflectance of three field-reference panels used by the RSG. Data in the 1100-2500 nm range were measured by the SWIR CCR.

the RSG's 100-cm SIS. In preparation for these measurements, Biggar and Spyak tested both CCRs. The two made SIS measurements with the VNIR SWIR CCRs for comparisons with the NIST VXR and several field radiometers. The CCR data showed that the SIS remained quite stable for the measurements and changes measured by the radiometers agreed well with those of the NIST measurements. Radiance results from these measurements were supplied to C. Johnson of NIST. In addition, Biggar and Spyak measured a recently-calibrated sphere owned by MTL, a contractor involved in calibration and ground-truth studies for mainly DOD-related activities such as HYDICE.

**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 continued work on the camera. He used data collected at White Sands in March to test several processing schemes using IDL. The data from White Sands have proven difficult to process due to surface inhomogeneities. Nandy is currently investigating methods to avoid these problems. The camera was used extensively during the Lunar Lake campaign to further test the data acquisition. These data proved to be more spatially homogeneous, so they should provide a good test bed for evaluating the system. In addition, several other participants also measured BRFs during the Lunar Lake campaign and these data should provide a means of testing the results from the camera. Efforts over the next six months will concentrate on laboratory evaluation of the system and attempts to perform pixel-to-pixel calibrations of the CCD array.

**Diffuse-to-global meter:** 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.

C. Burkhart completed the mechanical work on the diffuse-to-global meter. B. Crowther and Biggar reduced the diffuse-to-global data from a December White Sands trip for use in Crowther's dissertation. Crowther showed Biggar and J. Smith how to operate the instrument. Smith further tested the instrument and acquisition software in the laboratory prior to the Lunar Lake campaign. She also developed a short instruction manual to assist in setting up the instrument. The system was used on three days during the Lunar Lake campaign. On one day, Smith operated the instrument in tandem with a multi-filter, rotating, shadowband radiometer (MFRSR) operated by S. Schiller of South Dakota State University. These data will be used for a comparison of the two types of systems. Smith is currently processing the diffuse/global data from Lunar Lake, but preliminary results indicate that the system performed well during the campaign.

**TIR field radiometer:** This part of our work has seen several modifications. The original objective was to construct cross-calibration radiometers to cover the 3000- to 14500-nm spectral region, test these radiometers, and write control and data acquisition software. This plan was dropped because of budget reductions. It was decided to attempt to construct a field-compatible TIR radiometer which could also operate as a transfer radiometer. This radiometer, designed for precision only, would cover 8,000 to 14,500 nm. This work was delayed because of budget constraints. We have since modified our approach and intend to build/purchase a single-band radiometer that can be calibrated to high accuracy. This radiometer will be used for the vicarious calibration of a single band of both MODIS and ASTER. The intent is to use this single-band calibration to validate the results from the MODIS and ASTER onboard blackbodies. We are now presently evaluating commercially available systems to determine if they can meet our needs for this purpose. In addition, we continue to evaluate several other TIR radiometers.

Sicard spent a week in March working at Cimel in Paris where he changed the fieldstop diaphragm of the Cimel TIR radiometer. A rough FOV measurement was done in the laboratory and showed a FOV of 6.8 degrees that is slightly off-center and asymmetric. Sicard tested the effect of ambient temperature changes on the Cimel radiometer by measuring the signal from

water at 0, 26 and 54 degrees C with ambient temperatures of 10, 26 and 55 degrees C. Sicard also began work on an instruction manual for the CIMEL thermal-infrared radiometer.

**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.

E. Nelson and Spyak designed upgrades for the blacklab's shutter and chopper. Biggar, Burkhart, and Spyak made blacklab upgrades to measure four round-robin, reflectance samples from NIST. Biggar converted older blacklab programs to run with the lockin amplifier used with the SWIR CCR and to allow the same type of data collection with this radiometer as is used for the VNIR radiometers. Biggar also eliminated some stray light sources in the blacklab. Biggar, Burkhart, and Spyak designed a 2-inch-diameter mask (made of stainless steel and painted with Krylon Ultraflat Black) used to mask the 4 NIST samples and our reference standard to ensure we measure the same area of each sample. Burkhart machined this mask as well as new mounts for the NIST, round-robin samples. He also improved the mount for the VNIR radiometer used in the blacklab and machined leveling pads for the blacklab table. Biggar tested the improvements by measuring an Alfolon sample with and without the mask. Biggar and Spyak measured the NIST samples with the modified set up in both the VNIR and SWIR.

Biggar, Burkhart, and Spyak reassembled the blacklab after the group's move to a new facility. Burkhart performed maintenance on our Aerotech stages, shortened and leveled the blacklab table, and aligned the top surfaces of the two stages with their axes of rotation and with respect to each other. Burkhart developed a mount for a precision mirror on the front edge of a precision square as part of a yoke alignment fixture to facilitate the location of the axes of rotation for the stages at a height of 15 inches above the stages (the height of the center of rotation for the horizontal axis). In addition, Burkhart "blackened" a storage cabinet for the blacklab. He also constructed counterweights for the panels to balance the load on the blacklab stages. Spyak evacuated the dewar of the Optronic monochromator, as well as the dewar of the SWIR CCR using a newly received vacuum system.

After completing assembly, the system was aligned and tested in the VNIR. Biggar found a noise problem in our new temperature-stabilized detector/amplifier and replaced the detector package with the old system. Burkhart machined alignment jigs for the goniometer to make setup faster and easier. Biggar developed software for automatic current control of the source for measurements in the SWIR. Biggar, J. LaMarr and J. McCalmont made comparisons of results of blacklab measurements from our old facility and the new setup. This also included the fabrication of a new Algodon reference. These comparisons show that we have, for the most part, reproducible results. Further measurements are still planned to verify that this is the case and to determine the causes of any differences between measurements made at our new facility and the old facility.

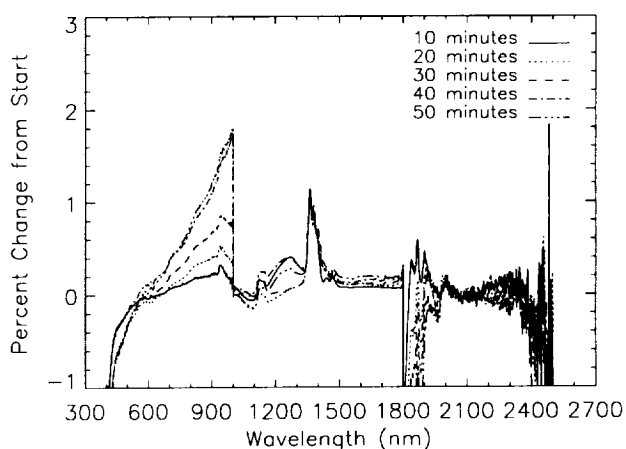
In preparation for the laboratory work preceding the Lunar Lake campaign, Biggar, Burkhart, and Spyak realigned and tested the blacklab in the VNIR and SWIR. Biggar modified software to streamline the data collection. Biggar, LaMarr, McCalmont, Z. Rouf, Spyak, and Zalewski made measurements of four field-reflectance references used by the RSG, three used by members of the Japanese ASTER Science Team, one reference each supplied by the Canada Centre for Remote Sensing, South Dakota State University, MISR Science Team, and NIST. The measurements, made from June 12-20, were of the panels' bi-directional reflectances and were made in both the VNIR and SWIR. The results of these measurements will be used to better understand the effect of reference panel calibration on the uncertainties in vicarious calibration. In addition, the results will be used to better understand uncertainties in measuring surface reflectance in support of algorithm validation. The NIST panel, that was brought to Tucson, was also measured at NIST prior to the experiment. This same panel is currently being measured in our laboratory along with the RSG's field references used for the Lunar Lake campaign. The NIST panel will then be measured again at NIST to provide further comparisons.

In addition to the panel BRF measurements, the 100-cm SIS that is part of our calibration laboratory was used to characterize several of the field radiometers. In preparation for these measurements, Biggar, Nelson, and Nandy set up and tested the sphere after the move into our new facility. Results of two sets of measurements made during the week prior to Lunar Lake with the RSG's ASD FieldSpec FR are shown in Figures 2 and 3. Figure 2 shows the percent change in signal as a function of wavelength for measurements taken over a 50-minute period.

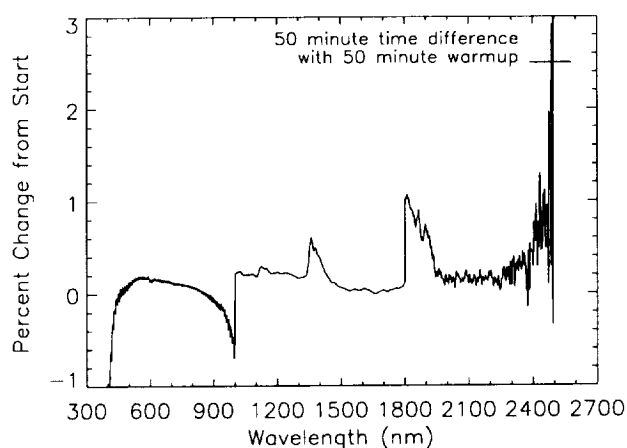


VNIR CCR and NIST VXR and SIS monitor detector measurements indicate that the sphere radiance during this period was stable to better than 0.5%. The FR results show the well-known effect that the FR requires about 40-50 minutes for the temperature of the VNIR spectrometer to thermally stabilize. The change in spectrometers at 1000 nm is clearly evident in the sharp change in the curves at this wavelength. There is an additional spectrometer change at 2000 nm and this is evidenced by the larger amount of noise in the data at wavelengths greater than 2000 nm. The large spike around 1380 nm is due to water vapor absorption, as is the larger percent difference at around 1800 nm.

Figure 3, shows this more clearly with the percent difference in the measured signal over a 50 minute period. In this case, the instrument was allowed to warmup for 50 minutes prior to the first measurement. The water vapor absorption features present in Figure 2 are clearly evident in Figure 3 as well and are indicative of changes in water vapor absorption during the time between the two measurements. These results are critical for developing techniques for using this instrument in the field. Preliminary radiance results from the SIS measurements by the CCRs have been provided to the participants. The data are currently being processed with updated results expected by the end of July.



**Figure 2.** Percent change in measured sphere signal as a function of wavelength and time as measured by the ASD FieldSpec FR without proper warmup.



**Figure 3.** Percent change in measured sphere signal as a function of wavelength and time with proper warmup of the ASD FieldSpec FR

**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 development of the cross-calibration software that is being written in IDL. She completed a module that provides a graphical user interface for the 6S radiative transfer program and integrated site reflectance data of Lunar Lake, White Sands Missile Range, and Ivanpah Playa into this module. In addition, Scott began work on the error analysis part of the program that included running iterations of 6S to determine sensitivity to different inputs. The cross-calibration software will contain a module where the most important inputs will be randomly perturbed using given uncertainties to determine the overall uncertainty of a calibration.

Scott also developed software to register the images that would be used for a cross-calibration. Her current approach uses a combination of an edge detection method and a standard correlation. The registration module contains the capability to display two images side by side (a reference image and uncalibrated image), to scale the images so that a ground control point (GCP) can be selected in each image, to input a search area range which reflects the accuracy of the input GCPs, to input a general correction factor for each set of data, and to perform an error check to ensure the image sizes, GCPs, and the search area range are consistent. The data are then sent to a correlation program which performs the correlation of the images and maps the pixels in the reference image with pixels in the uncalibrated image.

Because the targets that we typically use are large, bright areas surrounded by darker areas, we can use an edge detection step to emphasize the edges in the two images to perform a rapid correlation. The final correlation uses the original images where the position of maximum correlation found in the edge detection defines a starting point. This reduces the time needed to correlate the two images. Both translation and rotation errors will be considered in the final program, although these will not be significant for the case of ASTER, MISR, and MODIS. Scott also began exploring the use of FFTs to speed up the correlations.

Scott also created two new modules that allow the user to evaluate the quality of the correlation performed between the reference and uncalibrated images. The module displays the two images side by side and allows the user to click on one image and then the program displays the corresponding pixel in the other image. An input module has also been created that allows the user to select the calibration site characteristics desired, the type of error analysis to be performed, and the area in which the site search is to be conducted. The data will then be sent to a site search program which is now being written. Upon completion of the site search program a site review module will be created that will allow the user to review the characteristics of the sites found and select the sites to be forwarded to the later parts of the program. In similar work, Smith developed C-code to analyze pgm format image files. As of this date, the program searches for square or rectangular clusters of pixels within given parameters and outputs the locations of the clusters. This software will be used to specifically search the Tucson area for a small test site that can be used for ASTER work.

Thome continued work on the ASTER atmospheric correction. He submitted a revised set of input parameters for the generation of the ASTER LUT. In addition, he modified the radiative transfer code to include a separate phase function for stratospheric aerosols. Thome also modified surface-reflectance-retrieval software to include the new SWIR measurements. This software was used to determine the approximate difference in the retrieved reflectance of the Lunar Lake surface from last year's data. These results are described in greater detail below. Bigger installed the latest Sun Fortran and C compilers and related utilities on our Sun system. These new compilers should reduce the run-time of the radiative transfer code used to generate the ASTER atmospheric correction look-up table.

**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.

J. LaMarr received a new absolute shaft encoder for the RSG's autotracking solar radiometer, to replace the damaged one. He and W. Barber reviewed tracking-mount plans and Barber began upgrading its electronics. Burkhart machined a new front panel for the electronics housing of the autotracker and LaMarr continued reviewing ephemeris tracking software for

incorporation into the autotracker software based on solar ephemeris software developed by B. Crowther for the diffuse-to-global meter. LaMarr worked on construction of the digital i/o ribbon cable connection for the autotracking solar radiometer and began preliminary work on software for the system. Z. Murshalin started the design of the analog portion of the radiometer using new electronics. He also began to investigate the possibility of using new detectors in place of the lead-sulfide detectors to obtain better performance.

Nelson and Spyak designed new panel stands and carrying cases for the two Spectralon panels that were recently received. Burkhart machined the parts for these stands including six hinge-pins, and end plates. This stand was tested during the recent Lunar Lake campaign and has the advantage of built-in legs and bubble levels. The stand is currently being modified based on what was learned during the recent campaign and a second stand will be built for the other Spectralon panel that we have.

Murshalin and Rouf processed the radiance-based data from last year's Lunar Lake campaign. They registered the radiometer data from the aircraft using video data that were collected at the same time. The data over the site were then averaged for all flight lines from the June 2 and 3 dates. The two determined calibration coefficients for the radiometer used in the data collections by determining the band-averaged irradiance on a calibrated panel using data for a NIST-traceable standard lamp. Then this irradiance was converted to radiance using panel-BRDF measurements made in our blacklab. These radiances were compared to the voltage outputs of the Exotech radiometer while it looked at the panel to give the radiometer's calibration. Applying this calibration, the site spectral radiance was determined. The results from two runs from June 2 are shown in Table 1. One run was at an altitude of 140 m above the ground and the other at an altitude of about 1500 m above the ground. Along with these radiances are those predicted from radiative-transfer-code calculations using inputs from surface-based measurements. The decrease in radiance between the two altitudes is due to the increase in solar zenith angle between the times of the measurements. As can be seen from the table, the agreement is quite good.

Rouf and Murshalin also worked on solving problems with our polycorder data collection. They determined that a failure of the internal battery caused the Polycorders to lose the data collection programs during a Landsat-supported trip to Ivanpah Playa in March. R. Kingston

Exotech Band	Wave-length (nm)	Radiances at 140 m AGL			Radiances at 1500 m AGL		
		Meas.	RTC	% diff.	Meas.	RTC	% diff.
1	486	165.1	169.0	2.4	163.1	162.9	-0.1
2	549	202.5	201.0	-0.7	197.4	191.7	-2.9
3	653	209.0	212.6	1.7	203.0	202.4	-0.3
4	840	148.1	154.1	4.1	143.8	146.1	1.6

spoke with the manufacturer and arranged to have the systems fixed. Rouf and Murshalin continued work on the data processing of Exotech data collected with the Polycorder to make the whole process more user friendly and directly transform the voltage data obtained from the Exotech into radiance.

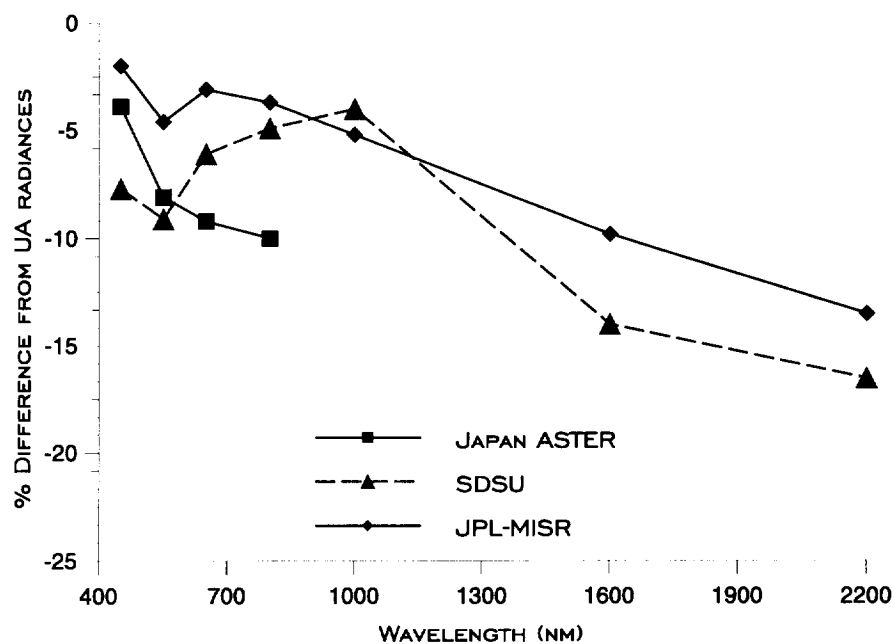
Biggar and Zalewski traveled to central Nevada from March 8-14 to examine the Lunar Lake and Railroad Valley test sites. They were accompanied by G. Fedosejevs, R. Gauthier, and P. Teillet of the Canada Centre for Remote Sensing. LaMarr, P. McIntosh, Nandy, R. Parada, Spyak, Thome, and Zalewski traveled to White Sands for calibrations of SPOTs-1 and -2 HRV as well as for Landsat-5 TM. The group was also accompanied by C. Catral and R. Stewart of K. Carder's group of the University of South Florida and the MODIS Science Team. Catral, Parada, and Stewart also traveled to the Steward Observatory on Mt. Lemmon for comparisons of solar radiometer data.

LaMarr planned a field campaign to the Jornada Experimental Test Range and to White Sands Missile Range. Barber, LaMarr, Murshalin, and Rouf traveled to Las Cruces from May 21-25 for this campaign that was part of the La Jornada Prototype Validation Experiment 97. Murshalin and Rouf helped F. Rahman and W. van Leeuwen, from MODIS-Science-Team-member A. Huete's group in the Soil and Water Science department of the University of Arizona collect surface reflectance data of ground transects that corresponded to aircraft flight lines.

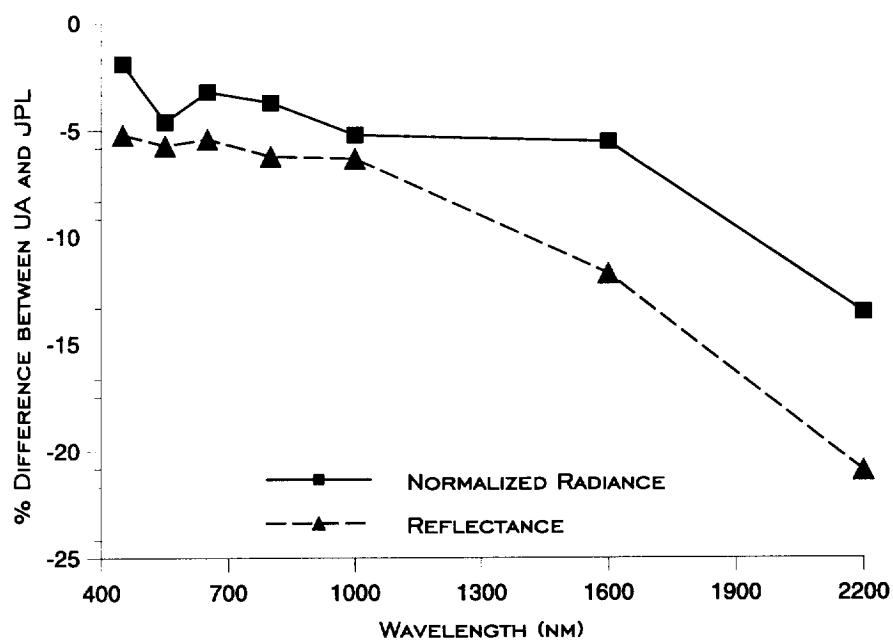
These data collections allowed us to further test the Polycorders as data loggers. Barber and LaMarr collected atmospheric optical thickness data at the Jornada site on May 23-24. Barber, LaMarr and Thome collected data for a calibration of Landsat-5 TM and SPOT-2 HRV at White Sands and further calibration data on May 26 for an additional French satellite. The TM and HRV data will be calibrated and supplied to PROVE participants. McCalmont and Nandy also used the FieldSpec FR as part of a joint experiment to validate a new spectroradiometer being developed by M. Descour of the Optical Sciences Center.

The second Lunar Lake campaign to compare vicarious calibration results took place from June 23-28. This campaign was a follow-on to the one held last June. The primary goal of the campaign was to understand differences in predicted radiances at the top of the atmosphere in vicarious calibrations. A total of six groups participated at the Lunar Lake portion of the campaign: two groups from the Japanese ASTER Science Team; the Remote Sensing Group representing the ASTER, MODIS, and Landsat-7 Science Teams, a group from JPL representing the MISR Science Team, representatives from the Canada Centre for Remote Sensing, and a representative from South Dakota State University. In addition, EOS Calibration Scientist, J. Butler, and C. Johnson and S. Brown of NIST attended a portion of the campaign to observe.

Much of the plans for the field and laboratory portions of this campaign were made with the results from last year's campaign in mind. Figure 4 shows the percent difference in the predicted, normalized radiances at top of the atmosphere relative to the results obtained by our group. As can be seen from the figure, these differences are quite large, especially in the SWIR. After further examination of the data sets, it was determined that much of the difference in the predicted radiances is due to differences in the retrieved surface reflectance. Figure 5 shows the percent difference between the RSG and the MISR group in the measured surface reflectance of the site and the predicted radiance at the top of the atmosphere. From this figure, it should be clear that most the differences are caused by reflectance differences.



**Figure 4.** Percent difference in normalized radiances at the top of the atmosphere over Lunar Lake on June 2, 1996 at 1800 UTC. Differences are computed relative to UA results and are for the seven monochromatic bands.



**Figure 5.** Percent differences between JPL-MISR and UA reflectances and normalized radiances for the seven monochromatic bands.

There were several proposed sources of the causes of these differences, such as site non-uniformity, instrumental differences, reference-panel composition, and reference panel calibration. The first two were dispelled as primary causes using measurements from Lunar Lake made by the RSG with our two independent instrument set ups to measure surface reflectance. The reflectances obtained from these two systems, one being the FieldSpec FR and the other a Barnes MMR, agreed to better than 3% throughout the solar reflective range, and better than 1.5% for the 500-1700 nm range. This left differences in the reference panels being used. Using the results of the reflectance-panel measurements shown in Figure 1, it could be determined that much of the difference seen in the SWIR bands was due to an incorrect assumption by the RSG about the reflectance of our panel in the SWIR. As mentioned, we assumed that the reflectance of the barium sulfate panel more closely resembled that of the fresh panel, when in fact it was the values shown in Figure 1 for the old panel. Additionally, there is approximately a 5% difference that is caused by the RSG using a directional calibration of the reflectance standard while all of the other groups used hemispherical reflectances.

Based on these results, several steps were taken this year to ensure that a consistent set of data could be collected that would allow us to better evaluate differences in retrieved surface reflectance. The first of these steps was to measure as many of the field reference panels as possible in the RSG's blacklab. This will allow us to process the data with RSG software and to eliminate differences between hemispherical and directional calibrations. The second step was to collect several data sets at Lunar Lake using the RSG's large Spectralon panel as the reference, in addition to each group using their normal reference. This will again allow us to examine the effects of different processing software and panel calibration assumptions. Finally, measurements were made of several small targets at various times of the day to look at incident sun angle effects and instrument linearity problems. The choice of small targets reduces the amount of time needed for each group to characterize the target, thus improving the comparisons.

In addition to these measurements, all of the groups also collected data on June 23 in conjunction with an overpass of SPOT-2 and also the ER-2 carrying AVIRIS and MAS. Unfortunately, cloud-cover prevented a successful data collection for the Landsat-5 and ER-2 overpasses on June 27. Some of the groups were also able to extend their time in the field to



collect data for a SPOT-2 overpass on June 28. This data collection also coincided with several overflights of the airborne CASI spectrometer supplied by CCRS.

Data from the campaign are currently being processed. Preliminary results from data collected on June 24 at 1800 UTC will be sent to Butler on July 11. Each group will supply the RSG with a written report of results by the end of August. These reports will be compiled and a joint report completed by October 1. This joint report will be submitted to all participating groups and the EOS Calibration Scientist for comments. A final report will be completed based on these comments by December 31, 1997. This final report will be sent out for general distribution. Plans are also underway to begin organizing a special journal issue based on the measurements made this year and last year at Lunar Lake.

**Faculty, staff, and students:** The personnel presently associated with the RSG are as follows. Faculty: Biggar, Slater, Thome, and Zalewski. Staff: Barber, Burkhart, Kingston, Nelson, and Recker. Students: Gustafson (MS), LaMarr\* (Ph.D.), McCalmont (Ph.D.), Murshalin (MS), Nandy (Ph.D.), Rouf (MS), Scott\* (Ph.D.), Smith (MS), and J. 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. Gustafson, McCalmont, Scott, and Walker are independently funded and the rest are supported by this and other contracts.

Paul Spyak left the group at the end of June to begin work at Hughes Aircraft in Tucson. He will remain associated with the group as an adjunct faculty member and his work will be continued by Biggar, LaMarr, and Zalewski. R. Parada, who had a NASA Global Change Fellowship, successfully defended his Ph.D. dissertation, titled "In-flight absolute calibration of radiometric sensors over dark targets using vicarious methods," in February. B. Crowther, who had a NASA Fellowship under the Graduate Student Research Program successfully defended his Ph.D. dissertation in March. The title of his dissertation is "The design, construction, and calibration of a spectral diffuse/global irradiance meter." P. McIntosh, an undergraduate, graduated and will be enrolled this fall in the graduate program at the University of Colorado working with A. Goetz.

Additionally, the group moved to a new facility in March. All members of the group spent the latter portion of February and early part of March preparing for the move. The process of unpacking was begun the latter portion of March, and while some files remain to be unpacked, the move is essentially completed.

### **Papers and publications**

Slater worked on an invited paper titled "Calibration of Optical Sensors" for the 7th International Symposium on Physical Measurements and Signatures in Remote Sensing in Courchevel, France. M. Dinguirard, the senior author, who works under contract for CNES in Toulouse, presented the paper. The paper has been submitted to a special (Spectral Signatures meeting) issue of *Remote Sensing of Environment*. Also, a paper titled "Unified approach to absolute radiometric calibration in the solar-reflective range" was recently completed by Slater, Biggar, J. Palmer, and Thome. This will be submitted for publication in another special issue of *Remote Sensing of Environment* devoted to calibration.

Spyak completed a draft of a paper on comparisons between MODTRAN and laboratory measurements of atmospheric absorption bands and sent the paper to G. Anderson of the Phillips Laboratory for review. Spyak had his paper on alignment of beam expanders, pinholes, and crosshairs to laser beams accepted for publication in *Applied Optics*. Sicard submitted a paper titled "Shortwave infrared spectroradiometer for atmospheric transmittance measurements" to the *Journal of Atmospheric and Oceanic Technology*. Sicard and Spyak submitted an abstract for the SPIE '97 annual meeting in San Diego titled "Characterization of a thermal-infrared field radiometer." Sicard and Spyak completed a draft of an article titled "Characterization of an internally calibrated thermal-infrared field radiometer and comparisons with other field instruments". Sicard and Spyak submitted a paper titled "Internally calibrated, thermal-infrared field radiometer: characterization and comparisons with other field instruments" to *Remote Sensing of the Environment*. A paper on the calibration of the OCTS sphere, with Biggar as one of the co-authors, was accepted for the NIST journal of research. Also, a total of six papers associated with the Remote Sensing Group will be presented at the upcoming SPIE conference to be held in San Diego at the end of July.

Semi-annual EOS Contract Report -- Report #66

Period: January 1 - June 30, 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:** Three major tasks occupied the group's efforts during this six months. The first was measuring the bidirectional reflectance properties of four reflectance samples provided by NIST. S. Biggar and P. Spyak made these measurements in both the VNIR and SWIR. The second major task was the group's move to a new facility in March. This required that our calibration laboratory and blacklab be disassembled and reassembled in addition to moving offices and other equipment. The third task was the joint vicarious calibration that took place the latter half of June. This campaign included two weeks of laboratory measurements by the RSG and nine days in the field. 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 developing a graphical interface to 6S, an uncertainty analysis code, and an image registration module. M. Sicard used a trip to Cimel in France to change the Cimel TIR radiometer's field of view and then characterized this new field of view. Z. Rouf and Z. Murshalin processed radiance-based data from last summer's Lunar Lake campaign.

**Introduction:** This report contains nine sections. The first eight 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 eight 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) TIR field radiometer; 6) Calibration laboratory; 7) Algorithm and code development; and 8) Field experiments and equipment. The ninth section contains information related to faculty, staff, and students.

On an administrative note, Edward Zalewski resigned as head of the Remote Sensing Group for health reasons. He remains a senior research member of the group but without administrative duties. Kurtis Thome accepted the position of permanent head of the Group effective May 9, 1997.

**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:**

Thome and Zalewski met with B. Eng, A. Kahle, A. Murray, M. Pniel, and A. Schwarz at JPL on March 20 to discuss modifications to the ASTER atmospheric correction in the VNIR and SWIR. Thome and Zalewski also travelled to Sioux Falls, South Dakota from May 19-23 for the Joint ASTER Science Team Meeting. Thome presented changes in the look-up table for the ASTER atmospheric correction at the US Science Team meeting and the Atmospheric Correction Working Group. He also presented plans for the joint calibration campaign at Lunar Lake, Nevada that took place from June 23-28.

**MODIS Activities:**

P. Slater attended the MODIS Consent to Ship Review May 12-13 at SBRS. S. Biggar attended the MODIS Science Team Meeting in College Park, Maryland from May 13-16 where he obtained a draft of Version 2.0 of the Level 1B Algorithm Theoretical Basis Document authored by Bruce Guenther and other members of MCST. Biggar combined comments on the document made by Slater, Thome, and Zalewski with his own and a 14 page list of comments was faxed to Guenther followed by a two-hour telephone conversation. There was agreement on most all issues, although some suggested additions will be omitted because of page limitations for ATBDs. Many of the points discussed related to new performance data, and their impact on calibration, recently made available at the pre-ship review at SBRS.

K. Thome attended the JORNEX96 meeting in Las Cruces on January 13-15 where he described ASTER's plans for validation and how the Jornada Experimental Test Range could be used. While at the meeting, Thome also met with J. Privette, W. van Leeuwen, and F. Raman of MODIS and J. Conel of MISR to discuss the possibility of an EOS AM-1 validation campaign at Jornada in May.

*Other EOS Related Activities:*

Slater reviewed two proposals submitted in response to the NASA Research Announcement titled "Satellite Remote sensing Measurement Accuracy, Variability, and Validation Studies". P. Spyak presented a paper on "A shortwave-infrared, calibration-transfer radiometer: design, characterization, and application" to the Council on Radiation Measurements 97 Conference held in Washington, D. C. April 26 to May 1. Sicard attended the 7th International Symposium on Physical Measurements and Signatures in Remote Sensing in Courchevel, France where he presented a poster showing the repeatability, reliability and stability of the CIMEL thermal-infrared radiometer.

**Cross-Calibration Radiometers:** This section describes work to design, fabricate, test, and calibrate a set of preflight cross-calibration radiometers (CCRs). These radiometers are to cover the wavelength region from 400 to 2500 nm. To accomplish this, two radiometers have been constructed, each optimized for a specific portion of the spectrum. They have very low stray light and polarization responses, exhibit sharp, well-defined fields of view and spectral response profiles, and be ultrastable with respect to temperature and time. The radiometers have been used to provide an important independent calibration and cross-calibration of the calibration facilities used by the Phase C/D contractors.

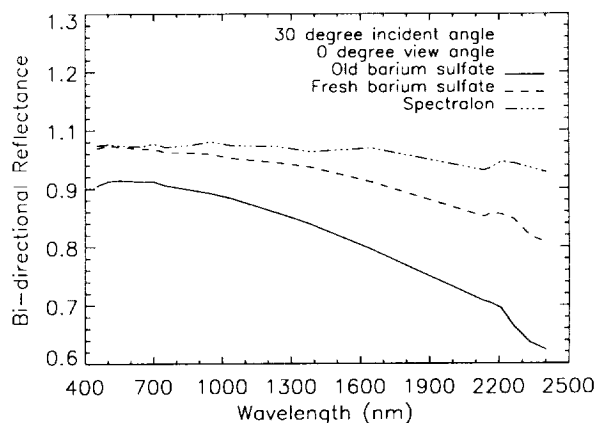
The objective of the VNIR portion of the project was to design and build a 400- to 900-nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. This radiometer is compared directly to NIST-calibrated and NIST-traceable standards of spectral irradiance. Biggar designed the radiometer with three silicon detectors in a "trap" configuration. Spectral selection is through interference filters, and two precision apertures determine the field of view. Heating the detector assembly, filters, apertures, and amplifier to

a stabilized temperature, a few degrees above ambient, provides thermal control of the system. The system uses a high accuracy voltmeter connected via GPIB to digitize the amplifier output. A commercial datalogger digitizes ancillary information such as detector temperature, and controls the amplifier gain through digital output ports. This datalogger sends the serial digital data to an MS-DOS compatible computer.

The objective of the SWIR portion of the project was to design and build a 1000- to 2500-nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. 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. Spectral selection is through interference and absorption filters, and the field of view is defined by a cryogenically-cooled baffle system. A chopper is used to optimize the signal-to-noise ratio.

Spyak and J. LaMarr used the SWIR CCR to make measurements of our field reflectance panels in the SWIR. Figure 1 shows the results of these measurements for a Spectralon and two barium sulfate panels. The figure also shows the results of measurements made in the VNIR using our usual blacklab radiometer. These SWIR measurements were critical in determining the cause of some of the differences in the retrieved reflectances in the 1.0-2.5  $\mu\text{m}$  spectral range seen in last year's Lunar Lake calibration campaign. In processing the data from last year, we assumed a spectral reflectance in the SWIR for our barium sulfate panel that more closely resembled that of a fresh panel. The actual panel that was used was the old panel. From the figure, it should be clear that this would cause a substantial difference in the retrieved reflectance. This point is discussed in further detail in the section on field campaigns.

Prior to the field portion of this year's joint Lunar Lake campaign, there were two weeks worth of laboratory measurements. These laboratory measurements included measurements using



**Figure 1.** Bidirectional reflectance of three field-reference panels used by the RSG. Data in the 1100-2500 nm range were measured by the SWIR CCR.

the RSG's 100-cm SIS. In preparation for these measurements, Biggar and Spyak tested both CCRs. The two made SIS measurements with the VNIR SWIR CCRs for comparisons with the NIST VXR and several field radiometers. The CCR data showed that the SIS remained quite stable for the measurements and changes measured by the radiometers agreed well with those of the NIST measurements. Radiance results from these measurements were supplied to C. Johnson of NIST. In addition, Biggar and Spyak measured a recently-calibrated sphere owned by MTL, a contractor involved in calibration and ground-truth studies for mainly DOD-related activities such as HYDICE.

**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 continued work on the camera. He used data collected at White Sands in March to test several processing schemes using IDL. The data from White Sands have proven difficult to process due to surface inhomogeneities. Nandy is currently investigating methods to avoid these problems. The camera was used extensively during the Lunar Lake campaign to further test the data acquisition. These data proved to be more spatially homogeneous, so they should provide a good test bed for evaluating the system. In addition, several other participants also measured BRDFs during the Lunar Lake campaign and these data should provide a means of testing the results from the camera. Efforts over the next six months will concentrate on laboratory evaluation of the system and attempts to perform pixel-to-pixel calibrations of the CCD array.

**Diffuse-to-global meter:** 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.

C. Burkhart completed the mechanical work on the diffuse-to-global meter. B. Crowther and Biggar reduced the diffuse-to-global data from a December White Sands trip for use in Crowther's dissertation. Crowther showed Biggar and J. Smith how to operate the instrument. Smith further tested the instrument and acquisition software in the laboratory prior to the Lunar Lake campaign. She also developed a short instruction manual to assist in setting up the instrument. The system was used on three days during the Lunar Lake campaign. On one day, Smith operated the instrument in tandem with a multi-filter, rotating, shadowband radiometer (MFRSR) operated by S. Schiller of South Dakota State University. These data will be used for a comparison of the two types of systems. Smith is currently processing the diffuse/global data from Lunar Lake, but preliminary results indicate that the system performed well during the campaign.

**TIR field radiometer:** This part of our work has seen several modifications. The original objective was to construct cross-calibration radiometers to cover the 3000- to 14500-nm spectral region, test these radiometers, and write control and data acquisition software. This plan was dropped because of budget reductions. It was decided to attempt to construct a field-compatible TIR radiometer which could also operate as a transfer radiometer. This radiometer, designed for precision only, would cover 8,000 to 14,500 nm. This work was delayed because of budget constraints. We have since modified our approach and intend to build/purchase a single-band radiometer that can be calibrated to high accuracy. This radiometer will be used for the vicarious calibration of a single band of both MODIS and ASTER. The intent is to use this single-band calibration to validate the results from the MODIS and ASTER onboard blackbodies. We are now presently evaluating commercially available systems to determine if they can meet our needs for this purpose. In addition, we continue to evaluate several other TIR radiometers.

Sicard spent a week in March working at Cimel in Paris where he changed the fieldstop diaphragm of the Cimel TIR radiometer. A rough FOV measurement was done in the laboratory and showed a FOV of 6.8 degrees that is slightly off-center and asymmetric. Sicard tested the effect of ambient temperature changes on the Cimel radiometer by measuring the signal from



water at 0, 26 and 54 degrees C with ambient temperatures of 10, 26 and 55 degrees C. Sicard also began work on an instruction manual for the CIMEL thermal-infrared radiometer.

**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.

E. Nelson and Spyak designed upgrades for the blacklab's shutter and chopper. Biggar, Burkhart, and Spyak made blacklab upgrades to measure four round-robin, reflectance samples from NIST. Biggar converted older blacklab programs to run with the lockin amplifier used with the SWIR CCR and to allow the same type of data collection with this radiometer as is used for the VNIR radiometers. Biggar also eliminated some stray light sources in the blacklab. Biggar, Burkhart, and Spyak designed a 2-inch-diameter mask (made of stainless steel and painted with Krylon Ultraflat Black) used to mask the 4 NIST samples and our reference standard to ensure we measure the same area of each sample. Burkhart machined this mask as well as new mounts for the NIST, round-robin samples. He also improved the mount for the VNIR radiometer used in the blacklab and machined leveling pads for the blacklab table. Biggar tested the improvements by measuring an Algoflon sample with and without the mask. Biggar and Spyak measured the NIST samples with the modified set up in both the VNIR and SWIR.

Biggar, Burkhart, and Spyak reassembled the blacklab after the group's move to a new facility. Burkhart performed maintenance on our Aerotech stages, shortened and leveled the blacklab table, and aligned the top surfaces of the two stages with their axes of rotation and with respect to each other. Burkhart developed a mount for a precision mirror on the front edge of a precision square as part of a yoke alignment fixture to facilitate the location of the axes of rotation for the stages at a height of 15 inches above the stages (the height of the center of rotation for the horizontal axis). In addition, Burkhart "blackened" a storage cabinet for the blacklab. He also constructed counterweights for the panels to balance the load on the blacklab stages. Spyak evacuated the dewar of the Optronic monochromator, as well as the dewar of the SWIR CCR using a newly received vacuum system.

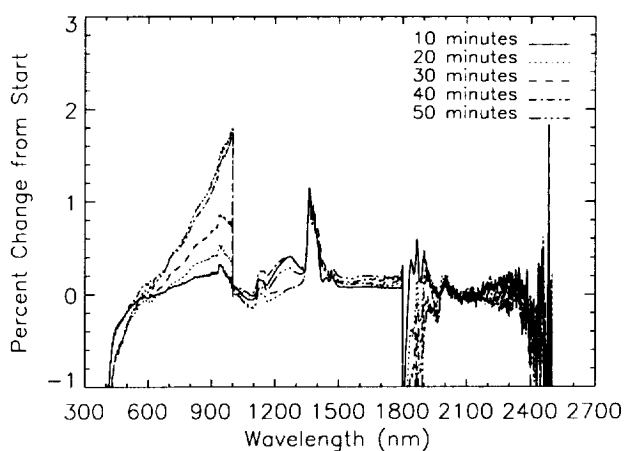
After completing assembly, the system was aligned and tested in the VNIR. Biggar found a noise problem in our new temperature-stabilized detector/amplifier and replaced the detector package with the old system. Burkhart machined alignment jigs for the goniometer to make setup faster and easier. Biggar developed software for automatic current control of the source for measurements in the SWIR. Biggar, J. LaMarr and J. McCalmont made comparisons of results of blacklab measurements from our old facility and the new setup. This also included the fabrication of a new Algodon reference. These comparisons show that we have, for the most part, reproducible results. Further measurements are still planned to verify that this is the case and to determine the causes of any differences between measurements made at our new facility and the old facility.

In preparation for the laboratory work preceding the Lunar Lake campaign, Biggar, Burkhart, and Spyak realigned and tested the blacklab in the VNIR and SWIR. Biggar modified software to streamline the data collection. Biggar, LaMarr, McCalmont, Z. Rouf, Spyak, and Zalewski made measurements of four field-reflectance references used by the RSG, three used by members of the Japanese ASTER Science Team, one reference each supplied by the Canada Centre for Remote Sensing, South Dakota State University, MISR Science Team, and NIST. The measurements, made from June 12-20, were of the panels' bi-directional reflectances and were made in both the VNIR and SWIR. The results of these measurements will be used to better understand the effect of reference panel calibration on the uncertainties in vicarious calibration. In addition, the results will be used to better understand uncertainties in measuring surface reflectance in support of algorithm validation. The NIST panel, that was brought to Tucson, was also measured at NIST prior to the experiment. This same panel is currently being measured in our laboratory along with the RSG's field references used for the Lunar Lake campaign. The NIST panel will then be measured again at NIST to provide further comparisons.

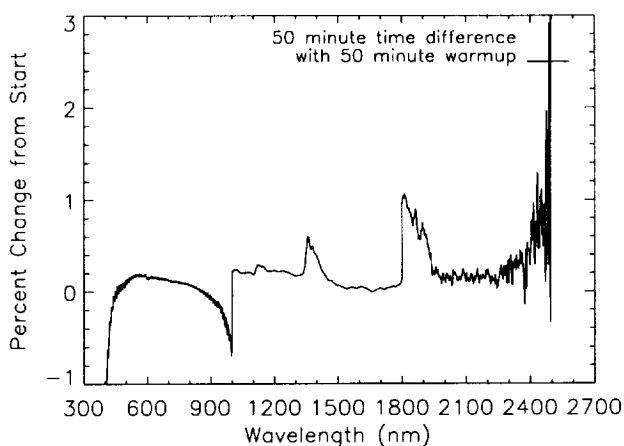
In addition to the panel BRF measurements, the 100-cm SIS that is part of our calibration laboratory was used to characterize several of the field radiometers. In preparation for these measurements, Biggar, Nelson, and Nandy set up and tested the sphere after the move into our new facility. Results of two sets of measurements made during the week prior to Lunar Lake with the RSG's ASD FieldSpec FR are shown in Figures 2 and 3. Figure 2 shows the percent change in signal as a function of wavelength for measurements taken over a 50-minute period.

VNIR CCR and NIST VXR and SIS monitor detector measurements indicate that the sphere radiance during this period was stable to better than 0.5%. The FR results show the well-known effect that the FR requires about 40-50 minutes for the temperature of the VNIR spectrometer to thermally stabilize. The change in spectrometers at 1000 nm is clearly evident in the sharp change in the curves at this wavelength. There is an additional spectrometer change at 2000 nm and this is evidenced by the larger amount of noise in the data at wavelengths greater than 2000 nm. The large spike around 1380 nm is due to water vapor absorption, as is the larger percent difference at around 1800 nm.

Figure 3, shows this more clearly with the percent difference in the measured signal over a 50 minute period. In this case, the instrument was allowed to warmup for 50 minutes prior to the first measurement. The water vapor absorption features present in Figure 2 are clearly evident in Figure 3 as well and are indicative of changes in water vapor absorption during the time between the two measurements. These results are critical for developing techniques for using this instrument in the field. Preliminary radiance results from the SIS measurements by the CCRs have been provided to the participants. The data are currently being processed with updated results expected by the end of July.



**Figure 2.** Percent change in measured sphere signal as a function of wavelength and time as measured by the ASD FieldSpec FR without proper warmup.



**Figure 3.** Percent change in measured sphere signal as a function of wavelength and time with proper warm up of the ASD FieldSpec FR

**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 development of the cross-calibration software that is being written in IDL. She completed a module that provides a graphical user interface for the 6S radiative transfer program and integrated site reflectance data of Lunar Lake, White Sands Missile Range, and Ivanpah Playa into this module. In addition, Scott began work on the error analysis part of the program that included running iterations of 6S to determine sensitivity to different inputs. The cross-calibration software will contain a module where the most important inputs will be randomly perturbed using given uncertainties to determine the overall uncertainty of a calibration.

Scott also developed software to register the images that would be used for a cross-calibration. Her current approach uses a combination of an edge detection method and a standard correlation. The registration module contains the capability to display two images side by side (a reference image and uncalibrated image), to scale the images so that a ground control point (GCP) can be selected in each image, to input a search area range which reflects the accuracy of the input GCPs, to input a general correction factor for each set of data, and to perform an error check to ensure the image sizes, GCPs, and the search area range are consistent. The data are then sent to a correlation program which performs the correlation of the images and maps the pixels in the reference image with pixels in the uncalibrated image.

Because the targets that we typically use are large, bright areas surrounded by darker areas, we can use an edge detection step to emphasize the edges in the two images to perform a rapid correlation. The final correlation uses the original images where the position of maximum correlation found in the edge detection defines a starting point. This reduces the time needed to correlate the two images. Both translation and rotation errors will be considered in the final program, although these will not be significant for the case of ASTER, MISR, and MODIS. Scott also began exploring the use of FFTs to speed up the correlations.

Scott also created two new modules that allow the user to evaluate the quality of the correlation performed between the reference and uncalibrated images. The module displays the two images side by side and allows the user to click on one image and then the program displays the corresponding pixel in the other image. An input module has also been created that allows the user to select the calibration site characteristics desired, the type of error analysis to be performed, and the area in which the site search is to be conducted. The data will then be sent to a site search program which is now being written. Upon completion of the site search program a site review module will be created that will allow the user to review the characteristics of the sites found and select the sites to be forwarded to the later parts of the program. In similar work, Smith developed C-code to analyze pgm format image files. As of this date, the program searches for square or rectangular clusters of pixels within given parameters and outputs the locations of the clusters. This software will be used to specifically search the Tucson area for a small test site that can be used for ASTER work.

Thome continued work on the ASTER atmospheric correction. He submitted a revised set of input parameters for the generation of the ASTER LUT. In addition, he modified the radiative transfer code to include a separate phase function for stratospheric aerosols. Thome also modified surface-reflectance-retrieval software to include the new SWIR measurements. This software was used to determine the approximate difference in the retrieved reflectance of the Lunar Lake surface from last year's data. These results are described in greater detail below. Bigger installed the latest Sun Fortran and C compilers and related utilities on our Sun system. These new compilers should reduce the run-time of the radiative transfer code used to generate the ASTER atmospheric correction look-up table.

**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.

J. LaMarr received a new absolute shaft encoder for the RSG's autotracking solar radiometer, to replace the damaged one. He and W. Barber reviewed tracking-mount plans and Barber began upgrading its electronics. Burkhart machined a new front panel for the electronics housing of the autotracker and LaMarr continued reviewing ephemeris tracking software for

incorporation into the autotracker software based on solar ephemeris software developed by B. Crowther for the diffuse-to-global meter. LaMarr worked on construction of the digital i/o ribbon cable connection for the autotracking solar radiometer and began preliminary work on software for the system. Z. Murshalin started the design of the analog portion of the radiometer using new electronics. He also began to investigate the possibility of using new detectors in place of the lead-sulfide detectors to obtain better performance.

Nelson and Spyak designed new panel stands and carrying cases for the two Spectralon panels that were recently received. Burkhart machined the parts for these stands including six hinge-pins, and end plates. This stand was tested during the recent Lunar Lake campaign and has the advantage of built-in legs and bubble levels. The stand is currently being modified based on what was learned during the recent campaign and a second stand will be built for the other Spectralon panel that we have.

Murshalin and Rouf processed the radiance-based data from last year's Lunar Lake campaign. They registered the radiometer data from the aircraft using video data that were collected at the same time. The data over the site were then averaged for all flight lines from the June 2 and 3 dates. The two determined calibration coefficients for the radiometer used in the data collections by determining the band-averaged irradiance on a calibrated panel using data for a NIST-traceable standard lamp. Then this irradiance was converted to radiance using panel-BRDF measurements made in our blacklab. These radiances were compared to the voltage outputs of the Exotech radiometer while it looked at the panel to give the radiometer's calibration. Applying this calibration, the site spectral radiance was determined. The results from two runs from June 2 are shown in Table 1. One run was at an altitude of 140 m above the ground and the other at an altitude of about 1500 m above the ground. Along with these radiances are those predicted from radiative-transfer-code calculations using inputs from surface-based measurements. The decrease in radiance between the two altitudes is due to the increase in solar zenith angle between the times of the measurements. As can be seen from the table, the agreement is quite good.

Rouf and Murshalin also worked on solving problems with our polycorder data collection. They determined that a failure of the internal battery caused the Polycorders to lose the data collection programs during a Landsat-supported trip to Ivanpah Playa in March. R. Kingston

Exotech Band	Wave-length (nm)	Radiances at 140 m AGL			Radiances at 1500 m AGL		
		Meas.	RTC	% diff.	Meas.	RTC	% diff.
1	486	165.1	169.0	2.4	163.1	162.9	-0.1
2	549	202.5	201.0	-0.7	197.4	191.7	-2.9
3	653	209.0	212.6	1.7	203.0	202.4	-0.3
4	840	148.1	154.1	4.1	143.8	146.1	1.6

spoke with the manufacturer and arranged to have the systems fixed. Rouf and Murshalin continued work on the data processing of Exotech data collected with the Polycorder to make the whole process more user friendly and directly transform the voltage data obtained from the Exotech into radiance.

Biggar and Zalewski traveled to central Nevada from March 8-14 to examine the Lunar Lake and Railroad Valley test sites. They were accompanied by G. Fedosejevs, R. Gauthier, and P. Teillet of the Canada Centre for Remote Sensing. LaMarr, P. McIntosh, Nandy, R. Parada, Spyak, Thome, and Zalewski traveled to White Sands for calibrations of SPOTs-1 and -2 HRV as well as for Landsat-5 TM. The group was also accompanied by C. Catral and R. Stewart of K. Carder's group of the University of South Florida and the MODIS Science Team. Catral, Parada, and Stewart also traveled to the Steward Observatory on Mt. Lemmon for comparisons of solar radiometer data.

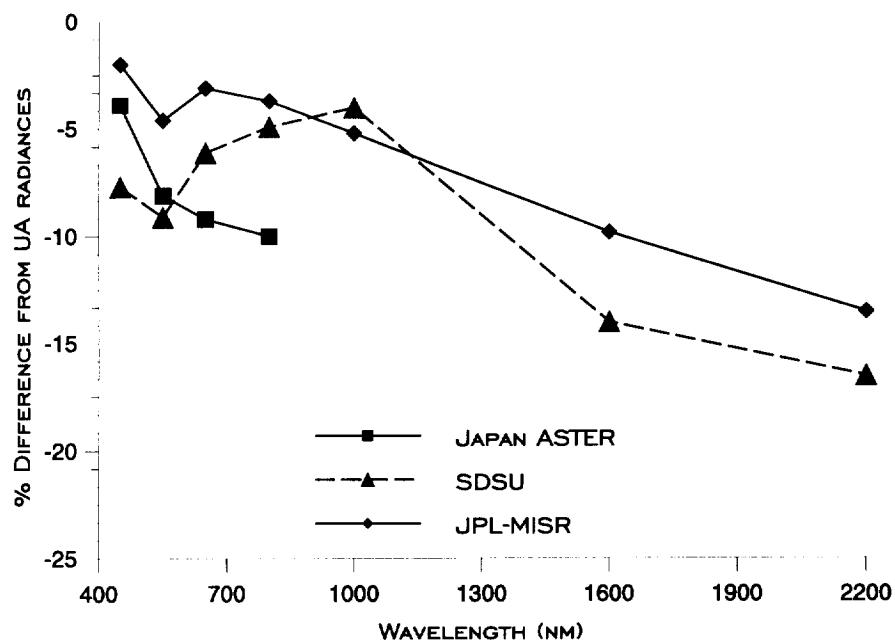
LaMarr planned a field campaign to the Jornada Experimental Test Range and to White Sands Missile Range. Barber, LaMarr, Murshalin, and Rouf traveled to Las Cruces from May 21-25 for this campaign that was part of the La Jornada Prototype Validation Experiment 97. Murshalin and Rouf helped F. Rahman and W. van Leeuwen, from MODIS-Science-Team-member A. Huete's group in the Soil and Water Science department of the University of Arizona collect surface reflectance data of ground transects that corresponded to aircraft flight lines.

These data collections allowed us to further test the Polycorders as data loggers. Barber and LaMarr collected atmospheric optical thickness data at the Jornada site on May 23-24. Barber, LaMarr and Thome collected data for a calibration of Landsat-5 TM and SPOT-2 HRV at White Sands and further calibration data on May 26 for an additional French satellite. The TM and HRV data will be calibrated and supplied to PROVE participants. McCalmont and Nandy also used the FieldSpec FR as part of a joint experiment to validate a new spectroradiometer being developed by M. Descour of the Optical Sciences Center.

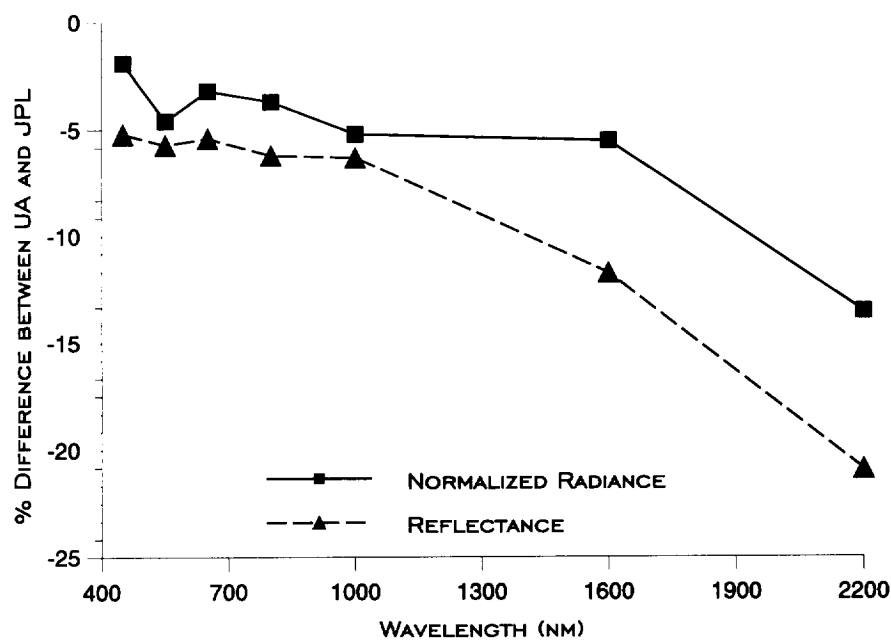
The second Lunar Lake campaign to compare vicarious calibration results took place from June 23-28. This campaign was a follow-on to the one held last June. The primary goal of the campaign was to understand differences in predicted radiances at the top of the atmosphere in vicarious calibrations. A total of six groups participated at the Lunar Lake portion of the campaign: two groups from the Japanese ASTER Science Team; the Remote Sensing Group representing the ASTER, MODIS, and Landsat-7 Science Teams, a group from JPL representing the MISR Science Team, representatives from the Canada Centre for Remote Sensing, and a representative from South Dakota State University. In addition, EOS Calibration Scientist, J. Butler, and C. Johnson and S. Brown of NIST attended a portion of the campaign to observe.

Much of the plans for the field and laboratory portions of this campaign were made with the results from last year's campaign in mind. Figure 4 shows the percent difference in the predicted, normalized radiances at top of the atmosphere relative to the results obtained by our group. As can be seen from the figure, these differences are quite large, especially in the SWIR. After further examination of the data sets, it was determined that much of the difference in the predicted radiances is due to differences in the retrieved surface reflectance. Figure 5 shows the percent difference between the RSG and the MISR group in the measured surface reflectance of the site and the predicted radiance at the top of the atmosphere. From this figure, it should be clear that most the differences are caused by reflectance differences.





**Figure 4.** Percent difference in normalized radiances at the top of the atmosphere over Lunar Lake on June 2, 1996 at 1800 UTC. Differences are computed relative to UA results and are for the seven monochromatic bands.



**Figure 5.** Percent differences between JPL-MISR and UA reflectances and normalized radiances for the seven monochromatic bands.

There were several proposed sources of the causes of these differences, such as site non-uniformity, instrumental differences, reference-panel composition, and reference panel calibration. The first two were dispelled as primary causes using measurements from Lunar Lake made by the RSG with our two independent instrument set ups to measure surface reflectance. The reflectances obtained from these two systems, one being the FieldSpec FR and the other a Barnes MMR, agreed to better than 3% throughout the solar reflective range, and better than 1.5% for the 500-1700 nm range. This left differences in the reference panels being used. Using the results of the reflectance-panel measurements shown in Figure 1, it could be determined that much of the difference seen in the SWIR bands was due to an incorrect assumption by the RSG about the reflectance of our panel in the SWIR. As mentioned, we assumed that the reflectance of the barium sulfate panel more closely resembled that of the fresh panel, when in fact it was the values shown in Figure 1 for the old panel. Additionally, there is approximately a 5% difference that is caused by the RSG using a directional calibration of the reflectance standard while all of the other groups used hemispherical reflectances.

Based on these results, several steps were taken this year to ensure that a consistent set of data could be collected that would allow us to better evaluate differences in retrieved surface reflectance. The first of these steps was to measure as many of the field reference panels as possible in the RSG's blacklab. This will allow us to process the data with RSG software and to eliminate differences between hemispherical and directional calibrations. The second step was to collect several data sets at Lunar Lake using the RSG's large Spectralon panel as the reference, in addition to each group using their normal reference. This will again allow us to examine the effects of different processing software and panel calibration assumptions. Finally, measurements were made of several small targets at various times of the day to look at incident sun angle effects and instrument linearity problems. The choice of small targets reduces the amount of time needed for each group to characterize the target, thus improving the comparisons.

In addition to these measurements, all of the groups also collected data on June 23 in conjunction with an overpass of SPOT-2 and also the ER-2 carrying AVIRIS and MAS. Unfortunately, cloud-cover prevented a successful data collection for the Landsat-5 and ER-2 overpasses on June 27. Some of the groups were also able to extend their time in the field to

collect data for a SPOT-2 overpass on June 28. This data collection also coincided with several overflights of the airborne CASI spectrometer supplied by CCRS.

Data from the campaign are currently being processed. Preliminary results from data collected on June 24 at 1800 UTC will be sent to Butler on July 11. Each group will supply the RSG with a written report of results by the end of August. These reports will be compiled and a joint report completed by October 1. This joint report will be submitted to all participating groups and the EOS Calibration Scientist for comments. A final report will be completed based on these comments by December 31, 1997. This final report will be sent out for general distribution. Plans are also underway to begin organizing a special journal issue based on the measurements made this year and last year at Lunar Lake.

**Faculty, staff, and students:** The personnel presently associated with the RSG are as follows. Faculty: Biggar, Slater, Thome, and Zalewski. Staff: Barber, Burkhart, Kingston, Nelson, and Recker. Students: Gustafson (MS), LaMarr\* (Ph.D.), McCalmont (Ph.D.), Murshalin (MS), Nandy (Ph.D.), Rouf (MS), Scott\* (Ph.D.), Smith (MS), and J. 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. Gustafson, McCalmont, Scott, and Walker are independently funded and the rest are supported by this and other contracts.

Paul Spyak left the group at the end of June to begin work at Hughes Aircraft in Tucson. He will remain associated with the group as an adjunct faculty member and his work will be continued by Biggar, LaMarr, and Zalewski. R. Parada, who had a NASA Global Change Fellowship, successfully defended his Ph.D. dissertation, titled "In-flight absolute calibration of radiometric sensors over dark targets using vicarious methods," in February. B. Crowther, who had a NASA Fellowship under the Graduate Student Research Program successfully defended his Ph.D. dissertation in March. The title of his dissertation is "The design, construction, and calibration of a spectral diffuse/global irradiance meter." P. McIntosh, an undergraduate, graduated and will be enrolled this fall in the graduate program at the University of Colorado working with A. Goetz.

Additionally, the group moved to a new facility in March. All members of the group spent the latter portion of February and early part of March preparing for the move. The process of unpacking was begun the latter portion of March, and while some files remain to be unpacked, the move is essentially completed.

### **Papers and publications**

Slater worked on an invited paper titled "Calibration of Optical Sensors" for the 7th International Symposium on Physical Measurements and Signatures in Remote Sensing in Courchevel, France. M. Dinguirard, the senior author, who works under contract for CNES in Toulouse, presented the paper. The paper has been submitted to a special (Spectral Signatures meeting) issue of *Remote Sensing of Environment*. Also, a paper titled "Unified approach to absolute radiometric calibration in the solar-reflective range" was recently completed by Slater, Biggar, J. Palmer, and Thome. This will be submitted for publication in another special issue of *Remote Sensing of Environment* devoted to calibration.

Spyak completed a draft of a paper on comparisons between MODTRAN and laboratory measurements of atmospheric absorption bands and sent the paper to G. Anderson of the Phillips Laboratory for review. Spyak had his paper on alignment of beam expanders, pinholes, and crosshairs to laser beams accepted for publication in *Applied Optics*. Sicard submitted a paper titled "Shortwave infrared spectroradiometer for atmospheric transmittance measurements" to the *Journal of Atmospheric and Oceanic Technology*. Sicard and Spyak submitted an abstract for the SPIE '97 annual meeting in San Diego titled "Characterization of a thermal-infrared field radiometer." Sicard and Spyak completed a draft of an article titled "Characterization of an internally calibrated thermal-infrared field radiometer and comparisons with other field instruments". Sicard and Spyak submitted a paper titled "Internally calibrated, thermal-infrared field radiometer: characterization and comparisons with other field instruments" to *Remote Sensing of the Environment*. A paper on the calibration of the OCTS sphere, with Biggar as one of the co-authors, was accepted for the NIST journal of research. Also, a total of six papers associated with the Remote Sensing Group will be presented at the upcoming SPIE conference to be held in San Diego at the end of July.