Semi-annual EOS Contract Report Period: January 1 - June 30, 1999 Remote Sensing Group (RSG), Optical Sciences Center (OSC) at the University of Arizona Principal Investigator: K. Thome Contract Number: NAS5-31717

Summary: During this six-month period, Remote Sensing Group personnel attended meetings related to MODIS and ASTER, including the ASTER and MODIS Science Team meetings. Evaluation of the BRDF camera continued. Results of a field campaign for characterization of the MASTER sensor were finalized and a campaign to calibrate the sensor while on the DC-8 platform at Ivanpah Playa took place in June. Improvements were made in the group's capabilities to characterize the BRDF of field reflectance standards with the inclusion of new filters, improved automation, and studies related to the use of a Hapke-model representation of the BRDF of these field standards. The launch of Landsat-7 was used as test bed for the types of field campaigns that will take place after the launch of Terra, including multiple simultaneous deployments at both White Sands and the Nevada test sites. Preparations began for a solar-radiation-based calibration of the SWIR cross-calibration radiometer as well as for a calibration round-robin at Ames Research Center using both the VNIR and SWIR radiometers.

Introduction: This report contains seven sections. The first six 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 six 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; and 6) Field experiments and equipment. The seventh section contains information related to faculty, staff, and students.

<u>Science Team Support Activities:</u> 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, K. Thome, and E. Zalewski attended the US ASTER Science Team Meeting on January 11 and the Joint ASTER Science Team Meeting January 12-14 in Pasadena. Thome presented a summary of the RSG's activities at the US Team Meeting. Biggar co-chaired the Radiometric Calibration Working Group Meeting and Thome chaired the Atmospheric Correction Working Group Meeting. Thome presented plans for the joint calibration campaign to Ivanpah Playa at both Working Group meetings and the current status of the VNIR/SWIR atmospheric correction to the Atmospheric Correction Working Group meeting. Thome revised the ATBD for the atmospheric correction of ASTER and sent this electronically to C. Leff of JPL. Thome also developed software to compute the aerosol phase functions for the MISR-type aerosol mixtures and sent the phase function files to B. Eng of JPL for incorporation into the ASTER atmospheric correction. Biggar and Thome will attend the initial meeting of the ASTER Calibration Team currently planned for August 19 and 20 in Tokyo. The meeting will address the radiometric and geometric calibration based on inflight data from the onboard calibrators and the vicarious calibration.

In MODIS-related meetings, Biggar attended the Solar Band Workshop at GSFC held on February 11 and 12. In response to queries from the meeting, Biggar sent a copy of J. Walker's dissertation on Hapke-based fits to the BRDF of reflectance standards to B. Guenther. Biggar and Thome attended the MODIS Science Team meeting in Greenbelt, Maryland on May 4-5. During the meeting, Thome presented the group's plans for radiance validation of MODIS after the launch of Terra and tentative field campaign plans. On May 3, Biggar and Thome received a tour from J. Butler of the calibration facilities in the new building at GSFC. The two then met with MCST personnel to discuss vicarious calibration plans for MODIS and attended the Ocean Discipline meeting that afternoon. Thome and Biggar also attended the Land discipline meeting on May 5. Thome revised the validation plan for MODIS and submitted this to D. Starr of GSFC.

Cross-Calibration Radiometers: This section describes work related to a set of 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 were used to provide an independent calibration and cross-calibration of the calibration facilities used for the preflight calibration of EOS sensors. 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 a trap-detector configuration and two precision apertures determine the field of view. The SWIR CCR operates in the 750- to 2500-nm spectral range and is compared to NIST-calibrated and NIST-traceable standards of spectral range and is compared to NIST-calibrated and NIST-traceable standards of spectral range and is compared to NIST-calibrated and NIST-traceable standards of spectral range and is compared to NIST-calibrated and NIST-traceable standards of spectral range and is compared to NIST-calibrated and NIST-traceable standards of spectral range and is compared to NIST-calibrated and NIST-traceable standards of spectral range and is compared to NIST-calibrated and NIST-traceable standards of spectral range and is compared to NIST-calibrated and NIST-traceable standards of spectral irradiance and pressed PTFE (Algoflon) targets. The system is designed around a chopped, lock-in amplified InSb detector and the field of view is defined by a cryogenically-cooled baffle system.

Biggar modified the SWIR CCR data collection software to overcome a data dropout communication problem between the instrument and computer when collecting blacklab data. The data loss does not affect the BRDF retrieval unless it happens for the 45-degree data point that is used to reference all other data. The software modification checks the standard deviation of the measurements to find bad data points and then retakes the data if this occurs.

Biggar evaluated the out-of-field rejection of the SWIR CCR by collecting reference data with and without a barium sulfate surround. Since the results between the two data collections differed by less than 0.2% for all bands of the radiometer and less than 0.1% for bands greater than 1200 nm, it appears the radiometer has a well-defined field of view (as also indicated by field-of-view measurements).

Zalewski made measurements of the radiometric response of the SWIR CCR in all bands using a high temperature, 750 C, blackbody source. Measurements as a function of distance using a

precision translation stage were used to verify the InSb detector linearity. Zalewski also fit the data from each band to a nominal Planck blackbody function in an attempt to improve on the absolute accuracy of the lamp-based radiance calibrations.

Biggar and C. Burkhart designed and constructed a mount for the SWIR CCR to perform a solarradiation-based calibration. The mount allows a Spectralon panel to be mounted perpendicular to the radiometer in a vertical orientation. A pinhole sight then allows the radiometer/panel setup to be aligned with the principal plane of the sun. The reason the panel must be vertical is that the SWIR CCR's liquid nitrogen dewar must be upright for operation of the radiometer. The mount will also allow our ASD FieldSpec FR spectrometer to be mounted as well as the VNIR CCR. The solarradiation-based calibration will be combined with laboratory calibrations in preparation for work at Ames Research Center in August and September for a calibration round-robin to evaluate the sources used for airborne sensors that are part of NASA's Earth Science Enterprise. Zalewski met with J. Myers, T. Hildum, M. Fitzgerald and P. Hajek at ARC in preparation for this round-robin.

BRDF Camera: 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.

Nandy replaced the chiller for the BRDF camera with a radiator-in-ice-bath system. This was done to require less power so that a small portable generator can be used with the system, thus giving it more portability. Testing of the camera system and new cooler showed no problems in ambient temperatures ranging from 0 to 35 degrees C. These tests included the use of the portable generator and testing of a new set of electronics cables designed to simplify the electronic connections of the camera. The system operated as expected and the new, longer cables showed a negligible increase in dark signal, no loss in signal, and greater flexibility for setting up the camera.

Laboratory testing of the camera included a check on the linearity of the camera's detectors. Nine different exposure times from 10 to 240 seconds were used and Nandy found the linearity to be better than 0.5%. An additional test of linearity was done using a lower-radiance source and three exposure times. These exposures were repeated at six different distances from the source and showed a similar 0.5% linearity with the difference from linearity well within the measurement uncertainties of the distance. If the detectors are assumed to be quadratic, the fit is better than 0.1%. Further work is planned to better understand these results since it is unlikely that the response of the CCD-camera is non-linear.

Nandy evaluated the BRDF camera's radiometric response by using the 6-inch SIS and collecting data with a fixed exposure for all four bands while the camera was rotated at 10-degree intervals on a rotation stage. The experiment was repeated with the camera rotated 90-degrees to the original orientation. Multiple fits to the data to determine the calibration for pixels not measured in the experiment were tried and Nandy found that a fourth-order polynomial worked best and fit the data to within 0.03% with a standard deviation of 1.2% (see Figure 1). Nandy then developed a 2-D calibration based on these

data. He found that calibration polynomials derived for the two orthogonal axes matched measured data to better than 0.25% out to 55 degrees from nadir. However, the polynomials are asymmetrical about nadir with as much as a 3% difference in the calibration coefficients at 40 degrees from nadir on



Figure 1 BRDF camera measurements of 6-inch SIS output as a function of angle compared to polynomial fit to the data

either side of nadir. Results of a 2-D calibration compared to the 1-D cases showed differences of 2% at 50 degrees from nadir for one azimuth but as much as 10% for other azimuths. Thus, it is clear that a best-fit calibration surface will cause normalization problems in certain sections of a BRDF camera data and methods for calibrating each individual pixel in the entire array must be developed.

Nandy began studying a calibration method that translates the BRDF camera across the exit port of the 40-inch SIS. As part of this work, he developed IDL-based software to register the linearlytranslated images using a technique that minimizes standard deviations between two data sets. Edgematching techniques were rejected because of the off-axis distortion fisheye lens. The translation method will be tested over the next six months to investigate the amount of translation needed, the angular limits of the method due to the limited port size of the 40-inch SIS, and the expected accuracy. The work will also include verifying the derived sphere uniformity by translating the VNIR CCR across the SIS port. Nandy has also begun a sensitivity analysis to determine what levels of accuracy are required in the retrieved BRDF of the surface for our vicarious calibration work.

Using the same setup developed to test the detector linearity, Nandy also collected data to determine stray-light effects. The results of these measurements show a ghost image at a level of 0.4% with the likely cause being reflection from the interference filters. The SIS setup was modified to place the camera 610 mm from the SIS with a 1.5 mm aperture. This provided a point source for the camera to assess the MTF/PSF of the system. A preliminary study of the results indicates a broad elliptical PSF on-axis with a semi-major axis of five-pixels. Tests using typical BRF models for our test sites indicate that this PSF has less than 0.1% effect on the retrieved BRDF. Nandy also investigated polarization effects and found that the sensor has nearly a 25% polarization effect at 70-degrees in the NIR band of the camera system.

Nandy processed BRDF camera data from the June 1998 Railroad Valley Nevada campaign to explain irregularities in results of AVHRR calibrations obtained by the Canada Centre for Remote

Sensing (CCRS). Data from several days during the campaign were examined, and morning BRDF data were selected to match solar and scattering angle geometries of the AVHRR data. BRDF data from the June 17, 1998 Railroad Valley field campaign were processed and a preliminary examination of the results indicate that BRDF effects could indeed be the source of the problem.

Nandy began work on a lightweight, portable version of a non-imaging system to retrieve surface BRDF. The system uses an ASD FieldSpec on a rotating frame and will be used to validate the BRDF camera and for use on campaigns where the camera cannot be deployed. The system was tested in the parking lot of the RSG using one of the RSG's 18-inch Spectralon panels. Data were collected at 10-degree increments over the panel from nadir angles of -70 degrees to +70 degrees in both the principle and perpendicular planes, for a variety of solar zenith angles. These data will be compared to those in the blacklab to determine the accuracy of the method.

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. The instrument was completed in March 1997. Subsequent work with the system, the results of which have been presented in previous reports, show the system to be repeatable and robust. It is now part of our regular data collections and future reports on results from the system will be included in the field experiment sections.

<u>Calibration Laboratory</u>: The objective of this project is to develop a calibration laboratory that provides the 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 1999.

A. Ahmad, Biggar, and E. Nelson continued testing the new shutter in the blacklab. Burkhart replaced the cardboard light shields with aluminum ones. Biggar and Ahmad continued work on the chopper assembly. A problem with programming the controller for the chopper forced the two to reset it to factory defaults and then back to appropriate values for our unit. This solved the communication problem with the device, but the chopper has since been disabled because of an inertia mismatch similar to what caused the shutter translator to fail. Biggar and Nelson have designed a method to overcome this problem and plan to implement the solution during the next six months.

Biggar worked with several other EOS-related groups to help them characterize their field radiometers and field-reflectance standards. This included VNIR measurements of the Spectralon reference panels used by CCRS and MODIS Science Team Member K. Carder from the University of South Florida. Biggar, J. LaMarr, and M. Kuester measured panels from Landsat-7 Science Team Member, S. Moran, and MODIS Science Team Member A. Huete in both the VNIR and SWIR. These measurements used a new set of interference filters that had been spectrally characterized by H. Kim, Kuester, and M. Mienko. Evaluation of the filters was done using IDL-based software developed by Kim to display and compute the wavelength/bandwidth of filters. This new set of filters includes an additional filter in the blue portion of the spectrum at 400 nm that should improve our reflectance measurements at the short end of the spectrum. The results of the blacklab measurements with the new filters were compared to those measured with the older filters and found to be in good agreement.

In addition to the panel measurements, Biggar worked with B. Stewart and C. Cattral of K. Carder's group to evaluate the radiometric response of their field spectrometers using the 40-inch SIS and our VNIR CCR to check the SIS output. Biggar and Burkhart developed a mount to measure the field of view of a GER spectrometer sent by R. Gauthier of CCRS. Biggar worked with Gauthier to make the field-of-view measurements in our calibration laboratory using our 6-inch collimator. The two also made measurements of our 40-inch SIS for an absolute calibration of the GER as well as the

RSG's VNIR and SWIR CCR and our two ASD Field Spec FRs. Biggar sent the results of the measurements to Gauthier.

The blacklab measurements described above also included a set of data collected by LaMarr at incident angles fixed at 30 and 45 degrees with variable viewing angles rather than the standard normal view angle with variable incidence angle. These data were used to test the accuracy of a Hapke model representation of the BRDF of Spectralon. Using the a Hapke model representation

for Spectralon as part of our surface reflectance calculations gives retrieved reflectances to within 0.4% of those based on a simple polynomial curve fit to the blacklab measurements (see Figure 2). Figure 2 is a spectral average of the percent difference between results derived from a Hapke-based BRF and that of a fourth order panel polynomial. For reference, differences in the BRDF of the panel derived from the fourthorder polynomial and those of a sixth-order polynomial are all less than 0.02%. From the



Polynomial vs. Hapke 0.6 0.4 Percent Difference 0.2 Zenith Anale Solar 78 Degrées 0.0 -0.2 -0.4 500 1000 1500 2000 2500 Wavelength [nm]

Figure 2 Percent difference between reflectances derived from a Hapke-based panel BRF and a polynomial-based BRF



Figure 3 Comparison of Hapke-based BRF and Figure 4 Percent difference between a Hapkepolynomial-based BRF as a function of solar based panel BRF and a polynomial-based BRF as zenith angle

a function of solar zenith angle

figure, it can be seen that the differences vary with solar zenith angle, and this is further illustrated in Figures 3 and 4 that show the differences between the Hapke-based BRF and the polynomialbased value as a function of solar zenith. Work is still underway to determine the cause of the differences. LaMarr also found that using standard blacklab measurements and additional data collected at fixed incident angles of 0 and 45 degrees gives a Hapke model representation that reproduces the measured BRF at a 30 degree incident angle to better than 3% for view angles out to 60 degrees viewing angle, and better than 0.5% out to 40.

A. Ahmad continued populating and modifying a database of the RSG's blacklab measurements. Biggar experimented with a simple fitting routine to evaluate BRDF measurements at angles that we cannot measure, and he modified the control program to allow measurements of BRF around the specular peak. Biggar further processed data from the panel intercomparisons done for the 1998 joint field campaign. He also compared multiple measurements of the NIST-supplied Spectralon reference. The measurements were taken several weeks apart and showed changes of less than 0.5%.

Biggar and Mienko continued work on a SWIR radiometer for the blacklab that is smaller and easier to set up than the SWIR CCR. This radiometer will allow us to characterize our references in the SWIR on a more frequent basis. A test amplifier circuit was developed for the radiometer, including the TE controller so that noise determination tests could be done. Mienko completed the optical layout and Burkhart machined the needed radiometer parts. Mienko continued work on the design and interconnection of the pre-amplifier to be used with the radiometer. He tested several different op-amp configurations in an attempt to achieve lower noise and was able to reduce the noise to the 0.2 to 0.3 mV level at a gain of 10e+7. Mienko is currently working on the layout and shielding of electrical components. Testing of the radiometer is expected to take place in August.

X. Ding and E. Zalewski collected and processed data to test the radiance stabilized circuit designed and built by E. Nelson for the 6-inch SIS. This circuit is a prototype for use with the 40-inch SIS and a similar design is being used for the calibration source of the airborne radiometer currently being built by Burkhart. The two found the repeatability to be better than 2% at 490 nm and better than 0.7% at 670 nm. The output of the sphere as measured by the monitoring detector also shows good agreement with the VNIR CCR. Ding and Zalewski intend to develop methods to allow the use of multiple bands to control the output of the SIS..

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

Thome coordinated a joint campaign with US and Japanese ASTER Team Members to Ivanpah Playa. The campaign took place January 15-19. Japanese participants were K. Arai, H. Fukasawa, T. Takashima, and S. Tsuchida. RSG members who participated were J. LaMarr, A. Lopez, B. Magi, P. Nandy, J. Smith, and Thome. The focus of the campaign was to compare vicarious calibration results for the solar reflective using a Landsat-5 overpass on January 17 and a MASTER overflight planned for the same day. The campaign was done in conjunction with a TIR campaign at the Salton Sea. Unfortunately, weather for all days of the campaign at Ivanpah was cloudy and no data were processed.

In January, LaMarr, Magi, Mienko, and Zalewski worked with MODIS Science Team Member, A. Huete to evaluate his three-band airborne imager during two-days of data collections south of Tucson. Unfortunately, poor weather hampered both days of the data collections. Nandy arranged a student field campaign in March to the Pima County Fairgrounds for a similar purpose of calibrating and characterizing Huete's MQUALS airborne system. The experiment was planned for March 17 to coincide with a Landsat-5 overpass. March 16 was used to test the data collection methods and to layout the test site. March 17 was heavily overcast in the morning but skies cleared partially around overpass. Surface reflectance data were collected over the site during the TM overpass as well as multiple passes of the MQUALS system. Examination of all-sky photographs indicated that clouds were present over the sun and overhead at the time of TM overpass. Thus, no data TM data were requested. Malfunctions in the MQUALS instrumentation has prevented any comparisons of results.

The group performed a set of extensive field campaigns related to Thome's Landsat-7 project. The impact of this work on the group's EOS projects is that it allowed the further testing of equipment and software developed for ASTER and MODIS calibrations using the reflectance- and irradiance-based approaches. Plans were also made to collect large footprint reflectance data that would be tested with the ETM+ data to evaluate methods for calibrating MODIS using our Nevada test sites. In addition, we deployed two separate calibration groups in order to collect data for ETM+ at two separate sites. The lessons learned from this activity should help us increase the usable number of data sets available for ASTER and MODIS calibration. Biggar characterized the BRDF of the group's field references in the blacklab for this work.

W. Barber, R. Kingston, and Nandy collected data for the White Sands portion of the campaigns. A. Ahmad, H. Ding, Thome, and E. Whittington worked the Ivanpah data collections while Thome was joined by N. Anderson, M. Kuester, Magi, and M. Mienko for the Railroad Valley portion of the campaign. The weather for all of the overpasses was sufficient to warrant attempts at the calibrations of the sensor and Thome has completed processing of the data and is awaiting the imagery. Unfortunately, poor weather during the early morning periods and on other dates of the campaigns prevented the collection of any large footprint surface reflectance data. The weather also prevented usable BRF data collection at Railroad Valley (several data sets were acquired at Ivanpah Playa).

Magi, M. Mienko, P. Nandy, and Thome traveled to Ivanpah Playa for a June 21 overflight of the MASTER sensor operating from NASA's DC-8. The flight was a repeat of an experiment flown last December using the B-200 flying from Nellis Air Force Base. The RSG group collected data for the VNIR and SWIR portion of the spectrum, while a group from JPL collected data at Lake Meade for the TIR and MWIR. While skies were not completely clear for the overflight, measurements indicate that the impact of the clouds should be minimal. Thome has completed preliminary processing of the data from the campaign and is awaiting further word from Ames Research Center regarding the success of the mission.

Based on further information supplied by S. Hook of JPL regarding flight times and image acquisition, Thome finalized results from the MASTER calibration campaign that took place last December. The percent difference between the measured radiances by MASTER and the predicted radiances from the reflectancebased approach are shown in Figure 5 as a function of



Figure 5 Percent difference between reflectance-based results and MASTER-reported radiances for December 2 overflight at Ivanpah Playa.

wavelength for the reflective bands. The results are quite good in regions without strong atmospheric absorption. There does appear to be a trend with altitude with the reflectance-based results underestimating the radiances at low altitude and overestimating at high altitudes. The trend as a function of wavelength in the VNIR is also under investigation. Further work is also needed to understand the larger uncertainties in the SWIR and to improve the group's abilities to predict radiances in spectral regions of absorption.

In software-related activities, Nandy incorporated software to load and display ASD FieldSpec FR data into J. Smith's IDL instructional/developmental software package. Biggar and Smith began development of software to correct for blocking the forward scatter contribution in the diffuse measurements of the diffuse-to-global meter. Biggar and R. Kingston upgraded the Sun network's operating system to allow an upgrade to IDL 5.2 for use with EOS data. Nandy developed IDL software to segment image data and to locate uniform regions suitable for use as reflectance-based calibration targets. Currently the program can select areas above a threshold DN and below a specified variance.

Thome installed a Cimel solar radiometer in February on the roof of OSC for inclusion in the AERONET and began making regular measurements with the group's automated solar radiometer for comparison. An apparent change in the instrument's calibration prompted the system to be returned in June to GSFC for calibration. The group began regular data collection of solar transmittance using a 10-channel automated solar radiometer at both the RSG laboratory and on the roof of OSC. The data from the 10-channel instrument are collected at much higher temporal resolution than the Cimel system and will be used to study short term variability of aerosols in the Tucson Valley.

Figures 6-8 give some sample results of the data collections showing comparisons between the Cimel and the 10-channel solar radiometer. As can be seen from the figures, there is reasonably good agreement between the two systems in retrieving optical depth (Figures 6 and 7), although the agreement is not the same from day to day for all bands. Considering that the results are using two independently calibrated system, no common calibration data sets, and different processing schemes, even the difference of 0.02 in optical depth seen in Figure 7 is quite good. Figure 8 shows a comparison of results of derived column water vapor between the two radiometers and those from radiosonde data obtained at the Tucson International Airport approximately 10 km from the radiometers. Again, the agreement between the radiometers is quite good with differences for the most part less than 10%. Agreement with the radiosonde results also show relatively good



Figure 6 Optical depth results from 10-channel **Figure 7** Optical depth results from 10-channel solar radiometer and Cimel for 440 and 670 nm. solar radiometer and Cimel for 440 and 670 nm.

agreement. Thome is currently analyzing the results of these measurements, both as part of this work, and as part of his work related to the Global Aerosol Climatology Project.

B. Magi continued work to upgrade the tracking software for the tracking mount of the spectropolarimeter. The software relies on an initial pointing of the



Figure 8 Water vapor retrieval comparisons between radiosonde, Cimel, and 10-channel radiometer.

instrument attached to the mount to determine the encoder positions for the drive motors. Then solar ephemeris calculations are used to track the solar position. Magi successfully used the mount to allow a solar radiometer to track the sun for over five hours. Burkhart developed an adaptor mount for the tracking platform to allow the water vapor meter or an Exotech radiometer to be used with the system. Magi developed software for the A/D board to log voltages from the water vapor meter to a file immediately after the tracking unit updates its position. He then performed several successful tests with the tracking unit and water vapor meter in the parking lot of the RSG. The system was also tested on the Railroad Valley campaign in late May and ran successfully during the dual overpass of Landsats 5 and 7 on June 1. Magi has begun work on scans in the principal and almucantar planes and the capability to point to celestial north. Magi encountered difficulties with the azimuth encoder. Magi believes that the encoder problem is due to a hardware problem that prevents the encoder from rotating freely. C. Burkhart is addressing the problem.

X. Ding and Zalewski developed a circuit for a stabilized light source that will be used as the calibration source for the airborne radiometer. Rather than relying on constant current control, the circuit is a feedback circuit that maintains constant output as determined by a monitor detector. The

work included developing models for the filament radiance of the lamp, photodetector, and electronics. The modeling also included the possible use of a sunlight filter to allow longer integration times to give better signal in bands with low output without saturating other bands. Ding completed a prototype of the circuit and is testing the stability of the lamp output. Ding and Zalewski also began work to improve the light collection of the airborne radiometer by examining the optical properties of the telescope used for the radiometer. Ding modeled the output of the radiometer when viewing reflected solar radiance and completed the optical design for the full eight-channel implementation of the radiometer.

Barber began work designing a new panel stand for use by the group in monitoring sky conditions during surface reflectance measurements. Data from this constant panel setup, so named because it constantly monitors downwelling irradiance, will be used in LaMarr's work to include a correction to surface reflectance measurements for downwelling sky irradiance. Whittington began development of software to collect data from the constant panel. The group currently uses software supplied with a Fluke Hydra datalogger. While adequate, the software does not automatically convert raw voltages to physical units and is not conducive to changing data collection rates needed for proper monitoring of atmospheric conditions at the time of sensor overpass.

Field work plans during the next six months will focus on preparations for campaigns planned after the launch of Terra. The plans originally called for a set of extensive campaigns at the end of September and early October and may have included collaboration with the SCAR-99 aircraft flights. With the slip in the launch date, currently scheduled for August 27, the first campaign related to Terra would take place October 31 at Railroad Valley. If the checkout of the ASTER instrument occurs faster than expected, it may also be possible to perform a calibration at Ivanpah Playa on October 24. The goal would then be to perform calibrations at Ivanpah on November 9 and Railroad Valley on November 16. Currently, the October 31 campaign is scheduled to be a joint campaign between the US and Japanese ASTER Science Team members. If the launch date of Terra slips past August, a reevaluation of field campaigns will take place due to the problems that would be anticipated with weather at the Nevada test sites in December, January, and February. **Faculty, staff, and students:** The personnel presently associated with the RSG are as follows: Faculty: Biggar, Slater, Thome, and Zalewski. Staff: Barber, Burkhart, L. Dancer, Kingston, Nelson, and S. Recker. Students: Ahmad (MS), Anderson (undergrad), Gordon (undergrad), Kim (MS), Kuester (undergrad), LaMarr* (Ph.D.), Magi (undergrad), Mienko (MS), Nandy*(Ph.D.), and 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. Magi recently graduated with a BS degree in Physics and will continue working with the group until August.

Papers and publications

Four papers appeared in a peer-reviewed, special issue of *Metrologia* based on papers presented at the 1998 Newrad conference. These are listed below along with their abstracts:

- Biggar, S. F., "Calibration of a visible and near-infrared portable transfer radiometer", *Metrologia*, **35**, pp. 701-706, 1998.
- **Abstract.** A portable transfer radiometer covering the spectral range 400 nm to 900 nm has been built and calibrated. This radiometer was designed to measure the output of spherical integrating sources with large apertures such as those used to calibrate spacecraft sensors for he Earth Observing System (EOS) of the National Aeronautics and Space Administration (NASA). The radiometer is a simple, robust, narrowband multifilter instrument using a silicon trap detector. The temperature of the filters, apertures, detectors and electronics is controlled slightly above ambient. There are no imaging optics and the radiometer throughput is controlled by Invar-spaced apertures.

The radiometer has been calibrated by two methods. First, the radiometer was calibrated in an irradiance mode by use of a National Institute of Standards and Technology (NIST) FEL lamp. Second, a Solar-Radiation-Based Calibration (SRBC) was carried out, in which the radiometer viewed a panel, calibrated with a bidirectional reflectance distribution function (BRDF), illuminated by the Sun. Differences between the NIST calibration and the SRBC method for a recent solar spectrum are quite small: less than 2.1% for the seven bands between 412 nm and 868 nm, and well within the estimated uncertainties for the two calibration methods.

- Johnson, B. C., P. Y. Barnes, T. R. O'Brian, J. J. Butler, C. J. Bruegge, S. Biggar, P. R. Spyak, and M. M. Pavlov, "Initial results of the bidirectional reflectance characterization round-robin in support of EOS," *Metrologia*, 35, pp. 609-613, 1998.
- Abstract. Laboratory measurements of the bidirectional reflectance distribution function (BRDF) of diffusely reflecting samples are required to support calibration in the Earth Observing System (EOS) programme of the National Aeronautics and Space Administration (NASA). To assess the ability of the instrument calibration laboratories to perform accurate BRDF measurements, a round-robin comparison with the National Institute of Standards and Technology (NIST) as the central laboratory was initiated by the EOS Project Science Office. The comparison parameters, which include measurement wavelength, spectral bandwidth, illumination and viewing geometry, sample type and alignment, and data format, were selected in consultation with the participants. The participants were selected based on their roles as metrology laboratories with direct connections to EOS or other international Earth remote-sensing satellite programmes. This paper briefly describes the format of the comparison, the status of the first round, and some preliminary results.
- Thome, K., S. Schiller, J. Conel, K. Arai, and S. Tsuchida, "Results of the 1996 Earth Observing System vicarious calibration joint campaign at Lunar Lake Playa, Nevada (USA)", *Metrologia*, **35**, pp. 631-638, 1998.
- Abstract. A joint campaign was held at Lunar Lake Playa, Nevada (USA) in June 1996 to evaluate the accuracy of reflectance-based, vicarious calibrations of Earth observing Systems (EOS). Four groups participated in the campaign and made independent measurements of surface reflectance and atmospheric transmittance on five different days. Each group predicted topof-the-atmosphere radiance for several bands in the 400 nm to 2500 nm spectral range. Analysis of the data showed differences of the order of 5% to 10% throughout the spectral region under study. Further study revealed that the major sources of discrepancy are differences in procedures and assumptions in finding the reflectance of field references used to determine the surface reflectance of the test site. Differences caused by varying radiative transfer codes and aerosol assumptions were found to be a relatively small error source, owing to the high reflectance and low turbidity of the test site. Differences in the solar irradiance values used by separate groups were found to be significant, but can be overcome by agreeing on a standard solar irradiance data set. The results from this campaign were used to plan a follow-up campaign in June 1997 that included developing a set of laboratory measurements to characterize the field radiometers which measure surface reflectance, and obtaining a consistent set of reference-panel reflectance factors. The expectation is that surface reflectance, and obtaining a consistent set of reference-panel reflectance factors. The expectation is that disagreement in absolute radiances at the top of the atmosphere generated by these field methods will be reduced to less than 3% if further cooperative work between groups is carried out to develop approaches which will account better for reference panel calibration, the consistent use of atmospheric characterization and radiative transfer codes.

- Yoon, H. W., B. C. Johnson, D. Kelch, S. Biggar, and P. R. Spyak, "A 400 nm to 2500 nm absolute spectral radiance comparison using filter radiometers," *Metrologia*, **35**, pp. 563-568, 1998.
- **Abstract.** An integrating-sphere source developed by MTL Systems, Inc. was calibrated for them by a commercial standards laboratory traceable to the National Institute of Standards and Technology (NIST), resulting in values of spectral radiance in the 400 nm to 2500 nm spectral region. The spectral radiance of the MTL sphere source was then measured using three filter radiometers, also NIST-traceable, that were developed for the Earth Observing System (EOS). In the visible and near-infrared, the values from two Si-photodiode filter radiometers and the supplied calibration values agree within their mutual uncertainties, but in the short-wave infrared, the agreement between the filter-radiometer results and the calibration values is less satisfactory. The reason for this discrepancy is not understood, and additional measurements should be performed.