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Coincident Aerosol and H_2O Retrievals versus HSI Imager Field Campaign Report

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May 2016

ARM
CLIMATE RESEARCH FACILITY

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Office of Science, Office of Biological and Environmental Research

Executive Summary

Two spectrally calibrated tarpaulins (tarps) were co-located at a fixed Global Positioning System (GPS) position on the gravel antenna field at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) site. Their placement was timed to coincide with the overflight of a new hyperspectral imaging satellite. The intention was to provide an analysis of the data obtained, including the measured and retrieved spectral albedos for the calibration tarps. Subsequently, a full suite of retrieved values of H_2O column, and the aerosol overburden, were to be compared to those determined by alternate SGP ground truth assets. To the extent possible, the down-looking cloud images would be assessed against the all-sky images. Because cloud contamination above a certain level precludes the inversion processing of the satellite data, coupled with infrequent targeting opportunities, clear-sky conditions were imposed.

The SGP site was chosen not only as a target of opportunity for satellite validation, but as perhaps the best coincident field measurement site, as established by DOE's ARM Facility. The satellite team had every expectation of using the information obtained from the SGP to improve the inversion products for all subsequent satellite images, including the cloud and radiative models and parameterizations and, thereby, the performance assessment for subsequent and historic image collections.

Coordinating with the SGP onsite team, four visits, all in 2009, to the Central Facility occurred:

- June 6-8 (successful exploratory visit to plan tarp placements, etc.)
- July 18-24 (canceled because of forecast for heavy clouds)
- Sep 9-12 (ground tarps placed, onset of clouds)
- Nov 7-9 (visit ultimately canceled because of weather predictions).

As noted, in each instance, any significant overcast prediction precluded image collection from the satellite. Given the long task-scheduling procedures (which were in place for each time period), coupled with other priorities and the satellite lifetime, no alternate SGP images could be obtained.

Acronyms and Abbreviations

AFRL	Air Force Research Laboratory
ARM	Atmospheric Radiation Measurement Climate Research Facility
ARTEMIS	Advanced Responsive Tactically-Effective Military Imaging Spectrometer", prim
DOE	U.S. Department of Energy
ENVI	Environment for Visualizing Images
FLAASH	Fast Line-of-Sight Atmospheric Analysis of Hypercubes
GMT	Greenwich Mean Time
GPS	Global Positioning System
MFR	multi-filter radiometers
MODTRAN	MODTRAN® (MODerate resolution atmospheric TRANsmission)
NOAA	National Oceanic and Atmospheric Administration
RT	radiative transfer
SGP	Southern Great Plains, an ARM megasite

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1.0 Background

1.1 Post-Campaign Modified Proposal

- Proposal title: Validation of Hyperspectral Imager's Aerosol Retrievals at First-Light over the Southern Great Plains (SGP) Site
- Principal Investigator: Gail P. Anderson
- Co- Principal Investigators: Dr. Peter Armstrong/Air Force Research Laboratory (AFRL) and Dr. John Cipar/AFRL
- Contributing Principal Investigator: Dr. H.E. Snell [as MT-CKD continuum provider]
- Timeline: April 15 2009 to October 15, 2009 (dates to be specified); last attempt, November 7–8, 2009
- ACRF Facility Being Requested: SGP.

1.2 Scientific Focus of Campaign

The scientific focus of the campaign will be to assist in establishing auxiliary vicarious calibration for a hyperspectral imaging satellite in the 0.4- to 2.5-um spectral range, similar to support provided to prior Airborne Visible InfraRed Imaging Spectrometer (aircraft), Hyperion, and A-Train assets. The effort will require only typical SGP ground support (e.g., sondes, aerosol, direct and diffuse solar, local surface albedos, and H_2O overburdens, all-sky imaging, etc.), plus placement of at least two large, spectrally calibrated tarpaulins (tarps) (12-plus m/side) to provide surface "ground truth" information. Primary issues to be addressed by the new satellite center on H_2O vapor and aerosol retrievals, identification of clear and partial cloud-fill, plus the impact of clouds, shade, and variable albedo contributions to the total (direct and scattered) outgoing shortwave radiation. A secondary investigation will center on the validation of MODTRAN®5 incorporation of the MT-CKD H_2O continuum in this spectral range (see Paynter and Ramaswamy (2012).

1.3 Relevance to ACRF Mission

With respect to the Mission Statement, the unique assets provided by SGP can support:

- Auxiliary vicarious calibration of this new satellite-borne, visible-to-shortwave infrared spectral data set and its analysis, including aerosol and cloud overburdens for partial cloud conditions
- Direct validation of MODTRAN®5 radiative transfer (RT) code's implementation of MT-CKD, as previously developed and funded under the U.S. Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility.

This represents one of the best opportunities to expand confidence in both the satellite and the flexible (both geometrically and spectrally) MODTRAN® RT code. Establishing the relationship of known albedos to the outgoing shortwave radiation measurement in the presence of aerosols and partial cloud cover and shade, can then be used to determine similar albedo-related properties at other global locations sampled by the satellite. The continuation of the SGP collections during the first 6 months of satellite operation will help to establish the continuity of the calibration and overall satellite performance. In addition, introducing fixed albedos (tarps) to the naturally varying agrarian albedos at the ARM site can provide some assessment of the spectral details of the local growth cycle.

1.4 Description of Proposed Campaign

Three to five times over a 6-month period, perhaps extended throughout the first year of operation, the Principal Investigator and support team will visit the SGP site. The dates will be based primarily on orbital geometry (due to planned precession) and weather forecasts because clear-sky conditions with only sparse cloud cover are necessary components for the calibration. Two spectrally calibrated tarps at fixed Global Positioning System (GPS) locations will be placed on the SGP gravel antenna field, with placement timed to coincide with overflight of the satellite. (Orbital characteristics may support revisiting SGP within the same broad time-window, but with varying viewing angles.) The tarps will be cleaned before and after each satellite data collection, recalibrated with an Analytical Spectral Devices, Inc., handheld spectrometer,[1] and finally removed and stored until needed for the next collection. If SGP finds the tarps useful for other satellite overpasses, they can be redeployed; however, they are not meant for permanent outdoor placement.

Data analyses for the satellite spectrometer will be based on a government version of FLAASH,[2] an atmospheric correction algorithm developed by AFRL and Spectral Sciences, Inc., available through the Environment for Visualizing Images (ENVI) software package. The algorithm uses a set of look-up tables that will yield H_2O column abundance, primitive aerosol overburden, and spectral surface albedo; this is accomplished through the minimization of residuals using standard atmospheric correction approaches. The validation of these quantities, for both sensitivity and precision, will necessitate excellent “ground truth,” as available at SGP. Known surface albedo information will support an alternate atmospheric correction algorithm (i.e., the Empirical Line Method). Use of the Empirical Line Method necessitates the spectrally calibrated tarps, whose albedos will be measured by the manufacturer and again on location.

A final report was intended to include the measured and retrieved spectral albedos for the spectrally calibrated tarps. In addition, a full suite of retrieved values of H_2O column, aerosol, etc., would be compared to the SGP ground truth assets, including the standard SGP albedo measurements. To the extent possible, the down-looking cloud images, if available, would also be assessed against the all-sky images. (Ref: “Spectral albedo measurements will be facilitated by the SGP Central Facility using downward facing Multi-Filter Radiometers (MFR) on the 25-m level of the 60-m tower over a wheat field, and on a 10-m tower over the adjoining pasture.”)

As noted, the expected amount of cloud cover at the time of a satellite data collection was inferred from local weather forecasts. In each instance of task scheduling the satellite to acquire the SGP site, the forecast was negative over the typically 2-day periods and ultimately supported by SGP surface-based instruments.

[1] Analytical Spectral Devices, Inc. (ASD), http://www.asdi.com/products/fieldspec-spectroradiometers, handheld spectro-radiometer used for ground calibrations.
[2] http://www.ittvis.com/ProductServices/ENVI/ENVIModules/ENVIFLAASHModule.aspx

2.0 Notable Events or Highlights

Because the SGP site is already included in the Department of Defense required listings for accessible U.S. overflight imaging, the AFRL team needed no special permissions to submit the SGP site into ARTEMIS task scheduling. All data collected over the Cloud and Radiation Testbeds site were meant to be open and shared, particularly as related to atmospheric correction, yielding specific surface albedos (and any required reports). Go to https://directory.eoportal.org/web/eoportal/satellite-missions/t/tacsat-3 for more information about the satellite.

Two large canvas (tan) tarps (~10 m/side) were available for placement at a selected GPS-tagged location within the main SGP facility, initially to explore preparation steps for subsequent scheduled (mostly) clear-sky overflights see Figure 1). The albedo characteristics of the tarps were spectrally defined (over white and black backgrounds; see Figure 2), with the expectation that this auxiliary background albedo would be combined with the normal SGP suite of data.

Figure 1. AFRL tarps, co-located at the SGP Facility.

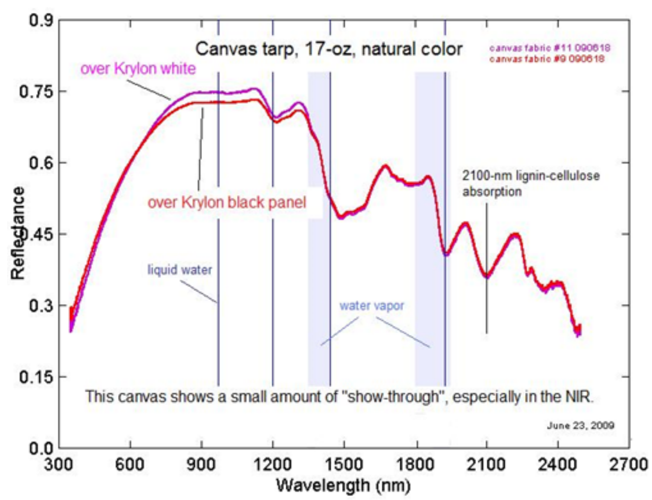

Figure 2. Spectral response of tarp against white and black backgrounds.

Determining which SGP assets might be required was based on the work of Liljergren (2007). The selection was intended to facilitate cross-validation of MODTRAN®5 with the Atmospheric and Environmental Research, Inc., RT codes for rotating shadowband spectral radiometer[3] performance assessment, etc. Coupled with lessons learned from collaborations between the National Oceanic and Atmospheric Administration (NOAA) and ARM focused on solar irradiance and methodologies, it is apparent that access to most of the standard suite of SGP's output would be selected, including total sky images, sondes, lidars, aerosol optical properties, aerosol and H_2O overburdens, and particularly the surface albedo determinations, as quoted in the report: "Spectral albedo measurements are only possible at the SGP central facility using downward facing Multi-Filter Radiometers (MFR) on the 25-m level of the 60-m tower over a wheat field, and on a 10-m tower over the adjoining pasture."

3.0 Campaign Purpose and Performance

Primary issues to be addressed by the new satellite centered on aerosol retrievals, identification of clear and partial cloud-fill, plus the impact of clouds and shade on varying albedo retrievals, and their contributions to the scattering/reflective component of the outgoing shortwave radiation. A secondary investigation was to focus on the validation of the MODTRAN®5 model's incorporation of the MT-CKD H_2O continuum in this spectral range.

Extra staffing or responsibilities for the SGP staff would be minimal, with AFRL undertaking the placement and removal of the tarps. Prior to launch, which was expected in late spring, approximately four validation instances, spaced within a 4- to 6-month period, were proposed. The orbital constraints, after launch, dictated 2-day, successive satellite overpasses within the acceptable sun-sensor-target geometry for acquisition. Depending on instrument stability, these collects could be pivotal in characterizing the ARTEMIS instrument and analyses performance (see Lockwood et al. 2006).

Performance of the analyses ultimately was hindered by the inability to task-schedule the satellite in times of clear-sky conditions at SGP. Scheduling requirements were complicated by the satellite orbital constraints (as noted above), and were done a month (or more) in advance. All planned collections ultimately overlapped with cloudy conditions at SGP. The last collection, planned for Saturday, November 7 (13:13 local time) and Sunday, November 8 (12:34 local time), was again canceled. Planning with SGP was always "on-demand" and was well-coordinated. While the SGP staff offered to place the tarps, this proved unnecessary because of the repeated weather cancelations. The two visits to SGP were well staffed by onsite personnel as well as the AFRL lead (Dr. John Cipar). In addition, e-mail exchanges were always timely and appropriate.

The near-forecast for that weekend was for clouds, which proved to be true. Satellite overpass was expected near or shortly after noon local time. This coincided with a 40% thin cloud cover on November 7 and an 80+% thick cloud cover on November 8 (see Figure 3. Supporting data for cloud contamination on these two days are shown in Figure 4.

[3] http://www.arm.gov/publications/proceedings/conf15/poster_abs/P00130

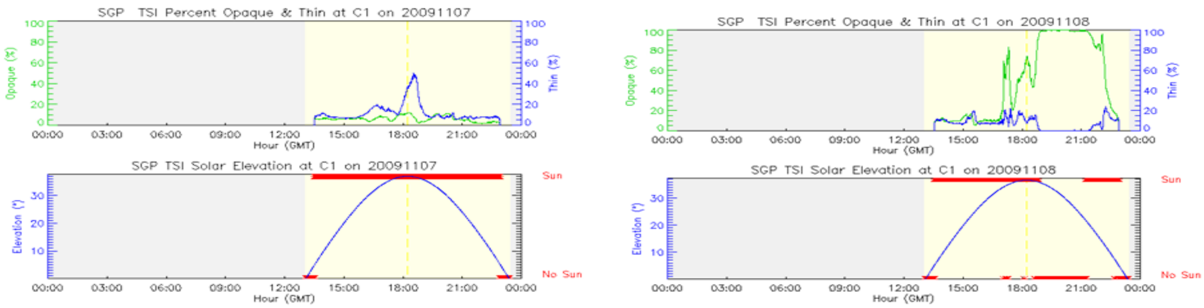

Figure 3. SGP TSI cloud cover for November 7, 2009 (left image) and November 8, 2009. Overflight was shortly after noon (18:00 GMT), 40-80% cloudy for both days. No satellite images were taken.

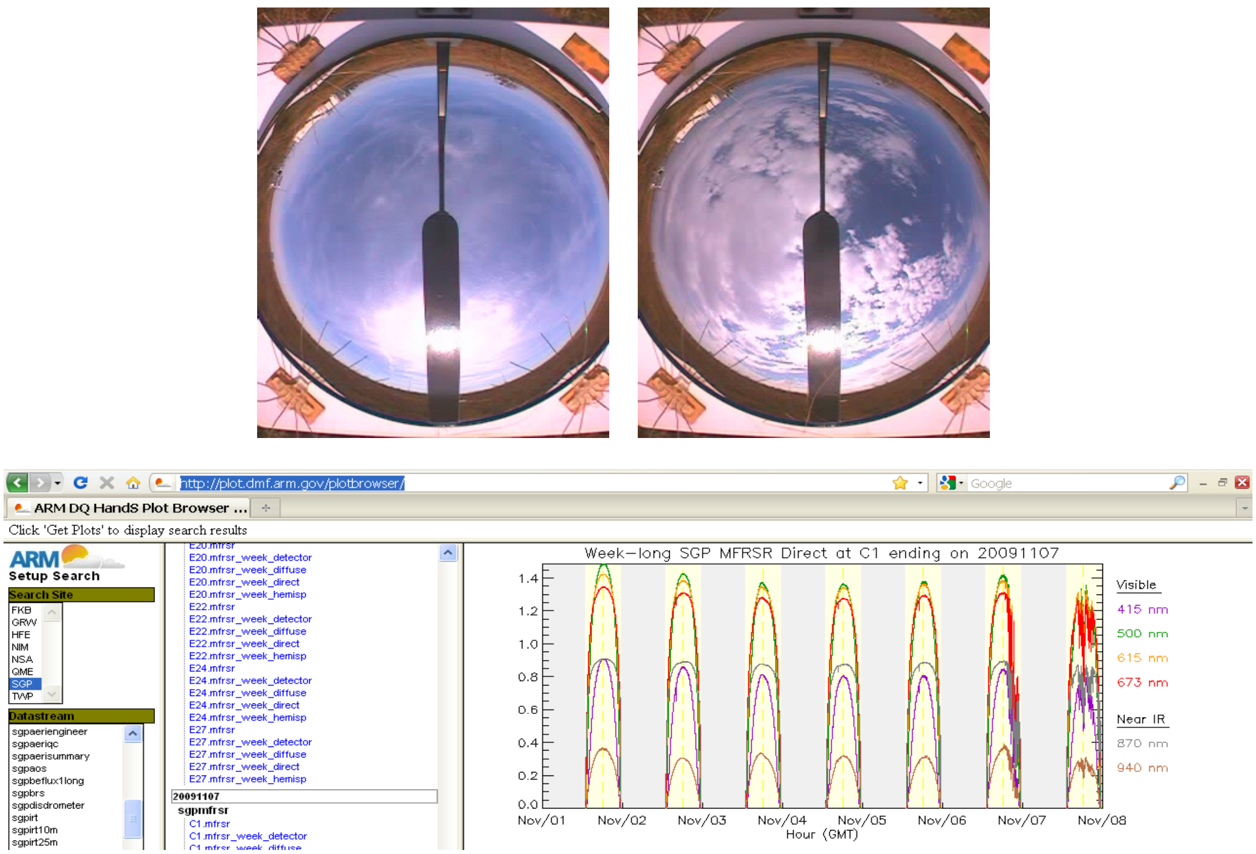

Figure 4. Supporting data for cloud contamination for November 7 and 8, 2009.

The other planned data collections were all similarly cloud contaminated.

Figure 5 through Figure 9 correspond to the planned scheduling of satellite collections, as noted earlier:

- June 6-8: Successful exploratory visit to plan tarp placements, etc.
- July 18-24: Canceled because of forecast for heavy clouds

- September 7-12: Ground tarps placed; onset of clouds
- November 7-9: Visit and collection ultimately canceled because of weather predictions.

All collections were canceled.

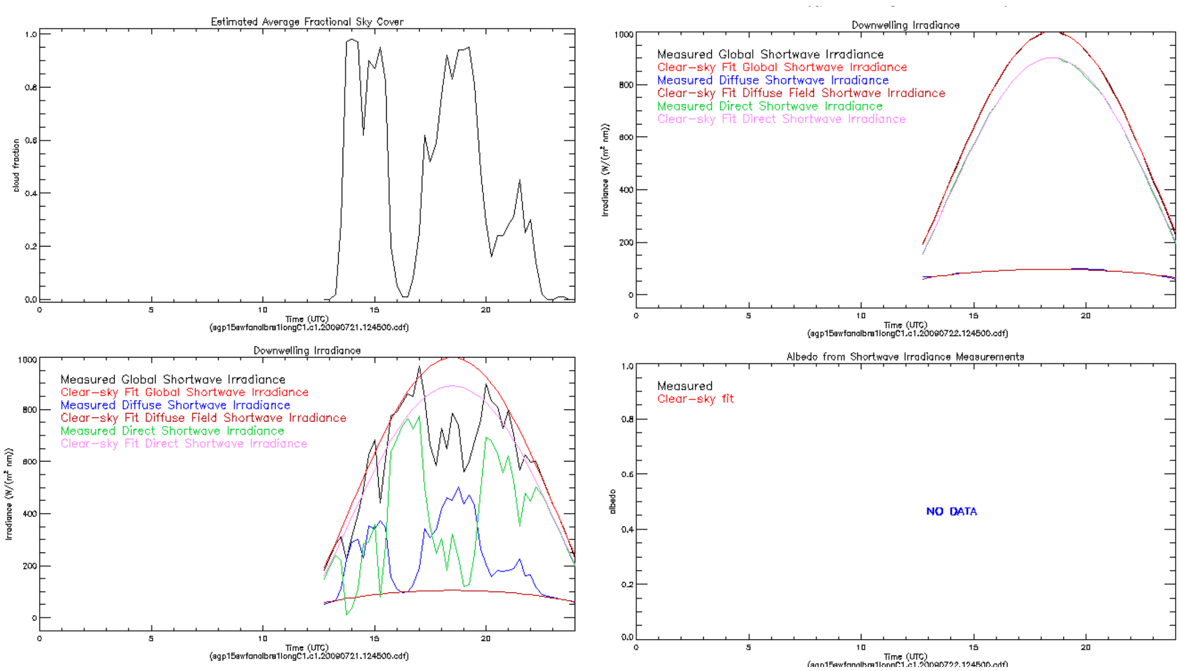

Figure 5. July 21 (left) and 22, 2009 (right); first cloudy, second NO DATA (from SGP or satellite).

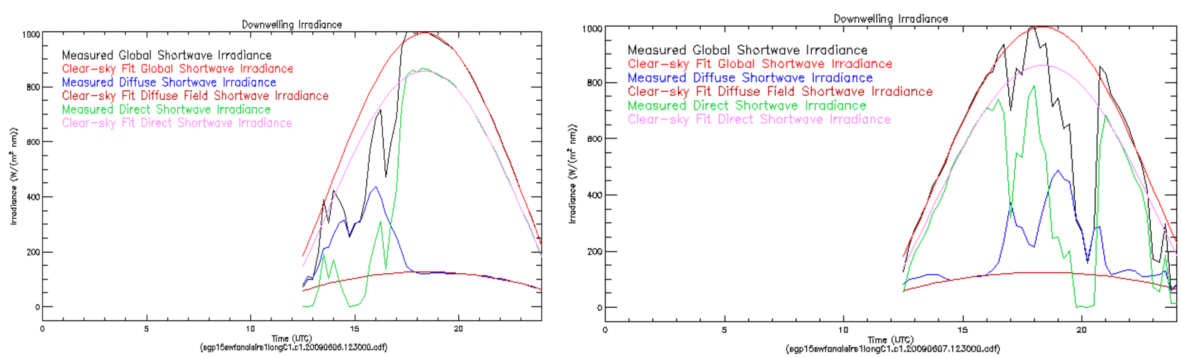

Figure 6. June 6 and 7, 2009 (no collection planned, exploratory visit).

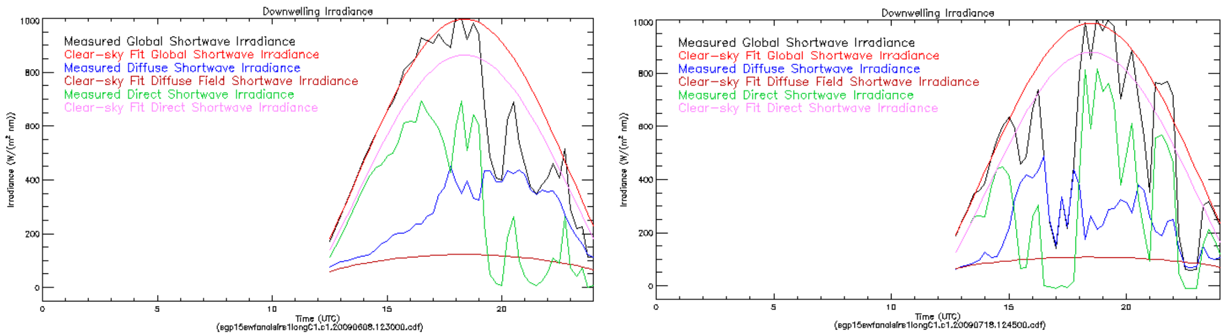

Figure 7. June 8, 2009 (no collection planned, exploratory visit), and July 18, 2009.

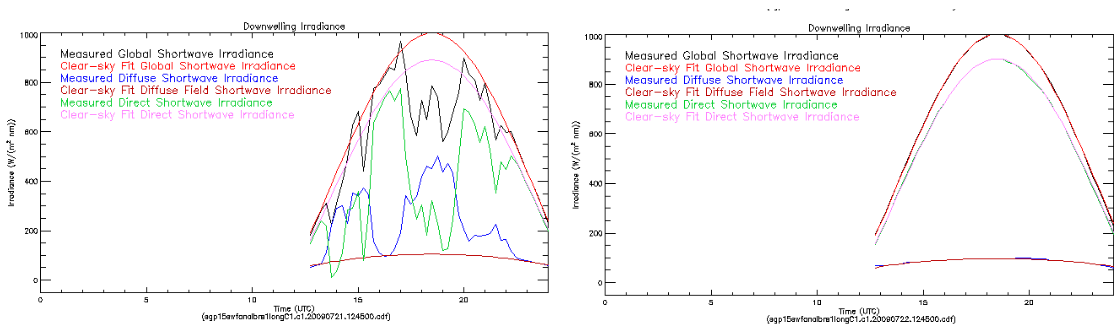

Figure 8. July 21, 2009 (very cloudy) and July 22, 2009 (clear, but collection already cancelled).

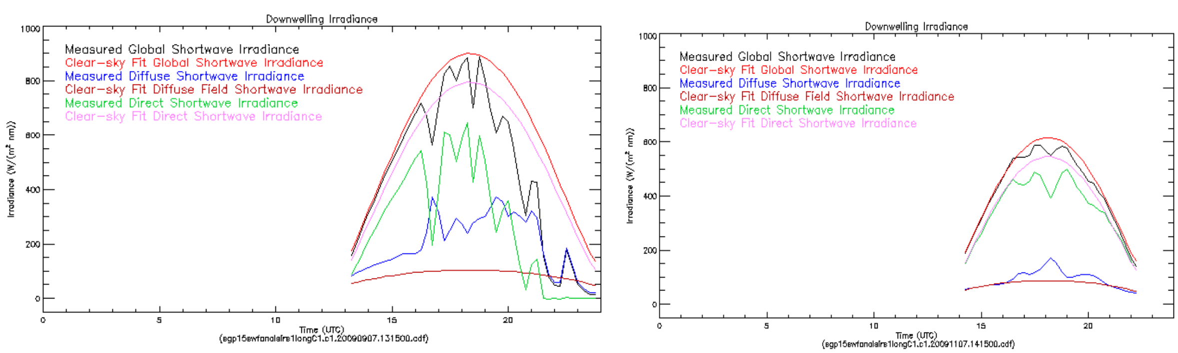

Figure 9. September 7, 2009 (left) and November 7, 2009 (right).

4.0 Lessons Learned

Interagency collaboration, as at SGP, was excellent. DOE/ARM personnel, both offsite and onsite, were responsive and helpful to any and all AFRL requests and questions (especially pertaining to rules of the site). Notable examples of the interagency collaboration and cooperation are discussed briefly below as are “lessons learned.”

Dan Rusk, SGP Operations Manager; Jimmy Voyles, Chief Operating Officer for the ARM Climate Research Facility; and Laurel Chapman, Science Liaison for the ARM Climate Research Facility, were particularly helpful.

The main lesson learned was realizing the difficulty of scheduling the satellite overpass to occur when clear conditions existed. The long lead time required for scheduling made coordinating the satellite overpass during optimal clear-sky periods problematic. In addition, orbital mechanics only allowed for optimum viewing geometries over typically two to three consecutive days. Unfortunately, given those limitations, the required clear-sky conditions did not exist for any of the three planned tests. This outcome perhaps would be expected, but if one day had been clear, the inversion algorithms could have been tested on partial cloud cover. Without the optimal clear-sky day, the experiment could not succeed. Fortunately, this did not impede the general operations at SGP as the burden of efforts for this project fell primarily on the visiting AFRL staff.

5.0 Results

With the satellite end of life, this validation opportunity was lost; however, other images have been captured, particularly with publication of the analyses of the Hawaiian volcano Halema'uma'u crater (Cidar et al. 2012) (see Figure 10). The experience in handling imagery, as associated with the planning of the ARM site collection, was most useful. Also, readers are referred to Green (1996) and Ramsey and Flynn (2004) for additional relevant information.

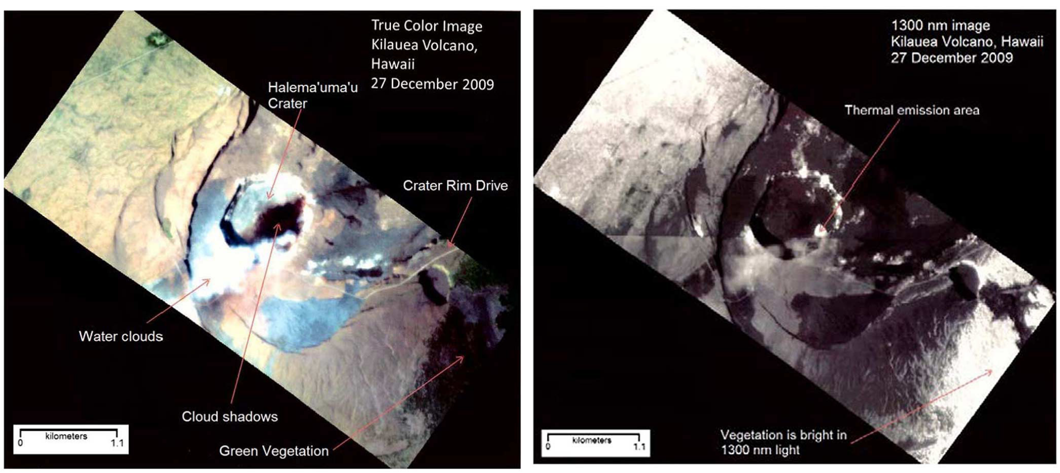

Figure 10. True-color image of Halema'uma'u Crater derived from ARTEMIS imagery (left image), coupled with an ARTEMIS image swath in 1300 nm light showing the area of elevated shortwave infrared radiance (right image) (from Cipar et al. 2012).

6.0 Public Outreach

Cover photograph for the June 14-16, 2011, 33rd Review of Atmospheric Transmission Models Meeting Advance Program. Image of the Arlington Virginia, Potomac River, and Washington, .D.C, obtained using TacSat-3's primary payload.

Two images from the Air Force Research Laboratory Advanced Responsive Tactically-Effective Military Imaging Spectrometer (ARTEMIS): one image of the National Mall, Washington, D.C. and the other of the Kilauea Volcano in Hawaii. See http://www.wpafb.af.mil/news/story.asp?id=123210022.

Description of Tactical Satellite-3 (TacSat-3). See https://directory.eoportal.org/web/eoportal/satellite-missions/t/tacsat-3.

7.0 Publications Related to Coincident Aerosol and H_2O Retrievals versus HSI Imager

7.1 Journal Articles/Manuscripts

Cipar, JJ, GP Anderson, and TW Cooley. 2012. "Temperature and power output of the lava lake in Halema'uma'u Crater, Hawaii, using a space-based hyperspectral imager." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 5(2): 617-624, doi:10.1109/JSTARS.2012.2184086.

Acton, QA (editor). 2013. "Temperature and power output of the lava lake in Halema'uma'u Crater, Hawaii, using a space-based hyperspectral imager." Reviewed in *Issues in Monitoring, Imaging, and Remote Sensing Technology*, 2013 ed., Chapter 6, p. 403, United States Air Force, Kirtland Air Force Base, Albuquerque, New Mexico.

7.2 Meeting Abstracts/Presentations/Posters

Poster: Cipar, JJ, GP Anderson, and TW Cooley. 2012. "Temperature and Power Output of the Lava Lake in Halema'uma'u Crater, Hawaii, Using a Space-Based Hyperspectral Imager." 2012-01-01, American Geophysical Union 83(47) Fall Meeting, Supplement, Abstract V71A-1263.

Cover photograph for the June 14-16, 2011, 33rd Review of Atmospheric Transmission Models Meeting Advance Program. Image of the Arlington Virginia, Potomac River, and Washington, .D.C, obtained using TacSat-3's primary payload.

Abstract: "Active Volcano Monitoring using a Space-based Hyperspectral Imager." Cipar,JJ, R Dunn, and T Cooley, in: http://www.researchgate.net/publication/253161929_Active_Volcano_Monitoring_using_a_Space-based_Hyperspectral_Imager

8.0 References

Cipar, JJ, GP Anderson, and TW Cooley. 2012. "Temperature and power output of the lava lake in Halema'uma'u Crater, Hawaii, using a space-based hyperspectral imager." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 5(2): 617-624, doi:10.1109/JSTARS.2012.2184086.

Green, RO. 1996. "Estimation of biomass fire temperature and areal extent from calibrated AVIRIS spectra." in Summaries of the 6th Annual JPL Airborne Earth Science Workshop, Pasadena, California, JPL Publication 96-4 vol. 1, pp. 105-113. Available at http://aviris.jpl.nasa.gov/proceedings/workshops/96_docs/16.PDF.

Liljegren, J. May 2007. "ACRF Instrumentation Status: New, Current, and Future." DOE/SC-ARM/P-07-002.5. Available at http://www.arm.gov/publications/programdocs/doe-sc-arm-p-07-002.5.pdf.

Lockwood, RB, TW Cooley, RM Nadile, JA Gardner, PS Armstrong, AM Payton, TM Davis, SD Straight, TG Chrien, EL Gussin, and D Makowski. 2006. "Advanced Responsive Tactically-Effective Military Imaging Spectrometer (ARTEMIS) design. In Proceedings of the 2006 IEEE International Geoscience and Remote Sensing Symposium, July 31-August 4, 2006, Denver, Colorado, doi:10.1109/IGARSS.2006.420.

Paynter, D, and V Ramaswamy. 2012. "Variations in water vapor continuum radiative transfer with atmospheric conditions. *Journal of Geophysical Research, Atmospheres* 117: D16310, doi:10.1029/2012JD017504, (2012).

Ramsey, MS, and LP Flynn. 2004. "Strategies, insights, and recent advances in volcanic monitoring and mapping with data from NASA's Earth Observing System" *Journal of Volcanology and Geothermal Research* 135(1-2): 1-11, doi:10.1016/j.jvolgeores.2003.12.015

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