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Overview of the 2015 Algodones Sand Dunes field campaign to support sensor intercalibration

Joel McCorkel,[a] Charles M. Bachmann,[b] Craig Coburn,[c] Aaron Gerace,[b,*] Larry Leigh,[d] Jeff Czapla-Myers,[e] Dennis Helder,[d] and Bruce Cook[a]

[a]NASA Goddard Space Flight Center, Biospheric Sciences Laboratory, Greenbelt, Maryland, United States

[b]Rochester Institute of Technology, Chester F. Carlson Center for Imaging Science, Rochester, New York, United States

[c]University of Lethbridge, Department of Geography, Lethbridge, Alberta, Canada

[d]South Dakota State University, Image Processing Laboratory, Brookings, South Dakota, United States

[e]University of Arizona, College of Optical Sciences, Remote Sensing Group, Tucson, Arizona, United States

Abstract. Several sites from around the world are being used operationally and are suitable for vicarious calibration of space-borne imaging platforms. However, due to the proximity of these sites (e.g., Libya 4), a rigorous characterization of the landscape is not feasible, limiting their utility for sensor intercalibration efforts. Due to its accessibility and similarities to Libya 4, the Algodones Sand Dunes System in California, USA, was identified as a potentially attractive intercalibration site for space-borne, reflective instruments such as Landsat. In March 2015, a 4-day field campaign was conducted to develop an initial characterization of Algodones with a primary goal of assessing its intercalibration potential. Five organizations from the US and Canada collaborated to collect both active and passive airborne image data, spatial and temporal measurements of spectral bidirectional reflectance distribution function, and *in-situ* sand samples from several locations across the Algodones system. The collection activities conducted to support the campaign goal is summarized, including a summary of all instrumentation used, the data collected, and the experiments performed in an effort to characterize the Algodones site. [DOI: 10.1117/1.JRS.12.012003]

Keywords: intercalibration; calibration; Algodones; field campaign; summary.

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1 Introduction

To support relative calibration efforts, space-borne imaging platforms continue to rely on pseudoinvariant calibration sites (PICS) across the globe. In particular, the Landsat program has a long history of using PICS to calibrate their optical instruments.[1] While PICS such as Libya 4 exhibit the desired characteristics (i.e., spatial and temporal uniformity) required for sensor calibration, their utility is diminished for the intercalibration of two sensors, as the characterization of these sites through field campaigns is prohibitive due to their accessibility. With NASA decadal survey missions [e.g., Climate Absolute Radiance and Refractivity Observatory (CLARREO)] coming online in the next few years, a rigorous characterization of a site's bidirectional reflectance distribution function (BRDF), spatial uniformity, and geophysical parameters is desirable to enable an accurate intercalibration between two instruments.

In March 2015, a major field campaign was conducted over the Algodones Dunes system in California, USA, with the primary goal of assessing its potential to be used for future

*Address all correspondence to: Aaron Gerace, E-mail: gerace@cis.rit.edu

Fig. 1 The Algodones Dunes system in southern California. Its proximity (2 h east of San Diego) and accessibility make it suitable for major field campaigns.

intercalibration efforts. The Algodones site was identified as an attractive intercalibration site due to its spatial and temporal uniformity. Logistically, its location in the continental US makes it suitable for major field campaigns, as it is readily accessible for the deployment of ground equipment and airborne traffic (Fig. 1).

The research conducted at the Algodones Dunes, California was undertaken to provide the information needed to perform an absolute radiometric correction using vicarious methods. Ground-based spectrometers and goniometers were used to measure the spectral BRDF of the site's native sand material, both temporally and spatially throughout the dunes. Core samples of the sand were obtained and their geophysical properties measured (e.g., density, particle-size distribution, and moisture content) to assess the spatial distribution and uniformity of the material. Image data were collected from an airborne platform to provide a macroscale characterization of the system's terrain and spectral BRDF to complement the ground campaign.

This paper summarizes the efforts of the five organizations that contributed to the 2015 Algodones campaign [NASA Goddard Space Flight Center (GSFC), Rochester Institute of Technology, University of Lethbridge, University of Arizona, and South Dakota State University]. Specifically, a summary of the ground-based and airborne instrumentation used in the campaign, the samples obtained, and the experiments conducted to support intercalibration efforts is provided.

2 Algodones Dunes Campaign Overview

Several efforts were conducted to enable the characterization of the Algodones Dunes system's geophysical and reflective properties. Figure 2 shows the study area, with the zoom window illustrating the various locations of activities that were conducted over the system. The long northwest to southeast green lines represent the flight paths that were flown to characterize the large area features (e.g., DEM and uniformity) while the short, dense (circled) green lines represent the flight paths that were flown to support ground-based BRDF measurements. The pin markers in Fig. 2 represent locations were BRDF and/or *in-situ* samples were obtained. This section provides an overview of the instrumentation used, the collection schedule, and the locations that were sampled throughout the Algodones campaign.

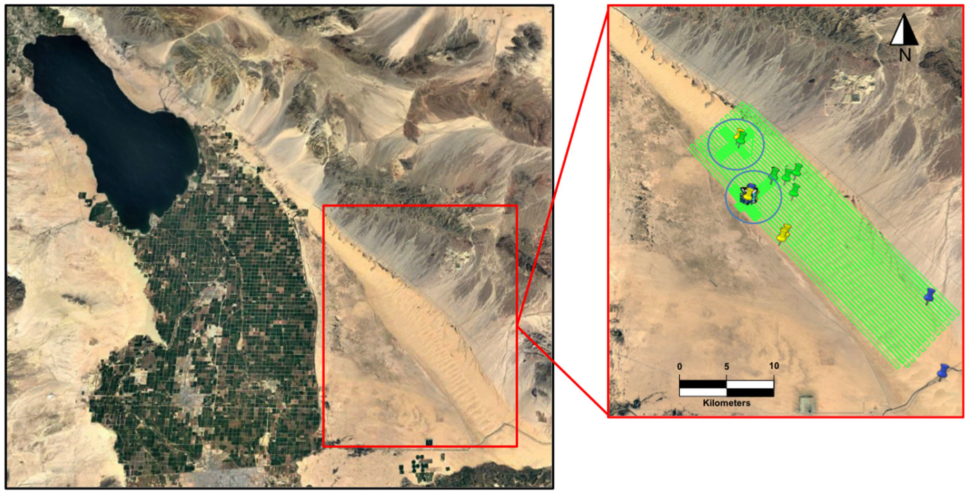

Fig. 2 Illustration of the various activities conducted during the Algodones Dunes system campaign. The long northwest to southeast green lines in the zoom window represent the flight paths that were flown to characterize the large area features while the short dense (circled) green lines represent the flight paths that were flown to support ground BRDF measurements. The pin markers represent locations were BRDF and/or *in-situ* samples were obtained.

2.1 *Instrumentation*

To support the various activities shown in Fig. 2, several ground-based and airborne systems were deployed. Ground-based spectrometers and goniometers were used to measure the spectral BRDF of the Algodones sand material, both temporally and spatially throughout the dunes. Core samples of the sand were obtained and their geophysical properties measured. Image data were collected from an airborne platform to provide a macroscale characterization of the system's terrain and spectral BRDF.

2.1.1 *Goniometer of the Rochester Institute of Technology (GRIT) and GRIT-Two*

The GRIT, shown in Fig. 3(a), was deployed at six sites throughout the campaign.[2] GRIT has a rotating ring that moves the zenith arc in azimuth. A second stepper motor drives the foreoptic down the half-arc. GRIT contains a single Analytical Spectral Devices (ASD) FR4 spectrometer that collects the full visible/near-infrared/short-wave infrared (VNIR/SWIR) spectrum from 350 to 2500 nm. It also carries a Ximea field-of-view camera to take true-color images for reference. Two global positioning system/inertial measurement unit (GPS/IMU) devices (the VectorNav100 and VectorNav 300) are mounted on GRIT to provide roll, pitch, and heading for all BRDF measurements.

A second-generation "GRIT-two" (GRIT-T) system[3,4] was fabricated after the Algodones campaign to facilitate future field collects [see Fig. 3(b)]. Unlike its predecessor, GRIT-T has two full VNIR/SWIR spectrum spectrometers onboard to enable contemporaneous skylight mapping and ground sampling. It has a more rigid and precisely machined half-arc (concentricity to within 200 μm) than the GRIT system. The GRIT-T also uses absolute encoders and has an onboard laser distance unit. All of these features combine to enable precision pointing. Additionally, its rotating head allows GRIT-T to follow the laser's ground point enabling the collection of microscale DEMs.

2.1.2 *University of Lethbridge Goniometer System-Two (ULGS II) Goniometer*

The ULGS II instrument was deployed at two locations throughout the campaign.[5] ULGS II is a robotic spectro-goniometer system that has a quarter circle arc mounted to a beam that serves as a pivot for the arc (see Fig. 4). This allows for a complete hemispherical sampling of the surface as the spectrometer is positioned along the arc and the arc is rotated about this mounting pivot.

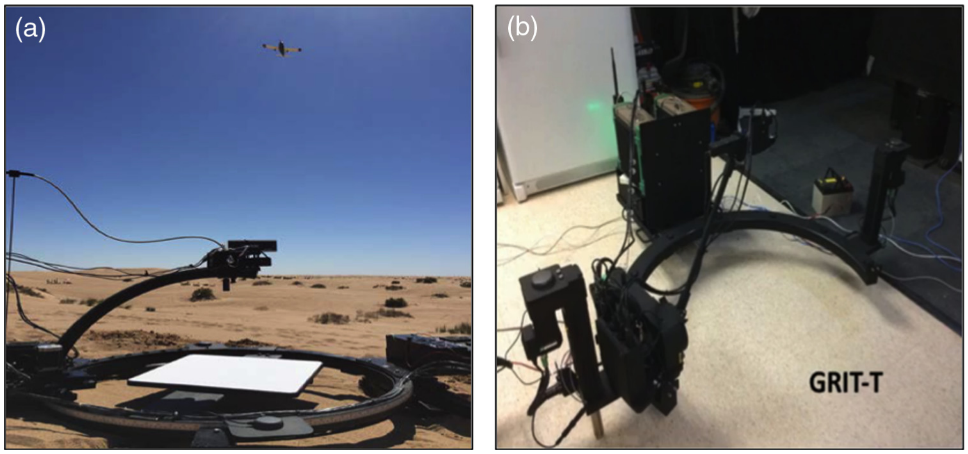

Fig. 3 (a) The first generation GRIT that was deployed during the Algodones Dunes system campaign. (b) The second generation GRIT-T that was developed after the campaign and used to process core samples.

Fig. 4 Field set-up of the ULGS II, a robotic spectro-goniometer system that has a quarter circle arc mounted to a beam that serves as a pivot for the arc, allowing for a complete hemispherical sampling of the surface from 400 to 900 nm.

The instrument has a large operating radius of 2 m as it was originally designed to measure BRDF for vegetation. ULGS II carries two Ocean Optics USB-4000 spectrometers that are used for measuring the target and monitoring downwelling illumination conditions. The target observing spectrometer uses an 8-deg foreoptic and produces a ground sampling pattern that is approximately 60 cm at the instrument focal plane, while the downwelling instrument incorporates a cosine receptor (made from Spectralon).

The ULGS II is a fully transportable field goniometer system that can be easily moved using all-terrain vehicles, which was significant considering the terrain of Algodones. It also incorporates spectral calibration by using a downwelling spectrometer to compute reflectance in real time. An ASD FieldSpecPro Full-Range Spectroradiometer was used to gather spectra of the sand target at the start of each measurement cycle to provide calibration data for the spectrometers mounted on the ULGS II.

2.1.3 *Goddard's LiDAR, Hyperspectral, and Thermal Airborne Imager*

The G-LiHT system, a fully integrated suite of passive and active sensors, was flown over the Algodones Dunes system to support the campaign. G-LiHT was developed by NASA Goddard Space Flight Center and is comprised of commercial off-the-shelf LiDAR, hyperspectral, and

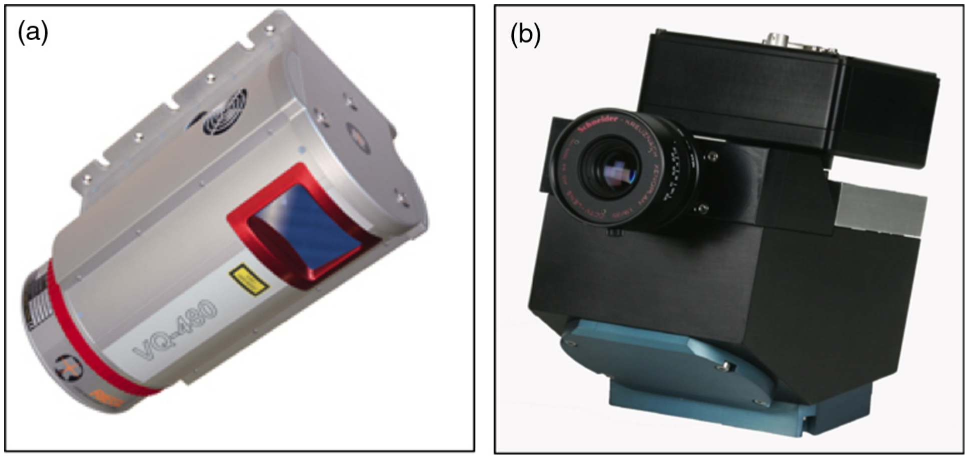

Fig. 5 Images of (a) the VQ-480 airborne scanning LiDAR and (b) the Headwall Hyperspec are housed on G-LiHT.

thermal components that are coaligned along a uniform optical axis. Including centralized processing and data storage, its components were assembled into a compact (<0.1 m^3) and lightweight enclosure (37 kg) making it suitable for integration onto a wide range of airborne platforms. Its nominal flight altitude of 335 m and 60-deg FOV yield a 387-m swath on the ground.[6]

G-LiHT houses the VQ-480 airborne scanning LiDAR that is comprised of an integrated high-performance laser rangefinder and a rotating polygon three-facet mirror that deflects a 1550 nm class 1 laser beam along a 60-deg swath perpendicular to the flight direction [see Fig. 5(a)]. The laser beam divergence is 0.3 milliradians yielding a 10-cm beam diameter at the nominal operating altitude of 335 m. The rotating multifacet mirror scan speed is set to 100 scans/s providing an angle measurement resolution of 0.001 deg.

G-LiHT's hyperspectral imaging system contains the Headwall Hyperspec [see Fig. 5(b)]. The Hyperspec is a pushbroom array with 402 spectral bands from 400 to 1000 nm at 1.5-nm resolution. With its 50-deg FOV and 1004 spatial pixels, the Hyperspec images about a 370-m swath at G-LiHT's nominal flying altitude with a spatial resolution of approximately 0.37 m.

G-LiHT contains the Oxford RT-4041 GPS/INS to enable accurately coregistered data. Although not directly used to support the experiments conducted for the Algodones campaign, G-LiHT also carries the Riegl LD321-A40 profiling LiDAR to support forest canopy and vegetation structure studies and the Gobi-384 thermal imaging camera to monitor surface temperature.

2.2 *Collection Schedule*

The Algodones campaign took place from Monday March 9, 2015, to Friday March 13, 2015. Figure 6 shows the activities that occurred over the course of the week with brown signifying ground-based efforts, blue signifying airborne efforts, and purple signifying space-borne collects. (Note that the Algodones Dunes system is located in the Pacific Time Zone and the collect occurred during daylight saving time so the local time in Fig. 6 is $t - 8$ h.) Monday served as a practice day for the ground campaign to identify any unexpected issues with the deployment of equipment. The campaign was intentionally planned to coincide with two Landsat overpasses, Landsat 7 (Tuesday) and Landsat 8 (Wednesday), to enable the assessment of Algodones' utility as an intercalibration site. Accordingly, these 2 days represented the primary mission for the campaign. Thursday and Friday represented makeup days in the event of overcast skies or inclement weather.

2.2.1 *Tuesday March 10, 2015*

Although the large area airborne survey began on Monday afternoon, Tuesday, March 10 represented the first full day of collection. In the morning, the airborne campaign obtained the

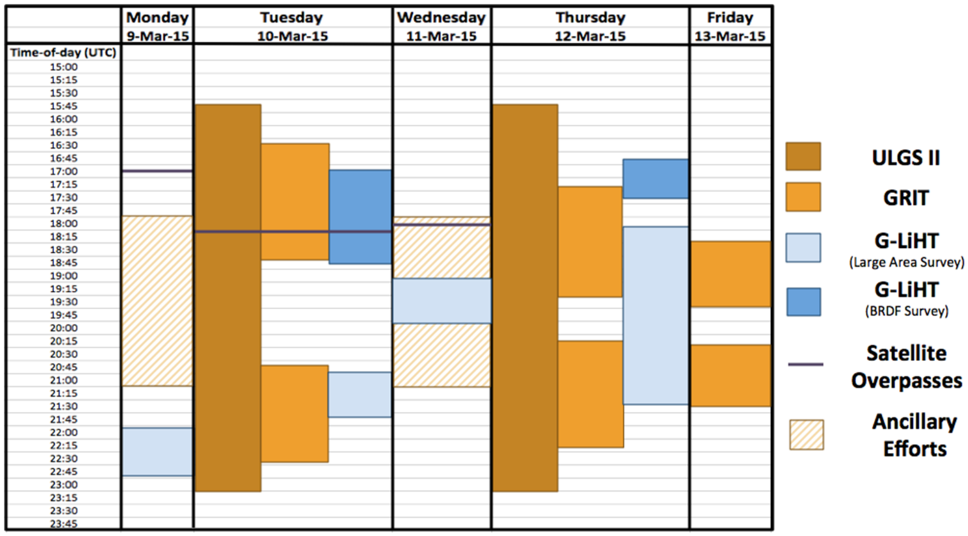

Fig. 6 Schedule of ground-based and airborne collections for the Algodones Sand Dunes system campaign. Note that the ground-based campaigns are represented in brown while the airborne campaigns are represented in blue. Purple lines represent the Landsat satellite overpasses. The Landsat 7 overpass occurred on Tuesday (March 10, 2015) while the Landsat 8 overpass occurred on Wednesday (March 11, 2015). The EO1 overpass occurred on Monday (March 9, 2015) and is included here for reference. (Note that the Algodones Dunes is in the Pacific Time Zone and the collect occurred during daylight saving time so the local time is $t - 8$ h.)

southwest/northeast flight lines shown in the zoom window in Fig. 7 (top right) to support the BRDF characterization of Algodones. These BRDF flight lines were flown in the morning to coincide (temporally) with the Landsat 7 and 8 overpasses (see Fig. 6).

At the same time, the ground-team deployed the equipment described in Sec. 2.1 to obtain contemporaneous reflectance measurements. Note that the circled region shown in Fig. 7 (bottom right) shows the spatial extent of the ground campaign conducted on March 10. Goniometers were set up in three regions, the UGLS II (represented with flags in Fig. 7) at a fixed point to measure the temporal BRDF and the GRIT (represented with yellow pins in Fig. 7) at two

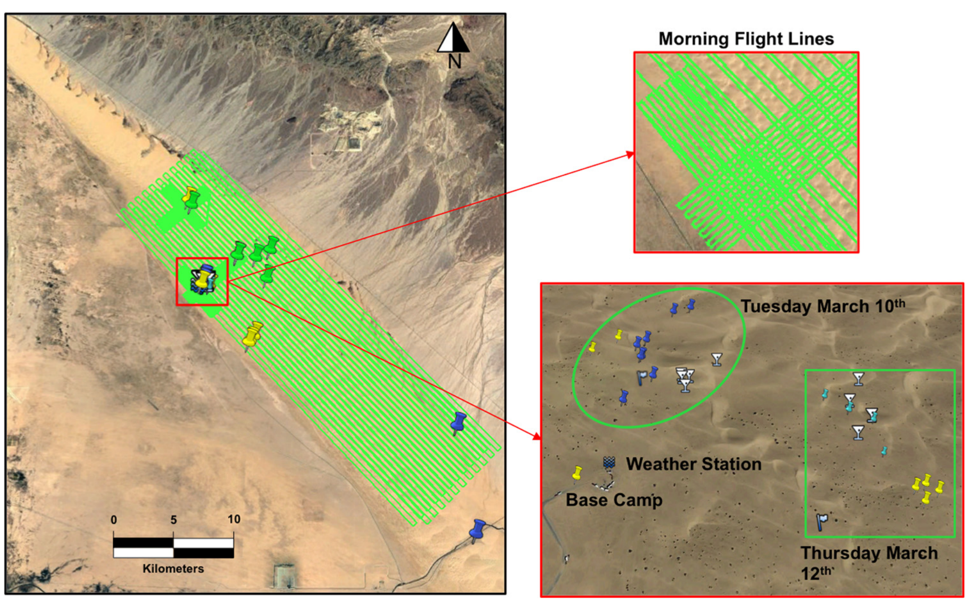

Fig. 7 Illustration of the Algodones Dunes system campaign. The zoom window highlights the activities conducted to support the BRDF characterization, with the top (right) zoom showing the morning flight lines and the bottom (right) zoom showing the ground campaign.

locations to measure BRDF spatially. The remaining symbols in Fig. 7 (bottom right) represent locations, where various ASD measurements (white markers and blue pins) were obtained.

In the afternoon, the long flight lines, designed to characterize large-area phenomenology at Algodones, were successfully obtained while ground efforts continued [see Fig. 7(a)]. All efforts were successful on March 10. Figure 8 shows the samples of the airborne and space-borne image data collected on March 10, 2015. Figure 8(a) shows LiDAR data collected with G-LiHT to support the detailed characterization of the Algodones terrain. Figure 8(b) shows a true-color image of the Landsat 7 data collected with ETM+ (data obtained from EarthExplorer[7]). Note that the BRDF ground locations shown in the zoom window in Fig. 7 fell at the edge and within the scan line gap of the image data as indicated with the arrow in Fig. 8.

2.2.2 *Wednesday March 11, 2015*

Due to overcast skies on Wednesday, the morning BRDF airborne collections were postponed. The afternoon large area airborne survey commenced while the ground-team split into two groups to obtain sand samples throughout the dunes system. Figure 9(a) shows the Landsat 8, Operational Land Imager (OLI) data collected on Wednesday March 11 (data obtained from EarthExplorer[7]).

2.2.3 *Thursday March 12, 2015*

Thursday, March 12 represented the second full day of collection. In the morning, the airborne campaign obtained the northwest/southeast flight lines shown in the zoom window in Fig. 7 (top right) to support the BRDF characterization of Algodones. Again, the ground-team deployed the equipment described in Sec. 2.1 to obtain contemporaneous reflectance measurements. Note that, for Thursday March 12, the rectangular region shown in Fig. 7 (bottom right) shows the spatial extent of the ground campaign. Goniometers were set up in similar fashion to day 1, with the GRIT (yellow pins) system measuring two more locations and ULGS II obtaining temporal BRDF measurements at one location. The remaining symbols in Fig. 7 (bottom right) again represent locations, where various ASD measurements (white markers and cyan pins) were obtained.

In the afternoon, the large area flight lines were again successfully obtained while ground efforts continued [see Fig. 7(a)]. Note that, in addition to the reflectance measurements that took

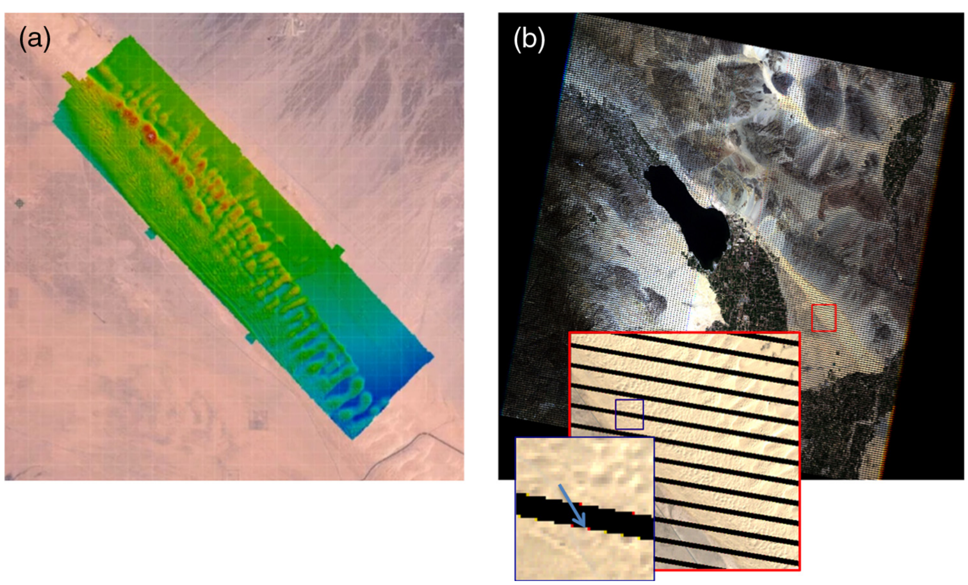

Fig. 8 Image data collected on March 10, 2015 to support the Algodones Dunes system campaign. (a) The LiDAR data collected with G-LiHT. (b) An RGB image of the Landsat 7 data collected with ETM+. Note that the BRDF ground locations shown in the zoom window in Fig. 7 fell at the edge and within the scan line gap of the image data as indicated with the arrow.

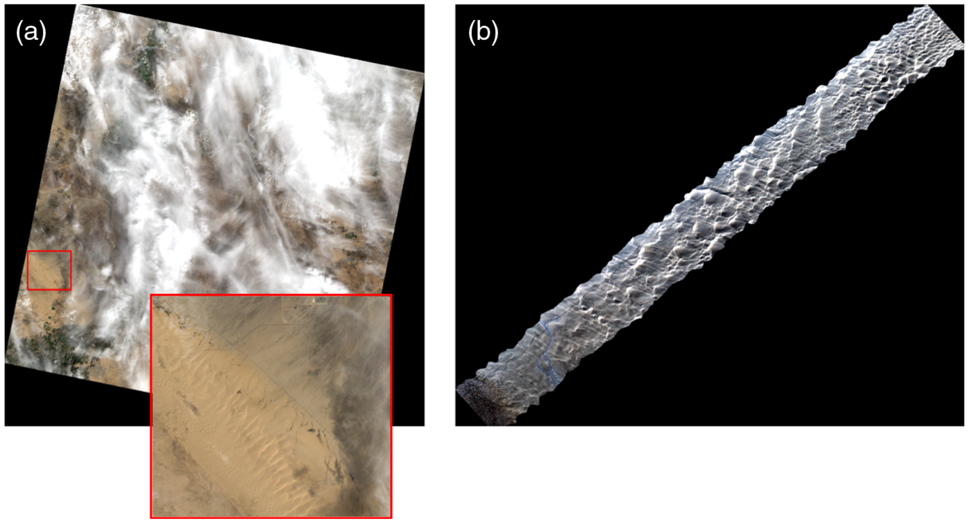

Fig. 9 Image data collected on March 11 and March 12, 2015, to support the Algodones Dunes system campaign. (a) This Landsat 8 OLI images show the overcast skies that led to most activities on March 11 being postponed. (b) A sample of the georeferenced G-LiHT hyperspectral data that was collected on March 12, 2015. This G-LiHT image strip corresponds to the southeast/northwest flight lines shown in Fig. 7 (top right) zoom window.

place within the zoom region of Fig. 7, additional effort was made to obtain *in-situ* samples of the native sand material across the Algodones Dunes system. The pins in Fig. 7(a) that fall outside the zoom window show locations of *in-situ* sampling. All efforts were successful on March 12.

Figure 9(b) shows a sample of the georeferenced G-LiHT hyperspectral data that was collected on March 12, 2015. This G-LiHT image strip corresponds to the southwest/northeast flight lines shown in Fig. 7 (top right) zoom window.

2.2.4 *Friday March 13, 2015*

As Friday was intended as a makeup day in the event of inclement weather, most ground-based and airborne efforts were cancelled. The GRIT ground team, however, took advantage of this day to acquire additional BRDF measurements at two more positions further into the dunes system.

3 Experiments Conducted

The primary goal of the Algodones Dunes campaign was to provide an initial characterization (both spectral and spatial) of the site to facilitate future intercalibration studies with space-borne instruments. The campaign efforts were successful and supported multiple scientific studies. This section provides a brief overview of the studies conducted based on measurements obtained during the 4-day field campaign.

3.1 *Temporal BRDF Characterization*

The rate of change of BRDF with changing Sun angle represents a significant gap that is required for accurate vicarious calibration and validation of modeling efforts. One of the limitations of most goniometer systems is that they are complex instruments to operate in the field and have trouble capturing detailed temporal patterns due to limitations in the number of samples that can be gathered in a day. During the Algodones campaign, Ref. 5 utilizes the ULGS II goniometer to measure and assess the temporal nature of the Algodones native sand material. By characterizing the temporal data gap, insight into uncertainty in the measurements is provided to ensure a high-quality absolute radiometric correction, and provide critical information on the temporal dynamics to assist in creating better models of temporal BRDF behavior.

In Ref. 5, the temporal dynamics of the site were evaluated by executing two different sampling schemes:

1. 5 deg increments to 30 deg in zenith every 10 deg in azimuth and
2. 10 deg increments to 60 deg in zenith every 10 deg in azimuth.

Each measurement was taken twice per hour from (approximately) sunrise to sunset to provide a complete diurnal cycle of change.

Sand surfaces are usually described as being forward scattering surfaces with strong non-Lambertian properties with this effect being more pronounced at larger solar zenith angles.[8] Past studies have commented on progression of this pattern toward a more Lambertian ideal with increasing solar angle.[8] Reference 5 confirms these interpretations but with the additional temporal information and finer zenith and azimuth sampling of the reflectance field, more complex patterns were revealed. Near specular behavior at near-infrared wavelengths for this sand surface was also observed with variation following solar zenith progression. This effect is most likely caused by the optical properties of the sand itself, and is not attributed to the dune ripples.

When the pattern of reflectance anisotropy was observed over time, the results indicate that in the backscatter direction, the progression of brighter observations at lower solar zenith angles and darker observations at solar noon was confirmed but was reversed at longer wavelengths in the forward scattering direction. Reference 5 also show that the strength of the pattern displayed, regardless of sample pattern used is not constant over the spectral range investigated. The overall rate of change of the BRDF from a strong bowl shape to a relatively flat near Lambertian surface is very rapid with increasing or decreasing solar angle and significant changes were measured between half hour intervals.

3.2 *Spatial BRDF Characterization*

Reference 2 considers hyperspectral BRDF measurements acquired at a number of sites within the Algodones Dunes system. Since the Algodones Dunes system has been chosen as a NASA vicarious calibration site, characterizing the spectral variability of the dunes was an important goal of both the RIT team and the overall multi-institution effort. At each site within the dune system where the RIT team collected BRDF with a portable hyperspectral goniometer system, the GRIT, they also collected geotechnical data to characterize geophysical properties of the dune system that were most likely to impact observed BRDF. These measurements included sediment properties such as density, grain size distribution, and moisture content. To further extend the range of applicability, the RIT team collected samples from the dune system at locations where they acquired field BRDF measurements and at other representative spots within the dune system. These samples were brought back to the laboratory where their geophysical properties could be manipulated and the BRDF recorded with GRIT and later a second-generation system, GRIT-T. Both field and laboratory measurements showed good correlation with airborne hyperspectral imagery collected by the NASA G-LiHT system during the Algodones Dunes field campaign. In particular, the laboratory manipulations of samples brought back from the system provided a more robust set of BRDF spectra that correlated well with portions of the dune system where measurements could not be acquired due to time limitations of the field campaign.

In addition to direct comparison with imagery, the acquired hyperspectral BRDF furthered a second goal of the RIT effort, which was to develop radiative-transfer models that could be used to invert and map the geophysical properties of the surface. A particular focus of this portion of the study was on inversion of the Hapke model to solve for the sediment fill factor.[9] The overall approach used a principle of invariance: the underlying single particle phase function of the sediment has the same form regardless of the illumination. An optimization procedure was developed that involves multiple stages but ultimately ensures the consistency between the phase function derived from the Hapke model for two sets of angular spectral measurements acquired under different illumination conditions. The derived fill factors correlate well with direct measurements of sediment density found in the laboratory.

3.3 *Physics-Based Modeling of Algodones to Facilitate Intercalibration*

Reference 10 leverages the data obtained from the Algodones campaign to develop a synthetic modeling environment that can be used to assess the feasibility of using Algodones as an intercalibration site. G-LiHT LiDAR and Headwall airborne data [see Figs. 8(a) and 9(b)] are used to provide terrain and spectral information to the model, respectively. Comparisons of modeled and actual at-sensor radiance for MODIS-Terra, MODIS-Aqua, and OLI-Landsat 8 show good agreement.

Additionally, Ref. 10 describes a technique that uses the Algodones simulation environment as a transfer standard between two sensors to facilitate their intercalibration. Specifically, studies are conducted that assess the impact of differing view angles and image acquisition times on intercalibration efforts from an International Space Station (ISS)-based platform.

4 Conclusion

Five groups led by NASA GSFC, and including Rochester Institute of Technology, University of Lethbridge, University of Arizona, and South Dakota State University collaborated to collect spectral and temporal BRDF measurements, core samples of the native sand material, and airborne image data. The Algodones Sand Dunes system campaign was a successful mission that was undertaken to provide information necessary to perform an absolute radiometric correction using vicarious methodologies. While the initial goal of the campaign was to develop knowledge of the region to support model-based intercalibration efforts,[9] interesting scientific observations and endeavors resulted from the collection.[2,5] Future efforts will leverage lessons learned, during the campaign and from the subsequent studies, to conduct a more targeted campaign of Algodones Sand Dunes system.

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Joel McCorkel is a physical research scientist in the Biospheric Sciences Laboratory at NASA's Goddard Space Flight Center where his current work involves development and characterization of next-generation environmental monitoring and Earth-observing sensors. He has experience planning and executing ground- and airborne-based campaigns for satellite sensor vicarious calibration and validation. Currently, he is the Landsat 9 TIRS-2 deputy instrument scientist leading the prelaunch instrument characterization and the GOES-R deputy project scientist for calibration/validation.

Charles M. Bachmann received his AB from Princeton University in 1984, his ScM in 1986, and his PhD from Brown University in 1990. He was a research physicist (1990–2013) at the Naval Research Laboratory, serving as a head of the Coastal Science and Interpretation Section in the Remote Sensing Division (1993–2013). He has been Frederick and Anna B. Wiedman chair at the RIT Chester F. Carlson Center for Imaging Science since 2013. His research emphasizes coastal hyperspectral remote sensing.

Craig Coburn received his BSc degree in geography from the University of Saskatchewan in 1994, his MSc degree in Earth and atmospheric science from the University of Alberta in 1996, and his PhD remote sensing from Simon Fraser University in 2002. Currently, he is an associate professor at the University of Lethbridge (Department of Geography) and a research scientist with the Alberta Terrestrial Imaging Centre, his research focuses on studying the BRDF of various Earth targets for use in calibrating Earth observation data.

Biographies for the other authors are not available.