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Holistic Interactions of Shallow Clouds, Aerosols, and Land-Ecosystems (HI-SCALE): National Geospatial-Intelligence Agency Calibration Target Placements Field Campaign Report

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ARM CLIMATE RESEARCH FACILITY

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Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement Climate Research Facility
BNL	Brookhaven National Laboratory
CAD	computer-aided design
CAVIS	Cloud, Aerosol, Water Vapor, Ice, Snow
DOE	U.S. Department of Energy
DOI	Digital Object Identifier
GPS	Global Positioning System
HI-SCALE	Holistic Interactions of Shallow Clouds, Aerosols, and Land Ecosystems
LES	large-eddy simulation
MHz	megahertz
NGIA	National Geospatial-Intelligence Agency
GIC	National Ground Intelligence Center
NIR	near infrared
SGP	Southern Great Plains
SWIR	shortwave infrared
WRF	Weather Research and Forecasting model

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1.0 Summary

The purpose of our research has been to develop a capability of simulating image collection from any sensor so as to account for sensor configuration, ground spectral radiance, and atmospheric contributions. Atmosphere is arguably the most difficult aspect of the image pipeline to accurately characterize and integrate into an image simulation. Some of the reasons for this include the highly variable spatial content of different absorbing and scattering species in the atmosphere. Additionally, the interaction of land and atmosphere can significantly impact the total radiation budget, especially in the southern Great Plains[1]

Mathematically, the spectral radiance of a target Φ is expressed as

$$\Phi = \frac{A_{detector}\pi \cdot (1-\varepsilon)}{4(f\#)^2}\int_{\lambda_{min}}^{\lambda_{max}} L_{target}(\lambda)\cdot \tau_{optic}(\lambda)d\lambda$$

Where $A_{detector}$ is the area of the detector, ε is the fraction of the optical aperture area obscured and $f\#$ is the f number, τ_{optic} is the transmittance of the optics and λ_{min} and λ_{max} defines the spectral band pass[2]. The calculation is simple if the optical path is uniform. In reality however, the solar radiance has many components as illustrated in Figure 1. The solar radiance is a mixture of contributions from direct sunlight, diffuse sunlight, and haze[3].

$$L_{\lambda} = L_{direct} + L_{diffuse} + L_{haze}$$

[1] Dobbs, B., “The Incorporation of Atmospheric Variability into DIRSIG,” RIT Master’s Thesis, available at http://scholarworks.rit.edu/theses/3011 (2006).
[2] Fiete, R.D. 2007. “Image Chain Analysis for Space Imaging Systems.” *Journal of Imaging Science and Technology* 51(2): 103-109, doi:10.2352/J.ImagingSci.Technol.(2007)51:2(103).
[3] Auelmann, R. R. 2012. "Image Quality Metrics." Richard R. Auelmann Technical Archive 5, available at http://www.techarchive.org/performance-modeling-of-optical-earth-imaging-satellites/.

where $L_{direct\lambda}$ is the direct spectral radiance due to solar rays that directly reflect off the scene, $L_{diffuse\lambda}$ is the diffuse spectral radiance due to solar rays that bounce off aerosols (in the atmosphere) and then reflect off the scene, and $L_{path\lambda}$ is the path spectral radiance due to solar rays that bounce off aerosols directly toward the sensor. Only $L_{direct\lambda}$ and $L_{diffuse\lambda}$ contribute to the "scene signal". $L_{path\lambda}$ (or "haze" radiance) is strictly a noise component. Note it is the diffuse component that allows one to image the shadowed portions of the scene.

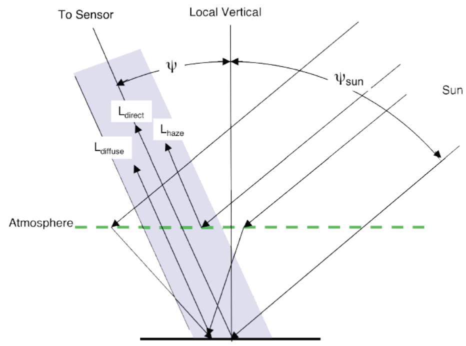

Figure 45. Three Radiance Components

Figure 1. The components of solar radiance.

Existing image collection simulations in the open scientific literature account for target and sensor attributes well, but cannot accommodate atmospheric dynamics with high spatial or temporal resolution.[4] Therefore, we have developed an image collection simulation that includes dynamical effects of the atmosphere on radiation transfer. The atmospheric model to be used in the image collection simulation is the large-eddy simulation (LES) developed by Brookhaven National Laboratory (BNL) based on the Weather Research and Forecasting model (WRF).[5] The LES model creates a time-stepping 3D representation of the structure of atmospheric parameters such as winds, pressure, temperature, water vapor, and cloud liquid water content. The LES model will make it possible to visualize clouds, precipitation, and other features that impair image interpretation, and may be able to help predict image quality for future collections, assist in correcting image product artifacts, and aid in understanding scene content and artifacts of historical imagery, by accounting for fine-scale atmospheric conditions at the time of collection.

To test the validity of the image collection simulation, Worldview-3 commercial satellite images of the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility Southern Great Plains (SGP) site were collected May 17-28, 2016. This period coincided with the end of the ARM HI-SCALE campaign running April-May 2016. The satellite image data set includes visible spectral bands ranging from blue to red, infrared from near infrared (NIR) to shortwave infrared (SWIR), and atmospheric sounding data from the Cloud, Aerosol, Water Vapor, Ice, Snow (CAVIS) instrument. During the period, calibration objects including colored tarps and hot plates are also placed on the ground in the SGP central facility. The commercial image data sets and the status records of the calibration objects have been uploaded to the ARM Data Archive. The spectral and thermal characteristics of the collected imagery will be compared to the simulated imagery produced by the image collection simulation combined with the LES model.

[4] Bierwirth,V., 2011. "Visualizing Airborne and Satellite Imagery" NASA USRP Internship Report http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110012861.pdf.

[5] Endo, S. et al., 2015. "RACORO continental boundary layer cloud investigations. Part 2: Large-eddy simulations of cumulus clouds and evaluation with in-situ and ground-based observations," *Journal of Geophysical Research - Atmospheres* 120(12): 5993-6014, doi:10.1002/2014JD022525.

2.0 Results

There were usually several opportunities for image collection each day. Most of the collections were severely cloud-covered. Some collections were good: that is, the calibration objects were visible. For the purpose of this experiment, the number of good collections is expected to be adequate to determine whether the image collection simulation will be feasible. A total of 94 Worldview-3 image files were generated, of which at least six seem to be good. Each image data set consisted of 15-17 files in a package that included multispectral, atmospheric, panchromatic, and SWIR bands. In several cases, the images had slight opacity from haze or thin cloud layer, which is ideal for testing the image collection simulation.

Our team placed the calibration objects on the ground, including colored tarps and hot plates. Two sites in the SGP central facility were used for placing objects: the IDP3 site at the north end of the compound, and the 50-MHz site to the south. Object locations were measured by the Global Positioning System (GPS). The temperature of the hot plates was stabilized using bricks coated with high-emissivity paint to create blackbodies, low-emissivity paint, or layers of high- and low-emissivity paint to simulate targets with medium emissivity. The hot plate systems were measured for temperature using data loggers, and for emissivity and temperature using handheld radiometers. The spectral and thermal properties of the hot plate/brick setups and the tarps over the wavelengths used by Worldview-3 were measured after the conclusion of the experiment by the National Ground Intelligence Center (NGIC).

As of this date, our scene generation modeling for the image collection simulation at the SGP site includes computer-aided design (CAD) building structures provided by ARM, CAD representations of our calibration objects, and virtual terrain generated by warping a Worldview-3 satellite image to a Digital Elevation Model. Our model is able to simulate commercial satellite imagery using the same collection angles and other parameters as the real commercial imagery collected during our campaign. The NGIC laboratory results are ready to be included in the image collection simulation, and will probably be added to the model in the next few weeks. The 3D atmospheric modeling corresponding to the period of the campaign is in progress. Additional camera specifications are expected to be included in the sensor model. After the 3D atmosphere is ingested into the scene model of the SGP site, image collection will be simulated, and the simulated imagery will be quantitatively compared to the Worldview-3 imagery for spectral features.

After the image collection model is developed, further research opportunities under consideration include:

- Dispersion behavior of smoke plumes, and effects on imagery
- Vegetation effects on the boundary conditions near the ground.

3.0 Publications and References

We intend to publish our results, but the publication will not be ready by the due date of this closeout report. We will request a Digital Object Identifier (DOI) for our field campaign data set so we can cite the ARM Climate Research Facility data in our publication(s).

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