SDSU VEGETATIVE SITE ANALYSIS FROM 2013 TO 2017 FOR RADIOMETRIC CALIBRATION OF EARTH OBSERVATION SENSORS

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ABSTRACT

Since its founding in 1988, the South Dakota State University Image Processing Laboratory (SDSU IP LAB) has become widely recognized for its contributions in the field of satellite sensor radiometric calibration. One of the numerous calibration methods performed by the laboratory is known as reflectance-based approach. The reflectance-based approach is based on the simultaneous measurement, during the satellite sensor overpass, of a well-known target on Earth. The SDSU IP LAB has a unique capability to use a darker, vegetative target that it is much more closely resembles of targets often used in applications of remote sensing data. This paper presents the results of a spectral and spatial characterization of the SDSU vegetative site during the period from 2013 to 2017, with the goal of understanding the uncertainties in calibration associated with the site. As an example, the radiometric calibration of the Landsat-7 ETM+ sensor with respect to this site during the same period is also presented.

***Key words* —** Radiometric Calibration, Uncertainty, Reflectance-based approach, Surface Reflectance, Landsat.

1. INTRODUCTION

The South Dakota State University Image Processing Laboratory (SDSU IP LAB) was founded in 1988 to conduct research in satellite image processing [1]. The research focuses primarily on the on-orbit radiometric characterization and calibration of remote sensing satellite and airborne imaging sensors operating in the visible and near infrared portion of the electromagnetic spectrum. The IPLAB closely partners with the USGS Earth Resources Observation and Science (EROS) Center and NASA's Goddard Space Flight Center in performing and monitoring radiometric calibration of the Landsat series of satellite sensors [2]. It also provides valuable calibration services for other government systems such as NASA's MODIS, Hyperion, and ALI sensors, and is increasingly providing similar services for commercial systems such as Worldview, Quickbird, RapidEye, and Planet Lab's "Dove" sensor series. With these civilian government and commercial partnerships, the IPLAB has become recognized worldwide for its innovations in on-orbit sensor calibration.

There are numerous approaches and methods to perform the radiometric calibration throughout the sensor's lifetime. This work focuses on the method knows as reflectance-based approach. Historically, the reflectance-based vicarious calibration approach has been proven over many years to provide reliable and accurate post-launch absolute radiometric calibration of Earth imaging sensors [3,4]. The SDSU IPLAB has over 20 years of development and operational experience with this method, providing services through solid calibration science research. To review, the reflectance-based method is a vicarious technique that relies on ground-based measurements of surface reflectance (or radiance) and atmospheric conditions at a selected ground site to predict the top-of-atmosphere (TOA) reflectance measured by the sensor.

Many of the groups performing vicarious reflectance-based calibration use bright desert or other arid sites as the target, with relatively dry, low-aerosol atmospheres that can be more straightforwardly modeled. The SDSU IPLAB, however, is the only group that consistently perform the same calibration at a vegetative site. This approach is more challenging due to the lower signal and/or higher noise levels produced by a darker target, and atmospheric conditions that require more complex modeling. However, the results may be considered more valuable, as the national and international remote sensing communities have expressed great interest in analysis based on vegetative targets.

This work presents the results of a statistical analysis in the spectral and spatial domains of the SDSU vegetative site during the period from 2013 to 2017, with the goal of understanding the uncertainties in calibration associated with this site. In addition to this analysis, as an example, the radiometric calibration of the Landsat-7 ETM+ sensor during the same period is also presented.

2. MATERIAL AND METHODS

As mentioned earlier, reflectance-based calibration approaches typically use bright desert or other arid regions with relatively dry, low-aerosol atmospheres, as these are historically considered among the desired characteristics a calibration target should possess [3,4]. Although the researches list several characteristics for the site selection, in principle, any region on the Earth's surface can be used in the reflectance-based approach. The key is to know the surface reflectance (or surface radiance) of the site and the atmospheric characteristics around the site at the sensor's overpass time, which can be obtained, for example, in areas covered by vegetation that are considered non-ideal due to seasonal changes. The SDSU vegetative site is located in Brookings, South Dakota, USA (Figure 1). It is a 150m × 250m rectangular area, surrounded by a larger grass area of 300m × 500m, located at an altitude of approximately 505 m above mean sea level. The site is well maintained during SDSU's vicarious calibration campaign season, which generally runs from May to October.

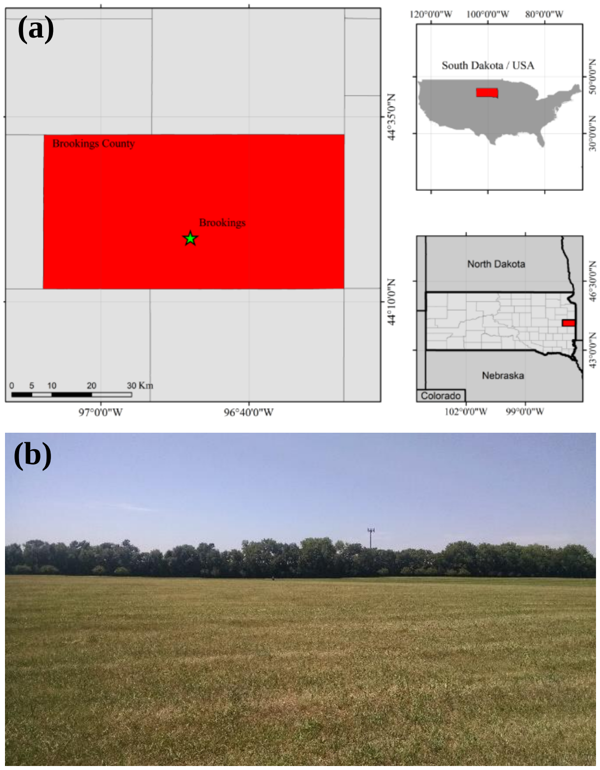

Figure 1. In (a) Location of the SDSU site; and (b) picture of the vegetative site on July 15, 2017.

The surface radiance of the site is measured with a portable hyperspectral spectroradiometer (350nm-2500 nm) that is carried and operated by IPLAB personnel. The site is divided into eight rows oriented north-south. During a typical campaign day, 50 measurements are taken in each row, as are measurements of a Spectralon reference panel located at predetermined points and oriented such that solar radiation is directly incident on the panel. The corresponding surface reflectance is determined from the target and reference panel radiance measurements as follows:

$$RF_{target}(\theta_i,\phi_i,\theta_r,\phi_r,\lambda)=\frac{L_{target}(\theta_r,\phi_r,\theta_i,\phi_i,\lambda)}{L_{panel}(\theta_i,\phi_i,\lambda)}\times k_\lambda \qquad (1)$$

where: L_{target} is the measured radiance of the target; L_{panel} is the measured radiance of the reference panel under the same specified conditions of illumination and viewing; λ is the wavelength; θ is the solar zenith angle; ϕ is the solar azimuth angle; and k_λ is the panel correction factor (usually determined in the laboratory). The subscripts i and r denote incident and reflected solar rays, respectively.

For this work, 45 field campaign days were evaluated in this work: 7 from 2013; 8 from 2014; 9 from 2015; 11 from 2016 and 10 from 2017. On some of these days, the entire site was measured twice, as a result, there are in a total of 58 measurements of the reflectance surface.

As previously mentioned, the goal of this work is to present a spectral and spatial analysis of the SDSU vegetative site from 2013 to 2017. To achieve this goal three steps were implemented: (1) calculate the overall surface reflectance of the site and its uncertainty for every campaign day; (2) calculate the surface reflectance of each row and its uncertainty for every campaign day; and (3) divide each row in three subareas – denoted by "top", "middle", and "bottom", and calculate the surface reflectance and its uncertainty in each subarea. This final calculation is also performed for every campaign date.

The surface reflectance profile estimated in step (1) is considered the "reference" hyperspectral profile, as it is the reflectance profile considered most representative of the site on a given campaign date. The degree of homogeneity of each row and subareas within each row are determined as a percentage difference between the row/subarea reflectance and the reference reflectance:

$$difference_{\lambda}\,\% = \left|\left(\frac{\rho_{Row/Subarea\lambda}-\rho_{reference,\lambda}}{\rho_{reference,\lambda}}\right)\times 100\right| \qquad (2)$$

With this procedure, it should be possible to answer the following questions about the SDSU vegetative site:

a) What is the typical reflectance of the site from 2013 to 2017?;
b) What is the typical uncertainty in the reflectance of the site from 2013 to 2017?;
c) Which row most represents the site as a whole (i.e. had the smallest difference as determined from Equation 2) ?;
d) Which row least represents the site as a whole?; and
e) Which local subarea within a row (top, middle or bottom of the row) most represents the site as a whole?

3. RESULTS AND DISCUSSION

Figures 2(a) and 2(b) show the spectral reflectance factor and associated uncertainty of the SDSU vegetative site from 2013 to 2017. The gaps around 1400 nm and 1800 nm are due to strong water vapor absorption near those wavelengths and the 2400 nm - 2500 nm spectral region shows larger variability primarily due to decreasing signal level.

The SDSU site has a spectral reflectance profile generally expected for a vegetated site: low reflectance (less than 10%) in the visible region and high reflectance (up to 40%) in the near-infrared between 0.7 and 1.3 µm. Not surprisingly, Figure 2 also shows the SDSU vegetative site is not temporally stable. This means that the site must be measured each overpass for the sensor to be calibrated.

According to Pinto et al. (2017) [4] the main source of uncertainty in the reflectance-based approach is the uncertainty associated with the surface reflectance factor. Here, the site reflectance uncertainty ranged from approximately 2.1% to 9.7% in the spectral region from 350 nm to 2500 nm. On average, an uncertainty of approximately 5.0% across all wavelengths is expected.

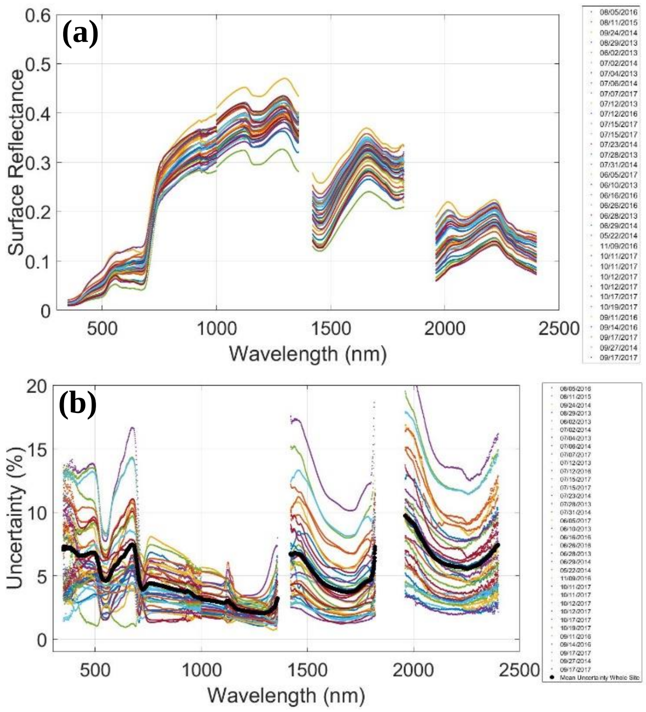

Figure 2. (a) Surface reflectance of the SDSU vegetative site for every campaign day from 2013-2017; (b) Associated uncertainty.

As mentioned previously, the SDSU vegetative site is divide into 8 north-south rows. The first row is located at the western edge of the site, and the eighth row is located at the eastern edge. Figure 3 presents the average absolute difference of each row for all of the study campaign days from 2013 to 2017. Note that the difference is calculate between the reflectance in the specific row and the reflectance estimated for the entire site (Equation 2).

On average across all wavelengths the absolute difference was 2.8% (Row 1), 3.4% (Row 2), 6.8% (Row 3), 3.4% (Row 4), 2.5% (Row 5), 3.5% (Row 6), 4.4% (Row 7) and 4.3% (Row 8). Based on these results, Row 5 was the most representative of the site as a whole, while Row 3 was the least representative. The SDSU vegetative site has a small valley located in the Row 3; as a result, its measured surface reflectance in Row 3 has the tendency to present a lower reflectance compared should be decreased relative to the other rows.

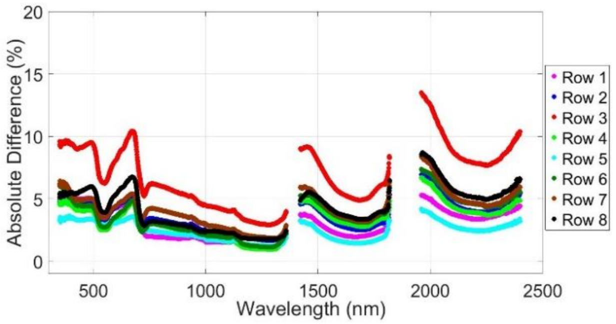

Figure 3. Average absolute difference between the reflectance in the row and the reflectance estimated for the entire site of all fieldwork days from 2013-2017.

The final spatial analysis of the SDSU site was related to determining which local subarea (as identified in step (3)) most represents the site as a whole. Figures 4(a)-4(c) present the average absolute difference of all campaign days from 2013 to 2017 for each subarea. The average difference across all wavelengths ranged from 4.2% to 9.8%. The subareas least representative of the site as a whole were the bottom of Rows 3 and 4 and the middle of Row 3, where the absolute reflectance differences ranged from 8.0% to 9.8%. Similarly, the subareas most representative of the site as a whole were the middle of Rows 1, 2, and 5, where the absolute differences ranged from 4.2% to 4.3%.

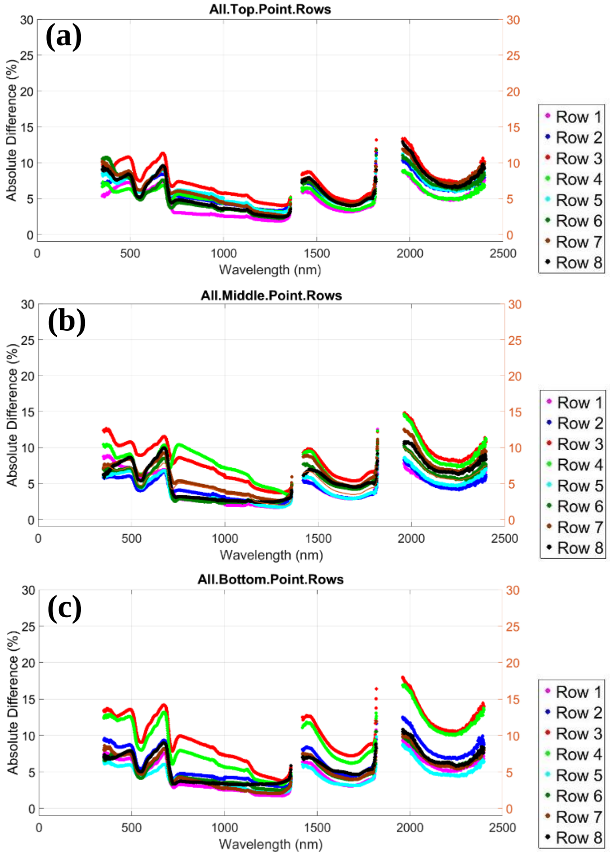

Figure 4. Figure 4. Average absolute difference between the reflectance in a specific row subarea and the overall site reflectance estimated for all campaign days from 2013-2017. (a) top subareas; (b) middle subareas; and (c) bottom subareas.

Lastly, as mentioned previously, the SDSU IP LAB works closely with USGS EROS and NASA's Goddard Space Flight Center particularly with respect to the Landsat series of satellite sensors. Then, to show the final uncertainties using the SDSU vegetative site, the results achieved in the radiometric calibration of the Landsat-7 ETM+ sensor is presented in Figure 5.

The average uncertainty of ETM+ Landsat-7 vicarious calibration over SDSU site from 2013 to 2017 was 3.9%, 4.6%, 6.5%, 5.2%, 5.5% and 7.6%, for the Blue, Green, Red, NIR, SWIR-1, and SWIR-2 bands, respectively. The average difference between the measured ETM+ at-aperture radiances and Top-of-Atmosphere radiances predicted by the MODTRAN radiative transfer code during the same time period, ranged from approximately 2.5% to 6.6%. The surface measurement absolute differences are within the MODTRAN uncertainty bounds, indicating there is no statistical difference between the estimated surface radiance values and the radiance values measured by the ETM+.

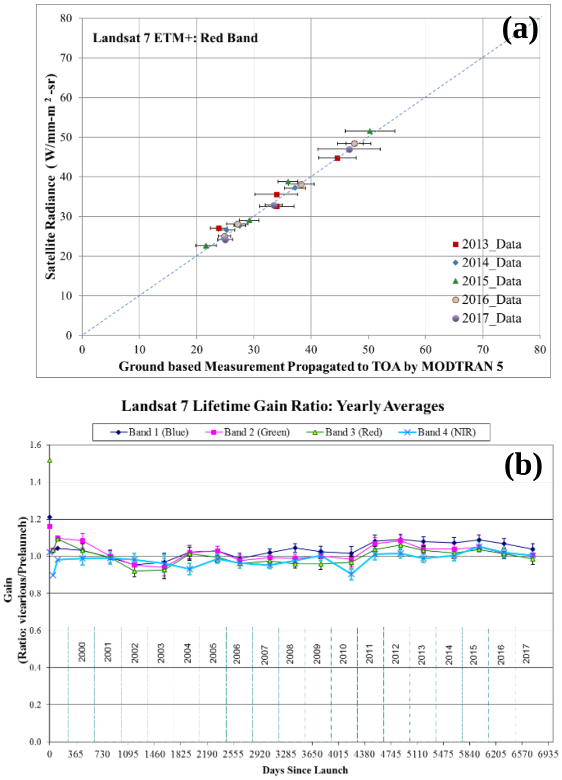

Figure 5. (a) Measured ETM+ Red band radiance versus MODTRAN-predicted surface radiance at SDSU site; (b) radiometric gain coefficient from 1999 to 2017 for ETM+ Blue, Green, Red and NIR spectral bands.

4. CONCLUSION

Founded in 1988, the primary efforts of the SDSU IPLAB have emphasized research and development of radiometric calibration algorithms for optical remote sensing satellite systems. One of the numerous contribution of the IPLAB involves radiometric calibration using surface reflectance-based manned vicarious calibration campaigns at a vegetative site. This work analyzed spectrally and spatially the SDSU vegetative site during the period from 2013 to 2017.

The SDSU site has a spectral reflectance profile representative of vegetation surface cover, with reflectance ranging from 1%-12%, 13%-41%, and 11%-40%, in the wavelengths from 350nm-700nm, 701nm-1300 nm, and 1301nm-2500 nm, respectively. The corresponding average uncertainty of the SDSU vegetative site reflectance in this time period ranges from approximately 2.0% to 9.9% between 350 nm and 2500 nm (~5.0% across all wavelengths). The site cannot be considered temporally stable, so accurate ground measurement of the site must be performed for every sensor overpass.

Between 2013 and 2017, Row 5 was the row identified as most representative of the site which better represent the site, with a difference between its reflectance and the overall site reflectance of approximately 2.5%, on average, across all wavelengths. Similarly, Row 3 was the row identified as least representative of the site, with a difference between its reflectance and the overall site reflectance of approximately 6.8%, on average, across all wavelengths; this is most likely due to the small valley significantly affecting the resulting measurements.

In order to illustrate the results that can be achieved using the SDSU vegetative site was presented the ETM+ radiometric calibration during the 2013 to 2017 period was also presented. The average uncertainty of ETM+ Landsat-7 vicarious calibration over SDSU site was 3.9 to 7.6%. In principle, similar calibration results should be achieved just through measurements of Row 5 and the reference panel, which could provide a significant reduction of effort required to perform the calibration.

This spatial homogeneity analysis is especially important in the future, where an automation of SDSU vegetative site could be considered. With these results it is possible to decided where, in the future, should be deploy the automated equipment to better characterize the site.

5. REFERENCES

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