Emerging Techniques for Vicarious Calibration of Visible Through Short Wave Infrared Remote Sensing Systems

Authors: Robert E. Ryan, Troy Frisbie, Thomas Stanley

Background

- The scientific community needs geometrically and radiometrically accurate products from the emerging remote sensing systems.
- Insight into the system construction, calibration, and performance will be limited in many cases.
- Most systems will not have any onboard radiometric calibration.
- Cal/Val (calibration/verification) is essential.
- Ground-based radiative calibrations currently require teams of trained staff taking coincident data at the time of overpass and analyst to estimate: Top-of-the-Atmosphere (TOA) radiance.
- Significantly coordination is required between the imagery provider and the calibration team.
- A variety of sites is needed.
- Improved TOA radiance estimates are needed.
- Level of confidence in ground truth data is limited due to the cost of radiometric calibration.
- Novel automated systems are clearly needed to effectively calibrate and validate products from such a large number of systems.
- Several years away
- Conceived, well-funded projects will be needed to be established.

Ground-Based Radiometric Cal/Val Needs

- Near-term: Increased confidence through independent validation of ground truth and modeling
- Measurement techniques that reduce or at least do not increase staff
- Simple and more accurate calibration approaches
- Mid-term: Development of techniques that are compatible with autonomous measurements
- Long-term: Fully autonomous vicarious calibration techniques and sites

SSC Near-Term Cal/Val Development Goals

- Improved accuracy and higher confidence in TOA radiance estimates
- Radiative transfer model application
- Alternative sun photometer calibration and validation
- Low-cost, simple, in-field, NIST-traceable radiometric calibration source

Stennis Verification & Validation (V&V) Site

- NASA SSC maintains four ASD FieldSpec FR spectroradiometers
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Typical Radiometric Vicarious Calibration

- Verify parameters used to generate MODTRAN solar irradiances estimate
- Measure the radiance of a Spectralon panel with a well-calibrated spectroradiometer
- Use the data to determine the TOA radiance of a model of MODTRAN solar reflectance to MODTRAN to predict the radiance of the TOA radiance measurement uncertainty is ~2%
- After panel bi-refractive Radiance Distribution Function (BRDF) correction and radiometric calibration with NIST-calibrated integrating sphere, the expected panel radiance measurement uncertainty is ~2%

Typical Sun Photometer Measurements

- Ground level irradiance
- Direct Normal (e.g., Arizona Solar Radiometer)
- Total, Diffuse, and Derived Normal (e.g., Multifilter Rotating Shadowband Radiometers)
- Solar atmospheric transmission
- Optical depth
- Note: TOA radiance estimates are very sensitive to atmospheric transmission measurements
- Most sun photometers support measurements in several bands to separate key molecular and aerosol scattering and absorption bands

University of Arizona Automated Solar Radiometer (ASR)

- 6 narrow bands
- 10 narrow bands
- 10 mm bandwidth
- Direct solar radiance

Traditional In-field Calibration of Sun Photometers

- Langley plot calibration requires many clear days with solar geometry conditions
- Not practical in many locations
- 5% or more errors in transmission are quite possible
- Radiometric and standard accuracy can be improved by using a vicarious calibration method in areas where atmospheric attenuation is not difficult to estimate.

Shadowband Sun Photometer Measurements

- Total irradiance is equal to the sum of the direct component and the diffuse component:
  \[ E_{\text{total}} = E_{\text{direct}} + E_{\text{diffuse}} \]
- The direct component of irradiance can be written in the following terms:
  \[ E_{\text{direct}} = E_{\text{sky}} \cos(\theta) \cos(\phi) \]
- Alternative Sun Photometer Implementation

- Spectra can be calculated using the following equation:
  \[ E_{\text{spectra}} = E_{\text{sky}} \cos(\theta) \cos(\phi) \]
- The reflectance factor \( \rho \) can be determined as a function of zenith angle and azimuth angle
  \[ E_{\text{spectra}} = E_{\text{sky}} \cos(\theta) \cos(\phi) \]
- Solving for \( \rho \):
  \[ \rho = \frac{E_{\text{spectra}}}{E_{\text{sky}}} \]
- Diffuse-to-global ratio (CDG) used to determine molecular scattering can be defined as:
  \[ E_{\text{diffuse}} = \frac{E_{\text{sky}}}{E_{\text{total}}} \]

Test Case Evaluations

TOA radiance values for selected targets on two days. Radiance values generated with alternative sun photometer optical geometry are compared to reference values generated with the standard method.

Differences in TOA radiance between the two methods are negligible in most cases.

Alternative Sun Photometer Summary

- Differences between the alternative and traditional sun photometer data (i.e., CDG) are relatively small in most cases (<5%)
- Additional analysis shows that in certain cases, the prototype may produce more accurate measurements than the traditional method in a Sonoil-like environment for lack of sufficient sunlight data
- Improved transmission in all sun photometer models
- Utilize existing commonly used vicarious calibration equipment
- Effective transfer of radiative and calibrated radiometer performance
- The need for early deployment to catch many sunrises and sunsets can be minimized
- Current configuration takes hyperspectral measurements
- Current processing uses spectral synthesis to generate bands for either MFRSR or ASR
- Spectrophotometer calibration critical to success
- High-quality, in-field calibration could be extremely beneficial

Desired In-field Radiometric Calibration Source

- Radiation level comparable to sea-level solar radiance values off terrestrial targets over the solar reflective region
- Radiometric stability equal to or better than 1% for several years
- Capable of operating over a wide temperature range (70-10°C)
- Spatially uniform light field over at least a 25 mm diameter aperture
- Spectral family
- Capable of operating for a continuous period of 6 hours without a line source
- Single-channel portable

Typical Laboratory Radiometric Sources

1. Integrating spheres (Not easily field deployable or reliable)
2. Spectrum panels with traditional Tungsten-Halogen lamps (radiometry source)

Illumination Sources

- New Calibration Approach: High-intensity LEDs

- Advantages
  - Extreme long life 50–100 thousands of hours of initial output
  - Reduced maintenance costs
  - Energy efficient
  - Small footprint
  - Cold state (no filament to break)
  - Disadvantages
  - Narrow spectrum (white phosphors help; sometimes an advantage)

LED-based Radiance Source

- Explode recent developments in high-power LED sources
- Utilize integrating sphere to create uniform light field
- Use high-contrast photodetector to achieve radiometric stability
- Test and characterize system with environmental chamber and independent spectrometer

- LED-based Radiance Source Characteristics
  - Temperature-stable white light LED
  - Spectral range 420-700 nm
  - Other LEDs would increase the spectral range
  - Temperature-stable phosphocoule and feedback loop stabilize integrating sphere radiance level
  - Short-term lamp drift <0.2%
  - Short-term drift <0.5% over temperature range 10-40°C and over large spectral range

- Comparison of LED Integrating Sphere with Traditional Sources
  - MODTRAN calculations for 30 degrees solar zenith, 2 km visibility and rural aerosol.

- TOA radiance levels calculated for 30% reflectance images and 1 m above Specralon panel
  - "C" sphere at 3200 K Tungsten lamp

Summary

- Autonomous Visible to SWIR ground-based multi-spectral Cal/Val will be an essential Cal/Val component with such a large number of systems.
- Robust automated calibration systems can improve accuracy in ground-truth data
- Validation of radiometric modeling
- Validation or replacement of traditional sun photometer measurements
- Should enable significant reduction in deployed equipment such as equipment used in traditional sun photometer approaches
- Simple, field-portable, white light LED calibration source promises wide range for visible (400-700 nm)
- Prototype demonstrated <0.5% drift over 0-40°C temperature range
- Radiometric stability required for many sun photometer applications
- Prototype and modified prototypes will be necessary to expand spectral range into the NIR and SWIR
- Performance should produce at least several hundred hours of useful time or more of stability, minimizing need for expensive calibrations and supporting long-duration field campaigns
- Enabling technology for developing autonomous sites