RADIOMETRIC CALIBRATION CONCEPT OF IMAGING SPECTROMETERS FOR A LONG-TERM ECOLOGICAL REMOTE SENSING PROJECT

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Abstract

The National Ecological Observatory Network (NEON), funded by the National Science Foundation, is a continental-scale ecological observation platform for discovering, understanding and forecasting the impacts of climate change, land-use change, and invasive species on ecology. An imaging spectrometer will be used by the **NEON Airborne Observation Platform (AOP)** to observe both the human drivers of climate change and the biological consequences of environmental change at a continental scale. To be meaningful as an ecological climate data record, the AOP data set must have a continuous and consistent calibration effort. This requires a robust calibration and validation plan to ensure data continuity from instrument-to-instrument, flight-to-flight, year-to-year, and over the 30-year lifetime of the NEON project. **The NEON Imaging Spectrometer (NIS)** will undergo maintenance and calibration in the laboratory prior to each flight season. Laboratory calibrations include pixel-to-pixel uniformity, radiance coefficient determination, radiometric spectral response, spectral uniformity, linearity, and out of band characterization. A detector-based method will be implemented with the use of a well-characterized and extremely stable NIST traceable transfer radiometer. Solar radiation based calibrations (SRBC) will be performed during laboratory testing as an independent check. An on-board calibrator will be used in the laboratory as a side-by-side comparison during radiometric testing and as a link between laboratory and in-field measurements. Monitoring flat field imagery in-flight from the on-board calibrator and watching for changes over time will determine radiometric stability. Pre-flight calibrations in the field with SRBC and lamp-diffuser setups will allow for the monitoring of calibration drift. Laboratory calibrations will be independently tested throughout the season with vicarious calibration techniques and cross-calibration with multispectral satellite sensors. In addition to the imaging spectrometer, AOP instrumentation includes a small footprint waveform LiDAR and a high-resolution airborne digital camera. The AOP calibration plan for the NEON Imaging Spectrometers during the lifetime of the NEON project is presented.

The NEON Imaging Spectrometer (NIS)

- Imaging spectroscopy measurements
  - Vegetation biochemical & biophysical properties
  - Cover type/fraction
- NIS Key measurement requirements
  - Spectral range: 380 to 2500 nm
  - Spectral sampling: 5 nm
  - Spatial resolution: 1 to 3 meters
  - Corresponding ground swath: 600 to 1800 meters AGL

NIS Calibration Requirements

Radiometric	
Signal-to-Noise Ratio (SNR)	Knowledge of to ≤ 5%
Linearity	Knowledge of to ≤ 1%
Radiance Calibration	> 95% absolute (< 5% uncertainty)
Uniformity	Knowledge of to ≤ 1%
Dark Signal Offset	Knowledge of to ≤ 1%
Spectral and Uniformity	
Spectral Cross-Track	> 95% Uniformity
Spectral-IFOV	> 95% Uniformity
Response uniformity	≥ 95%
Spectral calibration uncertainty	≤ 0.1 nm

On-board Calibrator (OBC)

- On-board calibration subsystem provides
  - Flat fielding
  - Traceability to laboratory calibration standards
  - A means for conducting trend analysis of spectrometer performance
- In conjunction with laboratory and vicarious calibrations provides
  - A means for cross calibrating between replacement sensors over the lifetime of the NEON observatory;
  - and between sensors flying on separate platforms

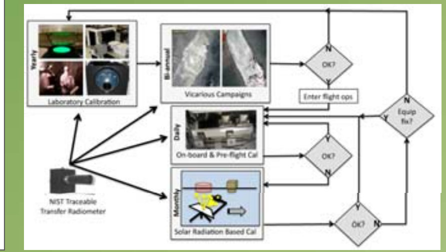
Radiometric Calibration Concept

- Annual NIST-traceable radiometric characterization at AOP Sensor Test Facility in Boulder, CO, USA
- Laboratory derived radiometric coefficients independently tested by vicarious calibration campaigns
- Detailed procedures followed to minimize systematic errors
- Detector-based method implemented in the laboratory with well-characterized and extremely stable NIST-traceable transfer radiometer
- Most calibrations performed in the laboratory performed with two different methodologies or approaches
- Operational tests performed in the field pre- and post-flight tracks validate laboratory-derived coefficients
- On-board calibrator monitors health of laboratory-derived coefficients & sensor in-flight
- Radiance model of expected output from the spectrometer used as operational diagnostic tool

Calibration Schedule for the NIS

TEST	YEARLY: Lab	YEARLY: Vicarious	YEARLY: Secondary Vicarious	MONTHLY: Tarmac	DAILY: In-flight
Pixel-to-pixel uniformity	X	X			X
Radiance Coefficients	X	X	X	X	X
Radiometric Spectral Response	X				
Spectral Uniformity	X	X			
Spectral Scale	X	X	X	X	X
Spatial		X			X
Dark Signal	X	X	X	X	X
Linearity	X				
Out of Band/Stray Light	X				

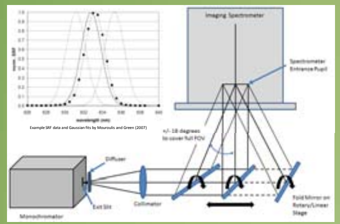
Radiometric Calibration Flow



Laboratory Calibration

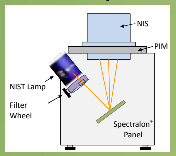
- NIS instruments undergo maintenance and calibration in the laboratory prior to each flight season
- Laboratory radiometric calibrations: pixel-to-pixel uniformity, radiance coefficient determination, radiometric spectral response, spectral uniformity, linearity, dark current trending, and out of band characterization
- Laboratory equipment undergoes annual maintenance and calibration as appropriate

Collimated Monochromator Test Set



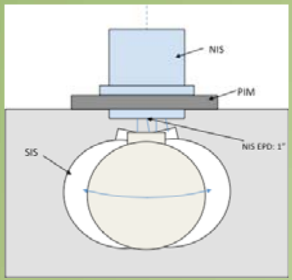
- Spectral response functions at discrete field positions are measured by changing fold mirror rotation and lateral position
- Resulting Gaussian profile characteristics are interpolated across the entire field

Lamp-Panel-Sensor Test Set



- Radiance coefficients
- Spectral position of discrete wavelengths
- Spectral Uniformity

Spherical Integrating Source (SIS)



- Radiance coefficients
- Radiometric range and linearity
- SNR
- Bad pixel map
- Dark current trending
- Out-of-band response

Solar Radiation Based Calibration (SRBC)

- SRBC performed during laboratory testing as independent check under operational conditions (i.e. illumination of target by sun).
- SRBC performed in field monthly on tarmac
  - Monitor the stability of the radiometric calibrations
  - May help determine that the on-board calibrator requires maintenance (e.g. replacing a lamp)

Operational Calibration

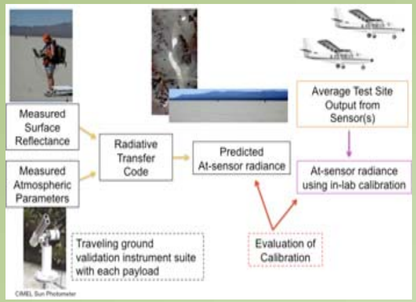
Several checks will be set in place while the instruments are in the field to ensure that the calibrations remain valid.

- NIS on-board calibrator used in laboratory as a side-by-side comparison during radiometric testing
- Monitor in-flight flat field data from the on-board calibrator and watch for changes over time to determine radiometric stability
- Pre-flight calibrations verified in the field with SRBCs and lamp-diffuser setups
- AOP flights coincide with satellite overpasses whenever possible
- Vicarious calibration campaigns independently validate laboratory-derived coefficients.

Vicarious Calibration Campaigns

- Annual vicarious campaigns planned at a well-known test site
  - Large in size, uniform, high reflectance, spectrally flat, consistently clear weather, and easily accessible
  - Candidate sites include Ivanpah Playa, CA, Lunar Lake, NV, and Railroad Valley, NV
- All three NIS instruments participate simultaneously
- Determines relationship between incident spectral radiance and sensor output for the spectrometer
- Result independent of on-board calibrators and pre-flight calibration
- Gives near-ideal situation for cross-calibration between imaging spectrometers in an operational state
- Cross-calibration with satellite sensors and other airborne spectrometers possible
- Biases between sensors can be identified and removed

Steps in Vicarious Calibration



Additional Validation Flights

- Additional validation flights held in regions across U.S.
- For example, a well-characterized large parking lot or natural feature is flown on the East coast to understand a more humid environment and how it affects the atmospheric correction and instrument data
  - Sites well characterized with ground measurements of spectral reflectance
  - Yearly evaluation with moderate resolution multi-spectral satellite data used to determine stability of calibration target
  - Unless > 5% change found in target with satellite data, target re-visited for ground measurements every 5 years

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