Calibration & Validation Explainer Sheet

At Pixxel, we are launching a cutting-edge constellation of hyperspectral Earth observation satellites designed to provide high-quality, accurate, and reliable data for a variety of applications including environmental monitoring, agriculture, mining, and more. To ensure the quality and precision of the data we deliver, our satellites undergo a thorough Calibration and Validation process. This explainer sheet outlines the key aspects of this essential process.

What is CalVal?

Calibration and Validation, commonly referred to as CalVal, are integral processes in the world of Earth Observation. Calibration involves fine-tuning and aligning satellite sensors to established physical standards and offers a regular assessment of instrument performance. Validation, on the other hand, establishes the crucial link between measurements taken from space and ground-based data, enabling the testing and verification of algorithms and models used to derive essential parameters and data products. Together, CalVal processes serve as a foundation for ensuring we deliver precise and accurate Earth observation data to customers and enable actionable insights.

The Calibration Process

Prior to launching a satellite, Pixxel conducts extensive laboratory characterization of our imagers. These primarily include radiometric, spatial, and spectral calibration of the imager. The data collected in these laboratory tests are used to develop a calibration model that can be applied to all imagery acquired by the sensor. The calibration model, among other items, takes into account the following factors:

- The spectral response of the sensor
- The sensitivity of the sensor
- The radiance of the calibration targets

Once developed, the calibration model is used to convert the raw image digital numbers (DNs) into a hyperspectral image in absolute radiance units. The calibration of our imagery to absolute units allows for quantitative analysis of the image data, such as physical property retrievals, and the comparison of our data to other calibrated data sources.

Radiometric Calibration

Radiometric calibration is the process of converting the raw data, or DNs, recorded by a satellite's sensor to a corresponding physical unit. For our imagers, this is a unit of radiance ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$). Prior to launching the imager, this equivalence between DN and radiance units is established through the use of light sources of known radiance, and a piece of equipment known as an integrating sphere to produce a constant target of known radiance level for the imager to observe.

By collecting many images of this constant radiance light source we're able to calculate the gain for each of the wavelength bands and spatial pixels on our detectors. By varying the light level of the target we're further able to refine our model of the imager's to account for the imager's nonlinearity with light level. Lastly, we measure the dark noise inherent in the system by collecting an image in the absence of light. This value of noise is the dark offset of the imager, and it varies by wavelength band and spatial pixel.

The final radiometric calibration model consists of gains and offsets for each of the imager's wavelength bands and spatial pixels covering the range of light levels we will encounter on-orbit.

Spectral Calibration

Pre-launch spectral calibration consists of verifying the spectral response function (SRF) of the imager. SRF is the combination of the band center wavelength, where in the spectrum the band is located, and the bandwidth of each band, or the region of the spectrum that the band observed. These two properties are measured through the use of a known wavelength light source. This known wavelength light source is observed and the resulting data collected by the imager is used to define the imager's SRF. A monochromator is used to provide this known wavelength light.

Vicarious Calibration

Once in orbit further monitoring and validation of the imagers' performance is known as vicarious calibration. As Pixxel's satellites do not carry internal calibration features or targets vicarious calibration is performed by imaging a series of well-characterized calibration targets such as those shown in *Figure 1*.

Calibration Sites

Due to the inability to conduct direct testing of spaceborne sensors in orbit, the prevailing method for calibration involves performing evaluations using ground reference targets. As a result, the development of excellent test sites is essential for executing ground reference targets and related instruments. Over the past few decades, numerous CalVal sites (*see Figure 1*) have been established across the globe and can be categorized broadly into four main types: radiometric calibration, geometric calibration, image performance assessment, and product validation.

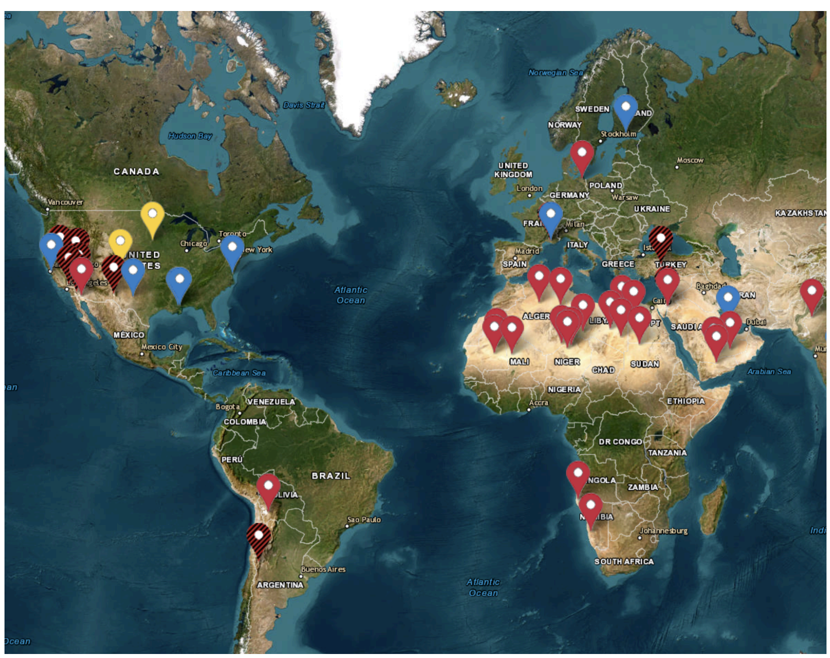

Figure 1: Map of various calibration locations across the globe.
Credit: USGS

There is an array of features, both manmade and natural, that may be used as calibration sites to characterize and monitor the imager's performance. These include flat, homogeneous areas such as dry lake beds and deserts, or manmade features such as roads or bridges that provide distinct contrast to their surroundings. Beyond opportunistic features, many purpose-built calibration sites have been constructed to calibrate remote sensing instruments. These can take the form of checkerboard patterns, fixed-size squares, or even targets with different spectral responses. Another subset of calibration sites is the active site. This type of site uses mirrors to reflect a known light source to the imaging satellite. This type of site can provide even more comprehensive calibration because the amount of light being reflected is measured and can even be varied.

Figure 2: Examples of commonly used calibration sites including the Railroad Valley, Nevada lakebed site (left) and a constructed calibration site in Shadnagar, India (right).
Credit: USGS (left) and Google Earth (right)

Geometric Calibration

Geometric calibration is the process of correcting for geometric distortions in imagery. These distortions can be caused by a variety of factors such as sensor geometry, the Earth's curvature, and atmospheric refraction.

Geometric calibration is typically performed using specific targets called ground control points (GCP). A GCP is a set of points on the ground with known coordinates. These points are an image and their coordinates are used to develop a model that can be used to correct image distortions. Geometric calibration is particularly important to make sure accurate image georeferencing is provided.

Pixxel's geometric calibration process is performed during a satellite's commissioning. A series of images are collected of geometric calibration ground sites and other locations and reference images are used to refine the pre-launch camera model for the satellite. Many images are combined to produce a robust camera model and once established the camera model, in addition to a digital elevation model (DEM) are used to accurately geolocate our images and orthorectify them to the surface.

Continuous Monitoring

Vicarious calibration serves as a method for continuous monitoring and correction of Pixxel's calibration models over the lifetime of our satellites. Immediately after launch during the commissioning phase, imagery will be collected over these CalVal ground sites to detect any changes from the pre-launch calibration values. Any observed changes will be further quantified and incorporated into the calibration models before data are delivered.

Beyond the commissioning of the satellites, the continual imaging of CalVal sites enables the Pixxel team to monitor the health of the imager and detect and track changes to the imager's calibration over its lifetime. As needed these results can be used to update an imager's calibration model to ensure high-quality data are delivered over the length of the satellite's life.

Continuous Improvement

Pixxel is in the business of continually improving our satellites, software, and processes to ensure that we deliver high-quality imagery to our customers. The work that we put into the Calibration and Validation of our imagers enables us to be confident in the data that we deliver.