ABSOLUTE RADIOMETRIC CALIBRATION

MAXAR

# THE BASELINE FOR SUCCESS

Absolute radiometric calibration provides an on-orbit check and any necessary adjustments to the pre-flight sensor calibration performed in a lab. An accurate calibration is the baseline for the successful integration and fusion of data from multiple sensors on multiple platforms. For example, a time-lapse series of images or measurements requires an accurate calibration to ensure that phenomena observed are due to actual changes on the ground versus changes in the sensor. Using calibration sites around the globe, Maxar has created an industry-leading absolute radiometric calibration process to ensure the quality of every remote sensing product we provide to our customers.

## A responsibility to our customers

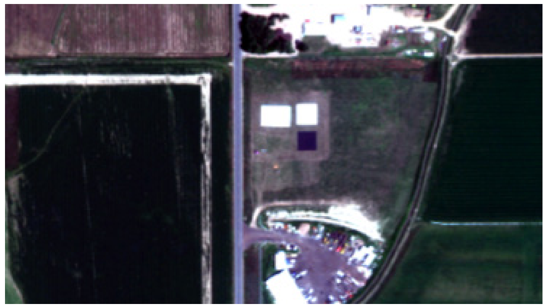
On-orbit calibration accounts for radiometric characteristics of the focal plane and filters that may change during the rigors of launch and in the space environment. Because monitoring radiometric output and stability is a responsibility to our customers across many industries, Maxar maintains an absolute radiometric uncertainty of ≤ 5%.

- Absolute radiometric calibration is a requirement for science projects related to customers in oil and mining, military intelligence, insurance, agriculture, and others.
- Products that use surface reflectance require a good absolute radiometric calibration as a baseline.
- Vegetation indices, spectral characteristics of materials (e.g. building rooftops), machine learning, and feature extraction all require calibrated radiances to work.

## The world-class Maxar calibration

As part of the calibration process, in-situ weather and surface measurements are collected on site to model surface and atmospheric behavior during sensor overpass. Located in rural Ft. Lupton, Colorado, the three-acre Maxar calibration range and laboratory is far from urban development and pollution—allowing for reliable measurement of atmospherics over the calibration targets. The instrument deck includes web-enabled weather stations and a sun photometer linked to NASA's AERONET system. A site in the Saharan desert is used for off-season calibration and radiometric stability analysis, and all calibrations are validated by secondary absolute radiometric calibration sites around the globe.

### STATE-OF-THE-ART FACILITY



Specialized calibration tarps are laid out at the Maxar calibration facility in Colorado

### ESTABLISHED INTERN PROGRAM

NASA Colorado Space Grant students install a weather station on the instrument deck

### ROBUST VALIDATION METHODS

Railroad Valley, NV, USA is used for validation and as a secondary calibration site

## Conversion of imagery Digital Numbers (DN) to Radiance ($L$)

Maxar products are delivered as relative radiometrically corrected image pixels. Their values are a function of how much spectral radiance enters the telescope aperture and the instrument conversion of that radiation into a digital signal or digital number (DN). That signal depends on the spectral transmission of the telescope and filters, the throughput of the telescope, the spectral quantum efficiency of the detectors, and the analog-to-digital conversion. Image pixel data are therefore unique to each sensor and should not be directly used in a radiometric sense. In addition, bands taken at different time delay integration (TDI) levels may give misleading spectral information if left in digital number space. Image pixels should be converted to top-of-atmosphere spectral radiance at a minimum.

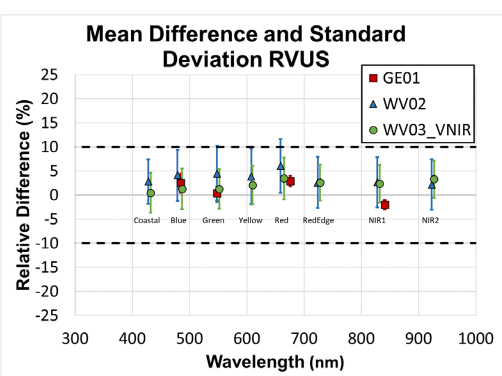
A pre-flight calibration has been performed and these data are provided in the .IMD metadata file that is delivered with the imagery. Since launch, Maxar has performed an extensive vicarious calibration campaign to provide an adjustment to the pre-launch values. The top-of-atmosphere radiance, L, in units of W μm-1 m-2 sr-1, is then found by converting from DN using the equation.

$$L = GAIN * DN\left(\frac{abscalfactor}{effectivebandwidth}\right) + OFFSET$$

The TDI-specific abscalfactor and effectivebandwidth are delivered with the imagery in the metadata file. The digital number, DN, is the pixel value found in the imagery. The GAIN and OFFSET are the absolute radiometric calibration band dependent adjustment factors that are given in Table 1 (and Table 3 for WorldView-3 CAVIS). Note that these values are revisited annually and improved upon, although the sensors themselves have been found to be very stable throughout their lifetimes. Note that the calibration uses Thuillier 2003 solar curve in the radiative transfer calculations performed during

## Validation via CEOS RadCalNet sites

Maxar utilizes the Committee on Earth Observation Satellites (CEOS) RadCalNet sites for validation of our on-orbit absolute radiometric calibration efforts. Maxar compares to RadCalNet Railroad Valley, Nevada (RVUS) site within +/- 5%. This includes the WorldView-3 SWIR instrument. RadCalNet data are given at Nadr. Maxar sensors will typically have an off-nadir angle of 5-30 degrees. Variation in off-nadir angle will increase the variability in Maxar data due to surface BRDF and longer atmospheric path. <10% is considered a good comparison.



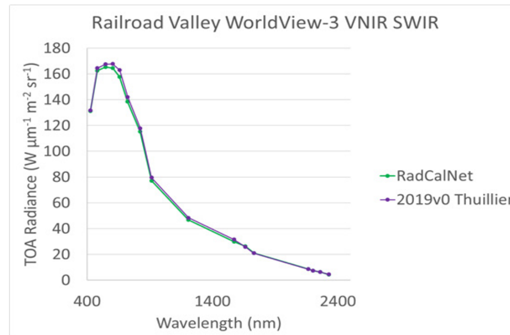

Maxar sensors compare to RadCalNet at about ±5%.

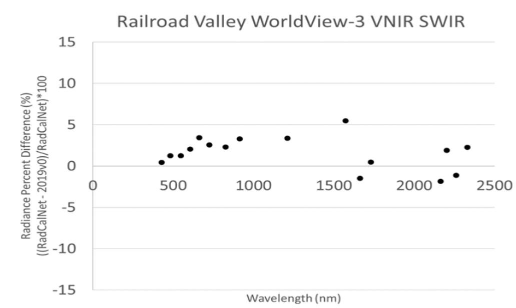
### CONVERSION TO REFLECTANCE

$$\rho = \frac{L_{pixel,band} d_{ES}^2 \pi}{E_{S_{band}} cos(\theta_S)}$$

- “L” is at-sensor radiance found independently for each band and pixel
- “dES” is the earth-sun distance in AU for the date (TLCTime goves the data and time of the collection)
- “Es” is the band-averaged solar exoatmospheric irradiance at 1 AU
- “θ” is the solar zenith angle (90-meanSunEl from IMD file)

### A SMOOTH TRANSITION FROM WORLDVIEW-3




Care is taken to ensure that the WorldView-3 and SWIR instruments display a smooth transition even though they are two completely different.

### MAXAR IS WELL WITHIN SPECIFICATIONS

The aim of absolute radiometric calibration is to assign absolute scientific SI units to pixels based on radiometric parameters such as scan direction, scan rate, TDI level, and DN value. For WorldView-class sensors, the absolute radiometric calibration product specification for ninety-five percent of products is:

- <10% of dynamic range there shall be no specification
- Between 10% and 85% of the dynamic range the absolute radiometric response specifications shall not exceed +/- 10% uncertainty for VNIR sensors and +/- 15% for SWIR sensors
- >85% of dynamic range there shall be no specification

## Table 1. Absolute radiometric calibration adjustment factors, GAIN & OFFSET

| SENSOR | WorldView-3 | | WorldView-2 | | GeoEye-1 | | WorldView-4 | | WorldView-1 | | QuickBird | | IKONOS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cal Version | 2018v0 | | | | | | 2017v0 | | 2016v0.Int | | | | 2014v3 | |
| BAND | GAIN | OFFSET | GAIN | OFFSET | GAIN | OFFSET | GAIN | OFFSET | GAIN | OFFSET | GAIN | OFFSET | GAIN | OFFSET |
| PAN | 0.955 | -5.505 | 0.949 | -5.523 | 1.001 | 0.000 | 1.000 | 0.000 | 1.016 | -1.824 | 0.870 | -1.491 | 0.907 | -4.461 |
| COASTAL | 0.938 | -13.099 | 1.203 | -11.839 | | | | | | | | | | |
| BLUE | 0.946 | -9.409 | 1.002 | -9.835 | 1.041 | 0.000 | 1.000 | 0.000 | | | 1.105 | -2.820 | 1.073 | -9.699 |
| GREEN | 0.958 | -7.771 | 0.953 | -7.218 | 0.972 | 0.000 | 1.000 | 0.000 | | | 1.071 | -3.338 | 0.990 | -7.937 |
| YELLOW | 0.979 | -5.489 | 0.946 | -5.675 | | | | | | | | | | |
| RED | 0.969 | -4.579 | 0.955 | -5.046 | 0.979 | 0.000 | 1.000 | 0.000 | | | 1.060 | -2.954 | 0.940 | -4.767 |
| REDEDGE | 1.027 | -5.552 | 0.980 | -6.114 | | | | | | | | | | |
| NIR1 | 0.977 | -6.508 | 0.966 | -5.096 | 0.951 | 0.000 | 1.000 | 0.000 | | | 1.020 | -4.722 | 1.043 | -8.869 |
| NIR2 | 1.007 | -3.699 | 1.010 | -4.059 | | | | | | | | | | |
| SWIR1 | 1.030 | 0.000 | | | | | | | | | | | | |
| SWIR2 | 1.052 | 0.000 | | | | | | | | | | | | |
| SWIR3 | 0.992 | 0.000 | | | | | | | | | | | | |
| SWIR4 | 1.014 | 0.000 | | | | | | | | | | | | |
| SWIR5 | 1.012 | 0.000 | | | | | | | | | | | | |
| SWIR6 | 1.082 | 0.000 | | | | | | | | | | | | |
| SWIR7 | 1.056 | 0.000 | | | | | | | | | | | | |
| SWIR8 | 1.101 | 0.000 | | | | | | | | | | | | |

WorldView-4 calibration is updated directly into the Factory cal tables and no further outside adjustments are required. It is important to note that there are discernable differences in top-of-atmosphere radiances that are derived from different published top-of-atmosphere solar irradiance data. We advise customers to use the Thuillier 2003 solar irradiance curve when performing atmospheric correction.

## Table 2. Solar exoatmospheric irradiance at 1 AU

| SENSOR | WorldView-3 | WorldView-2 | GeoEye-1 | WorldView-4 | WorldView-1 | QuickBird | IKONOS |
|---|---|---|---|---|---|---|---|
| PAN | 1574.410 | 1571.360 | 1610.730 | 1608.010 | 1478.620 | 1370.920 | 1353.250 |
| COASTAL | 1757.890 | 1773.810 | | | | | |
| BLUE | 2004.610 | 2007.270 | 1993.180 | 2009.450 | | 1949.590 | 1921.260 |
| GREEN | 1830.180 | 1829.620 | 1828.830 | 1831.880 | | 1823.640 | 1803.280 |
| YELLOW | 1712.070 | 1701.850 | | | | | |
| RED | 1535.330 | 1538.850 | 1491.490 | 1492.120 | | 1553.780 | 1517.760 |
| REDEDGE | 1348.080 | 1346.090 | | | | | |
| NIR1 | 1055.940 | 1053.210 | 1022.580 | 937.800 | | 1102.850 | 1145.800 |
| NIR2 | 858.770 | 856.599 | | | | | |
| SWIR1 | 479.019 | | | | | | |
| SWIR2 | 263.797 | | | | | | |
| SWIR3 | 225.283 | | | | | | |
| SWIR4 | 197.552 | | | | | | |
| SWIR5 | 90.418 | | | | | | |
| SWIR6 | 85.064 | | | | | | |
| SWIR7 | 76.951 | | | | | | |
| SWIR8 | 68.099 | | | | | | |

Maxar uses the COES-recommended solar irradiance curve Thuillier 2003. These are band averaged values for each sensor.

## Table 3. WorldView-3 cavis absolute radiometric calibration adjustment factors and banded top-of-atmosphere solar irradiance

The CAVIS absolute radiometric calibration is performed over the Saharan Desert. The USGS Radiometric Calibration site "Libya4" in the Saharan desert is used for monitoring the radiometric stability of the MAXAR sensors, to provide a winter use calibration site, and to perform absolute radiometric calibration of large pixel sensors (WV-03 CAVIS has a 30-m nadir pixel and cannot be calibrated on our 20 x 20 m tarps). Imagery taken over the site that is calibrated by our vicarious efforts in Colorado are used to create an empirical model of expected top-of-atmosphere reflectance. Comparisons to other agency instruments are performed over the secondary sites that include Libya4 and Railroad Valley in Nevada, USA.

| Version | 2016v1.L4 | | Thuillier 2003 |
|---|---|---|---|
| BAND | GAIN | OFFSET | E-Sun |
| Desert Clouds | 1.377 | 0 | 1718.25 |
| Aerosol-1 | 1.051 | 0 | 2001.13 |
| Green | 0.816 | 0 | 1831.3 |
| Aerosol-2 | 0.869 | 0 | 1537.38 |
| Water-1 | 0.849 | 0 | 955.658 |
| Water-2 | 0.677 | 0 | 866.791 |
| Water-3 | 0.819 | 0 | 807.875 |
| NDVI-SWIR | 0.842 | 0 | 460.196 |
| Cirrus | 1 | 0 | 361.412 |
| Snow | 0.897 | 0 | 230.349 |
| Aerosol-3 | 1.081 | 0 | 89.1345 |
| Aerosol-3 Parallax | 1.076 | 0 | 89.1345 |

## Training the next generation of scientists and technicians

Maxar is proud to invite students from the Colorado Space Grant Consortium at the University of Colorado in Boulder to work in our main radiometric calibration facility. Freshmen to graduate-level students from many different majors are given the opportunity to be a part of the scientific process and learn what it is like to work in a corporate aerospace environment.