In-Orbit Radiometric Calibration of the Planet Dove Constellation

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Topics

- Introduction to the Dove Satellite and Constellation
- The Dove Imaging Chain
- How radiometric calibration is updated in-orbit
Dove Satellite
## Dove Constellation

<table>
<thead>
<tr>
<th></th>
<th><strong>ISS Orbit</strong></th>
<th><strong>Sun Synchronous Orbit</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expected Lifetime</strong></td>
<td>1 year per satellite</td>
<td>2-3 years per satellite</td>
</tr>
<tr>
<td><strong>Mission Continuity</strong></td>
<td>Up to 55 satellite constellation (continually replenish / upgrade satellites)</td>
<td>100-150 satellite constellation (continually replenish / upgrade satellites)</td>
</tr>
<tr>
<td><strong>Inclination</strong></td>
<td>52 deg</td>
<td>98 deg</td>
</tr>
<tr>
<td><strong>Orbital Insertion Altitude</strong></td>
<td>420km</td>
<td>505km</td>
</tr>
<tr>
<td><strong>Ground Sampling Distance (Nadir)</strong></td>
<td>2.7m-4.0m</td>
<td>4.0m</td>
</tr>
<tr>
<td><strong>Sensor Type</strong></td>
<td>Bayer-masked CCD camera</td>
<td></td>
</tr>
<tr>
<td><strong>Spectral Bands</strong></td>
<td>Blue: 420-530nm Green: 500-590nm Red: 610-700nm NIR: 760-860nm</td>
<td></td>
</tr>
</tbody>
</table>
Dove Constellation

Active Satellites in Sun Synchronous Orbit

Flock 2p (12)

Flock 3p (88)

Flock 2k (48)
Dove Imaging Chain
Radiometric Correction Flow
Image Calibration

Pixel-Level Calibration
● Removes effects of the optics on the imagery (vignetting)
● Removes dust and smudges
● Normalizes image for acquisition environment
● Normalizes image to nominal acquisition parameters

Image Calibration
● Converts corrected pixel DNs to units of Radiance
● Calibration model is unique to each satellite
● Monitored and updated through time using on-orbit methods
Dark Fielding and Flat Fielding

These 2 steps ALWAYS go together

\[ C = \frac{(R - D) \times m}{(F - D)} \]

Where

- \( C \) = corrected image
- \( R \) = raw image
- \( F \) = flat field image
- \( D \) = dark field
- \( m \) = image-averaged value of \((F-D)\)
The Dark Field

Corrects:
- Camera bias and reduces tap imbalance

Measurement:
- Collected pre-launch
- On-Orbit: Images over the Pacific at night when the satellite is in eclipse.
- Scaled by Analog gain of image being processed

Operational Range:
0 - 65 degrees C
Creating and Storing Dark Field

- Dark Field temperature model created for each tap, for every satellite
- Model is predicted DN by temperature range
- Dark Fields are always collected with an Analog Offset of 64 (equivalent of 16 DN).
The Flat Field

Corrects

- Vignette, smudges & dust, and some tap imbalance

Measurement:

- Collected pre-launch - average of 100 scenes from integrating sphere
- On-Orbit: Average of 2000 cloud scenes
- Each ‘component’ image is dark subtracted
- Unique FF for each TDI camera setting used on-orbit
TDI Flat Fields

- All Dove Cameras operate using Time Delayed Integration (TDI).

- TDI Results in a physical shift in how the pixels integrate - increases SNR

- Artifacts like dust get elongated compared to their shape without TDI.

- If you use a flat field generated with a different number of TDI lines (Or direction) than the image being corrected, you introduce image artifacts.

Image artifact (dust on optics) made worse by using a Flat Field that didn’t match TDI of scene
Blue Band

Before On-Orbit Dark Field/Flat Fielding
Blue Band

After On-Orbit Dark Field/Flat Fielding
Smudge on the Lens

Dust on the Lens
Mostly removed...
Collect Settings & Debayer

**Final offset correction and reconstruction of full image**

**Collect Settings:**

- Corrects for scene settings at time of acquisition
  - Exposure Time and TDI
  - Analog Gain & Offset

- Mosaics Bayer Mask image to a 4 band image using Microsoft Debayering Algorithm.
Convert to 16-Bit Scaled Radiance

Corrected DNs to Scaled Radiance (W m\(^{-2}\) sr\(^{-1}\) um\(^{-1}\))

Calibration Coefficients: Gain and Offsets

- Calibration Coefficients are calculated pre-launch and updated through on-orbit calibration methods.

- Same scaling factor across all satellites: 100

Relationship between each sensor and radiance is empirically derived.
TOA Radiance to TOA Reflectance

As Dove Constellation is of successive satellite generations and versions, each Flock and often each satellite has unique Relative Spectral Responses - resulting in unique ESUN values for 100+ satellites.

Every Analytic Product is published with per-band ReflectanceCoefficients, pre-calculated for each band derived from the following equation:

$$
\text{ReflectanceCoefficient}_\lambda = \frac{\pi \cdot d^2}{100 \cdot \text{ESUN}_\lambda \cdot \cos \theta_s}
$$

- All ESUN Values calculated with the Thuillier Solar Irradiance Model
- Note: The 100 multiplier is to remove the scaling from the native Scaled Radiance of the Analytic Product
TOA Radiance Image - Analytic Product
In-Orbit Radiometric Calibration
Calibration Approach

Cross Calibrating Doves to RapidEye

- Instantaneous crossovers sampled, corrected, and stored.
  - Crossovers sourced from RapidEye (RE) and Dove to Dove Crossovers if RE data lacking

- Crossovers cover the brightness range from 50 to 150 watts/m-2 sr-1 um-1

- Average of 5 crossover events and 500 samples used per-satellite/band to update calibration
Calibration Sites

Globally distributed network of desert calibration sites

27 sites covering a range of bright and dark features to capture full dynamic range
Calibration Site Sampling

Criteria for Calibration Site Sampling

- Sample size is 1000 X 1000 Pixels (~3.5 km resolution)
- Sampling in spectrally homogenous locations within calibration site
- Spectra is characterized using Hyperion Imagery

Example Calibration Site sample grids

- Dunhuang
- Namibia B
- Railroad Valley
Characterizing Calibration Sites

Hyperion-Derived Spectra
Initial process: Derive a single spectra for a calibration site representing the yearly average spectra.

- Derived from 12 hyperion images per site
- Source 1 hyperion image for each month
  - Query for available 2015 data and moving backwards in time until a collect for a given month is found
- Future steps will be to derive seasonal average spectra
Hyperion-Derived Spectra

Example Hyperion-derived yearly average spectra

Nambia B          Railroad Valley          Dunhuang
Dove & Landsat 8 RSR
Crossover Sample Processing

Crossover samples are compared in TOA Radiance Space

Spectral Band Adjustment Factor (SBAF)
Calculated per-band to adjust for RSR differences between sensors

\[
SBAF_{1 \rightarrow 2, b} \equiv \frac{\int q(\lambda) RSR_{2, b}(\lambda) d\lambda}{\int RSR_{2, b}(\lambda) d\lambda}
\]

Sun Angle Correction
Adjusts for up to 2 hour time difference between collects

\[
R_{LSatLcor} = R_{LsatOrig} \times \frac{\cos \left(1 - \theta_{SunPL}\right)}{\cos \left(1 - \theta_{SunLsat}\right)}
\]

* Applied to Landsat 8 imagery, correcting Landsat 8 to Planet Dove bands & crossover illumination
Fitting Calibration Model

Uses a Bayesian Approach: Mixed Linear Models

- A ridge parameter is estimated using crossover data from all satellites in the constellation

- Offset for each satellite is forced to be constant across constellation
  - Measured as the per-band average offset for scenes near 40 W m\(^{-2}\) sr\(^{-1}\) μm\(^{-1}\) radiance

- Per-satellite fits are estimated using their discrete crossovers with Rapideye, weighted by the ridge parameter of the constellation and forced through the constellation-wide offset.

Fitting the ridge parameter with all crossover data
Assessing Ground-Derived Calibration

Absolute Accuracy & Precision @1sigma by satellite

Before correction: F2E and F2P absolute accuracy vs. RE and L8
After Calibration Update Applied

Absolute Accuracy & Precision @1sigma by satellite
Monitoring Satellite Health

The lunar data is used to monitor long term trends and satellite health

- The first satellites started capturing moon shots in Q4 of 2016 and have had continuous monitoring shots since then
- Moon shots have helped to diagnose and validate fixes to misaligned star cams and other hardware problems
- This graph shows the results for a satellite’s four taps in all the bands
Thanks!

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