Improving the Image Quality of the SkySat Constellation

Norberto Hernández Castilla, Colm Lynch and Hannah Bourne

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Our Speakers

Colm Lynch
Senior Computer Vision Engineer,
Imaging Ops,
Planet

colm@planet.com

Norberto Hernández Castilla
Computer Vision Engineer,
Imaging Ops
Planet

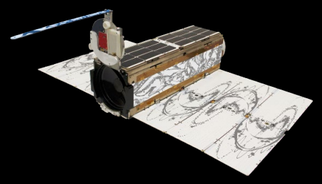
Norberto@planet.com

Hannah Bourne
Engineering Manager,
CalVal Pod,
Planet

hannah.bourne@planet.com

Agile Space Missions

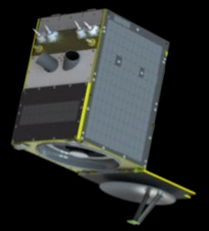
CURRENT CONSTELLATIONS



SuperDove

Always-on Monitoring

- ~180 satellites
- Up to 300 million km^2 / day
- 8-band
- Unique scanning

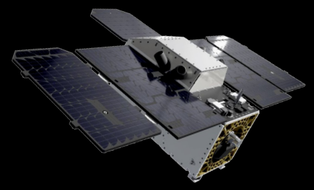


SkySat

High-Resolution Tasking

- ~20 satellites
- 50cm resolution
- RGB, NIR, and Pan bands
- Sub-daily tasking

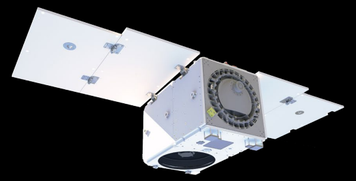
PLANNED FUTURE CONSTELLATIONS



Tanager

Hyperspectral Tasking

- 400 - 2500 nm
- ~400 5nm bands
- Technical demo planned to launch late 2023



Pelican

Very High Resolution Tasking

- Initial fleet of up to 30 satellites[1]
- 30cm resolution
- Pan + 6 RGB+NIR bands
- Up to 30 revisits/day

[1] Does not include initial 2 demonstration satellites planned for FY'24.

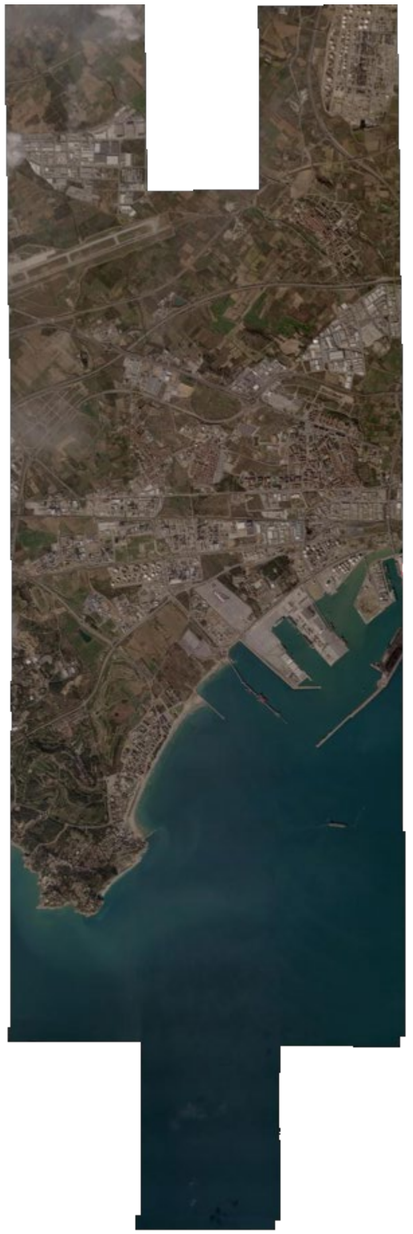
SkySat Constellation Overview

- The SkySat constellation is a distributed constellation of ~20 satellites
- First launched in 2013
- Calibration is updated at regular intervals to account for any sensor-level changes

SkySat Sensors

Each SkySat contains three cameras, operated in a push-frame configuration.

- CMOS sensors
- Separate Panchromatic and Multispectral sensor halves for each camera
- Six pairs of flatfields and darkfields are required for each SkySat



Sensor Correction

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Corrections for sensor-level properties

Sensor-related corrections are managed by the Payload group.

- Flatfield correction accounts for Photo-Response Non-Uniformities (PRNU)
- Darkfield correction corrects for sensor bias and dark noise
- Additional corrections are implemented to account for inter-camera variations and bad pixels

Pre-launch Characterization

Correction for Photo-Response Non-Uniformities (PRNU) is performed with flatfields for each SkySat camera and detector half.

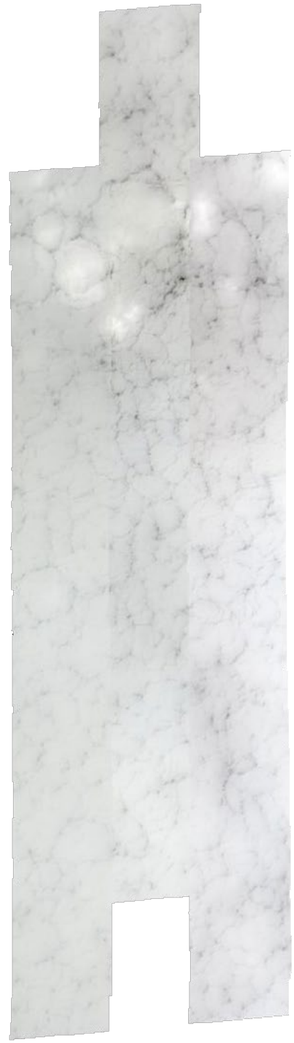
- Per-pixel corrections
- A pair of gains and offsets are required for each camera/half ⇒ 6 pairs in total for each Skysat
- Pre-launch gains are derived using flatfields captured with integration spheres
- Darkfields are captured with closed-door darkfield images

On-orbit Characterization

Flatfield generation - previous approach

Flatfields are derived by averaging multiple collects to remove the spatial variation within a scene.

- Previously these were derived using thousands of L0 image
- Images captured across > 15 collects
- Deep convective cloud are useful as these are already mostly featureless
- Specific calibration tasks are required



On-orbit Characterization

Flatfield generation - current approach

The current approach is to average L0s from production collects.

- Thousands of L0s from > 300 collects are combined to produce averaged flatfields
- Reduces dependence on calibration collects
- Enables retroactive updates to flatfields
- Example flatfield generated from 300 collects is shown on the right

On-orbit Characterization

Darkfield generation

Darkfield are possible by specific calibration collects during eclipse

- Night time ocean collects
- Deep space collects
- Averaging performed across all contributing L0 frames
- Corrective effects of proper flatfields and darkfields is observed in the example on the right

Related Sensor Corrections

Inter-Camera normalization

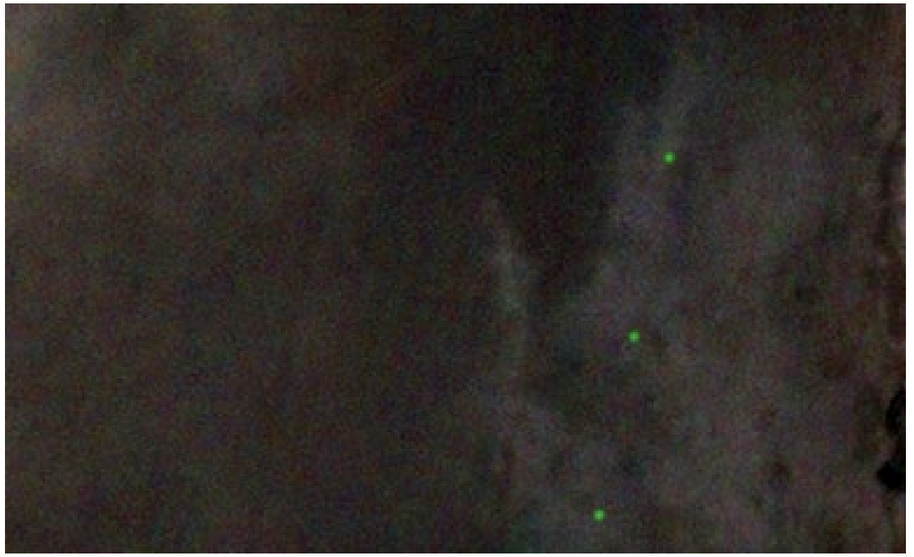
Due to slight discrepancies between contributing cameras, a correction is required to normalize between the lateral and central detector

- Lateral and central cameras have a deliberate overlap
- Allows for the derivation of linear correction factors from overlapping pixels

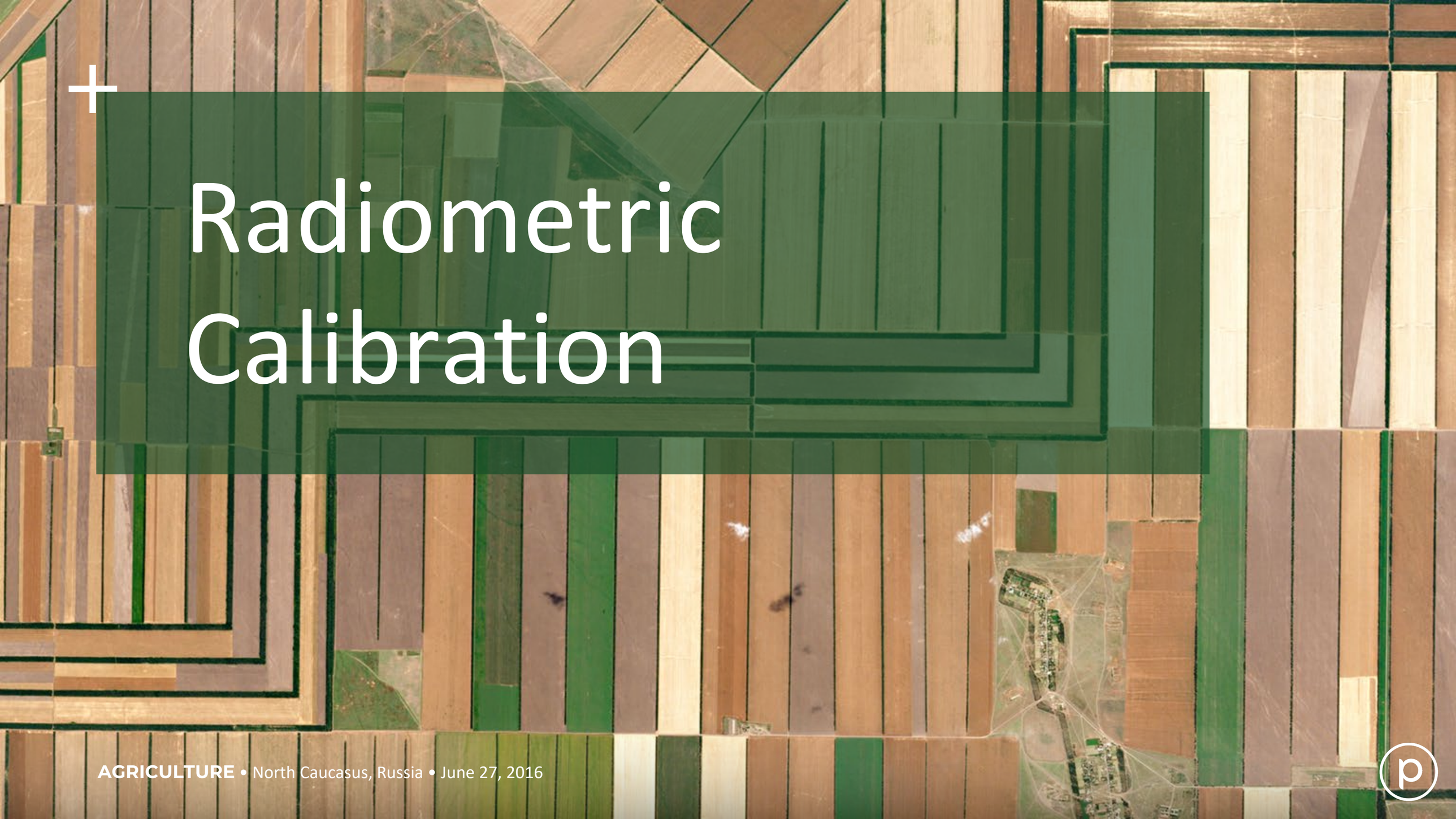
Related Sensor Corrections

Bad Pixel Correction

- Bad pixels are identified using all scenes in a collect
- Maps of bad pixels are maintained for each satellite
- Known bad pixels are interpolated



Radiometric Calibration



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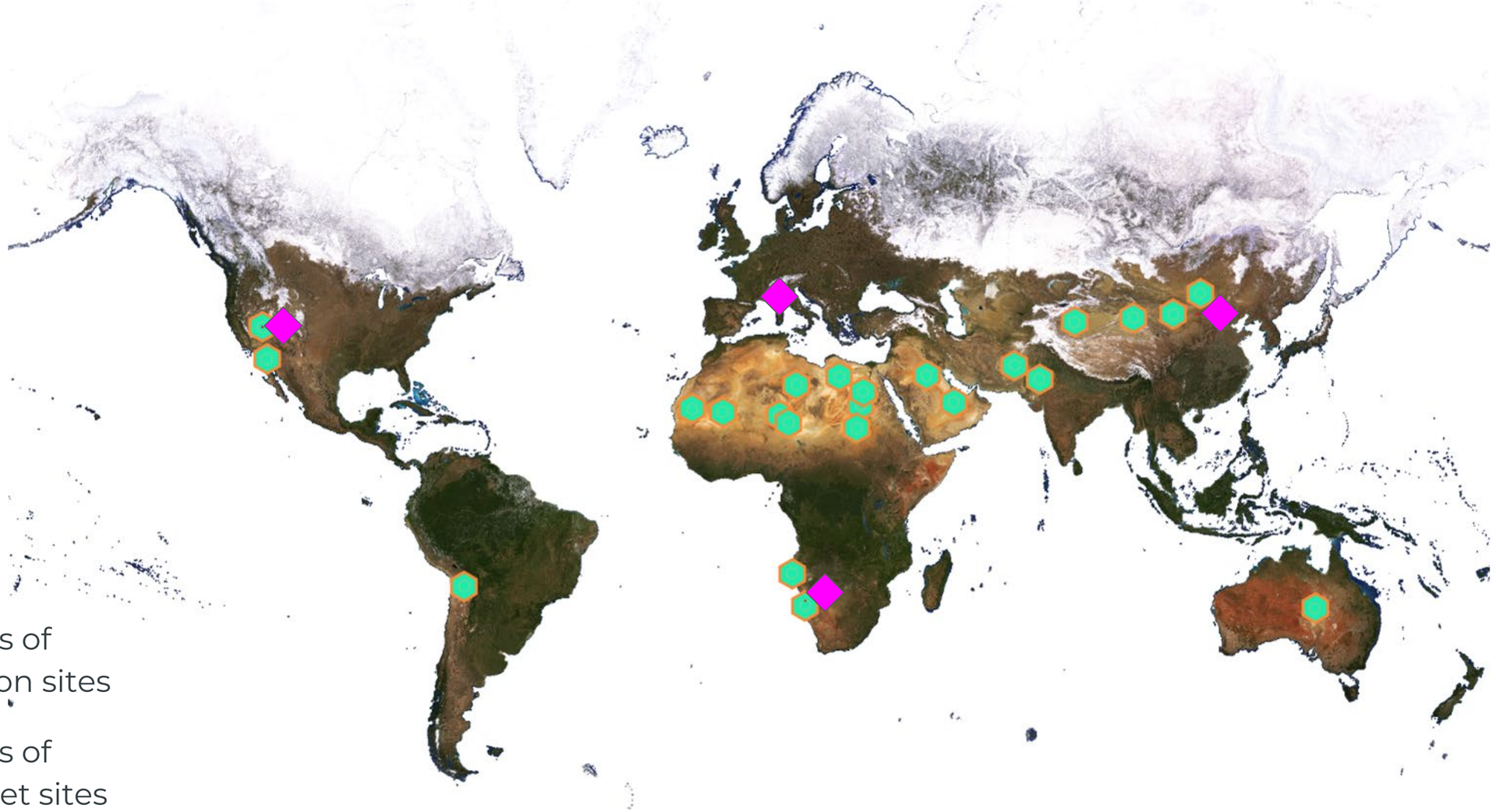
Overview

Current Methodology

- Calibrations are based on gathering a dataset of near **simultaneous crossovers with a reference satellite**
  - A simultaneous crossover between a reference image and a Planet image for the same point
  - Same reference satellite: **Sentinel-2**
- **SkySat uses:**
  - Standard set of calibration sites, “homogeneous” sample regions
  - **Hyperion spectra** for characterizing the surface reflectance to calculate SBAFs
  - Less than 10 degree view angle, less than 20% cloud cover

Calibration Sites



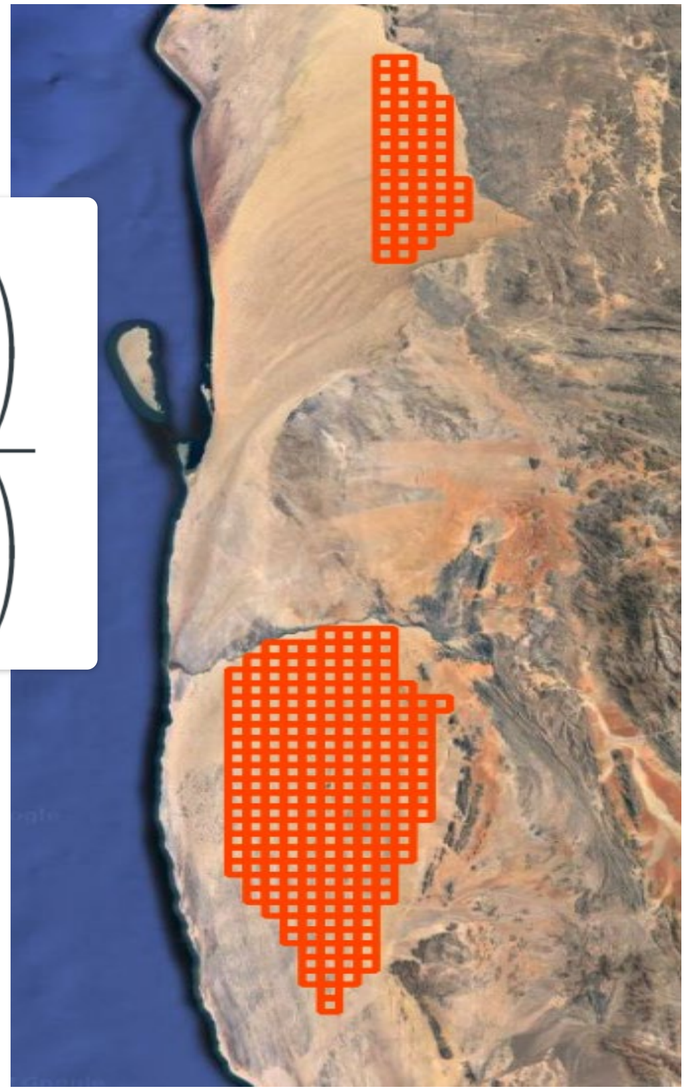
Locations of Calibration sites

Locations of RadCalNet sites

Sample Areas / Details

- 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

$$SBAF_{B\rightarrow A} = \frac{\bar{\rho}_{\lambda(A)}}{\bar{\rho}_{\lambda(B)}} = \frac{\left(\frac{\int \rho_\lambda RSR_{\lambda(A)} d\lambda}{\int RSR_{\lambda(A)} d\lambda}\right)}{\left(\frac{\int \rho_\lambda RSR_{\lambda(B)} d\lambda}{\int RSR_{\lambda(B)} d\lambda}\right)}$$

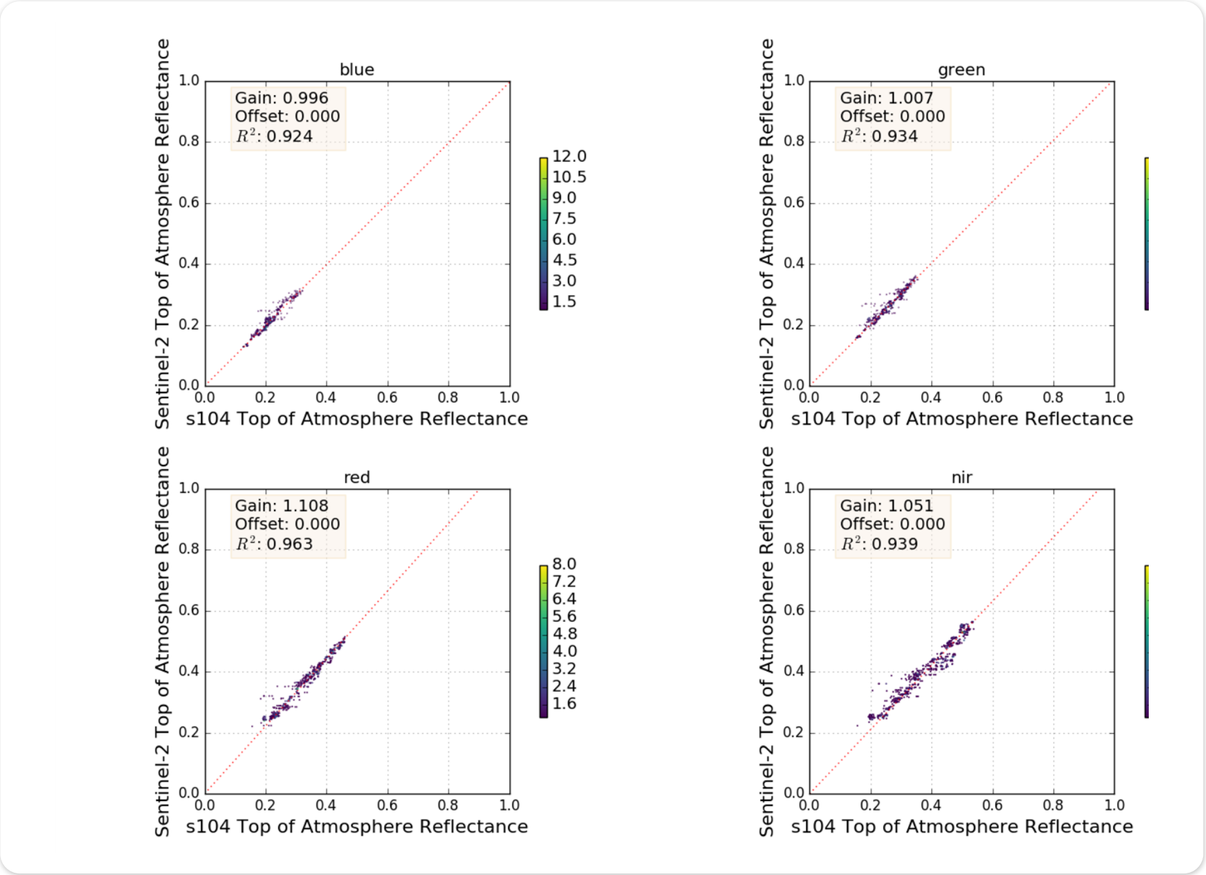


Where:
A refers to **Sentinel-2**
B refers to **SkySat**
ρ refers to the **hyperion TOA reflectance** for a given wavelength

Example Calibration

s104

- Crossovers collected between September 2020 and December 2021
- Overlapping scenes processed to top of atmosphere reflectance
- Median value of each scene pair calculated



Example of per-band gain adjustment factors for SkySat s104. Each point represents one scene pair.

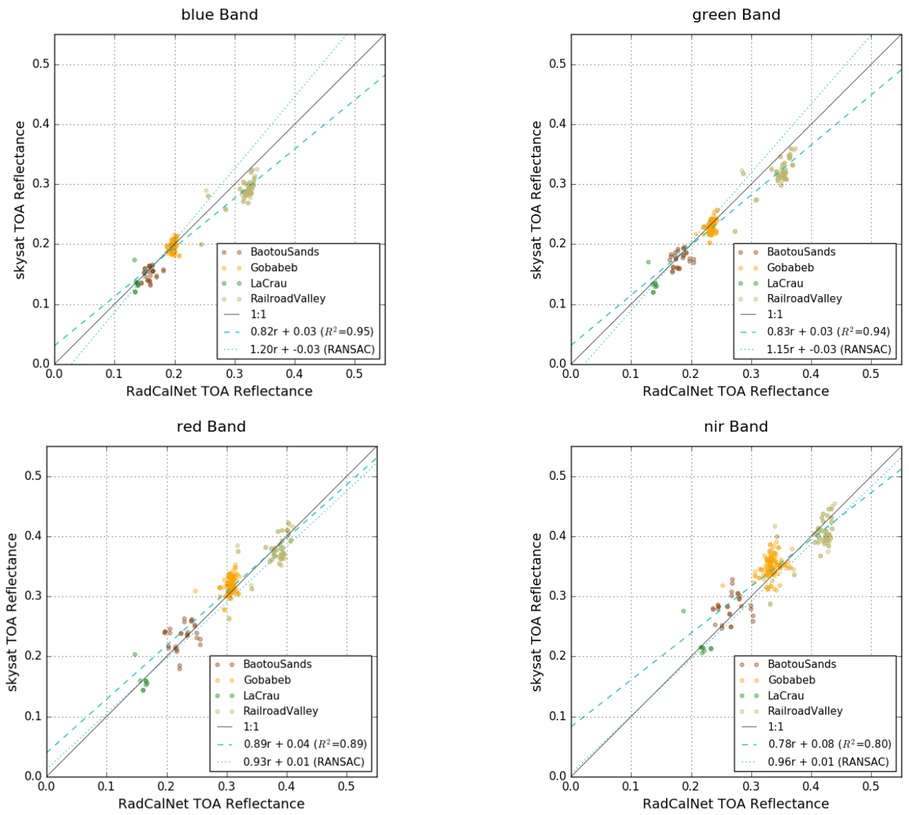
SkySat calibration update

First calibration update using Sentinel-2 crossovers released in spring 2022

SkySat images overlaying a Sentinel-2 image of a calibration site over Libya prior to calibration update.

SkySat images of calibration site over Libya post calibration update.
SkySat images become more consistent across the flock post calibration update.

SkySat RadCalNet Validation

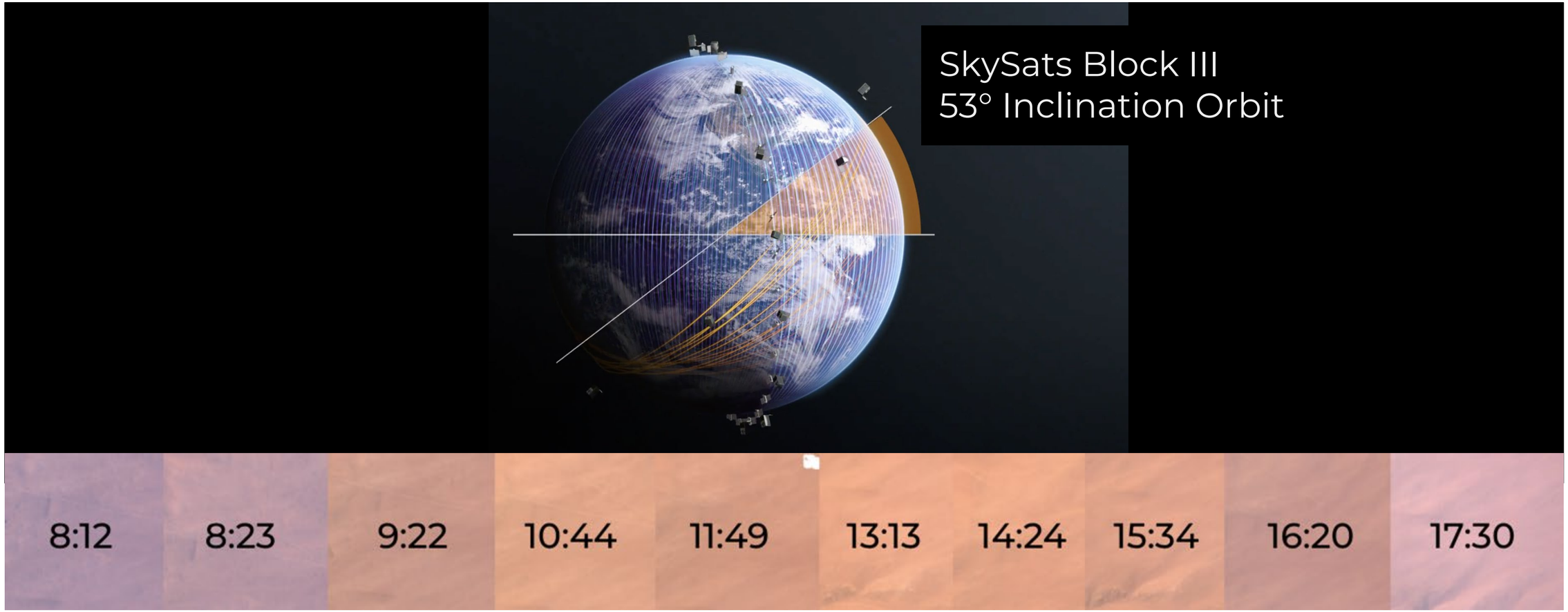


Validation of SkySats (excluding block III SkySats) using independent datasets from the RadCalNet automated calibration sites which provide SI traceable top of atmosphere spectrally-resolved reflectances. 176 scenes total.

Band	Absolute Accuracy	Uncertainty (68 Percentile)
Blue	-3.91	9.41
Green	-4.41	11.03
Red	2.37	12.77
NIR	1.29	12.8

Accuracy of SkySats Relative to RadCalNet. Validation dataset collected from December 1, 2020 to December 1, 2021.

Block 3 Variable Crossing Times



Visually showing the effects of imaging at different times of day over stable RadCalNet calibration site Gobabeb. (The contrast stretch is the same for all images.)

SkySat RadCalNet Verification

Sun Elevation <40°

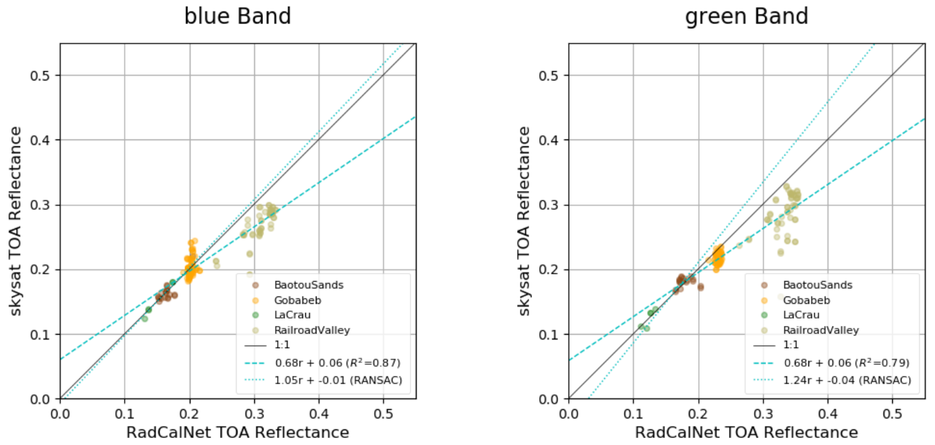
Band	Absolute Accuracy	Uncertainty (68 Percentile)
Blue	-4.79	10.56
Green	-8.04	12.48
Red	-3.95	12.24
NIR	-3.83	11.99

Sun Elevation >40°

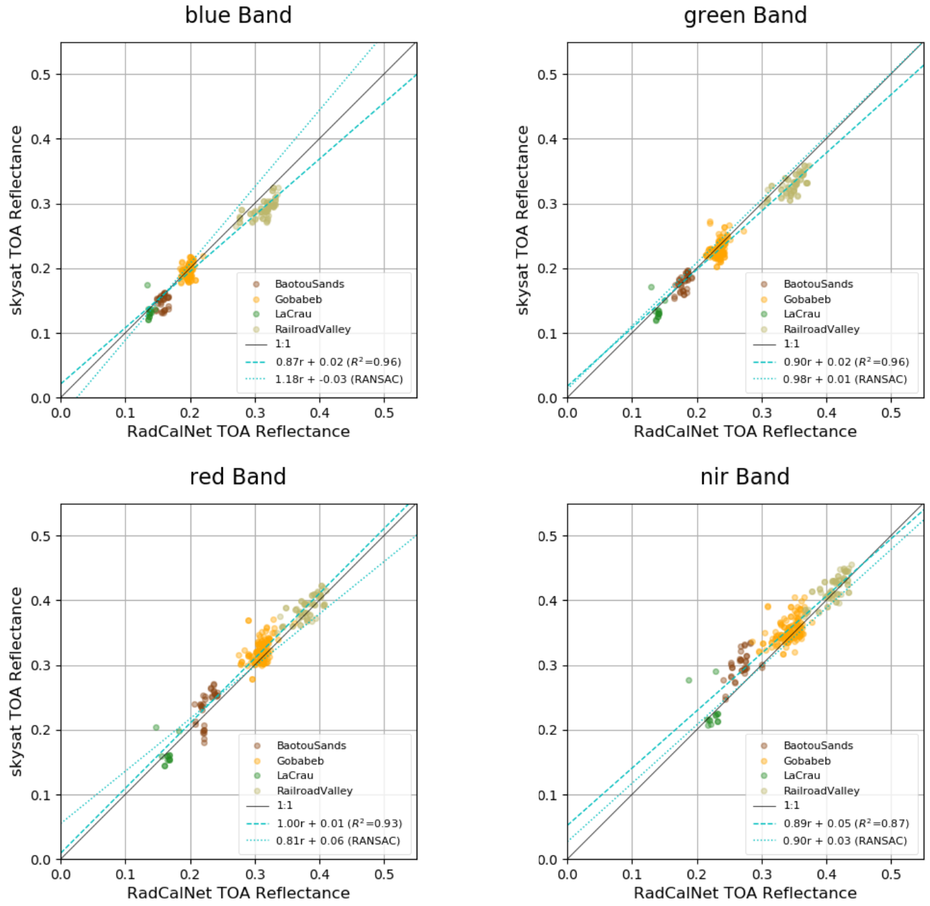
Band	Absolute Accuracy	Uncertainty (68 Percentile)
Blue	-3.01	6.49
Green	-2.57	6.13
Red	4.09	8.00
NIR	3.36	7.17

SkySat RadCalNet Verification

Sun Elevation <40°



Sun Elevation >40°



Independent Ground Based Validation

Annual SDSU Vicarious Calibration Campaign

“The difference on average between the TOA radiance measured by the Dove and Skysat constellation and ground based measurement propagated to TOA by MODTRAN over SDSU calibration site from 2022 site was 6.2% and 8%, respectively, across all spectral bands. On average, the uncertainty on vicarious calibration results for Dove and SkySat was 6.2% and 6.3%, respectively.”

Summary

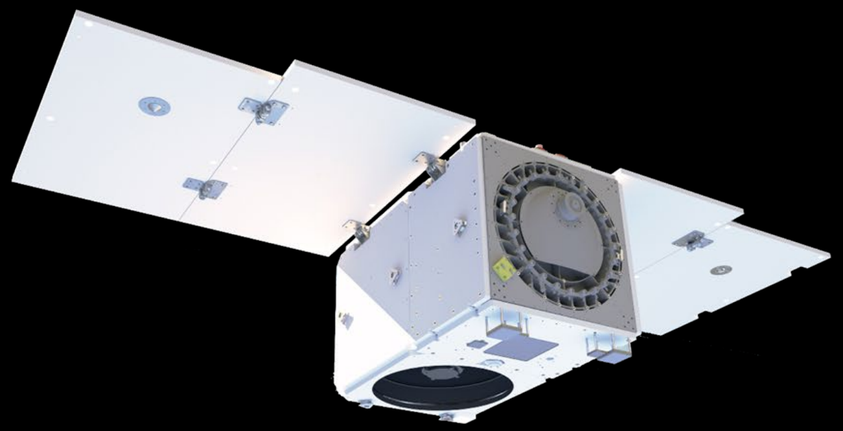
CAPE TOWN • South Africa • September 8, 2021

Summary

- Improved, automated methodology allows for more frequent flatfield updates
- New SkySat calibration methodology updated Spring 2022
- Quarterly data quality reports
- This process has been described in the white paper:
  - https://assets.planet.com/docs/radiometric_calibration_white_paper.pdf

High Revisit, High Res Data

Meet Pelican



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EXPANSIVE COVERAGE

UP TO

30

satellites[1]

GREATER PRECISION

30

cm resolution

MORE CAPTURES

UP TO

30

captures per day

HIGHER DAILY REVISITS

Approximately

30

minute revisit time

[1] Does not include initial 2 demonstration satellites planned for FY'24.

Thank You.

Norberto Hernández Castilla
Computer Vision Engineer, Imaging Ops
Norberto@planet.com

Colm Lynch
Senior Computer Vision Engineer, Imaging Ops,
colm@planet.com

Hannah Bourne
Engineering Manager, CalVal
hannah.bourne@planet.com

planet.