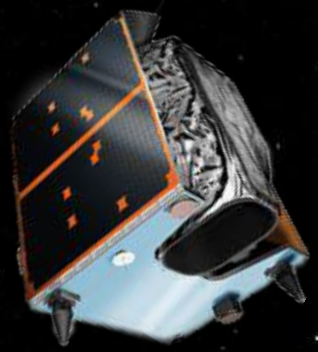
Absolute calibration and validation of Skysat constellation

Monte Fitz Roy, Patagonia – March 19, 2018

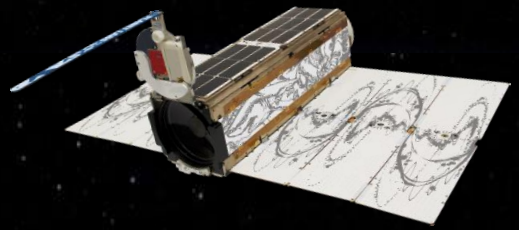
Adrian Gonzalez - CalVal team - Planet

VH Roda November 2019

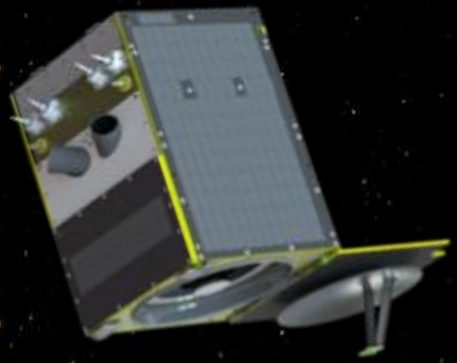
PLANET'S CONSTELLATION



5 RapidEye Satellites



130+ Dove Satellites PlanetScope



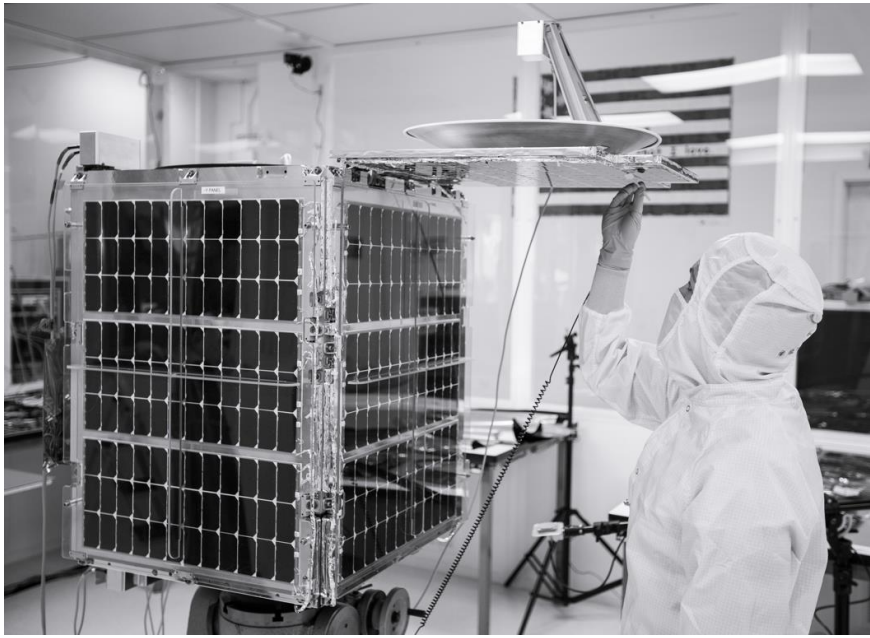
15 SkySat Satellites

OUR CONSTELLATIONS

Flock	**Dove-Classic (PS)**	**RapidEye**	**SkySat**	**Dove-R (PS)**
Sensor Type	Four-band frame imager with a split-frame NIR filter	Multispectral push-broom	Multispectral / Panchromatic push-frame	Four-stripe push-frame imager
Spectral Bands	Blue: 455 - 515 nm Green: 500 - 590 nm Red: 590 - 670 nm NIR: 780 - 860 nm	Blue: 440 - 510 nm Green: 520 - 590 nm Red: 630 - 685 nm Red Edge: 690-730 nm NIR: 760 - 850 nm	Blue: 450 - 515 nm Green: 515 - 595 nm Red: 605 - 695 nm NIR: 740 - 900 nm PAN: 450 - 900 nm	Blue: 490 nm Green: 565 nm Red: 665 nm NIR: 865 nm
Orbit	SSO	SSO	SSO	SSO
GSD	~3.0 m	~6.5 m	~1.0 m (~0.8 pan)	~3.0 m
Frame Size / Swath Width	~ 24.6 km x 16.4 km	77 km	~ 3.2 km x 1.4 km (single camera)	~ 26 km
Crossing Time	9:30 - 11:30 am	11:00 am	10:30 - 13:00	9:30 - 11:30

SkySats at a Glance

- SkyBox Founded in 2009 by 4 Stanford grad students
- Raised $110M over 3 financing rounds from local VC’s
- Google Acquisition July 2014
- Planet Acquisition May 2017
- 15 satellites launched, all collecting imagery daily, operating 24x7 from San Francisco and Berlin

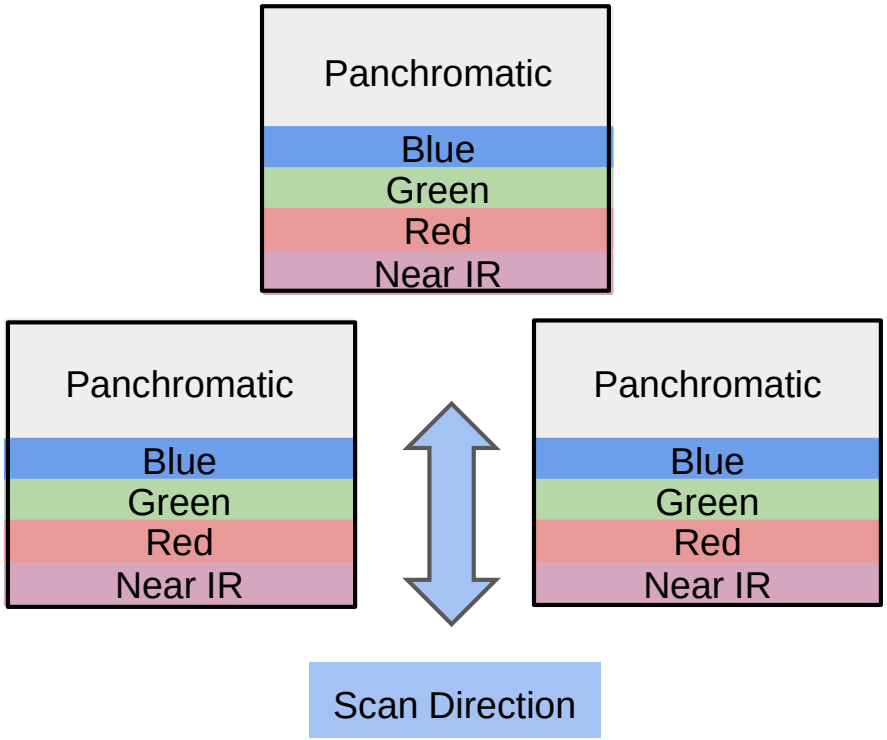


**SkySat-C Class*

Pushframe Imaging

Pushframe Architecture

- Collect short exposure (400 - 19000 us) overlapping images
- Use image registration & reconstruction to generate final full color imagery
- Improve both SNR and ground sample distance (GSD) with super-resolution (pseudo tdi)
- Compress and transmit to the ground
  - JPEG 2000 compression on board (potentially lossless)



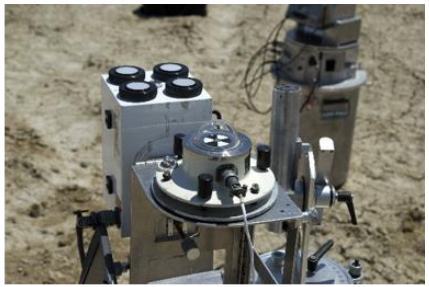
SS-C3 First Light - Rome, Italy on September 23, 2016

Vicarious Calibration

SkySat doesn’t have onboard equipment to support calibration activities.

Uses ground measurements on homogeneous sites while a satellites flies over the site and captures an image.

Atmospheric and ground properties are measured to simulate the at sensor radiance on site.



RadCalNet

- RadCalNet is a network of four robotic reference stations
- https://www.radcalnet.org
- Freely available measurements on 4 homogeneous sites
- Measurements every 30 minutes between 9:00 and 15:00 (local)
- Spectral coverage between 400 and 2500nm
    - (Baoutou 400 - 1000nm)

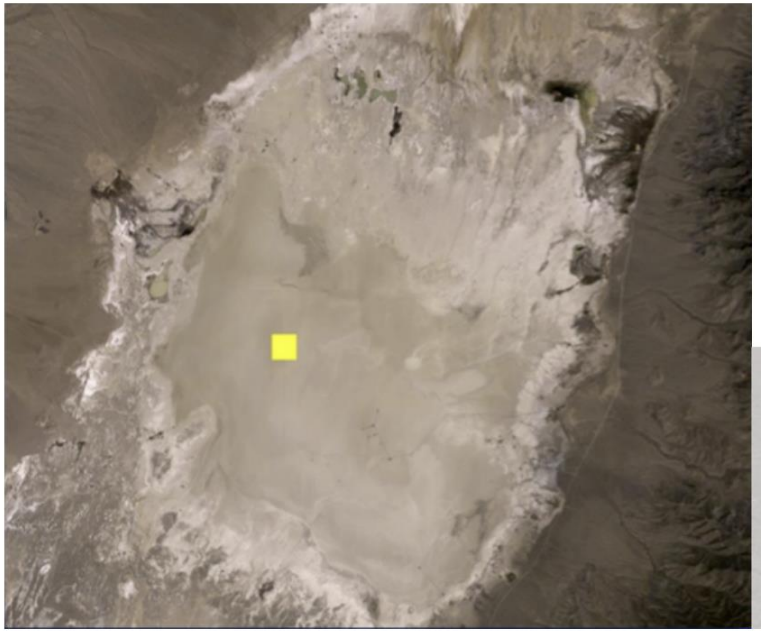
RadCalNet Sites

Railroad Valley

Homogeneous salt flat site

Size 1 km x 1 km

Long heritage for vicarious calibration purposes

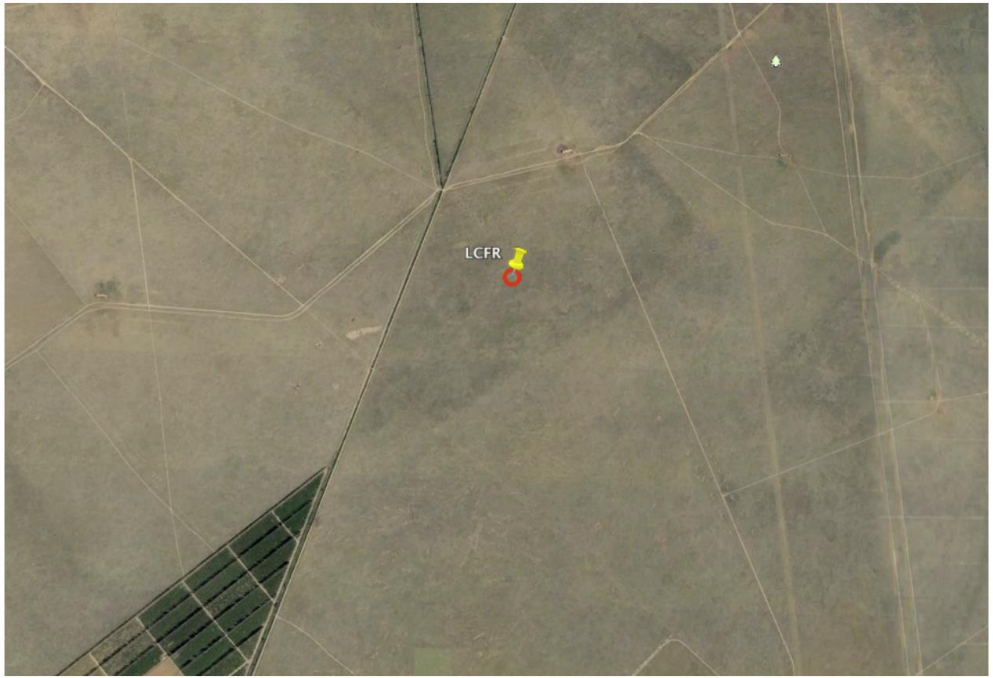


RadCalNet Sites

La Crau

Homogeneous dry grassland site in southern France

Spectra represent a disk of 30 m diameter



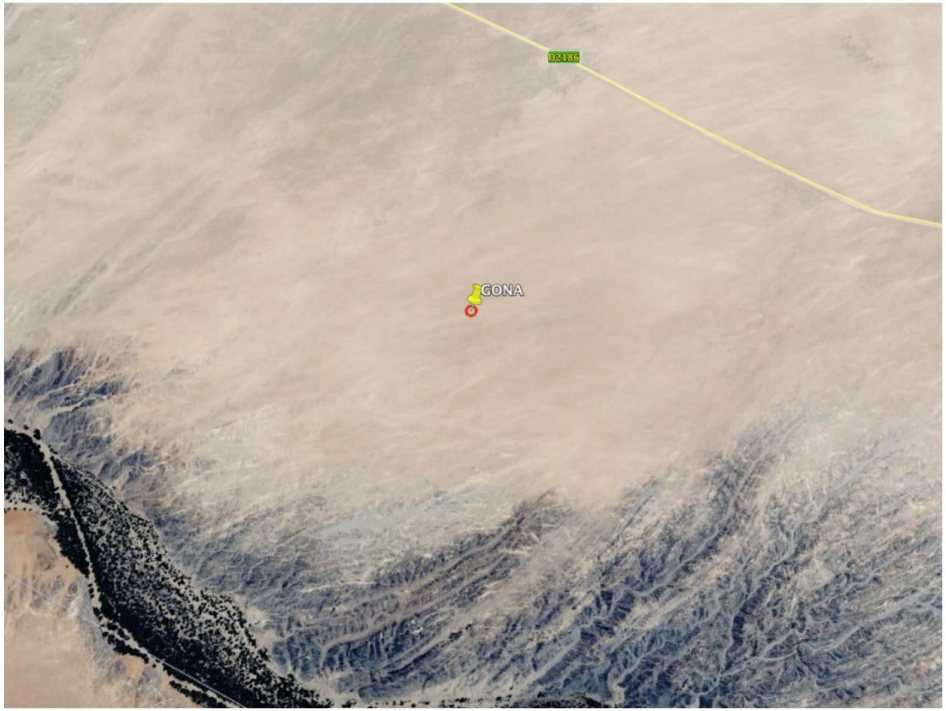
RadCalNet Sites

Gobabeb

Homogeneous desert site in Namibia

Data since 2017

Spectra represent a disk of 30 m diameter



RadCalNet Sites

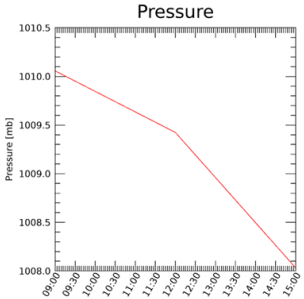
Baotou

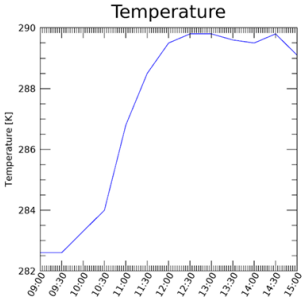
Artificial gravel target in China

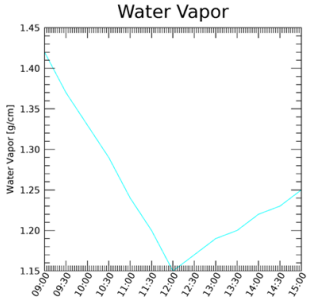
Chessboard pattern with three different Shades (2 * white, grey and black)

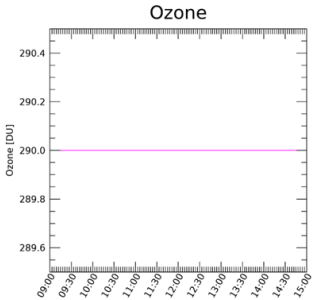
Radcalnet spectra represent the grey area

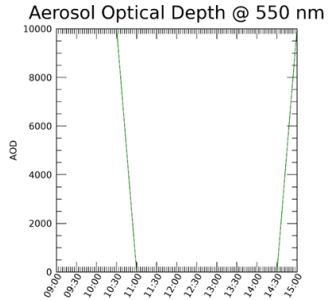
Atmospheric Information

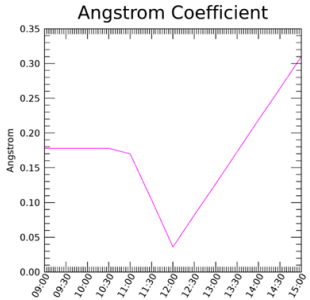








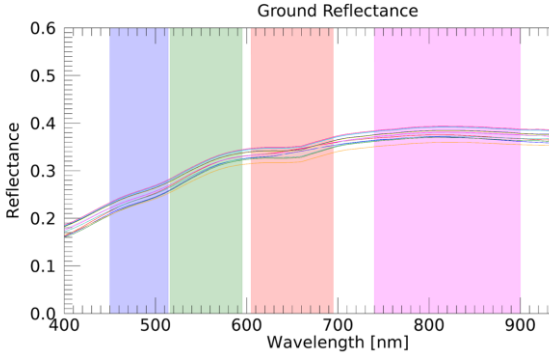




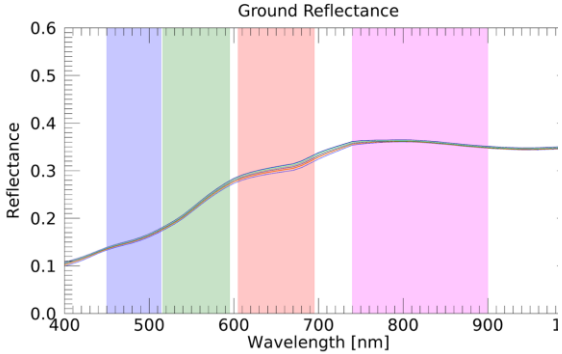
- Air pressure [mb]
- Temperature [K]
- Water Vapor [g/cm^3]
- Ozone [DU]
- Aerosol Optical Depth @550 nm
- Angstrom coefficient

In 30 minute intervals between 9:00 am and 3 pm
(13 measurements daily)

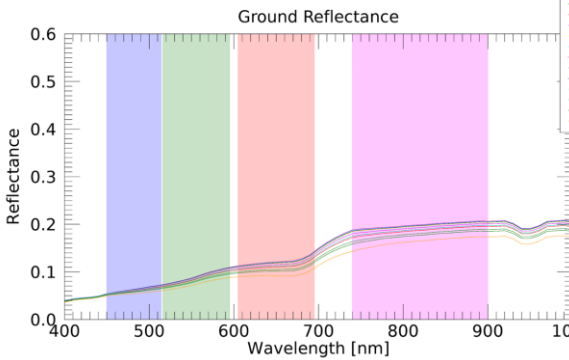
Ground Reflectance



Railroad



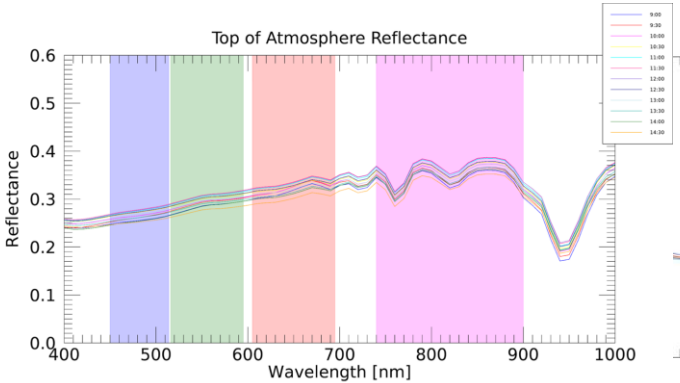
Gobabeb



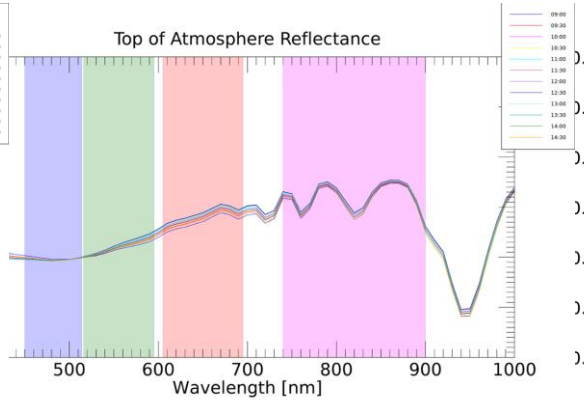
La Crau

Surface Reflectance together with atmospheric information is used in MODTRAN 5 to model top of atmosphere reflectance using a standardized RADCALNET procedure

Top of Atmosphere Reflectance



Railroad Valley



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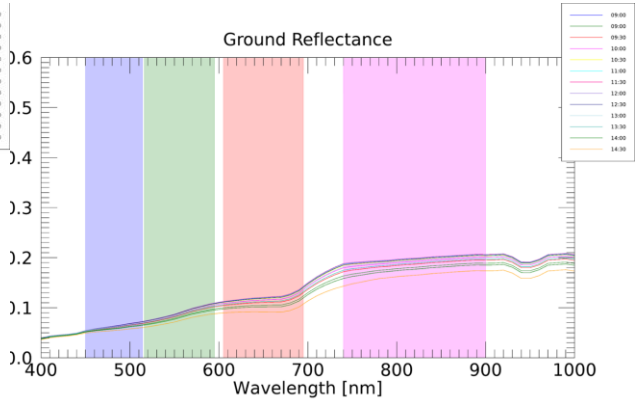
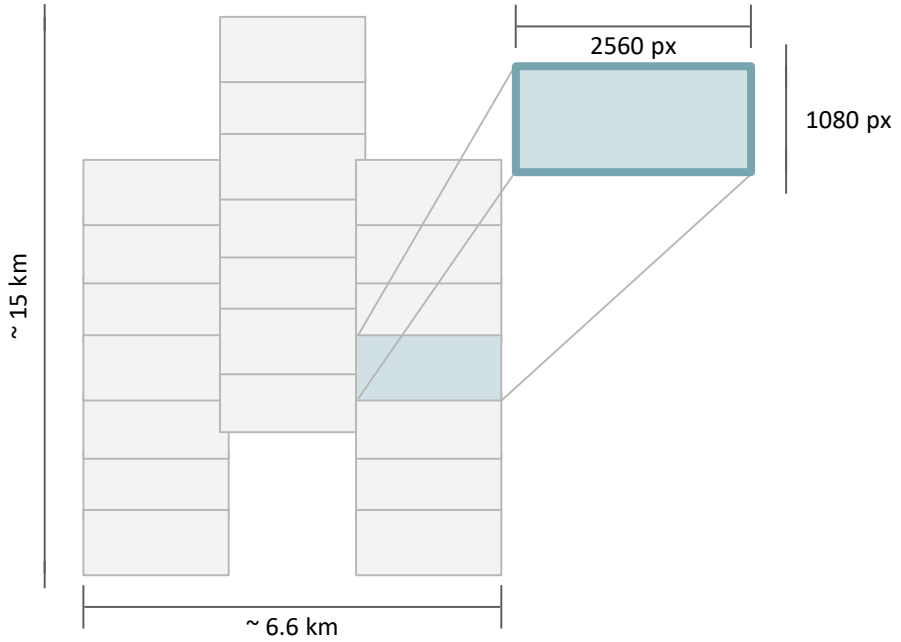


La Crau

Three different brightness levels allow line fits between Satellite and Ground Data
This dataset is used for absolute vicarious calibration!!!

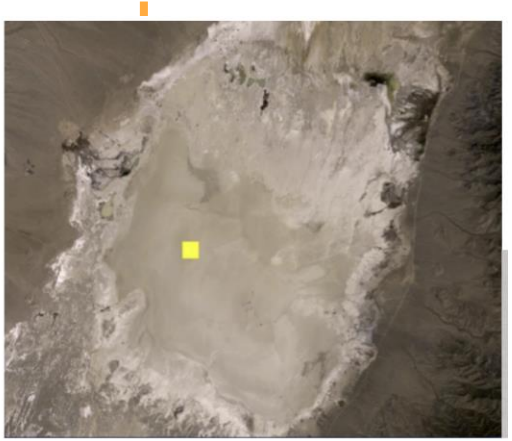
SkySat Cameras

Camera Attributes	
Attribute	**Value**
Image Configurations	Multispectral Sensor (Blue, Green, Red, NIR)
	Panchromatic Sensor
Sensor Type	CMOS Frame Camera with Panchromatic and Multispectral halves
Spectral Bands	Blue: 450 - 515 nm Green: 515 - 595 nm Red: 605 - 695 nm NIR: 740 - 900 nm Pan: 450 - 900 nm
Product Framing	SkySat Satellites have three cameras per satellite, which capture overlapping strips. Each of these strips contain overlapping scenes. One scene is approximately 2560 x 1080 pixels. (see right graphic)

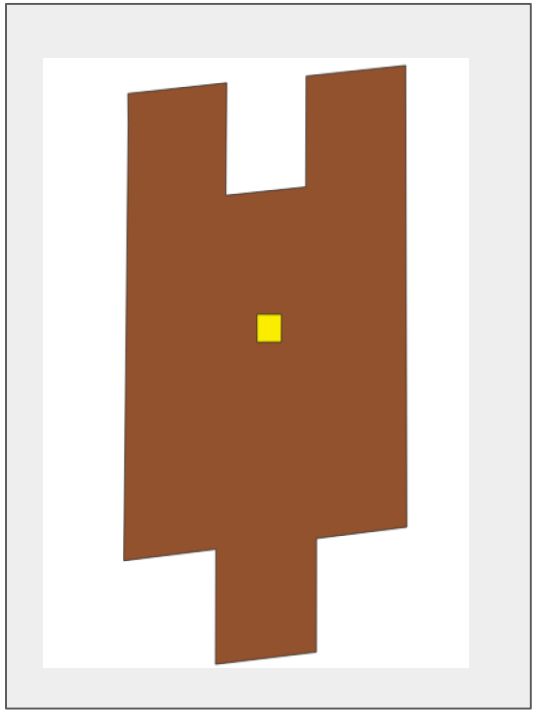


*Individual **scenes** above*

Tasking Railroad valley



Site and location



Tasking

Acquired collect

Planet Procedure for SkySat

All RadCalNet info is stored in the cloud

Code developed to:

- search the archive for crossover collects (within 15 minutes of RadCalNet datapoint)
- Orthorectify frames
- Subset frames to the actual subset of the RadCalNet data
- Report creation for each individual crossover for all sites

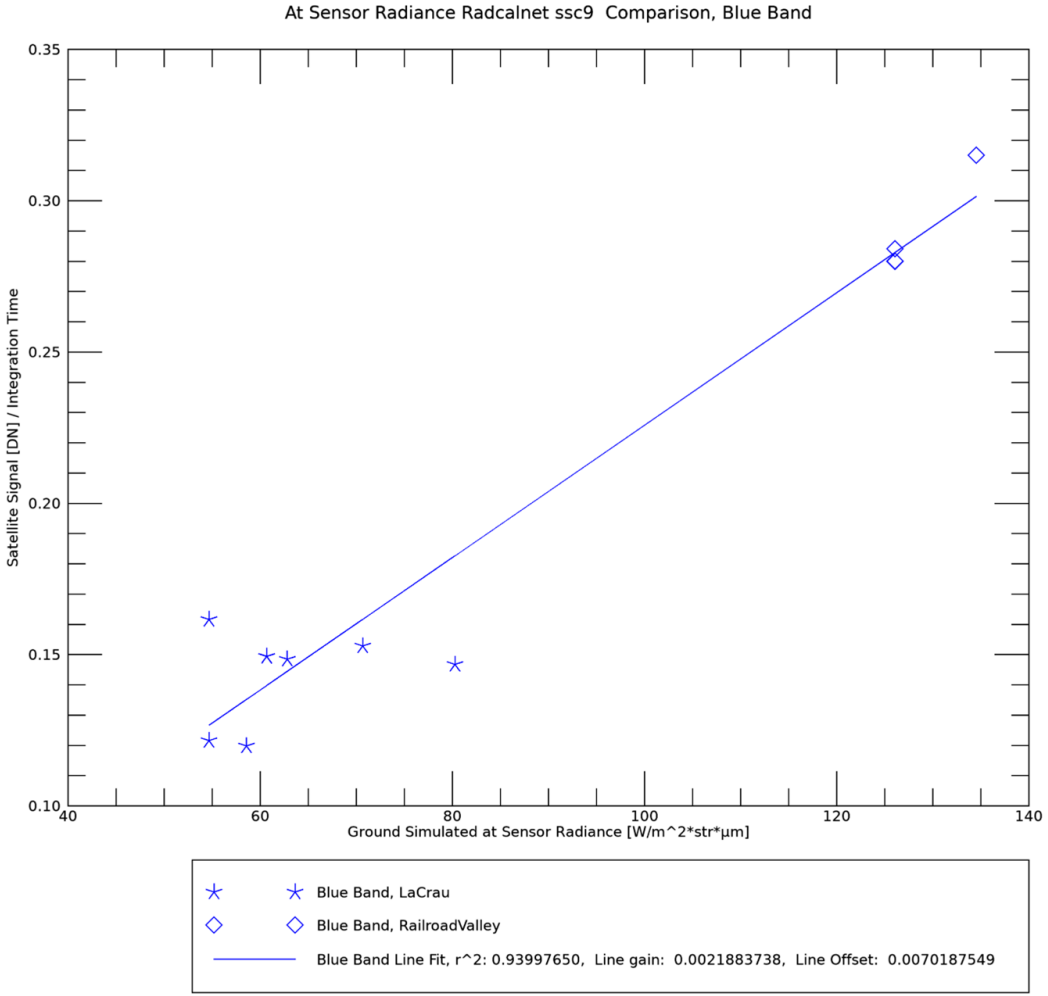
Planet Procedure

Code developed to analyze the results

- Previous retrieved report as input
- Plots per Sat/Band, fits between image DN (corrected by integration time) and reference
- Detects outliers
- Visualizes other analytics like error/look angle dependency, time trends, …
- Calculates gains and offsets to transfer DN into Radiance
- Creates per file and sat/band reports

Results

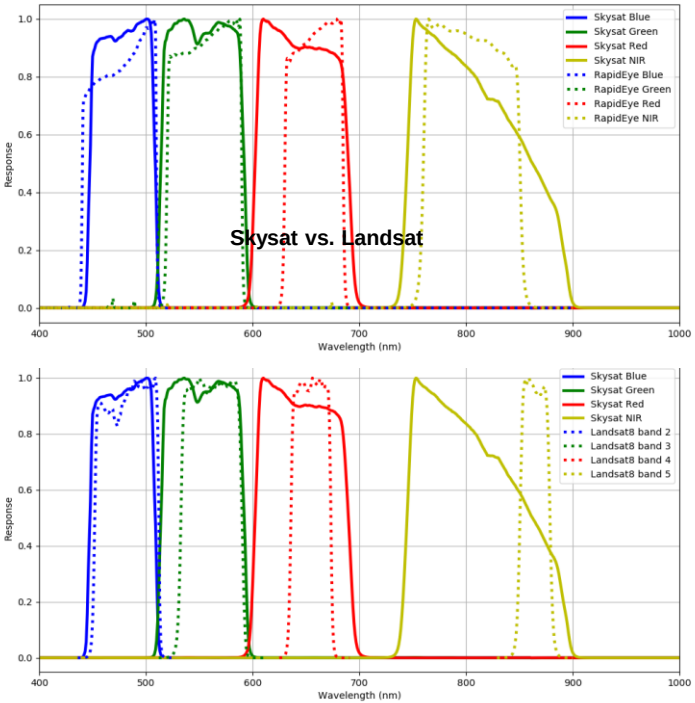
- Fitted calibration lines for each spacecraft and band,
- Including r^2 and line fit coefficients
- Ideally these plots contain points from all three radcalnet sites
- Recurrent procedure, each time more radcalnet reference points are used



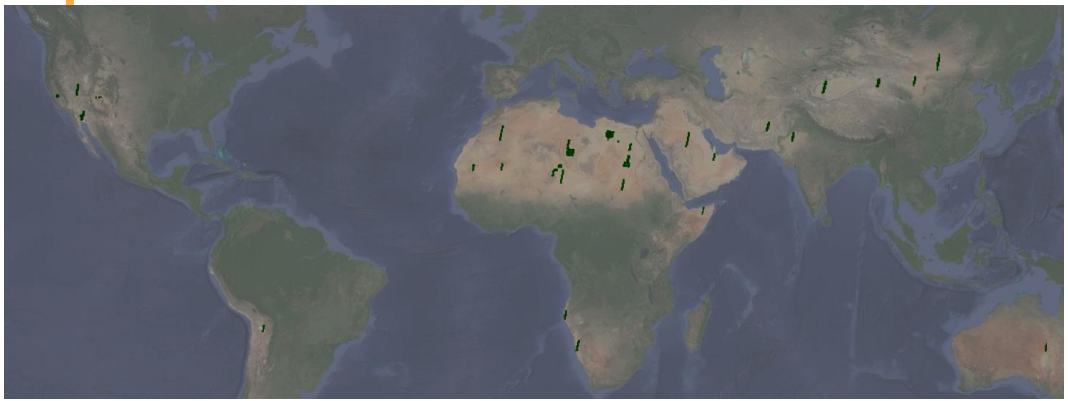

planet.
Validation of Skysat constellation
Monte Fitz Roy, Patagonia – March 19, 2018

Crossovers with RapidEye and Landsat

- **Crossover must occur within a characterized calibration site.**
- **Maximum time delta of 2 hours between crossover images.**
- **Maximum 20 degree view angle of any satellite.**
- **Maximum of 20% of pixels saturated in any one band for any image.**
- **Maximum of 20% clouds in for any image.**
- **All saturated and cloud pixels must be masked.**

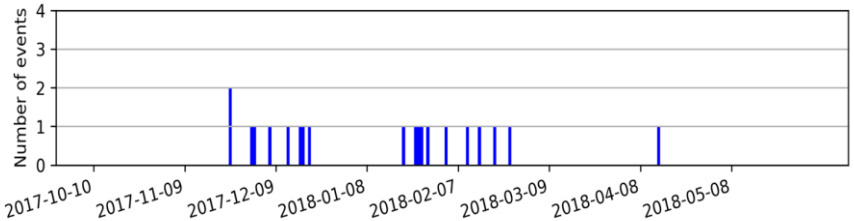


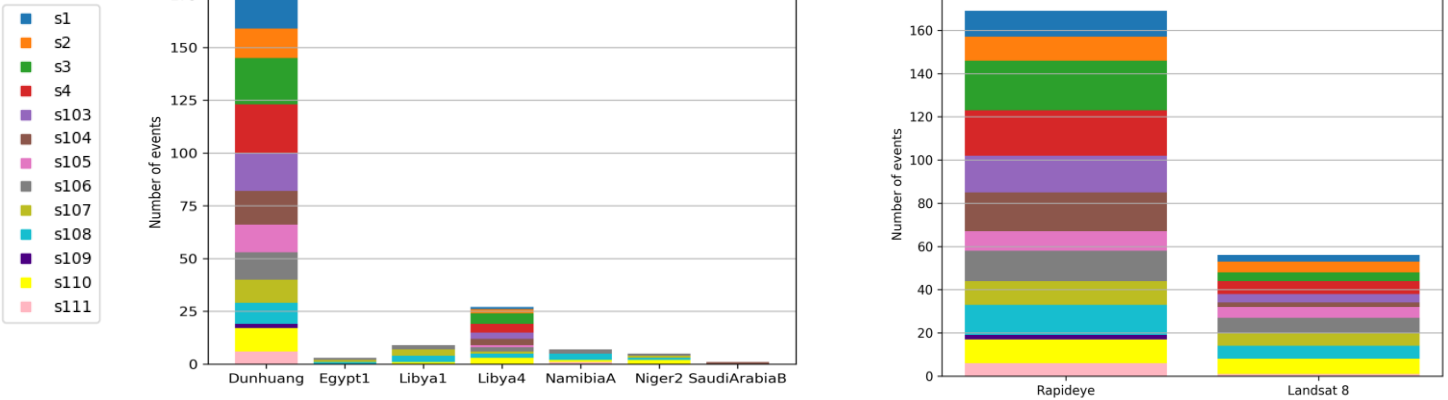
Calibration sites for Crossovers



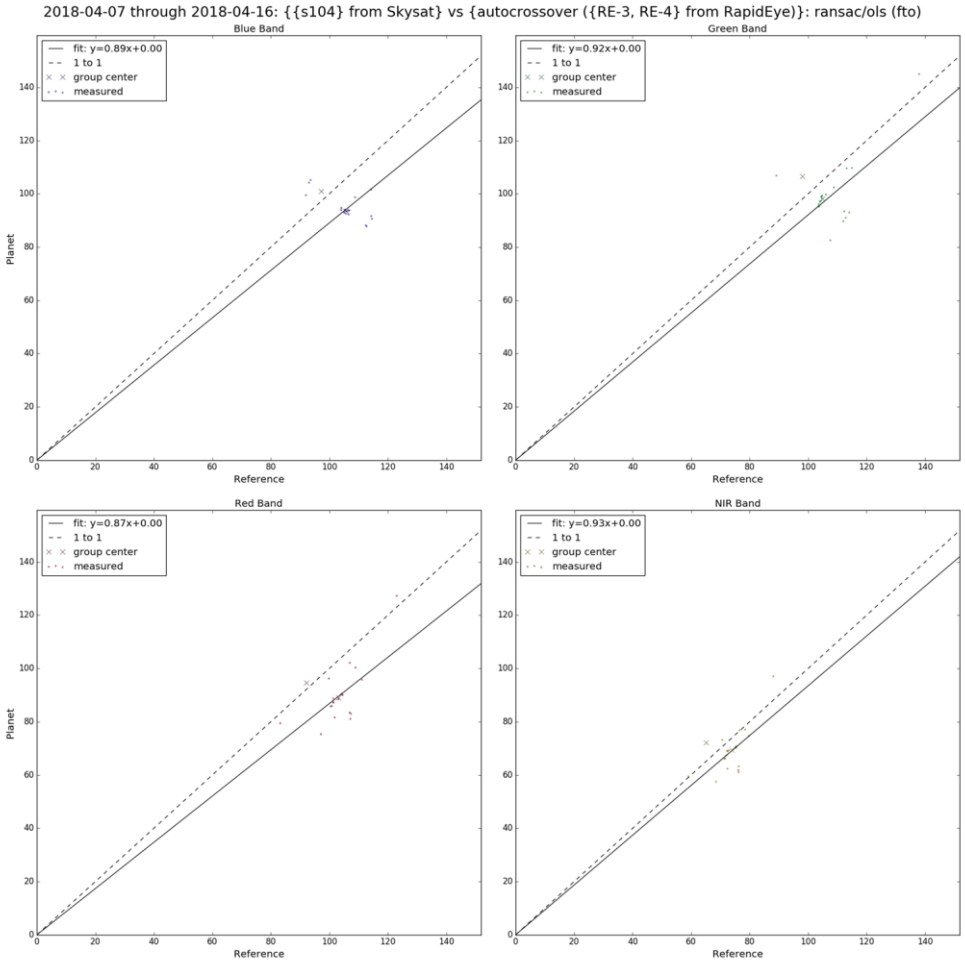
Name	Lat, Lon	Description
Dunhuang	40 / 94	Desert (Gobi), flat, dry, overall homogeneous, no vegetation. Possibly affected by atmospheric aerosol due to sandstorms and dust.
Egypt 1	27/ 26	Desert, flat, dry, large, patchy across larger areas.
Libya4	29 / 23	Desert (Sahara), flat, dry, large, dunes at multiple scales, but overall homogeneous, no vegetation.
Libya1	25 / 13	Desert (Sahara), flat, dry, large, dunes at multiple scales, but overall homogeneous, no vegetation.
Niger 2	21 / 11	Desert (Sahara), flat, dry, large, dunes at multiple scales, but overall homogeneous, no vegetation.
Namibia	-16 / 12	Desert, flat, dry, large, somewhat homogeneous, no vegetation.
Saudi Arabia	29 / 45	Desert, flat, dry, dune patterns at several scales, but homogeneous when averaged over larger areas, no vegetation.

Crossover criteria and example

Skysat-C8	



Crossovers results



SkySat	S104	
Band	Gradient of fit	Uncertainty (%)
Blue	0.89	10.13
Green	0.92	9.74
Red	0.87	7.17
NIR	0.93	7.60

Conclusions

- **Developed and defined clear method to calibrate and validate Skysat constellation**
- **All SkySat satellites and bands are calibrated to an uncertainty of 10% or better**
- **Add the Brookings cal site once 2019 data becomes available**
- **Combine this method with Cross Validation to RapidEye, Landsat8 and Sentinel2**
- **Periodically enhance samples size with new RadCalNet data**

London Array Wind Farm, United Kingdom – April 17, 2016

Thanks for your attention!

Questions?

Offline questions:
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London Array Wind Farm, United Kingdom – April 17, 2016