Planet Calibration and Interoperability

+The Planet Team, Planet Labs, Inc.

Otago, New Zealand – July 31, 2019

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Current products

+The Planet Team, Planet Labs, Inc.

Otago, New Zealand – July 31, 2019

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interoperability *is* usability

LANDSAT-8
Sentinel-2
MODIS
Sentinel-3
VIIRS
AVHRR

Hyperion
EnMAP
SkySat
WorldView
TerraSAR-X
Sentinel-1

Super Doves

calibration
interpolation
superresolution
georeferencing
tasking

harmonized stacks that are more than the sum of the parts

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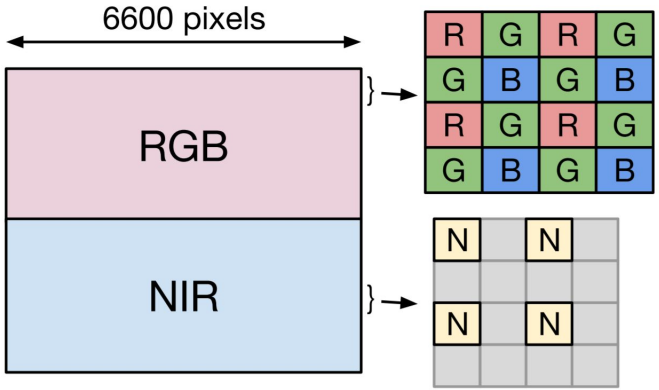
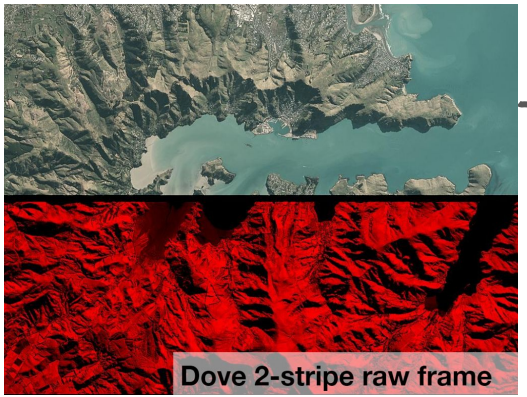
ARD strategy processing levels

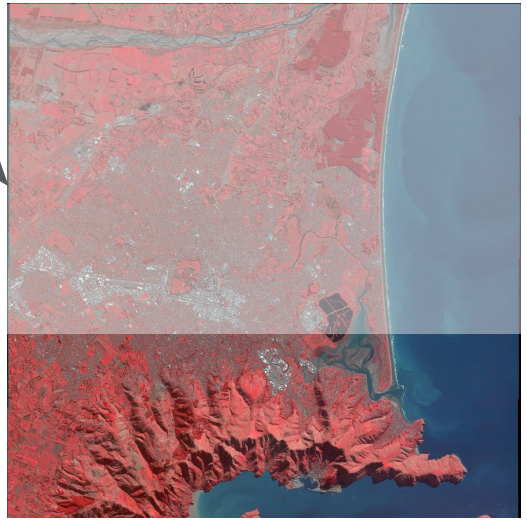
Level	motto	Dove	SkySat	RE	Sentinel-2	MODIS	Landsat-8	HLS	latency	geometry	radiometry	delivery
L0	raw	raw frames		N/A					3 hour	G0	R0	internal, R&D
L1a	raw video frames	radiometrically-corrected at-sensor radiance										
L1b NRT	ortho ready	L1b, registered, rectified sensor-space, geolocated, TOAR		as provided NRT L1 TOAR products					6 hours	G1	R1	**catalog**, orders API
L2v XYZ	visual	CIE XYZ color-space, 8- or 16-bit, with color profiles, TOAR-based, web-mercator or UTM-projected								G2	R3	orders API
L2b ARD	SR+GRI*	6SV-corrected via MODIS/VIIRS, UTM projected, with RSRs and SBAF matrices							12 hours		R2	**catalog**, orders API
L3h HLS	timeseries	harmonized to HLS/sen2like, gap-filled, cloud-masked, CESTEM-based, polygon-based, streamable										orders API
L3c CRD	streaming	8-bit curved TOAR, chips, image pyramid flat catalog, 3D geometry descriptors							6 hours			orders API
L3d LAS	3D mesh	TBD 3D mesh from single capture 7.5km x 7.5km							1 day	G3	R5	orders API

Dove Classic sensor layout





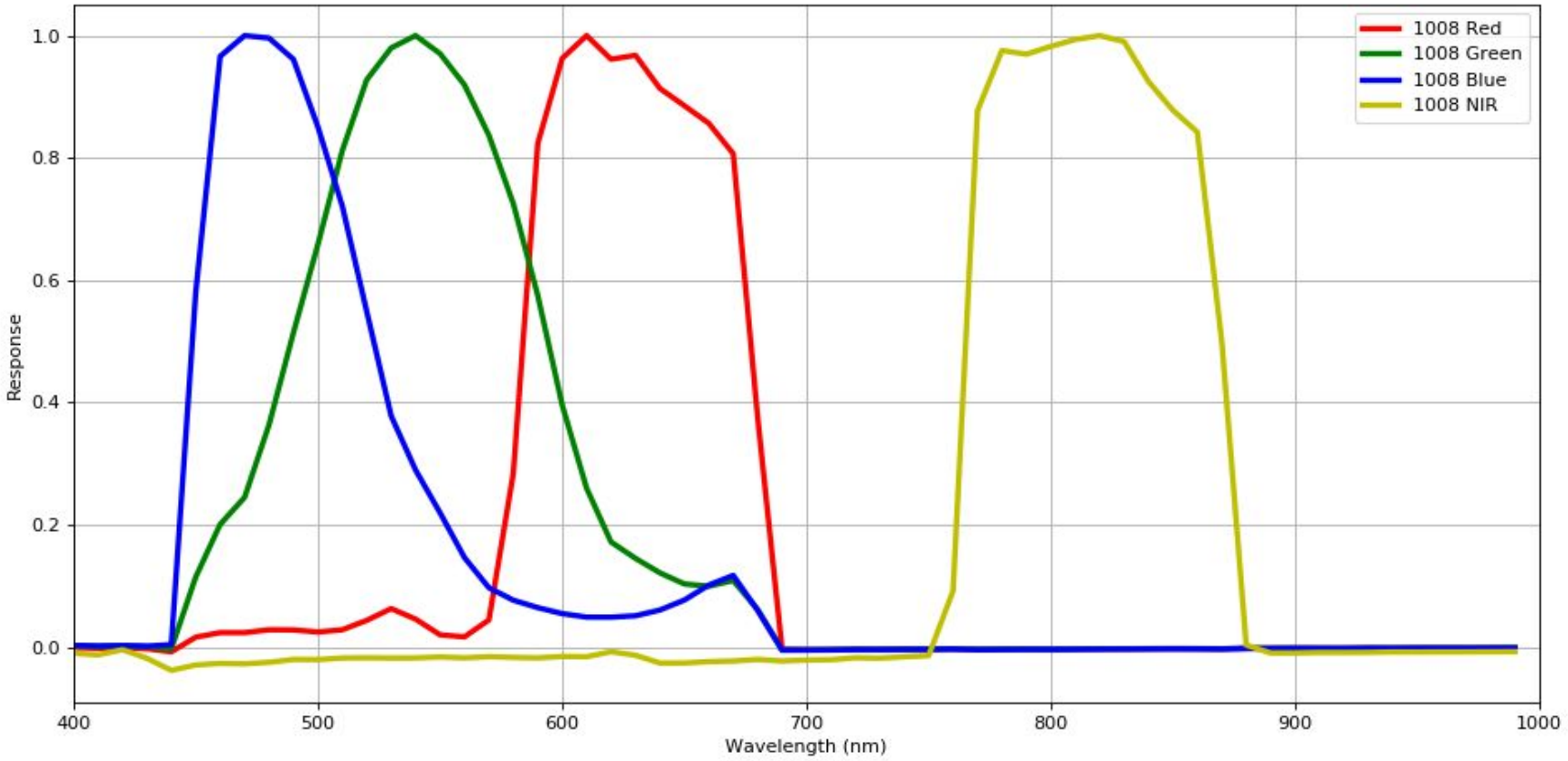
orthorectification



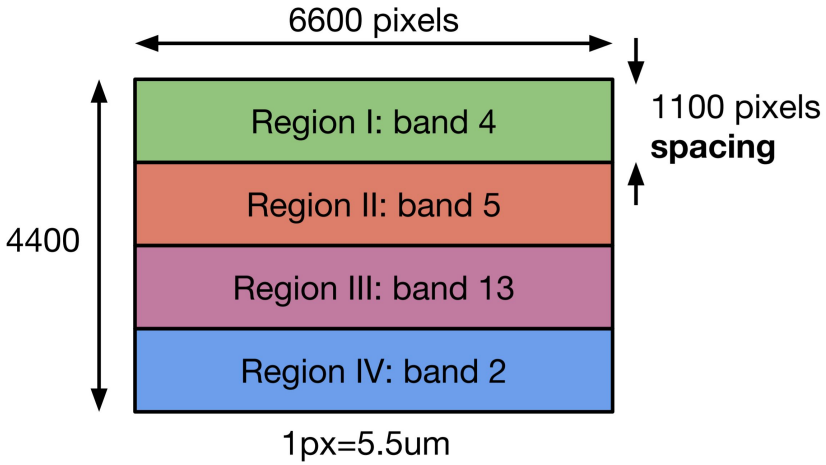
2-stripe half-frame composite

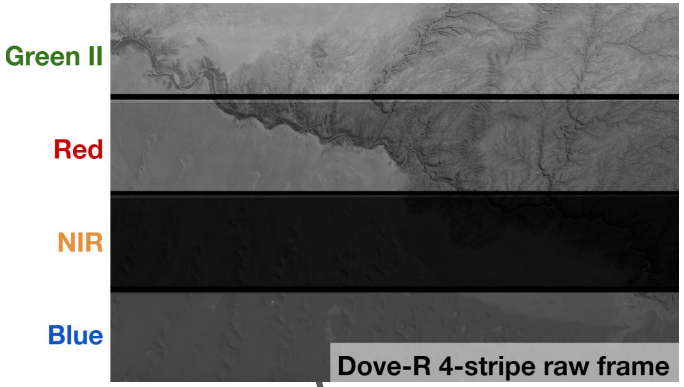
- This is the layout of the two-stripe Dove
  - The top stripe contains the red, blue and green bands in a Bayer pattern
  - The bottom stripe contains the NIR band
  - The orthorectification process allows a four band composite image to be produced

Typical Dove Classic RSR (measured at 10nm resolution)

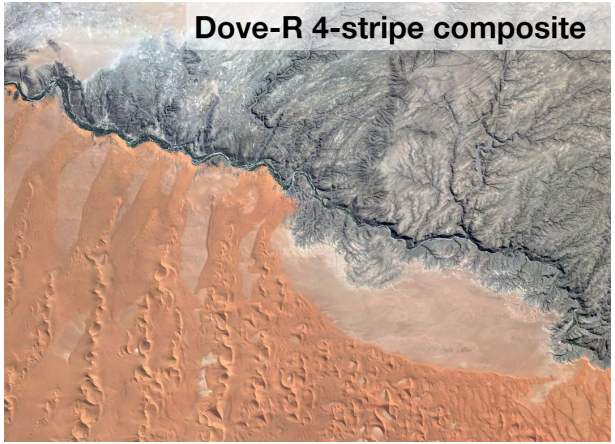


Dove-R sensor layout



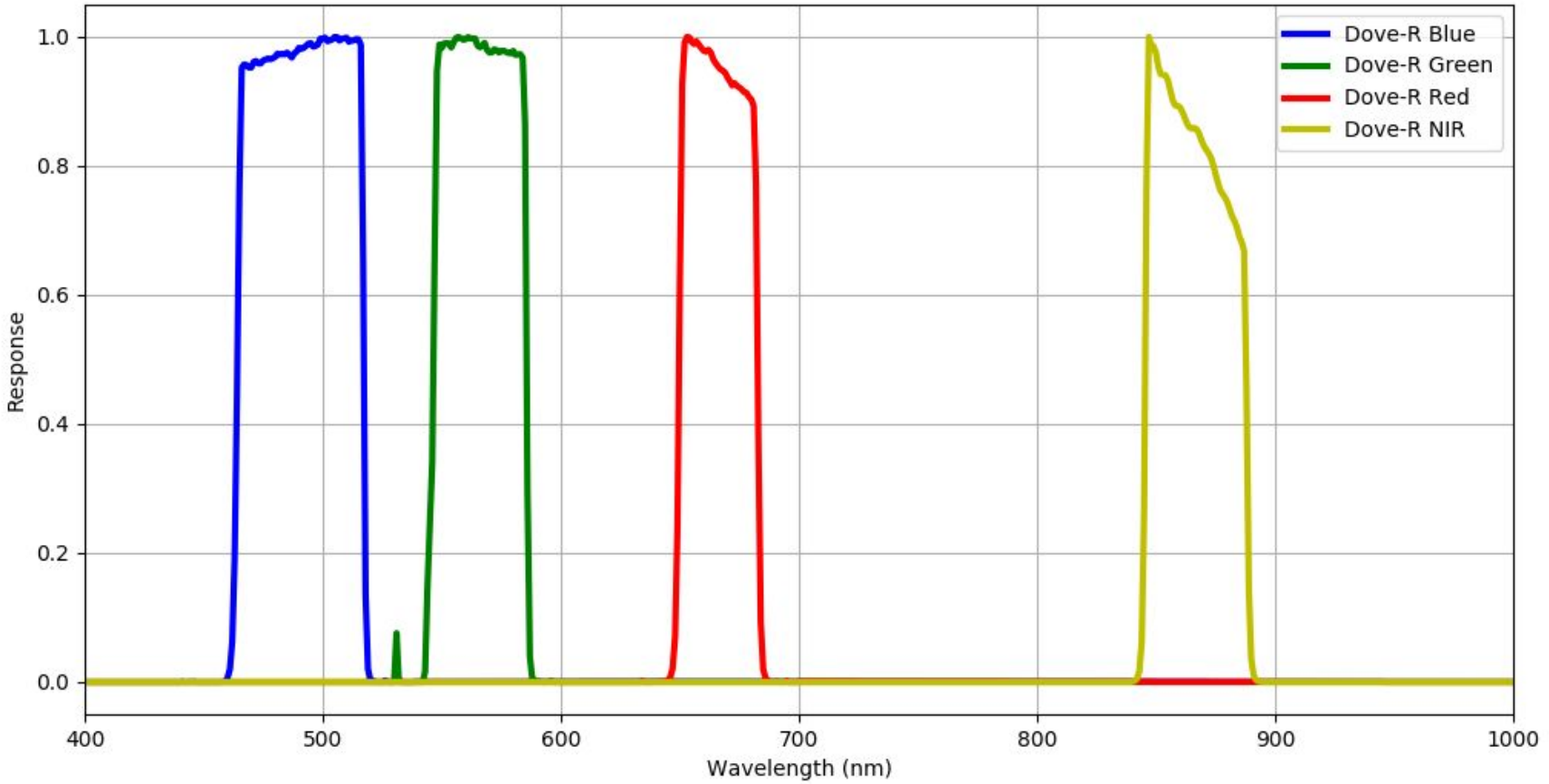


Structure from Motion pipeline

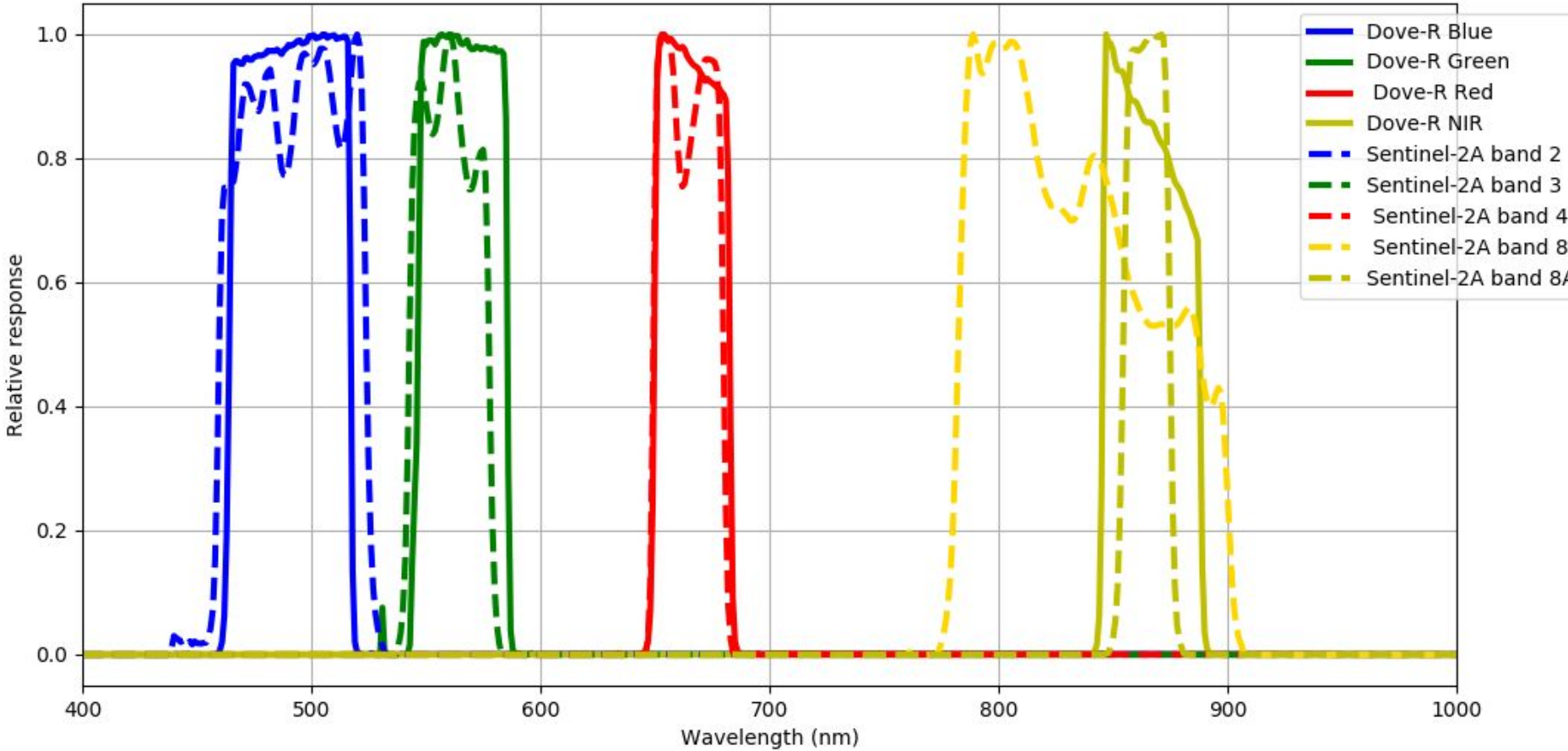


- This is the layout of a Dove-R
  - The four bands are arranged vertically across the sensor
  - Multiple images are taken in rapid succession so that the same point on the Earth is imaged by all the filters as the satellite orbits
  - Subsequent frames are composited together in a structure from motion pipeline to create a four band composite image

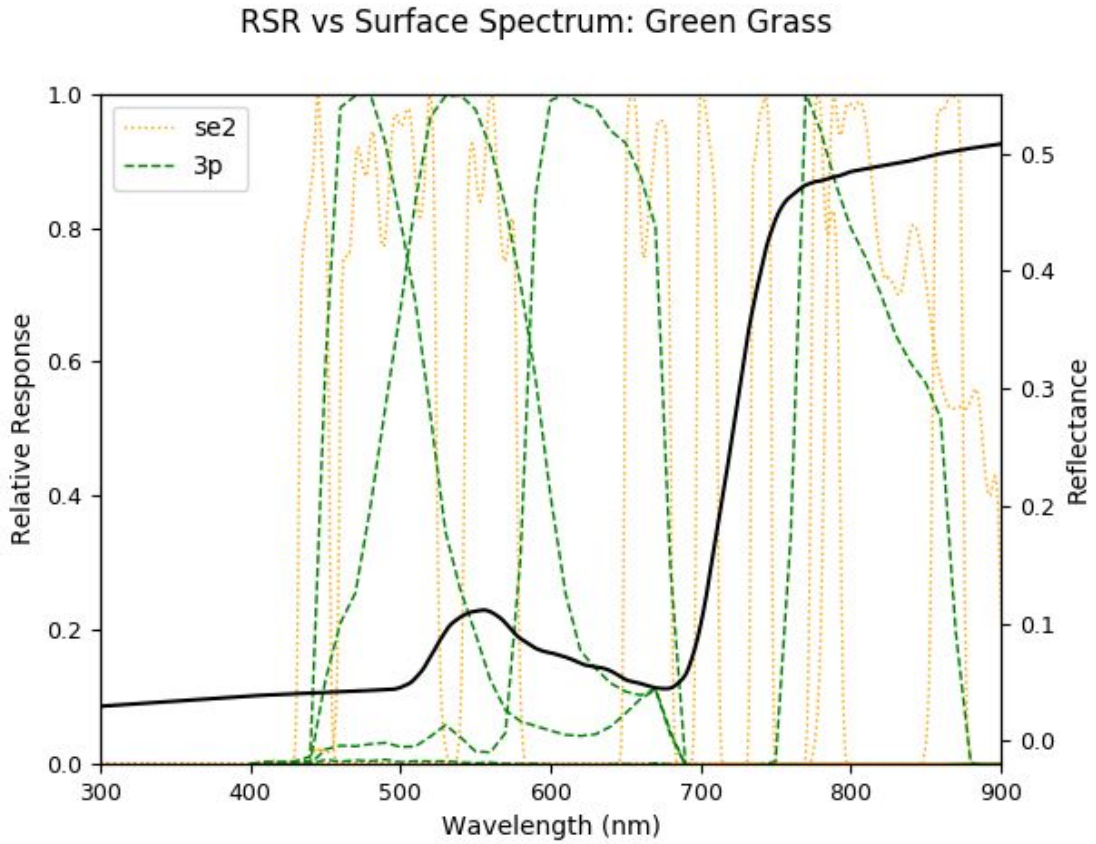
Typical Dove-R RSR (from manufacturer data)



RSR compared to Sentinel-2A



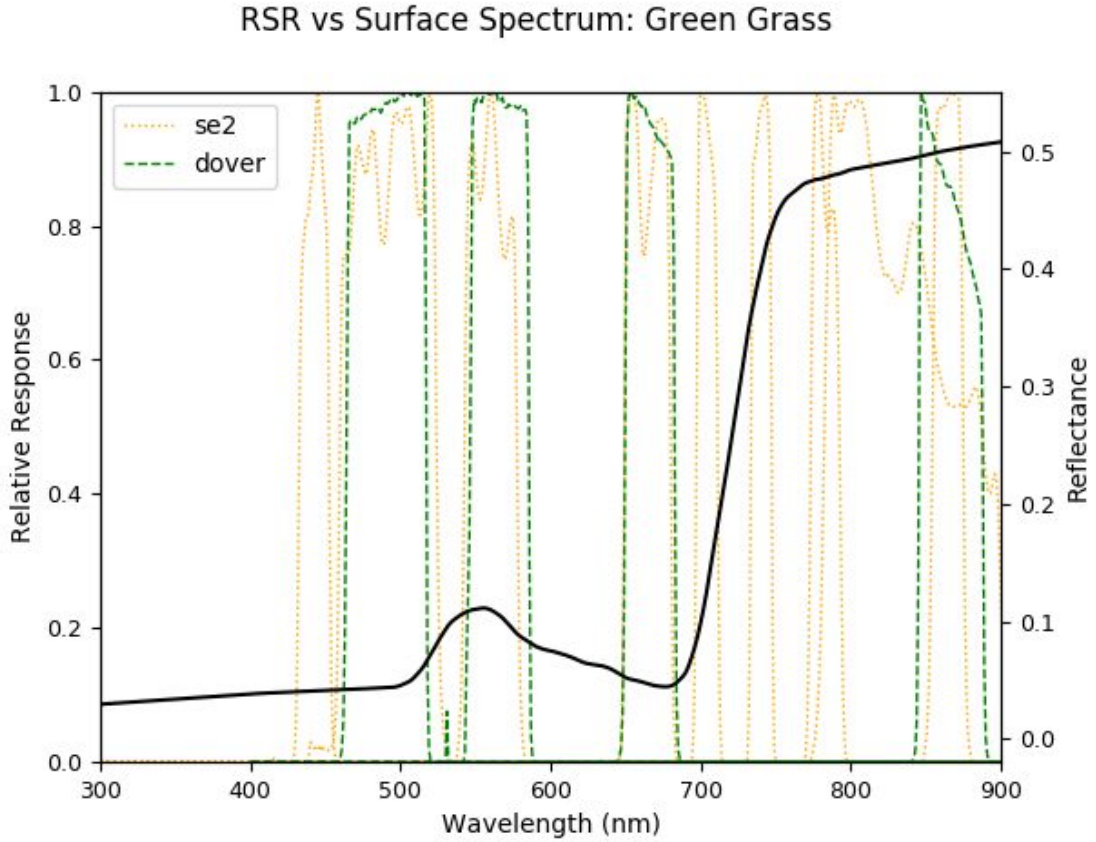
Effects of Differing Responses: **Dove Classic**



SBAF Corrections *Dove Classic → Sentinel-2*	
Blue	0.942
Green	1.368
Red	0.768
NIR	1.036

Calculating the spectral band adjustment factors between Sentinel-2 and Dove Classic

Effects of Differing Responses: **Dove-R**



SBAF Corrections *Dove-R → Sentinel-2*	
Blue	1.031
Green	1.042
Red	0.970
NIR	1.000

Calculating the spectral band adjustment factors between Sentinel-2 and Dove-R

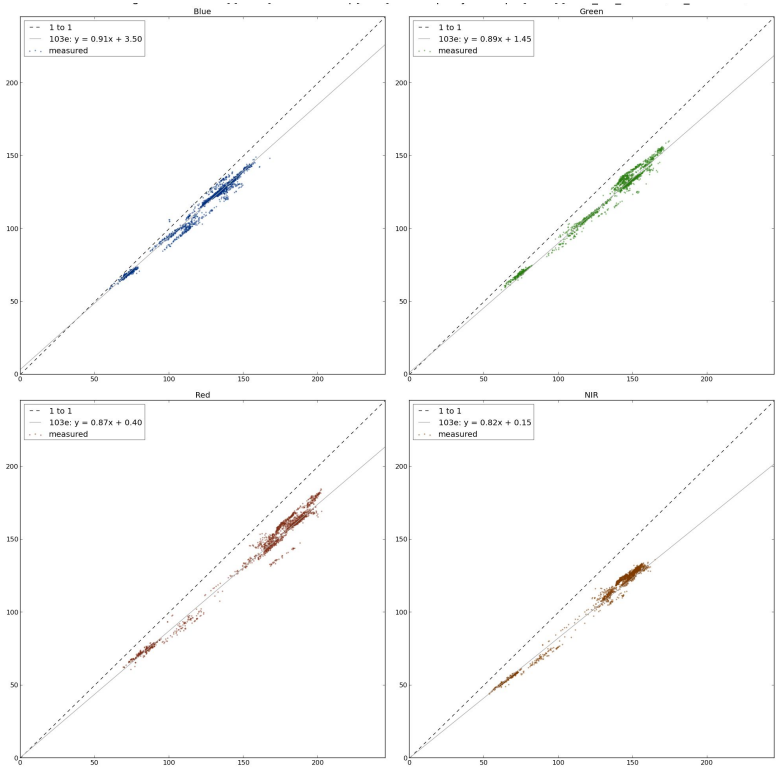
Current calibration process

Iguazú National Park, Brazil – September 23, 2016

Calibration Approach

Cross Calibrating Doves to RapidEye

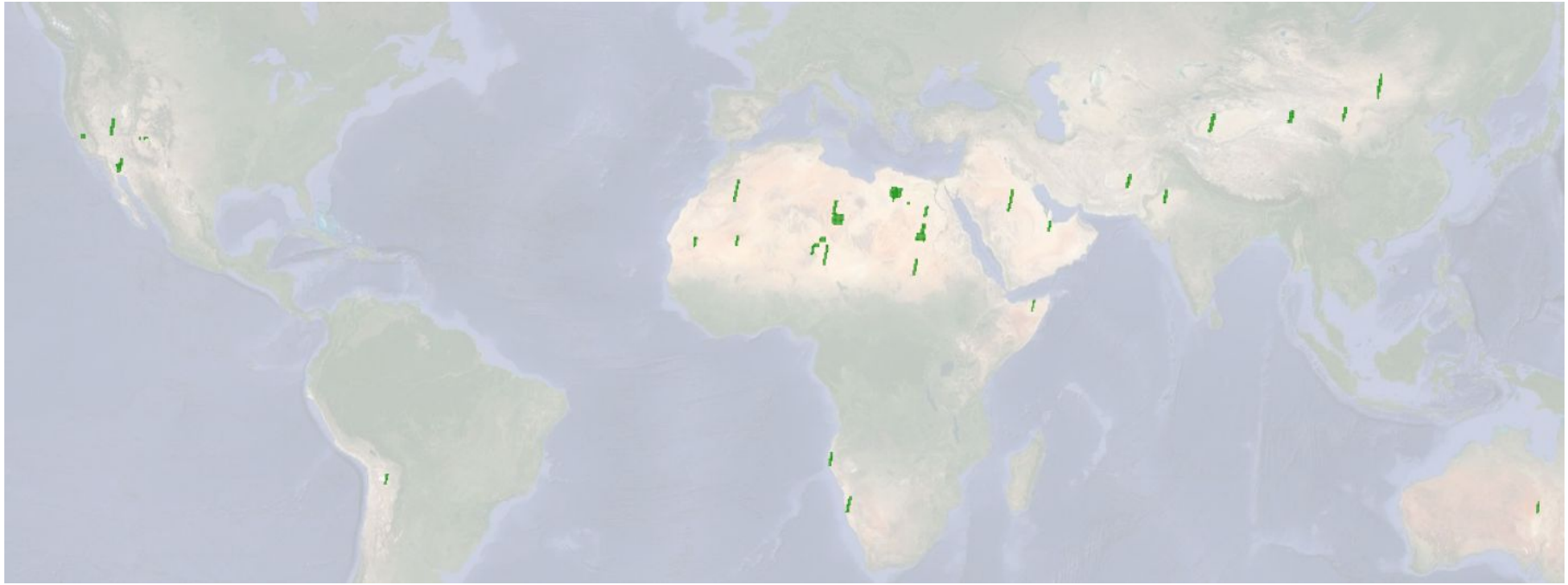
- Instantaneous crossovers sampled, corrected, and stored.
  - Crossovers sourced from RapidEye (RE) and Dove to Dove Crossovers if RE data lacking
- Crossovers cover the brightness range from 50 to 150 watts/m-2 sr-1 um-1
- Average of 5 crossover events and 500 samples used per-satellite/band to update calibration



Calibration Sites

Globally distributed network of desert calibration sites

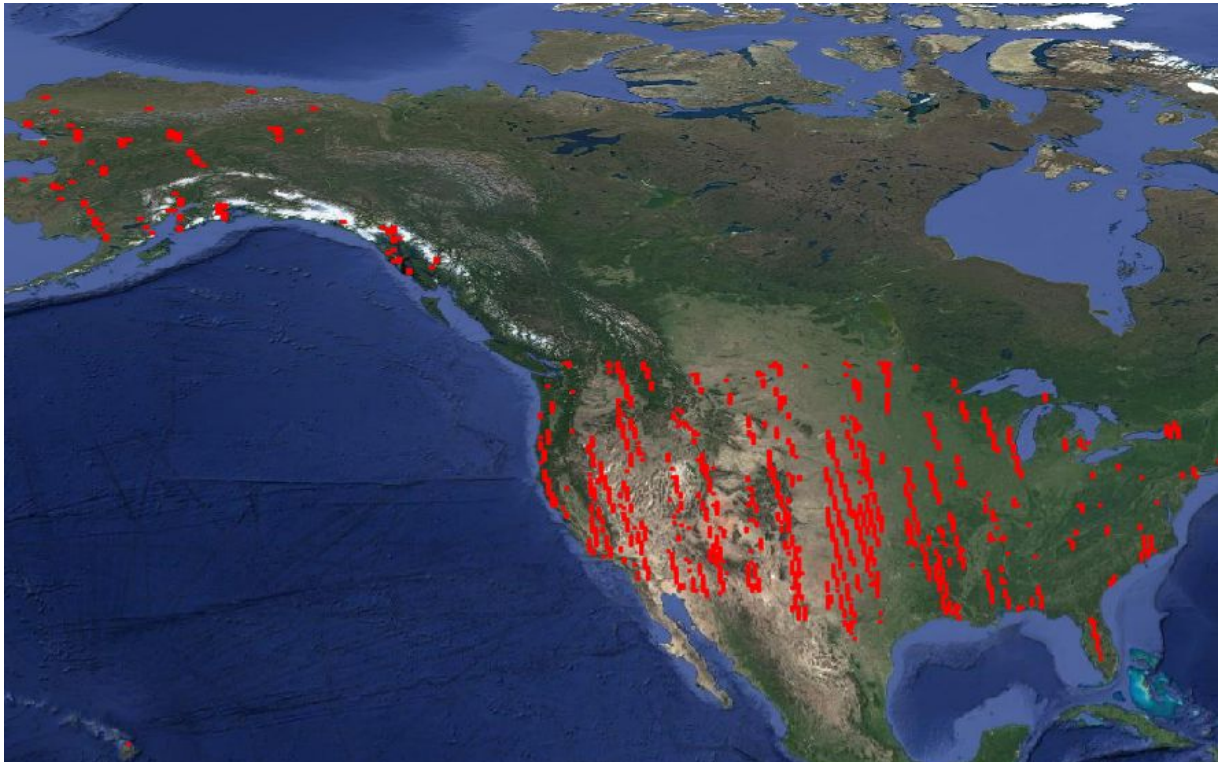
27 sites covering a range of bright and dark features to capture full dynamic range



Revised calibration process

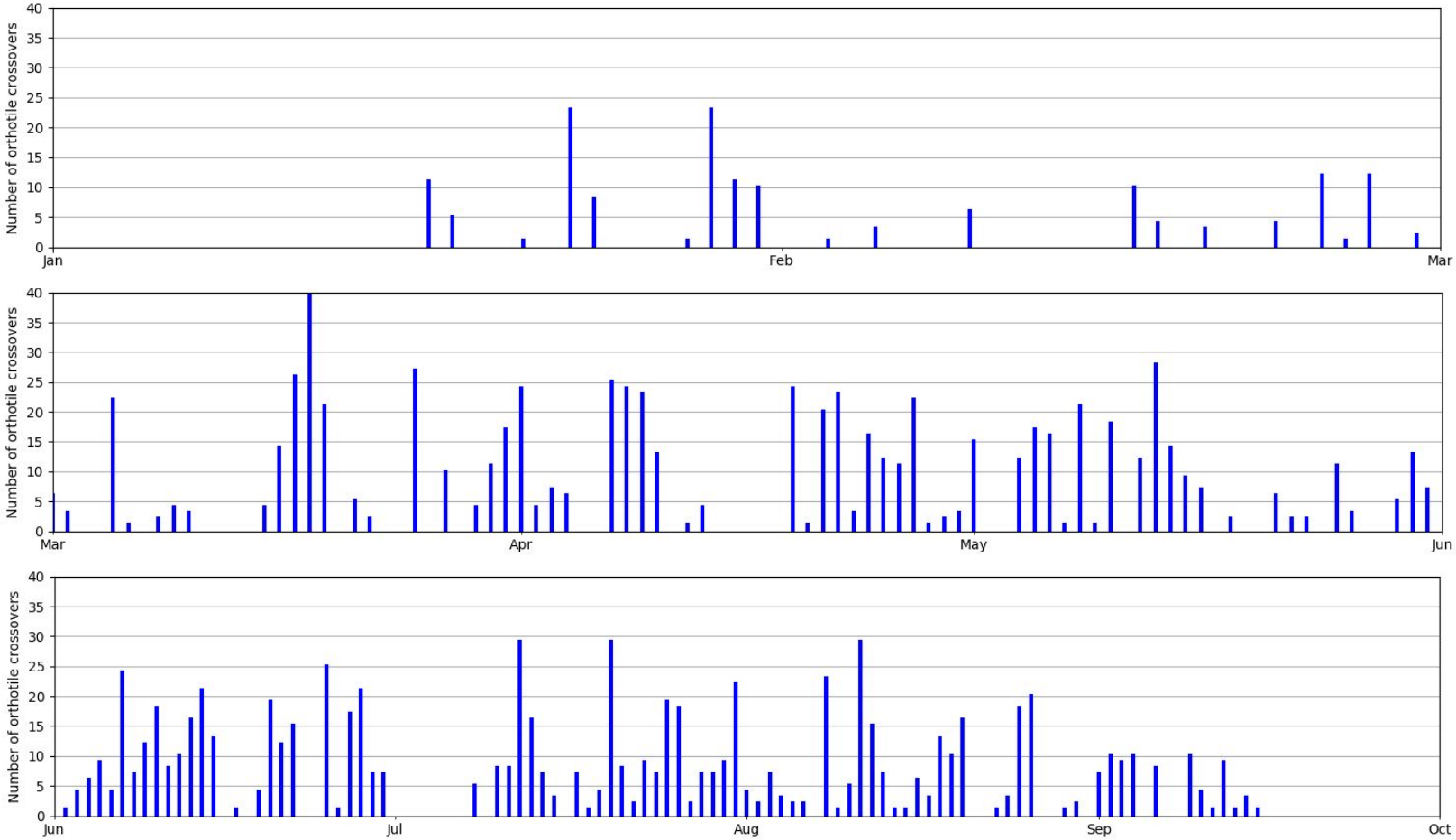
Iguazú National Park, Brazil – September 23, 2016

A summary of the crossovers for a single satellite



Showing the footprint of the crossovers for a single satellite. The entire set of crossovers was filtered using statistics to filter out the images affected by clouds.

A timeline of the crossovers



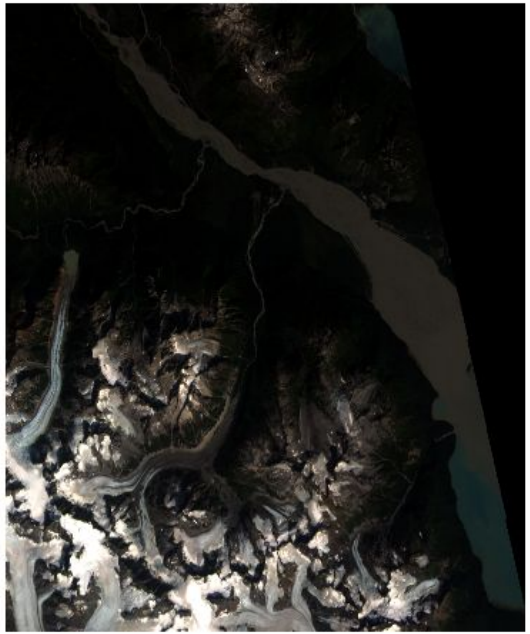
The number of crossover orthotiles for each day in the time of interest. The orthotiles were filtered so that only crossover events that overlapped over 50% of the orthotile.

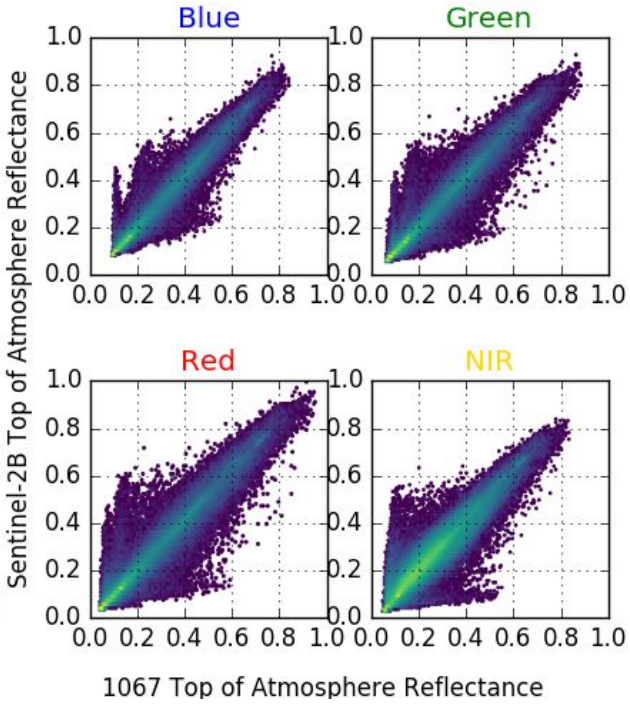
Results for a single satellite

Iguazú National Park, Brazil – September 23, 2016

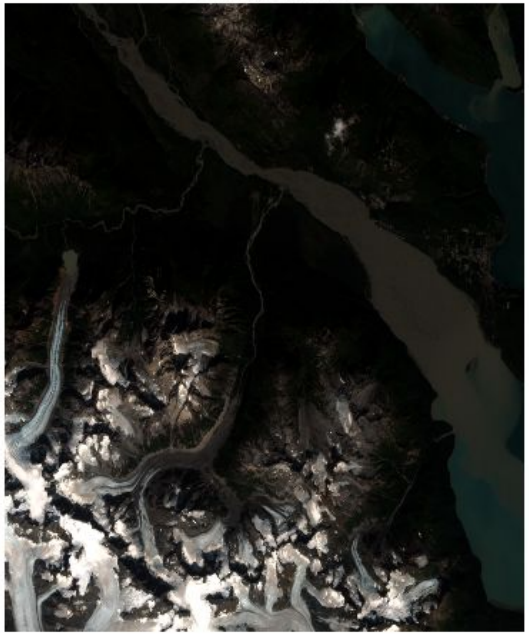
An example crossover

1067

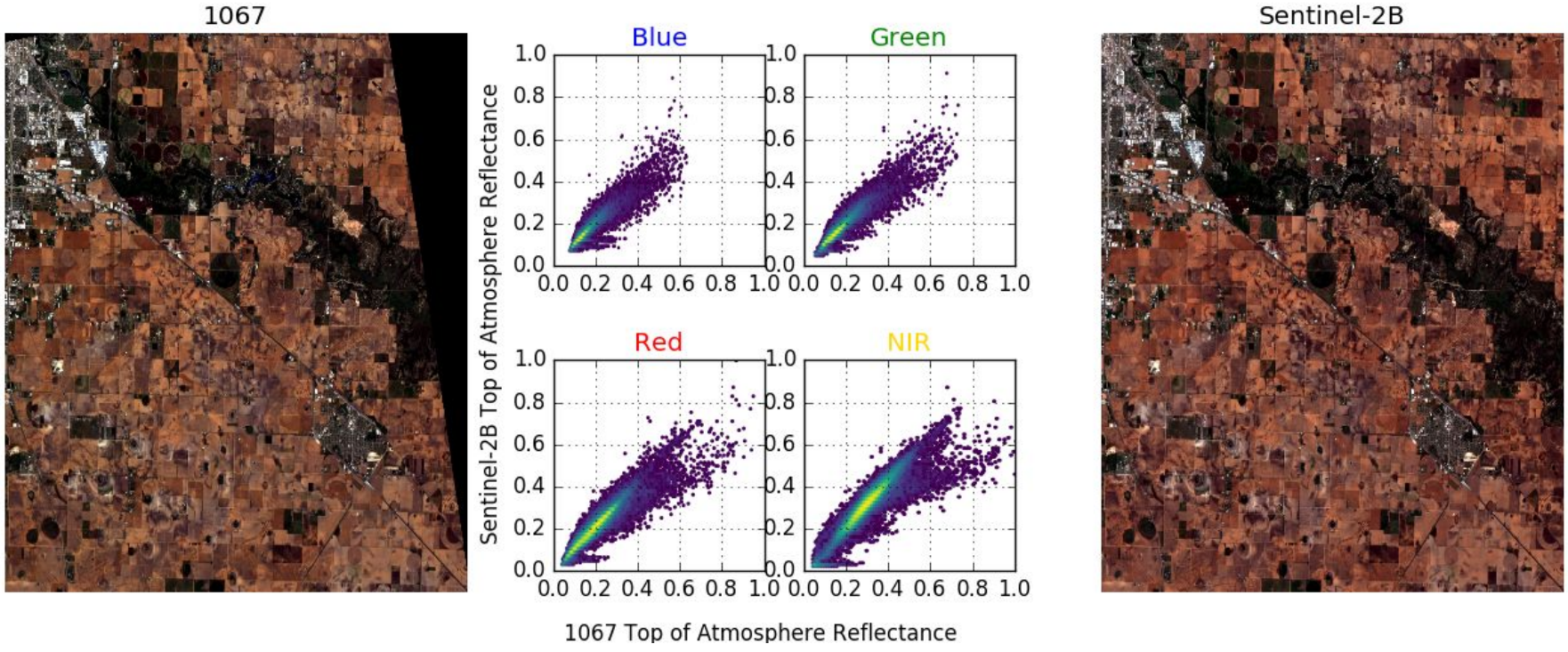




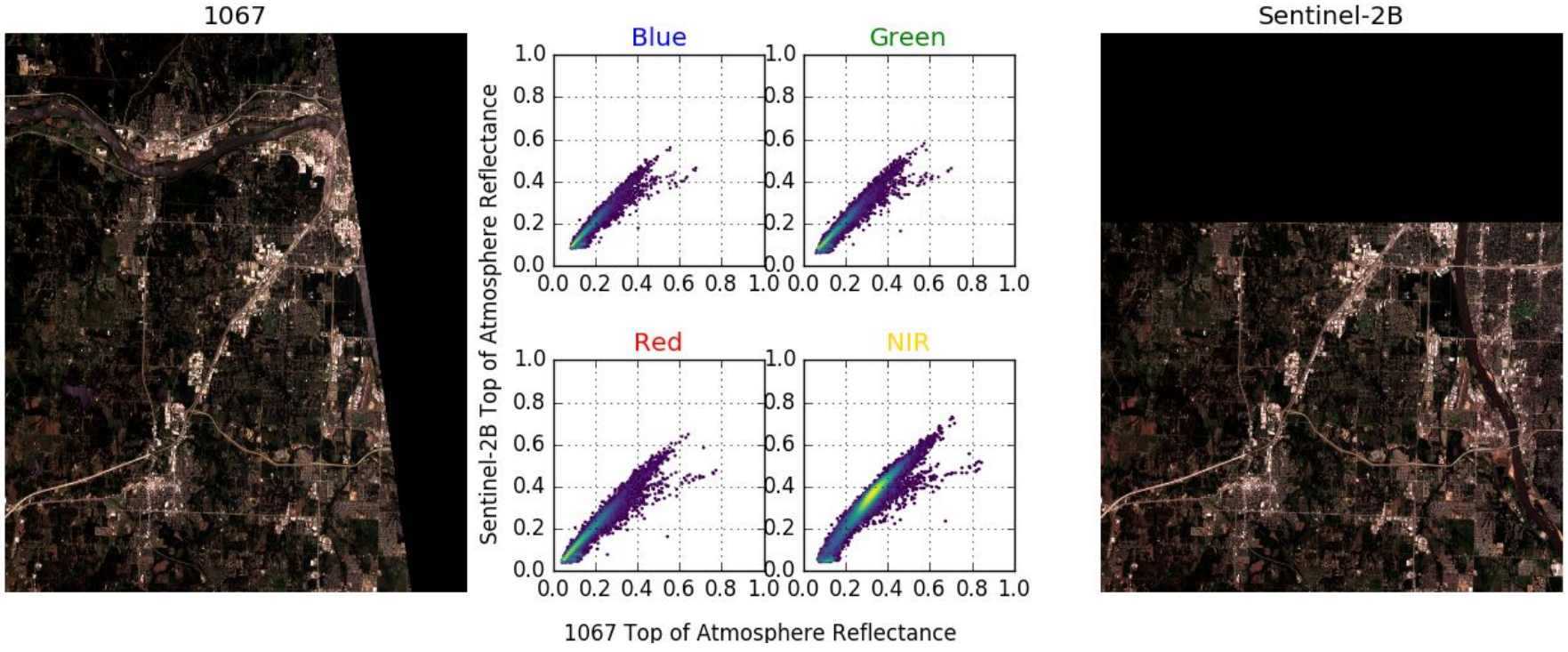
Sentinel-2B



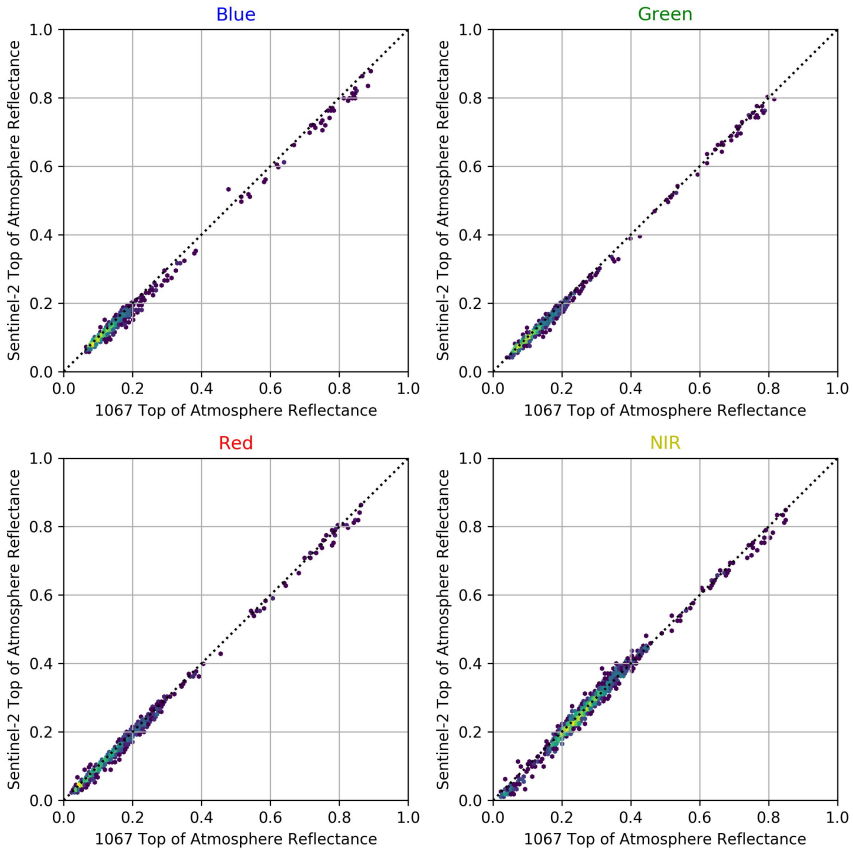
An example crossover



An example crossover

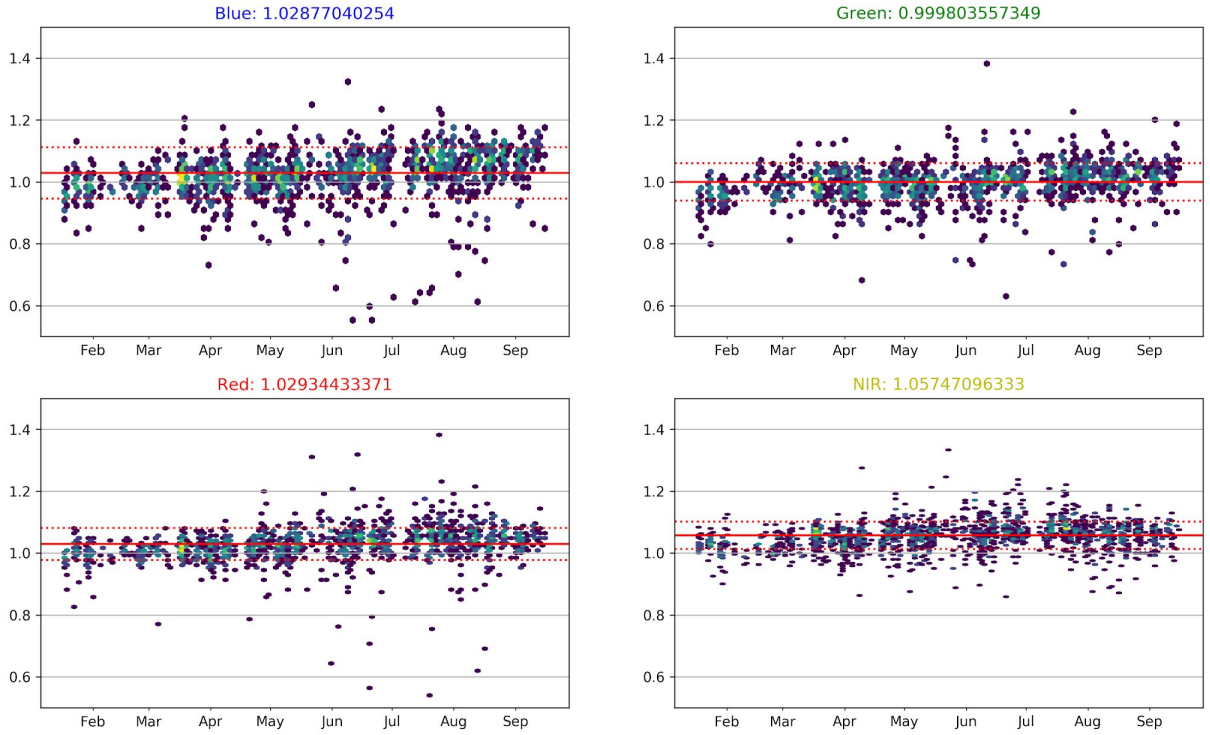


All the crossovers for a single satellite



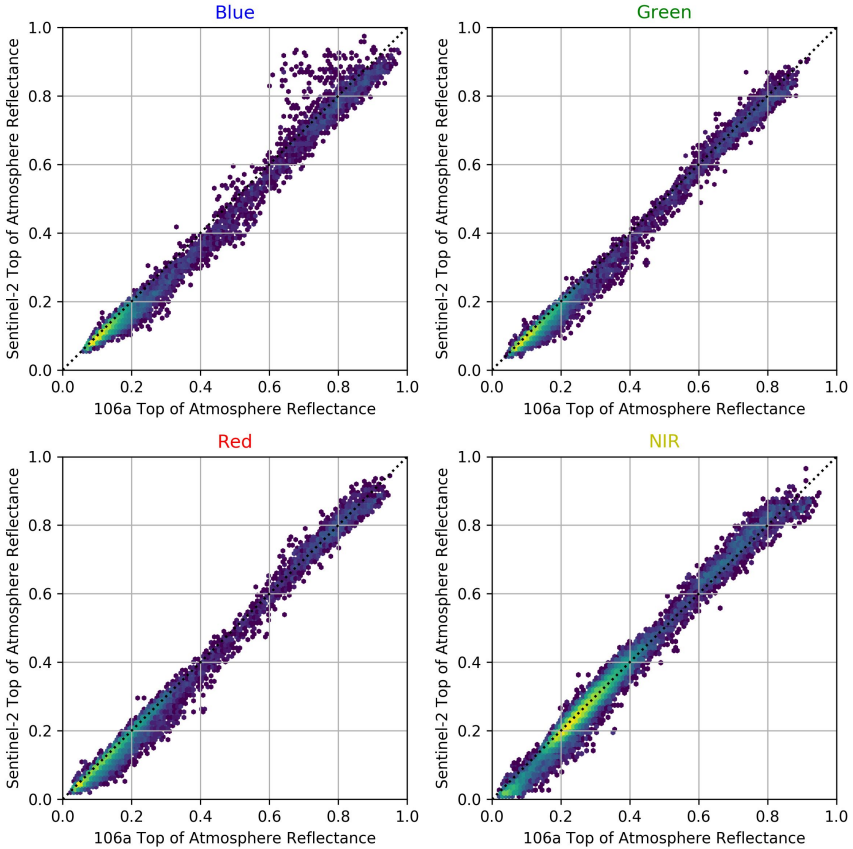
All 1644 orthotile events on a single plot. Each orthotile event was summarised as a single statistic in this scatter plot. The joint-mode of the candidate and reference measurements over the entire orthotile was chosen as the summary statistic (mirroring our own calibration process). The dynamic range of the dataset is much wider than with calibration sites, with a lot of data in over darker scenes. This reflects the data over terrain types where the data is frequently used (e.g. agricultural areas)

The fit of all the crossovers over time



Showing the range of fits over time. The fit between the reference and candidate measurements for each orthotile crossover event is shown to investigate if there is any seasonal variation.

All the crossovers for all Dove-Rs



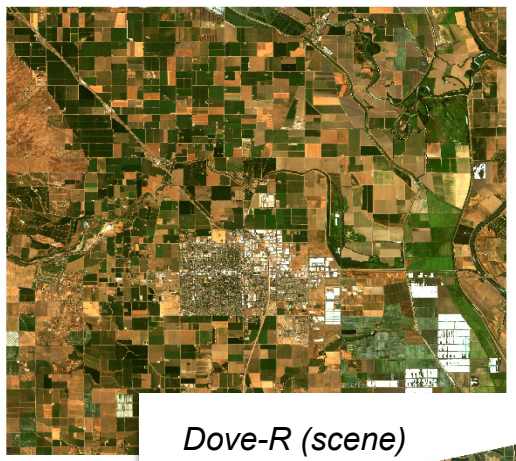
All 33452 orthotile events for all satellites (over 257 days) on a single plot. The same filtering was done as for a single satellite.

ARD strategy processing levels

Level	motto	Dove	SkySat	RE	Sentinel-2	MODIS	Landsat-8	HLS	latency	geometry	radiometry	delivery
L0	raw	raw frames		N/A					3 hour	G0	R0	internal, R&D
L1a	raw video frames	radiometrically-corrected at-sensor radiance										
L1b NRT	ortho ready	L1b, registered, rectified sensor-space, geolocated, TOAR		as provided NRT L1 TOAR products					6 hours	G1	R1	**catalog**, orders API
L2v XYZ	visual	CIE XYZ color-space, 8- or 16-bit, with color profiles, TOAR-based, web-mercator or UTM-projected									R3	orders API
L2b ARD	SR+GRI*	6SV-corrected via MODIS/VIIRS, UTM projected, with RSRs and SBAF matrices							12 hours	G2		**catalog**, orders API
L3h HLS	timeseries	harmonized to HLS/sen2like, gap-filled, cloud-masked, CESTEM-based, polygon-based, streamable									**R2**	orders API
L3c CRD	streaming	8-bit curved TOAR, chips, image pyramid flat catalog, 3D geometry descriptors							6 hours			orders API
L3d LAS	3D mesh	TBD 3D mesh from single capture 7.5km x 7.5km							1 day	G3	**R5**	orders API

Samples

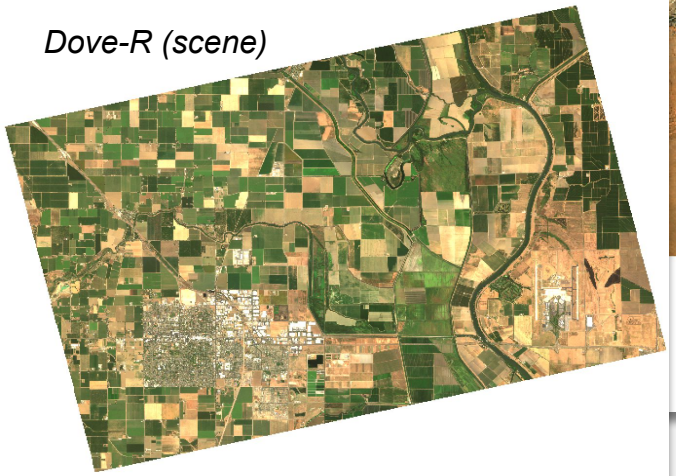
RapidEye (tile)



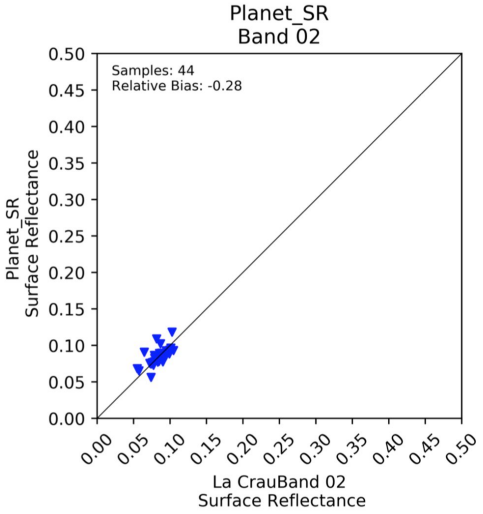
SkySat (collect)

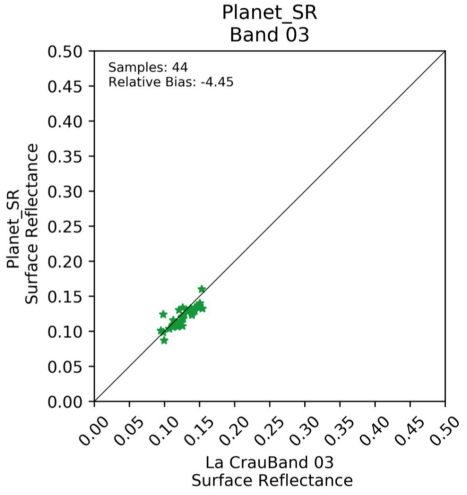
Dove (partial strip)

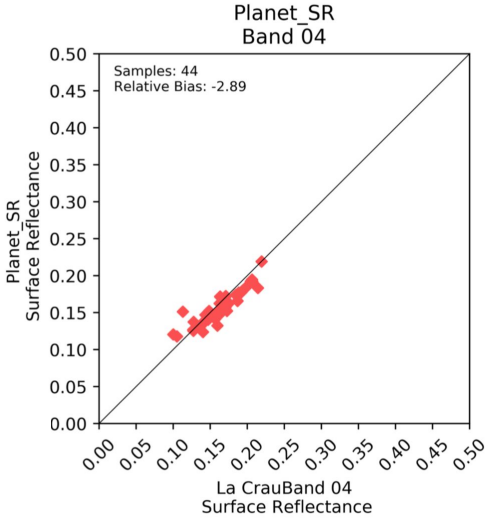
Dove-R (scene)

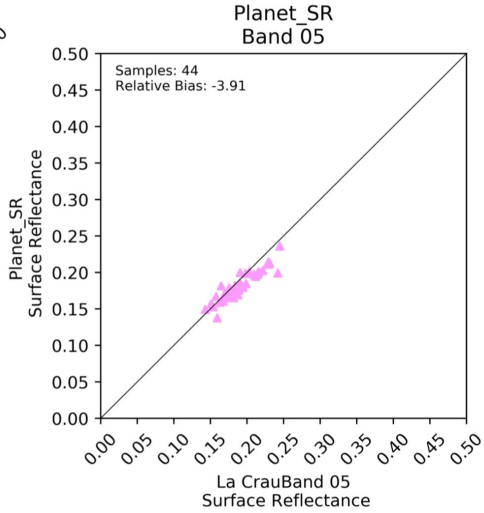


Results of the ACIX exercise



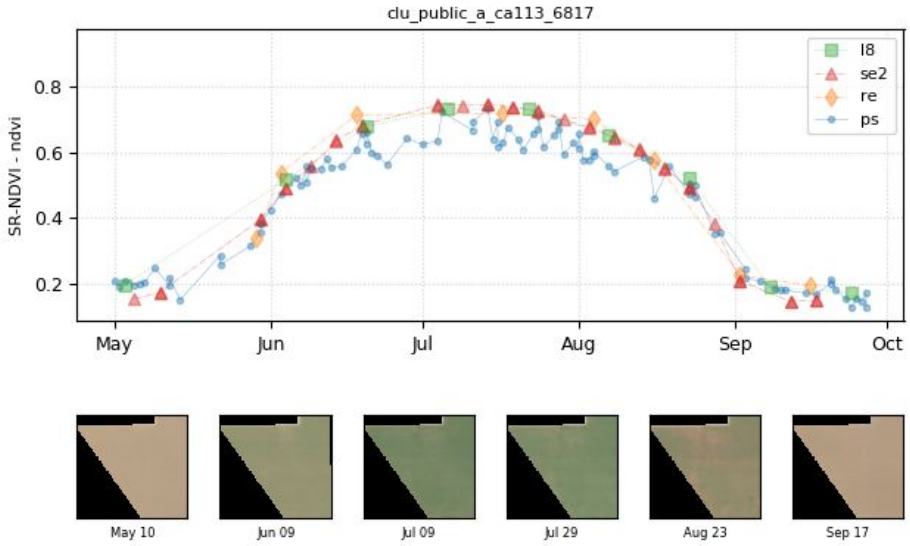






Results comparing Surface Reflectance

Time Series Comparison



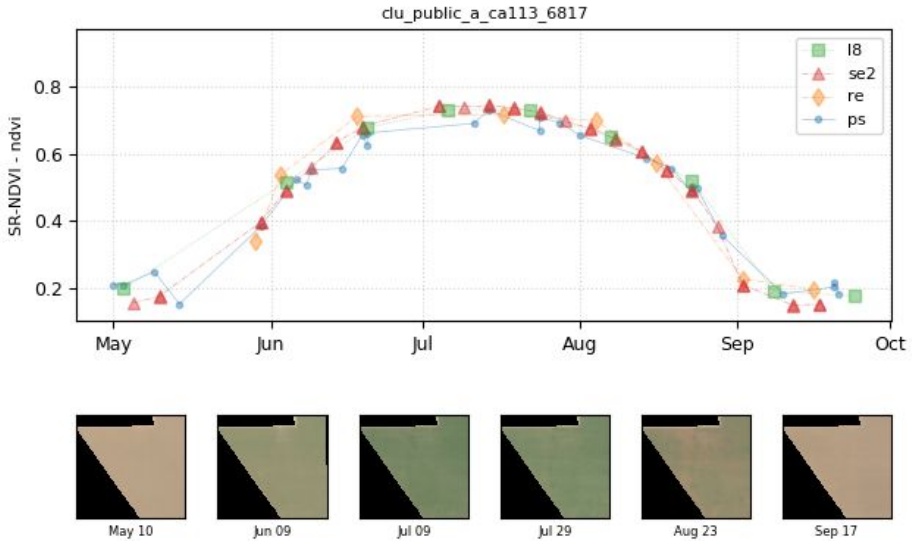
Collects from Sacramento Valley for summer 2019.

Includes imagery from Dove-C, Dove-R, RapidEye, Landsat-8 and Sentinel-2.

All results are from Planet's correction algorithm.

Results comparing Surface Reflectance

Time Series Comparison



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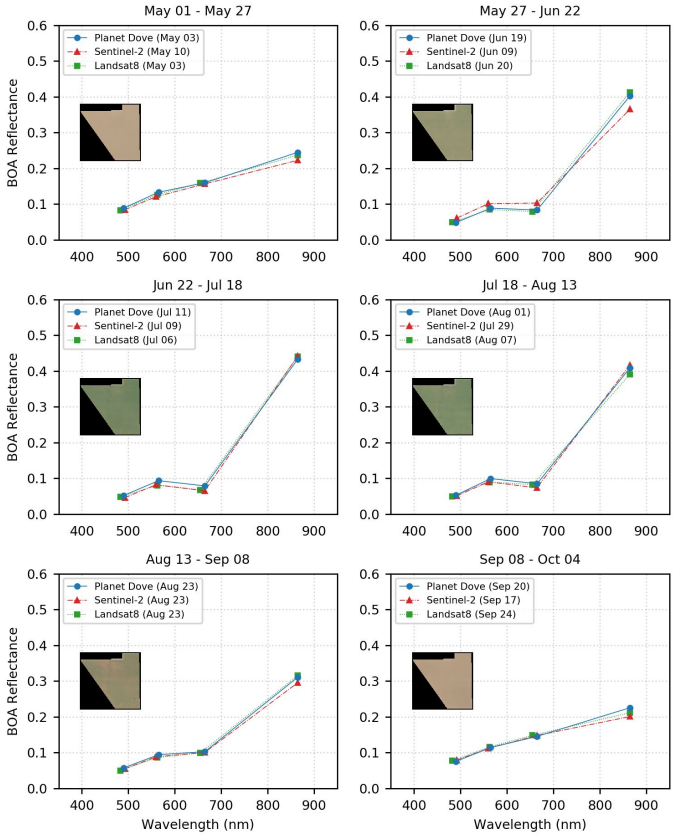
Results comparing Surface Reflectance



Time Series Comparison

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Data quality reports

+ The Planet Team, Planet Labs, Inc.

Otago, New Zealand – July 31, 2019

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DATA QUALITY REPORTS AT PLANET
Content

	L1 PS	L1 SSat	L2 PS			L1 PS	L1 SSat	L2 PS
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Performance Overview	✔	✔	✔		Interoperability	✔		
Exposure Settings	✔				**Noise**	✔	✔	
Geom. Reference Data	✔	✔			**Focus**	✔	✔	
Absolute Geolocation	✔	✔			Product Format	✔	✔	✔
Band Registration	✔	✔			**Product Anomalies**	✔	✔	✔
Temporal Registration	✔	✔			Pixel Status	✔		
Relative Geolocation	✔	✔			**Product Features**	✔	✔	✔
Radiometric Status	✔	✔			Active Satellites	✔		

L1 Data Quality Report PlanetScope

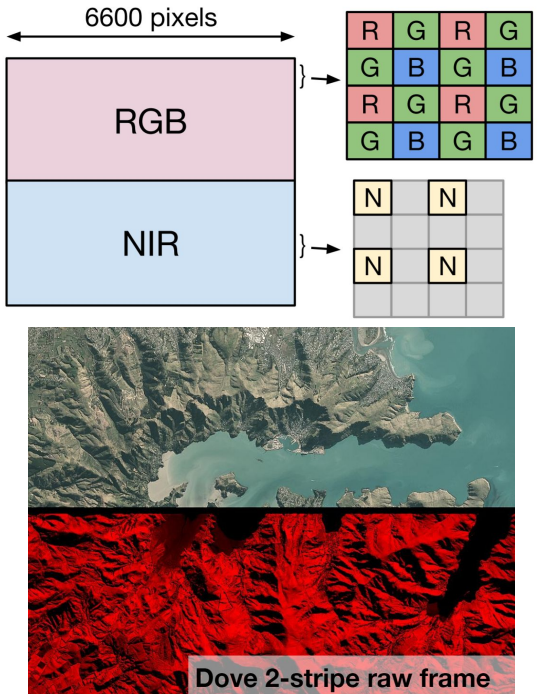
Woody Island, South China Sea – March 28, 2018

PLANETSCOPE SATELLITES

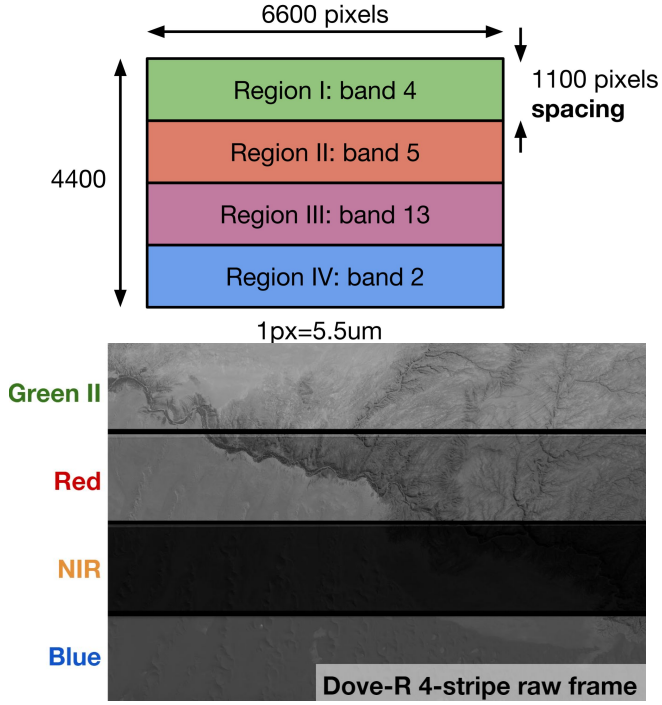
Dove-Classic and Dove-R (Refresh)

- Currently Dove-R makes up ~35% of the PlanetScope data

Dove



Dove-R



L1 DATA QUALITY REPORT PLANETSCOPE

Geometry

Dove-Classic shown

Absolute Geolocation

Average RMSE rad [m]	PCTL90(RMSE rad) [m]	STD(RMSE rad) [m]
3.6	6.8	2.3

Temporal Registration

Average RMSE rad [m]	PCTL90(RMSE rad) [m]	STD(RMSE rad) [m]
1.8	3.1	2.4

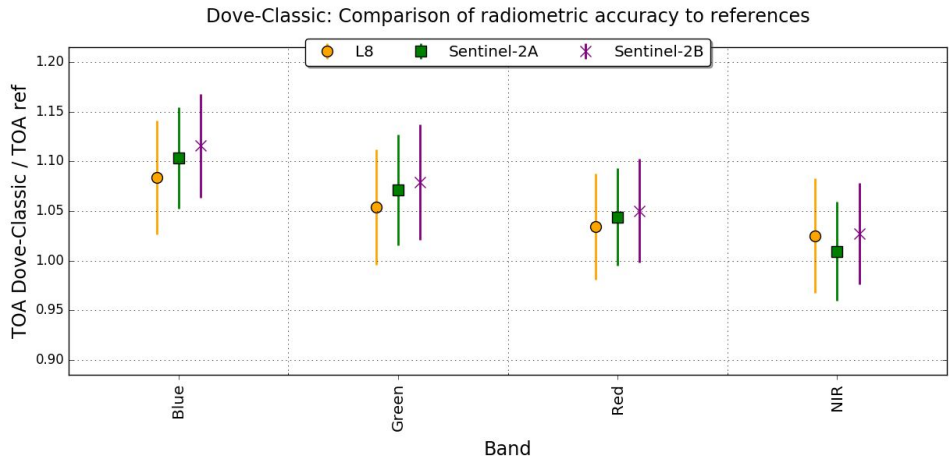
Relative Geolocation

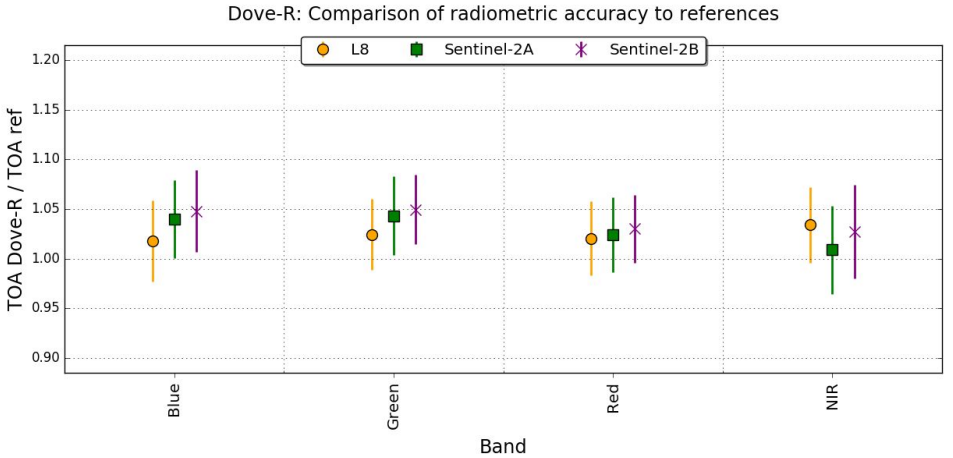
Average RMSE rad [m]	PCTL90(RMSE rad) [m]	STD(RMSE rad) [m]
1.2	2	1.6

Band Registration

Band Combination	Average RMSE rad [m]
Blue - Green	0.140
Blue - Red	0.158
Blue - NIR	1.602
Green - Red	0.160
Green - NIR	1.550
Red - NIR	1.671

L1 DATA QUALITY REPORT PLANETSCOPE
Radiometry





Band	Dove-Classic		Dove-R	
	Gain Coefficient	Standard Deviation	Gain Coefficient	Standard Deviation
Blue	1.103	0.054	1.036	0.042
Green	1.070	0.058	1.040	0.038
Red	1.044	0.051	1.025	0.036
NIR	1.019	0.052	1.021	0.045

L1 DATA QUALITY REPORT PLANETSCOPE

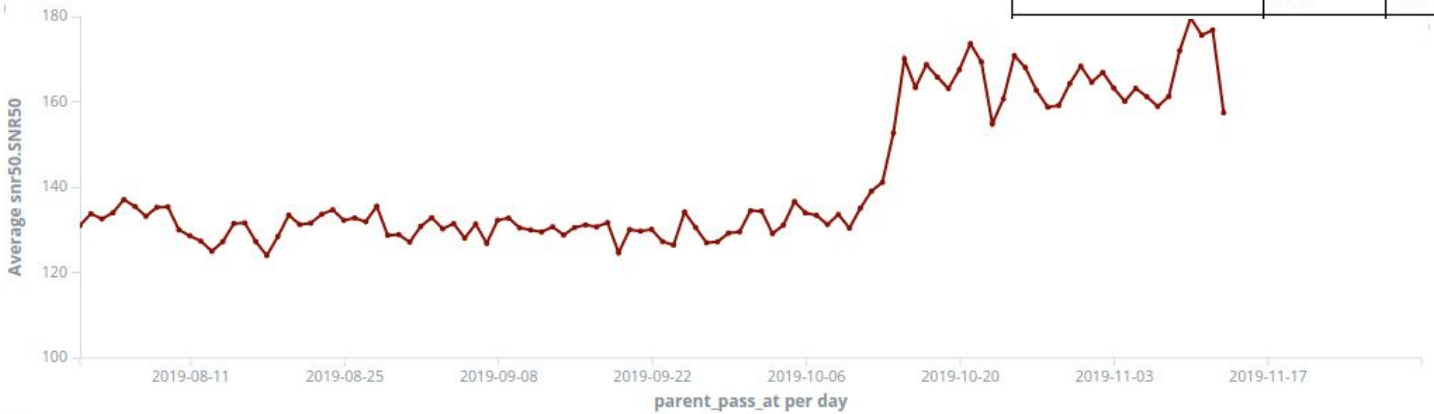
Noise

Dove-Classic shown

SNR50 - measured from the raster data at 50% of the dynamic range of each scene

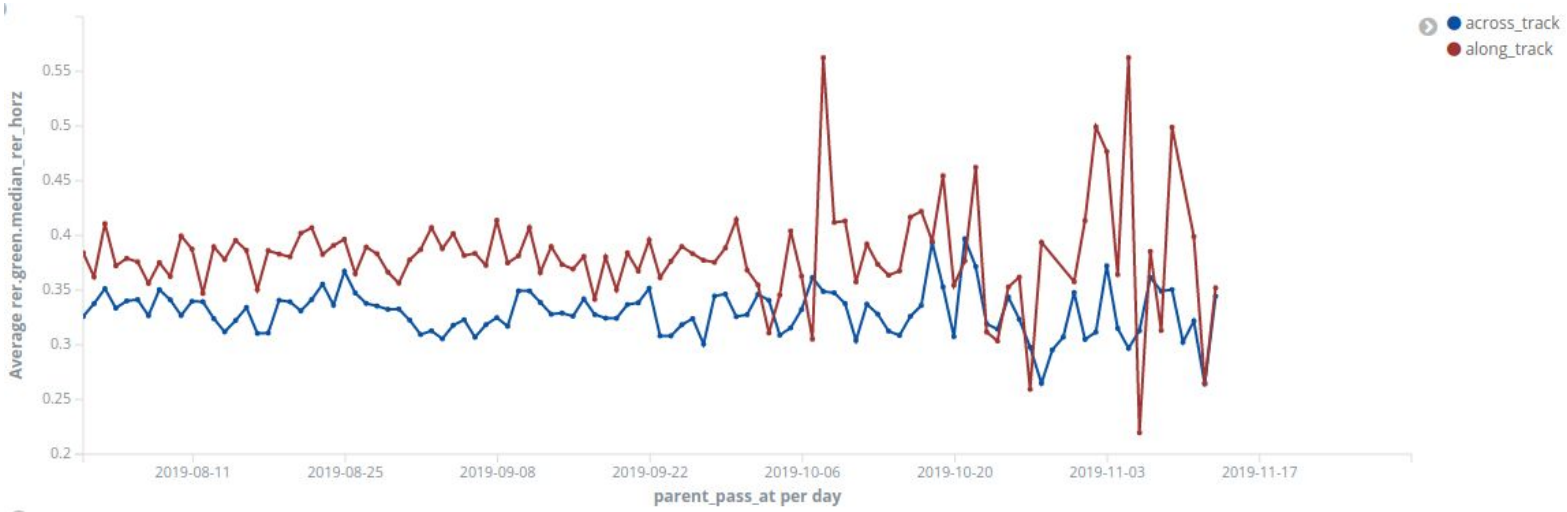
Satellite	SNR50 luminance
Two-stripe Dove-Classic	140.777

Satellite	Band	Average reference radiance (W·sr−1·m−2)
Two-stripe Dove-Classic	Red	110
	Green	86
	Blue	130
	NIR	266



L1 DATA QUALITY REPORT PLANETSCOPE
Focus

Satellite	RER green across track		RER green along track	
	native	Normalized to 3m GSD	native	Normalized to 3m GSD
Two-stripe Dove-Classic	0.329	0.26	0.378	0.297
Four-stripe Dove-R	0.329	0.25	0.362	0.274



L1 DATA QUALITY REPORT PLANETSCOPE

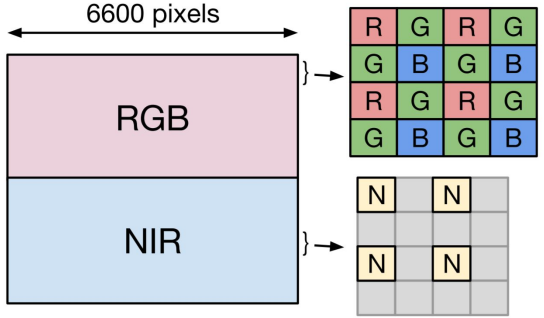
Product Anomalies

Major known anomalies, actively being worked on and planned to be fixed in the future

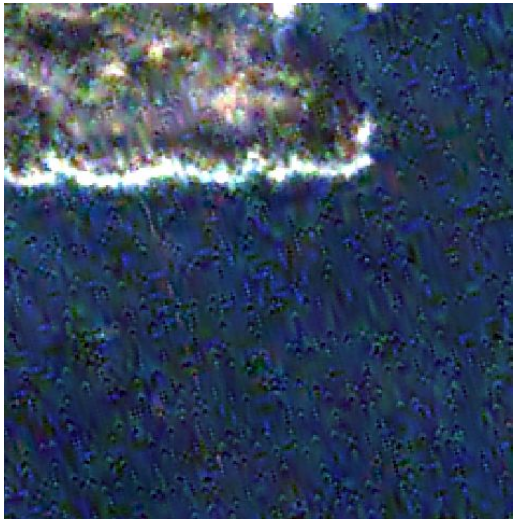
- Blurry overlap between successive scenes
- Tonal difference between successive scenes
- Saturation and Blooming - significantly less frequent in Dove-R
- Tap imbalance
- NIR misalignment - only Dove-Classic
- Misalignment between successive scenes
- Missing scenes in a Strip
- Frame-rate issue

L1 DATA QUALITY REPORT PLANETSCOPE

Product Features - Dove-Classic



- J2K compression artifacts
- Zipper artifact through debayering

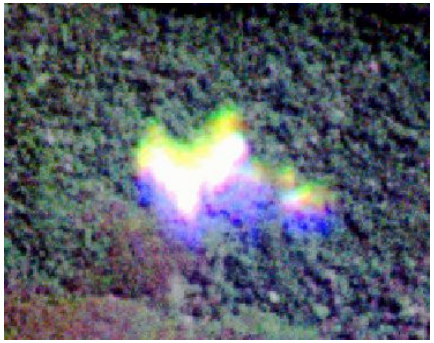


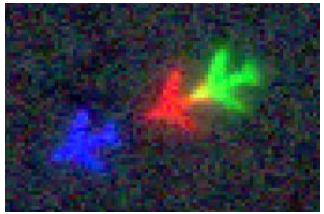
L1 DATA QUALITY REPORT PLANETSCOPE

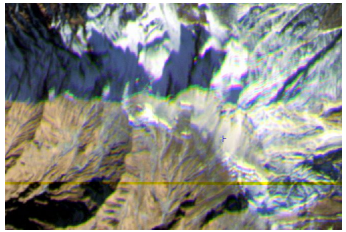
Product Features - Dove-R

- Clouds
- Planes
- Steep terrains
- Waves

Region I: band 4
Region II: band 5
Region III: band 13
Region IV: band 2







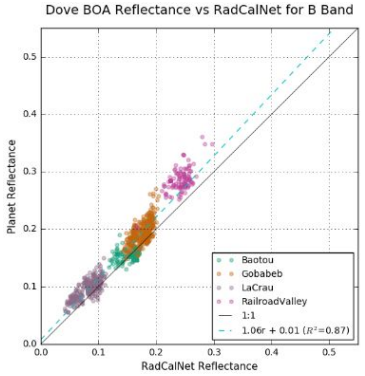
L2 Data Quality Report
PlanetScope

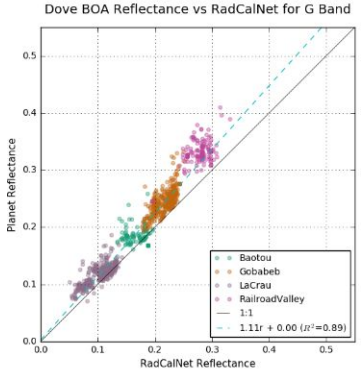
Woody Island, South China Sea – March 28, 2018

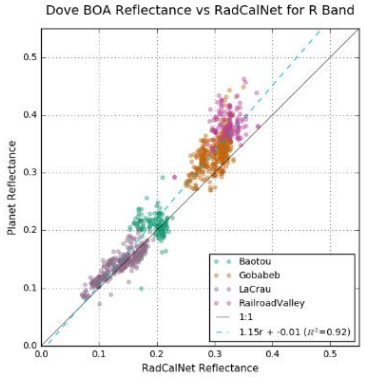
L2 DATA QUALITY REPORT PLANETSCOPE

- No formal product requirements exists

- Radiometric Accuracy of Surface Reflectance Product
- Product Anomalies
- Product Features







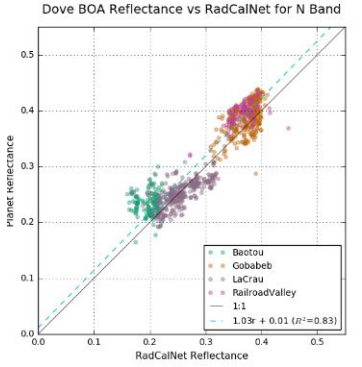


Table 1: Measured Performances for Doves

Band	Absolute Accuracy %	Precision %	Uncertainty % (1 sigma)
Blue	10.42	13.59	17.13
Green	11.62	11.90	16.64
Red	10.30	11.32	15.31
NIR	7.91	11.81	14.21

Future products

+The Planet Team, Planet Labs, Inc.

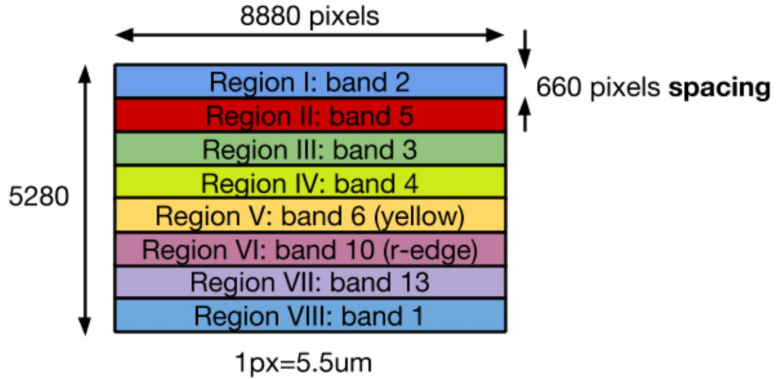
Otago, New Zealand – July 31, 2019

planet.

ARD strategy processing levels

Level	motto	Dove	SkySat	RE	Sentinel-2	MODIS	Landsat-8	HLS	latency	geometry	radiometry	delivery
L0	raw	raw frames		N/A					3 hour	G0	R0	internal, R&D
L1a	raw video frames	radiometrically-corrected at-sensor radiance										
L1b NRT	ortho ready	L1b, registered, rectified sensor-space, geolocated, TOAR		as provided NRT L1 TOAR products					6 hours	G1	R1	**catalog**, orders API
L2v XYZ	visual	CIE XYZ color-space, 8- or 16-bit, with color profiles, TOAR-based, web-mercator or UTM-projected								G2	R3	orders API
L2b ARD	SR+GRI*	6SV-corrected via MODIS/VIIRS, UTM projected, with RSRs and SBAF matrices							12 hours		R2	**catalog**, orders API
L3h HLS	timeseries	harmonized to HLS/sen2like, gap-filled, cloud-masked, CESTEM-based, polygon-based, streamable										orders API
L3c CRD	streaming	8-bit curved TOAR, chips, image pyramid flat catalog, 3D geometry descriptors							6 hours			orders API
L3d LAS	3D mesh	TBD 3D mesh from single capture 7.5km x 7.5km							1 day	G3	R5	orders API

SuperDove 8-band sensor layout



Band	Name	Notes	Wavelength (fwhm)	spatial sampling	GSD (m)	L_{ref} (W $sr^{-1}um^{-1}$ m^{-2})	SNR @ L_{ref} (t=10ms)*
1	Coastal Blue	core visible bands	443 (20)	**0.25x**	**12**	130	193
2	Blue		490 (50)	**1x**	**3**	130	170
3	Green I		531 (36)	**1x**	**3**	130	150
4	Green II		565 (36)	**1x**	**3**	130	154
5	Red		665 (31)	**1x**	**3**	130	138
6	Yellow	sediments, PC	610 (20)	**1x**	**6**	70	63
10	Red edge I	important for data compatibility with Sentinel-2	705 (15)	**1x**	**6**	70	57
13	NIR	narrow NIR	865 (40)	**0.5x**	**6**	130	137

Patent Pending (US20180098014A1)

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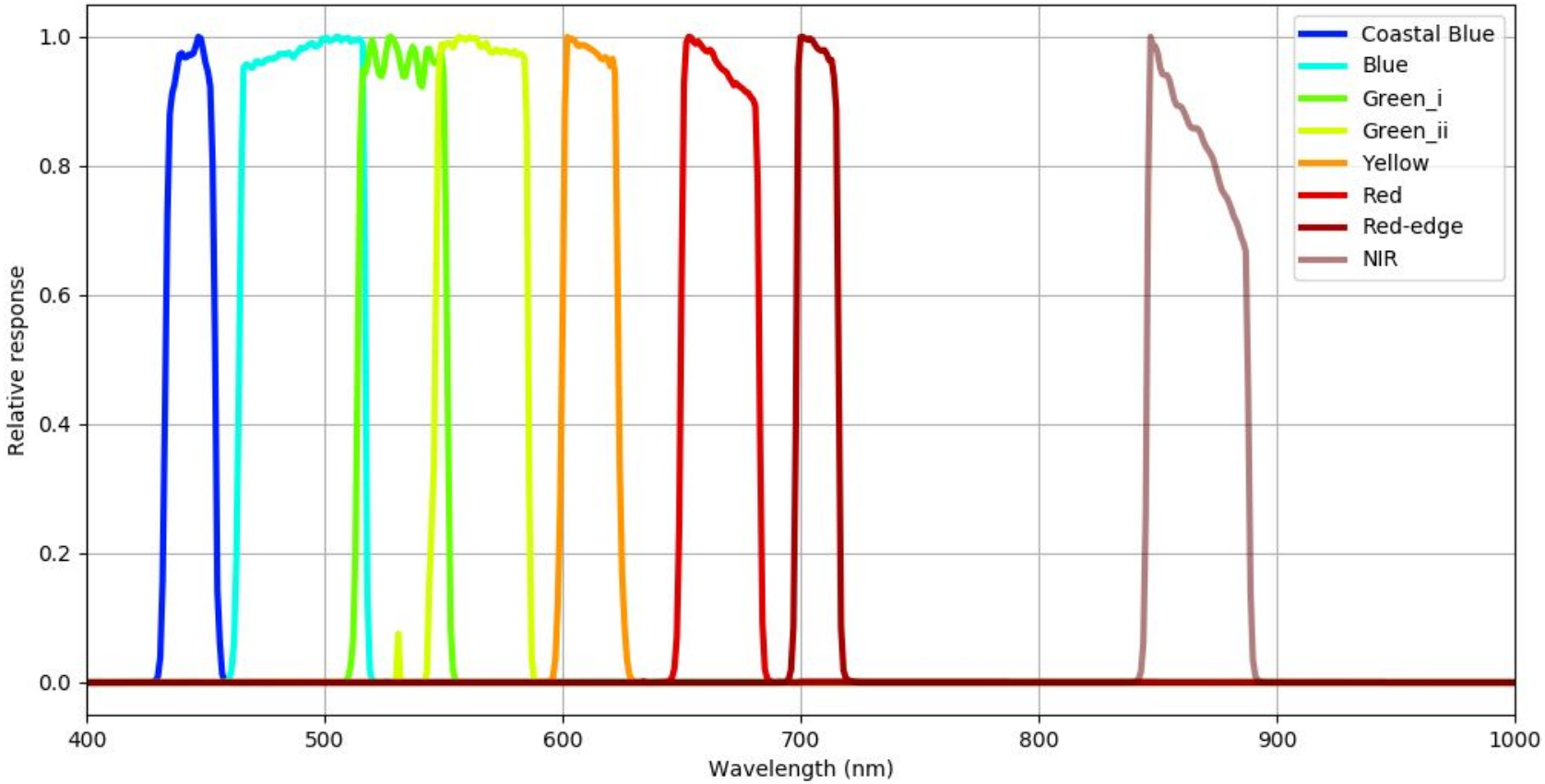
Superdove RSR (from manufacturer data)



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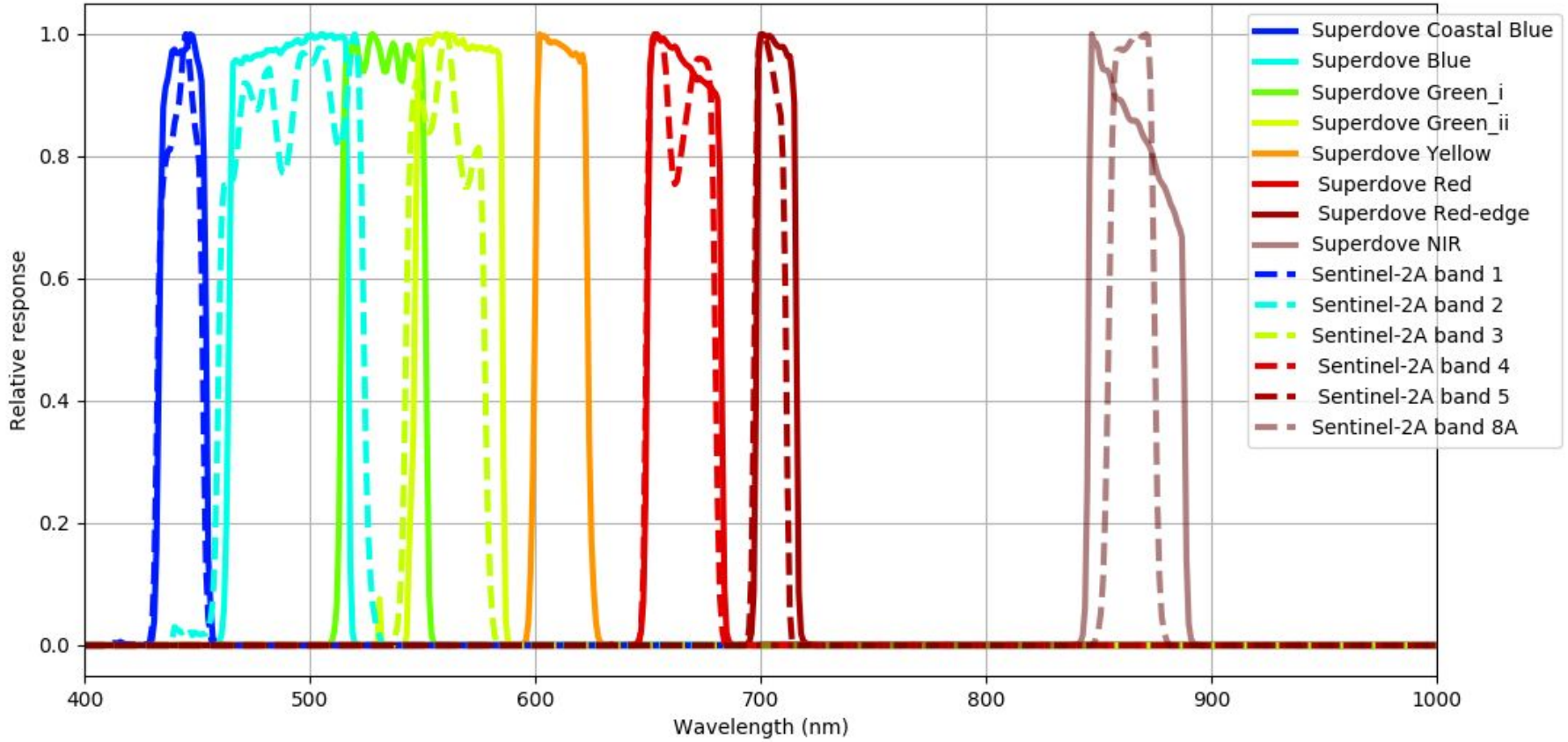
RSR comparison with Sentinel-2



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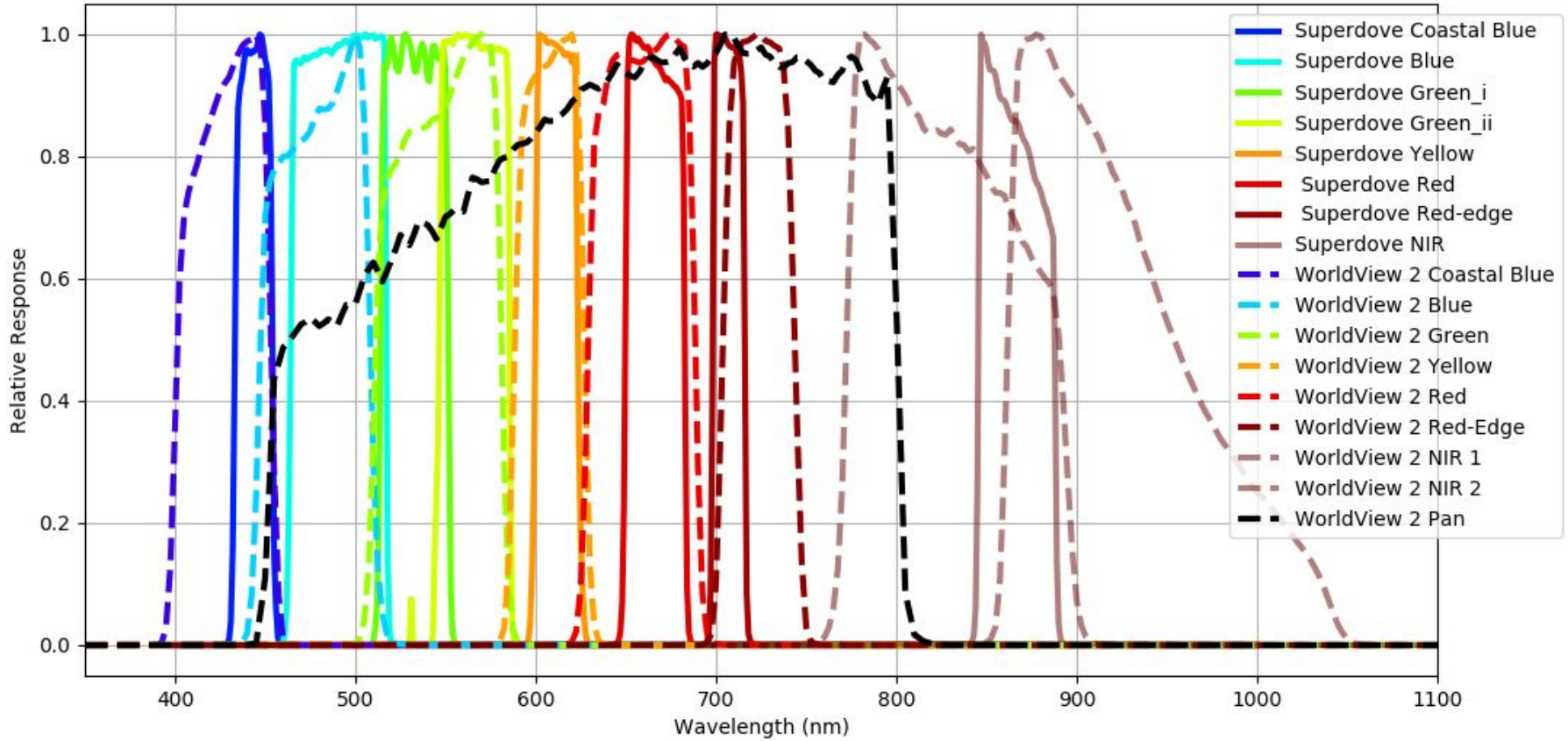
RSR comparison with WorldView 2



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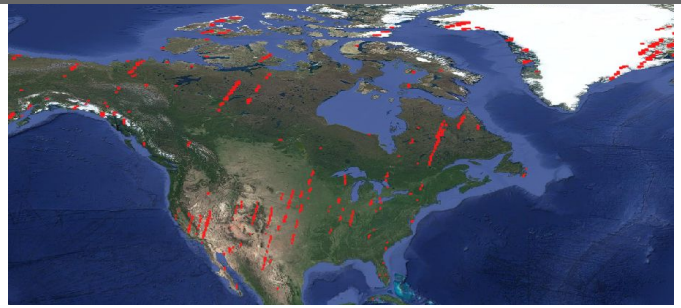
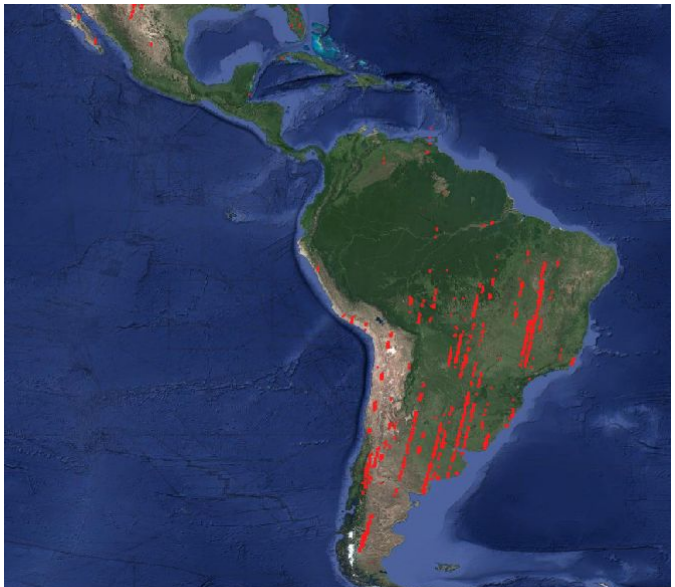
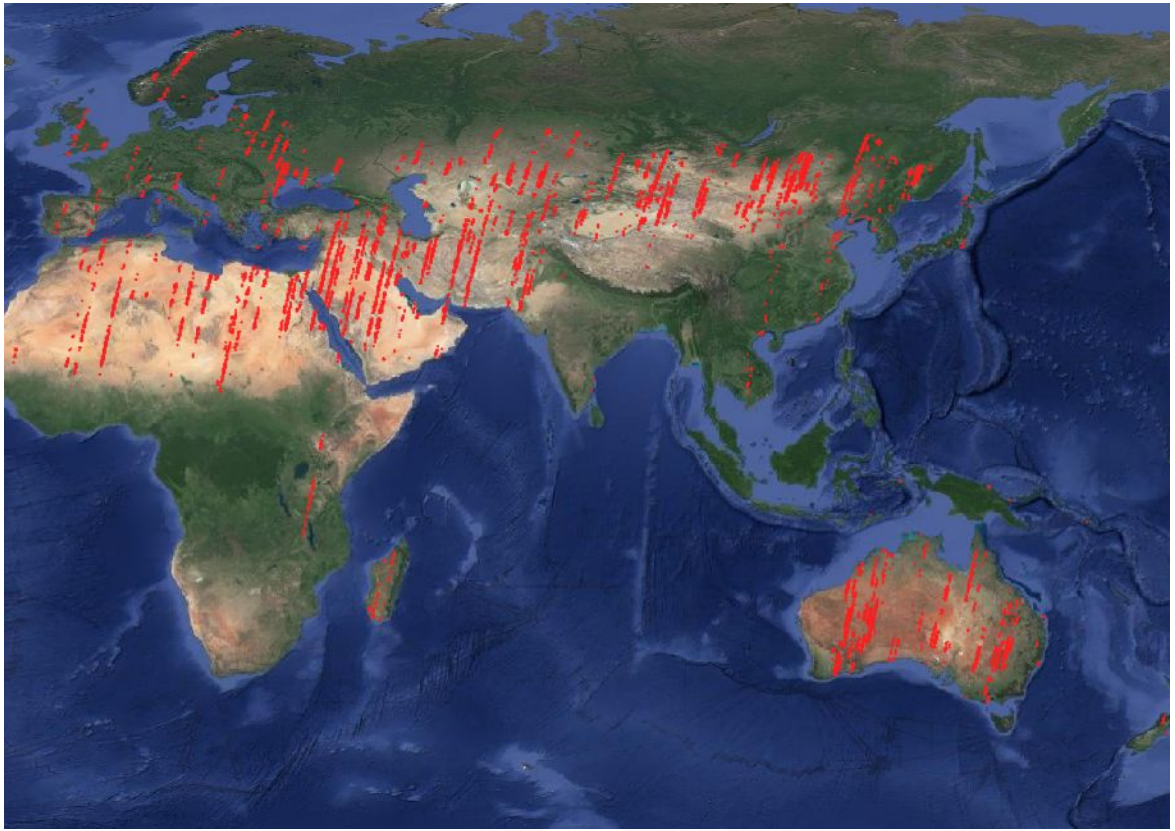
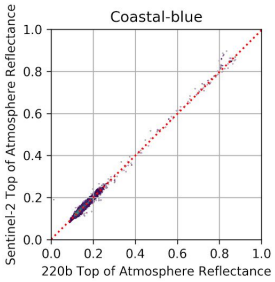
Global crossovers between a Superdove and Sentinel-2 for September

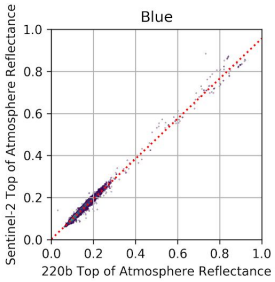


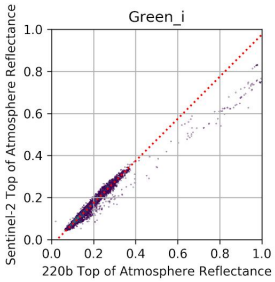


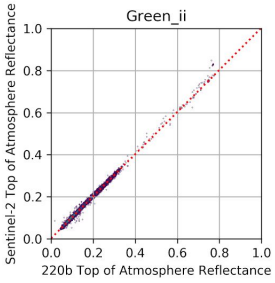


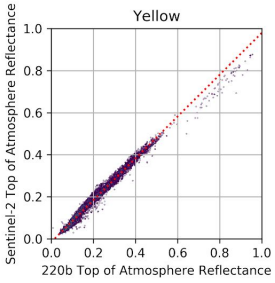
Global crossovers between a Superdove and Sentinel-2 for September

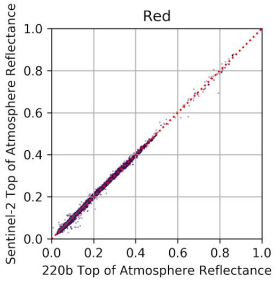


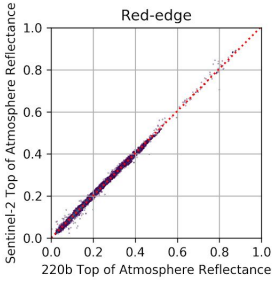


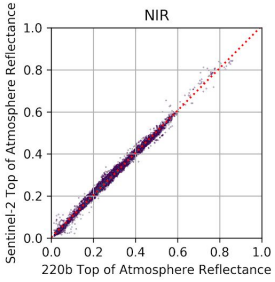






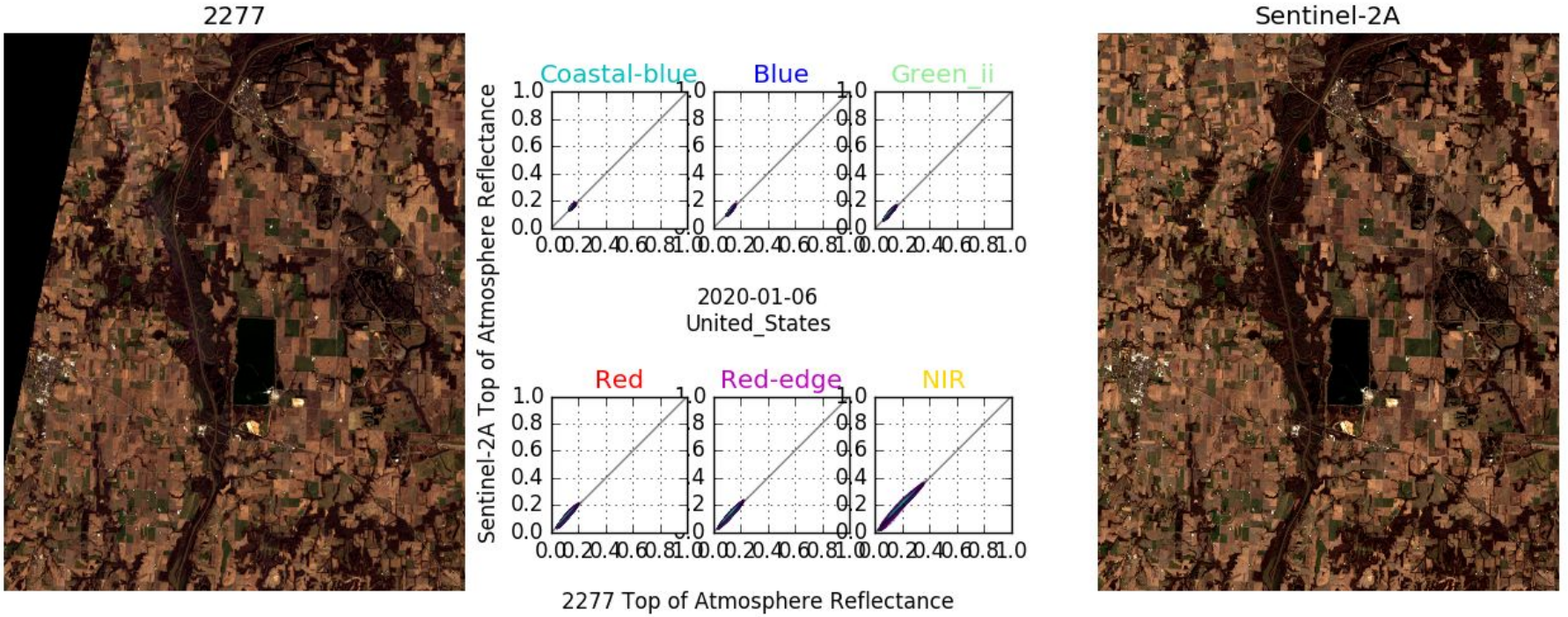






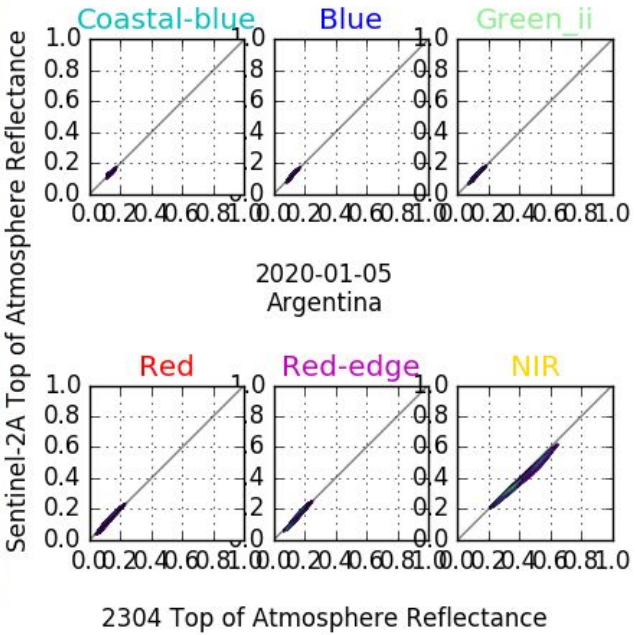
All 9304 orthotile events between a Superdove and Sentinel-2 for September. This dataset covers 19 separate dates in September and shows the results of the initial calibration.

United_States - 2020-01-06



Argentina - 2020-01-05

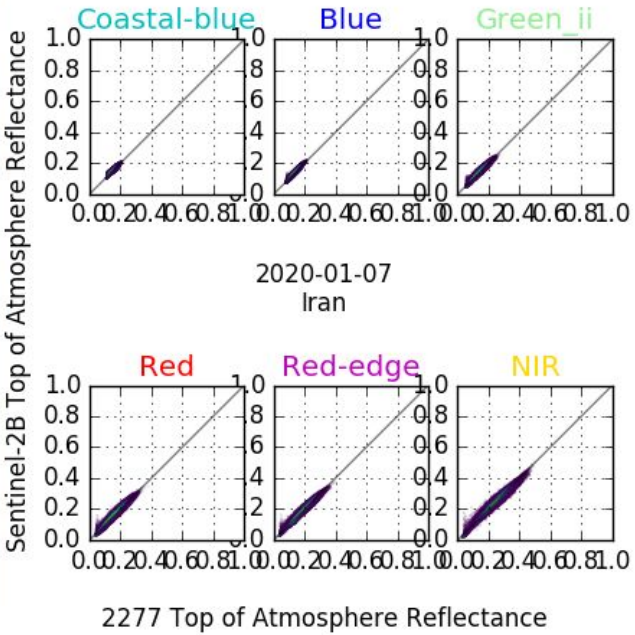
2304



Sentinel-2A

Iran - 2020-01-07

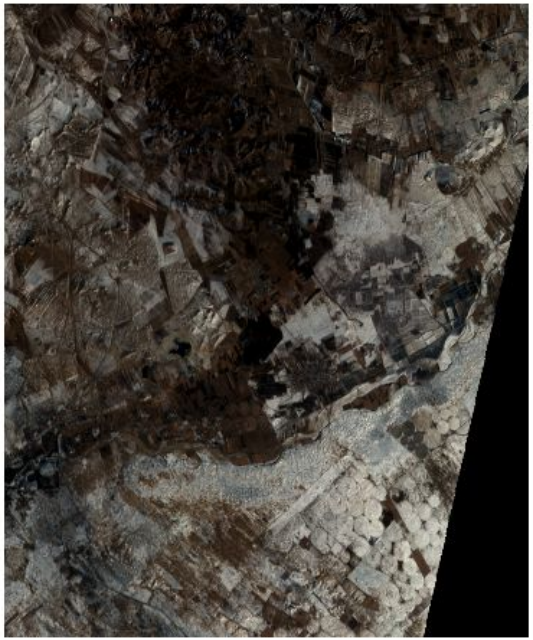
2277

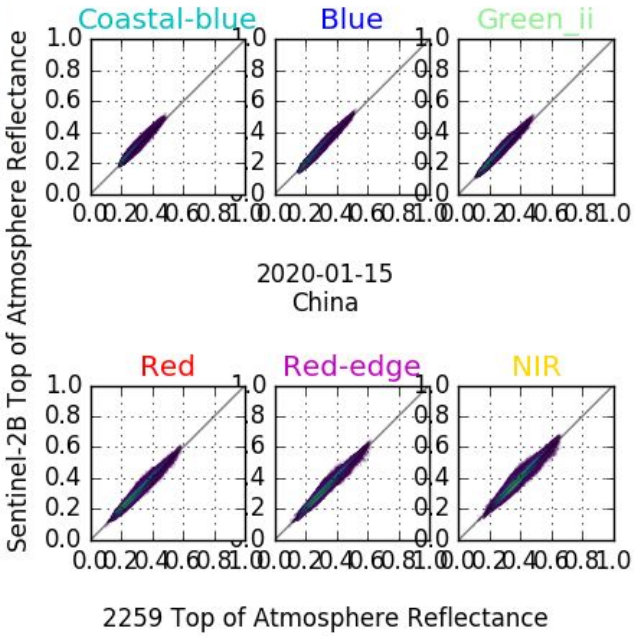


Sentinel-2B

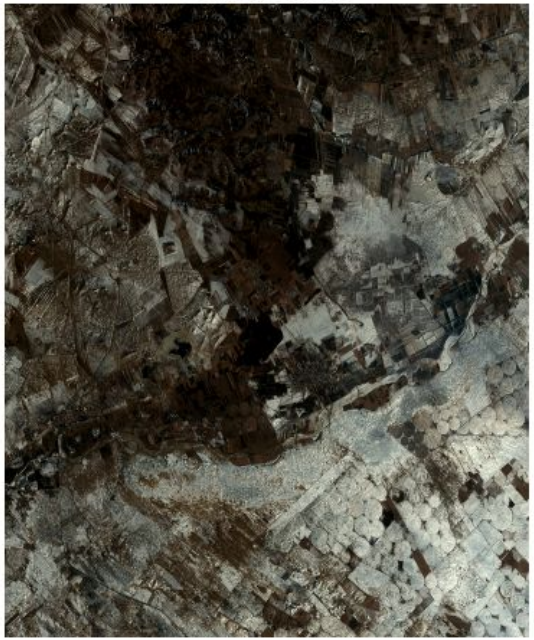
China - 2020-01-15

2259



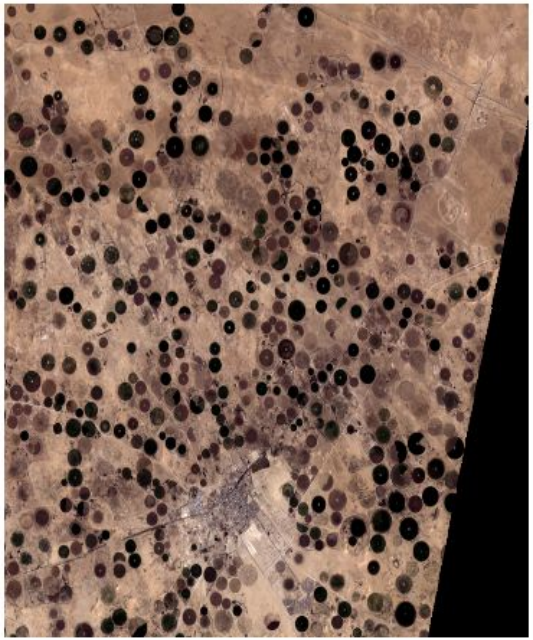


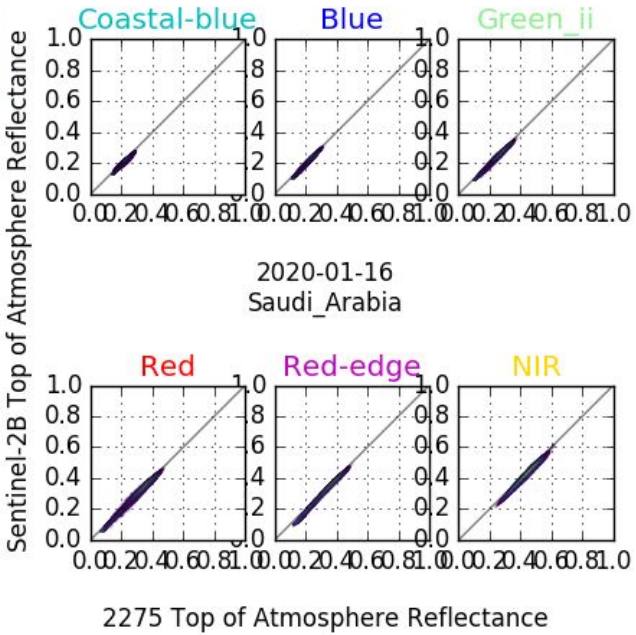
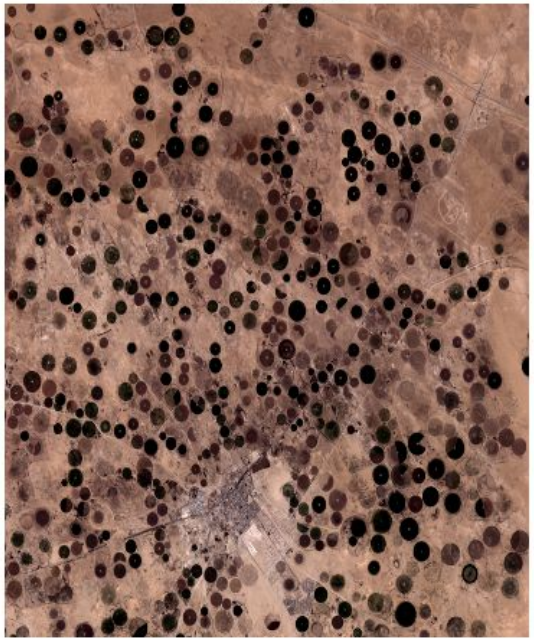
Sentinel-2B



Saudi_Arabia - 2020-01-16

2275





Sentinel-2B