On-orbit validation of interoperability between Planet SuperDoves and Sentinel-2

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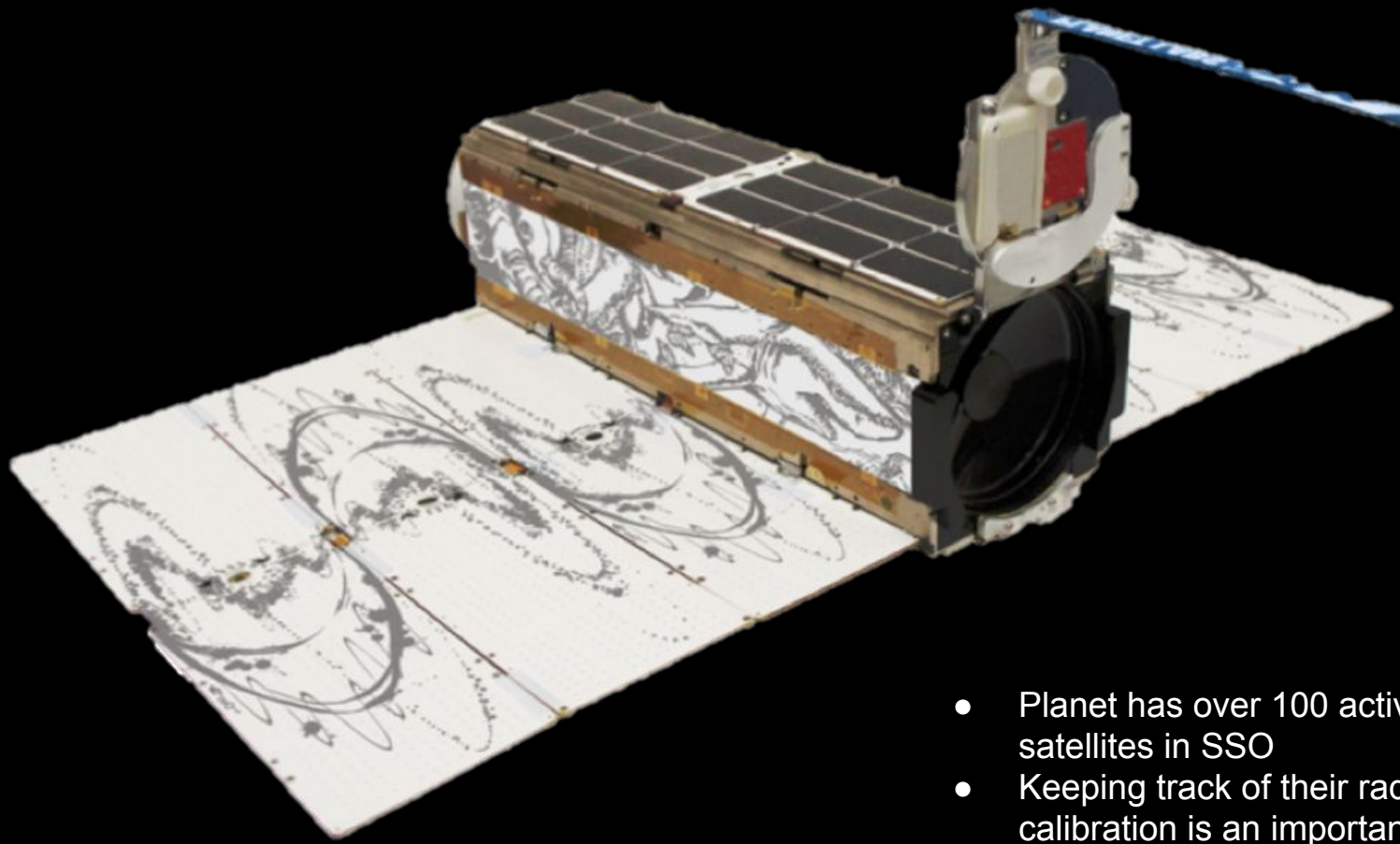
Kure Atoll, Hawaii, USA – May 12, 2016

Introduction

Singapore Strait, Singapore – July 29, 2016

Overview

- Introduction to Planet
- Methodology for SuperDove calibration
- Results of an on-orbit interoperability study for a single SuperDove
- Summary



- Planet has over 100 active calibrated satellites in SSO
- Keeping track of their radiometric calibration is an important task

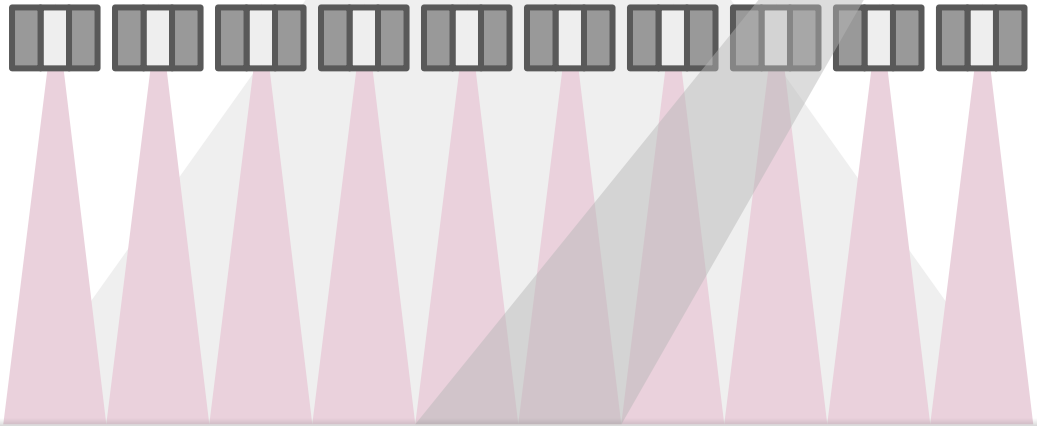
Why **SuperDoves**?

SuperDove is a high resolution mapping mission with SPOT-5-class resolution with the spectral coverage of SENTINEL-2⁄3 **plus**

- 2° max elevation orthophotos
- daily revisit today
- full effective FOV
- true 1-day revisit
- low stray light
- 2X NIR QE

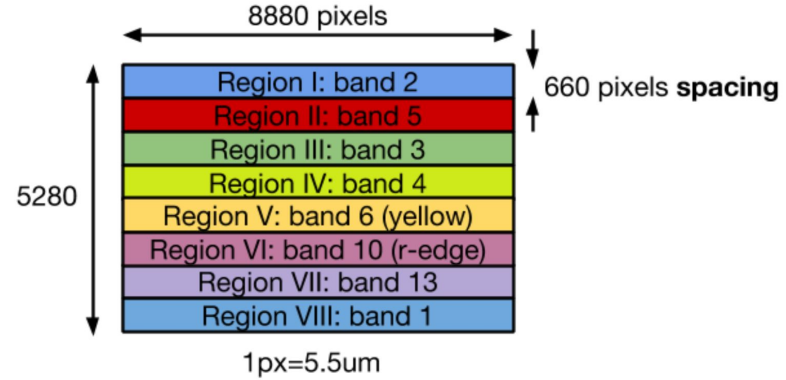
SENTINEL-2
~750km
10° incidence
12-60m GSD
9-bands
5-day revisit
(15-day effective)

SPOT-5
~800km
0-27° incidence
2.5-5.0m GSD
4-bands



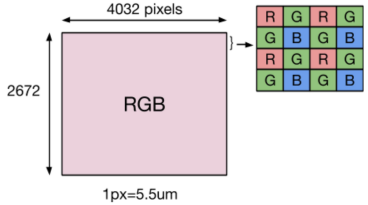
SuperDove	**Dove-R**
~500km	~500km
2° incidence	1.5° incidence
3-12m GSD	3m GSD
8-bands	4-bands
1-day revisit	1-day revisit

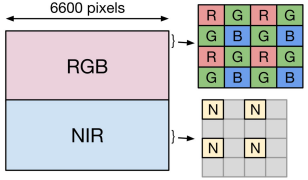
SuperDove sensor layout

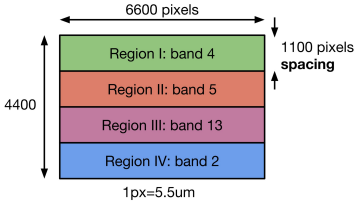


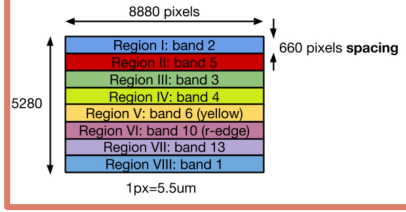
Band	Name	Notes	Wavelength (fwhm)	spatial sampling	GSD (m)	L_{ref} (W $sr^{-1}um^{-1}$ m^{-2})	SNR @ L_{ref} (t=10ms)*
1	Coastal Blue	core visible bands	443 (20)	**0.25x**	**12**	130	193
2	Blue		490 (50)	**1x**	**3**	130	170
3	Green I		531 (36)	**1x**	**3**	130	150
4	Green II		565 (36)	**1x**	**3**	130	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)	**0.5x**	**6**	70	57
13	NIR	narrow NIR	865 (40)	**0.5x**	**6**	130	137

Planet payloads over the years



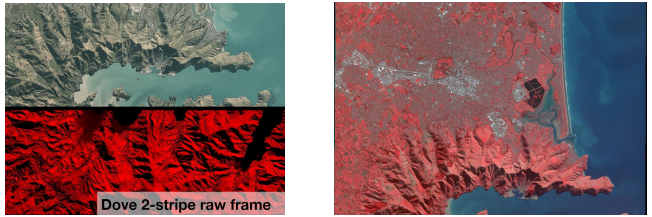




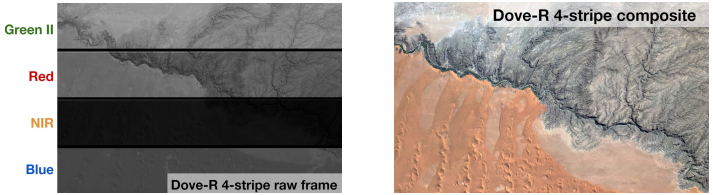


Dove Pilot (~50 satellites)

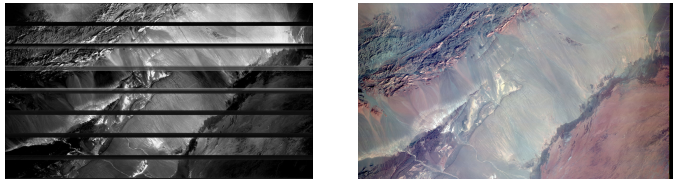
Dove (~150 satellites)



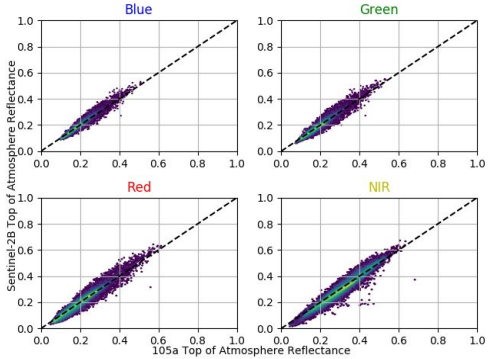
Dove-R (24 satellites)



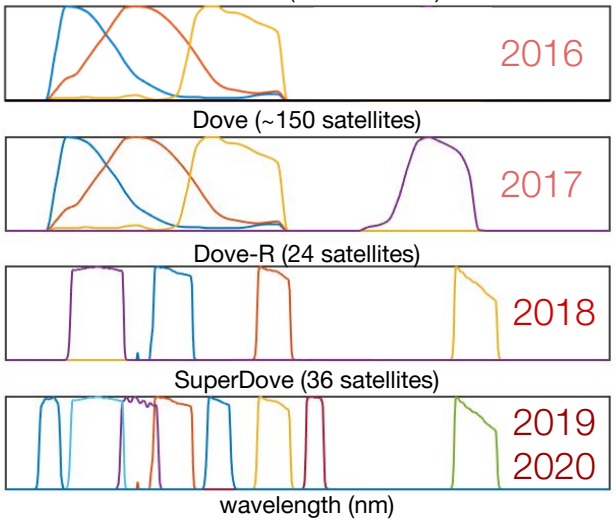
SuperDove (~64 satellites)



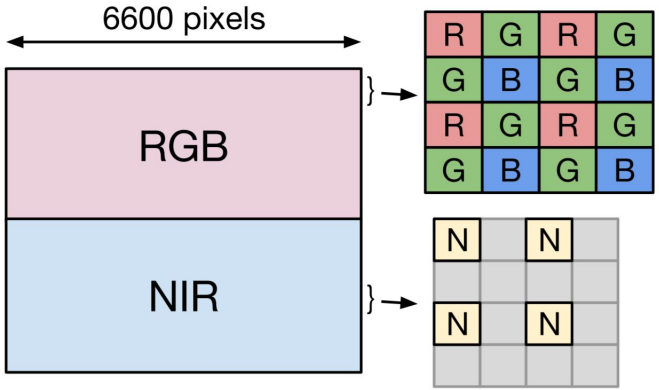
Dove-R versus Sentinel-2

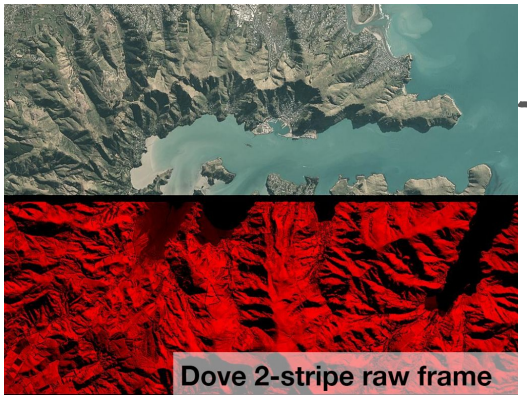


Dove Pilot (~36 satellites)

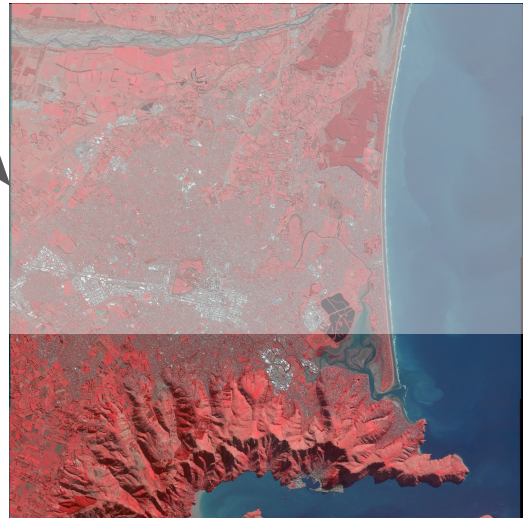


Dove Classic sensor layout





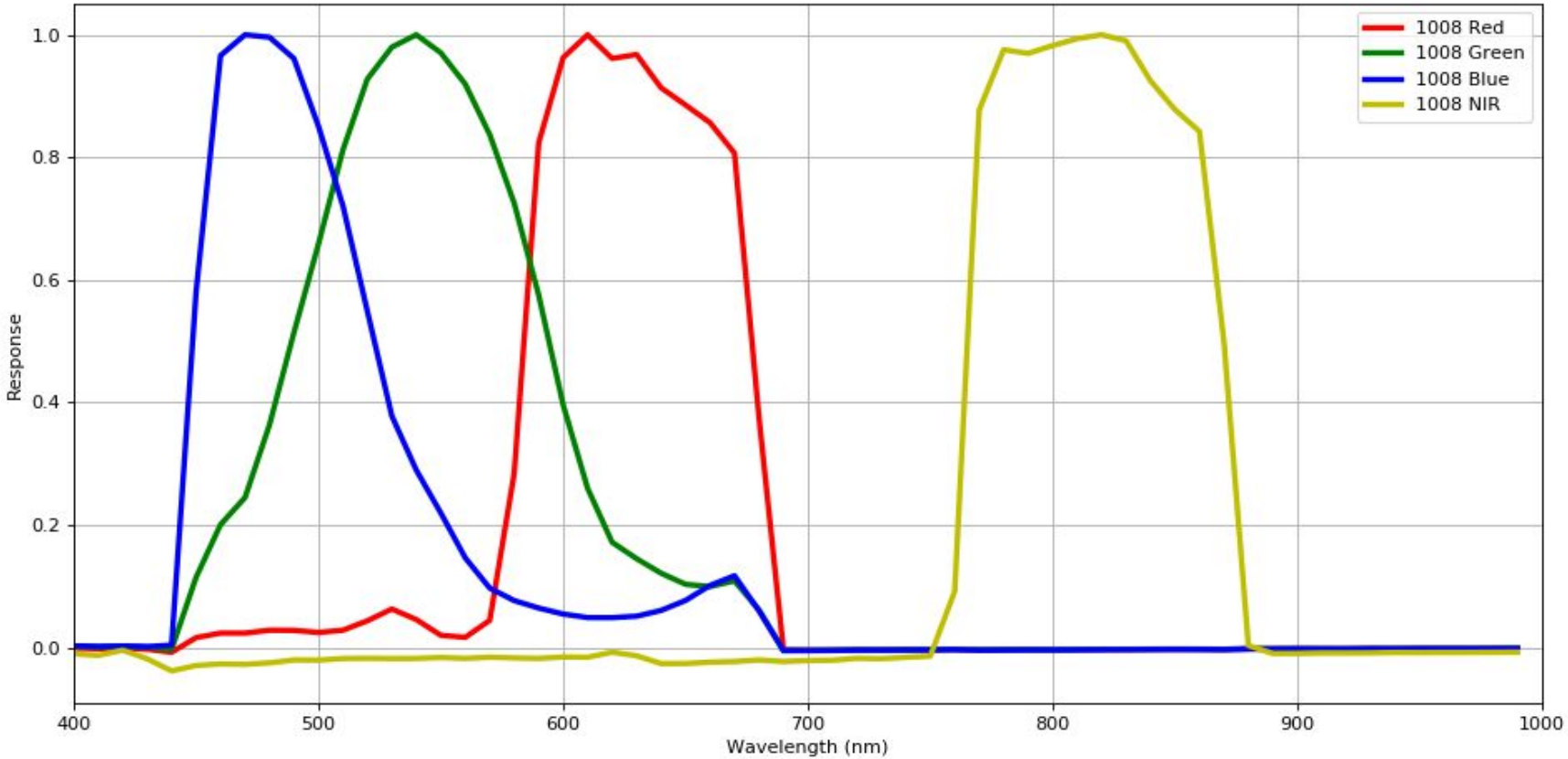
orthorectification



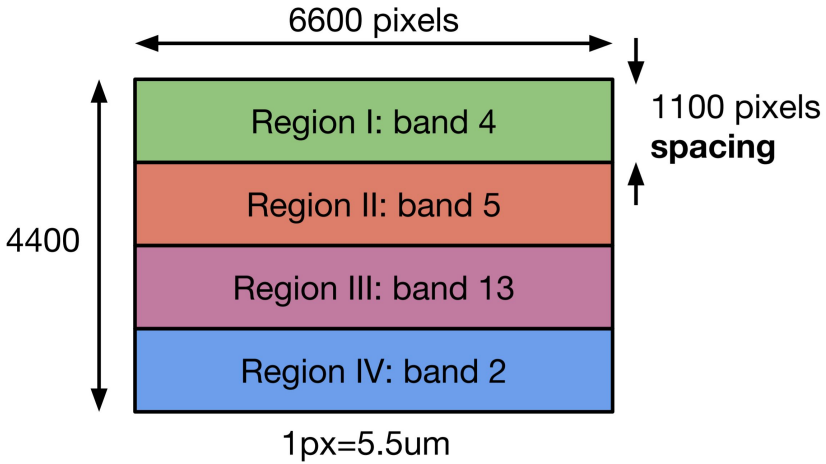
2-stripe half-frame composite

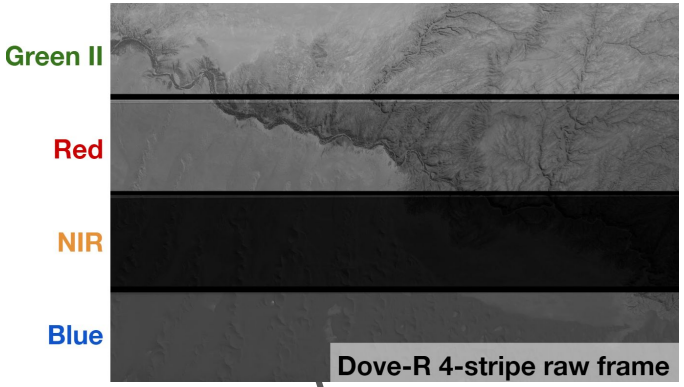
- This is the layout of the two-stripe Dove
  - The top stripe contains the red, blue and green bands in a Bayer pattern
  - The bottom stripe contains the NIR band
  - The orthorectification process allows a four band composite image to be produced

Typical Dove Classic RSR (measured at 10nm resolution)

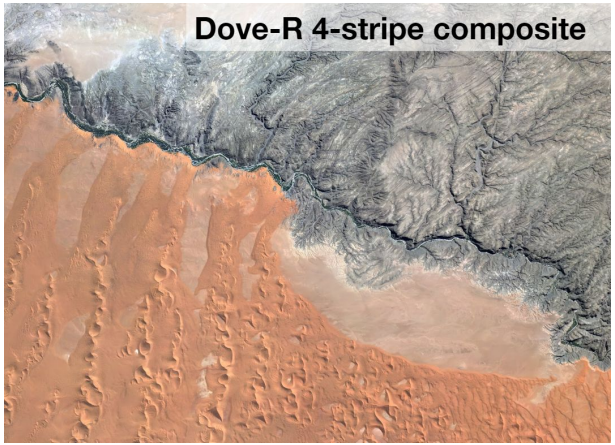


Dove-R sensor layout



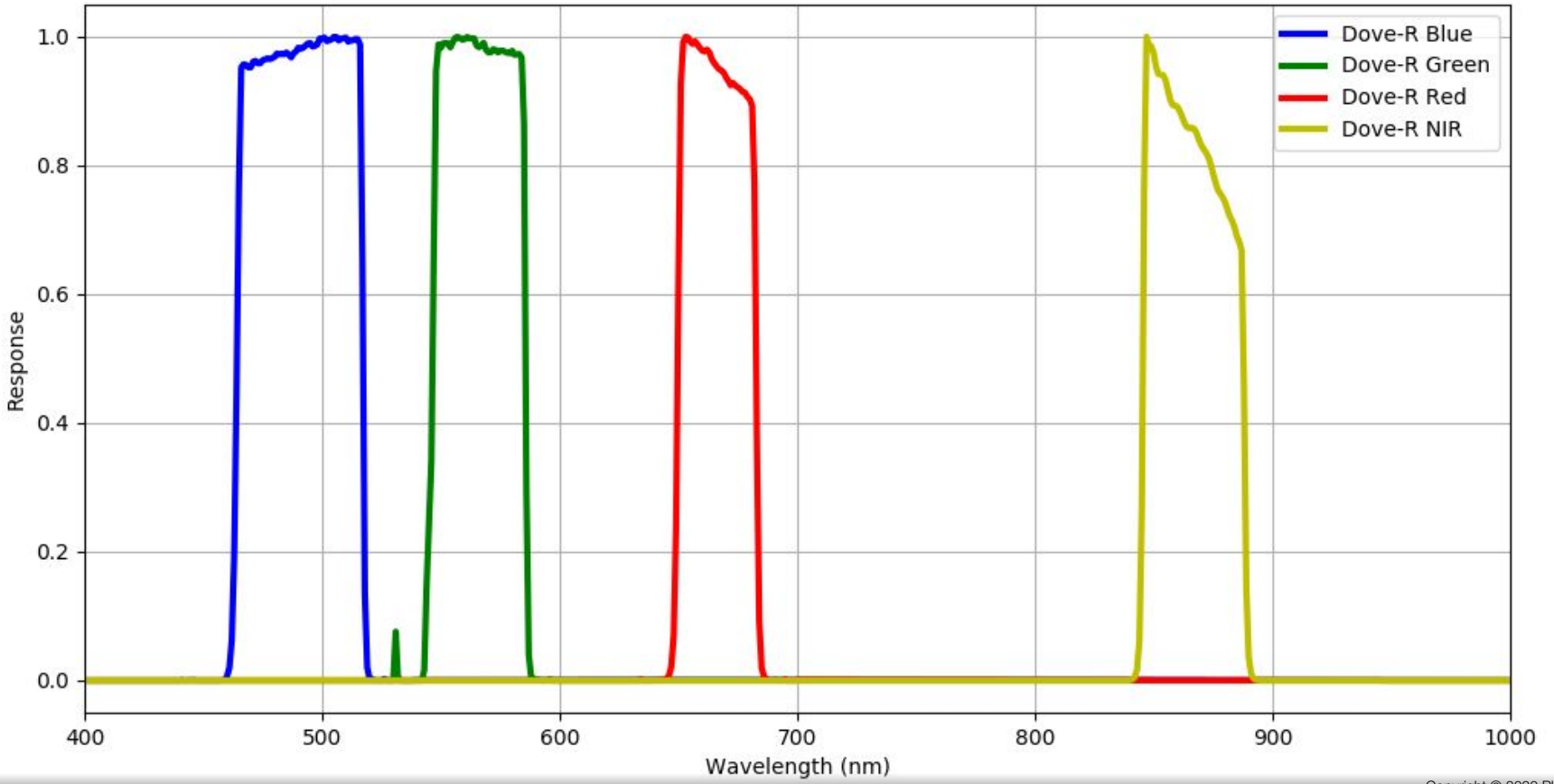


Structure from Motion pipeline

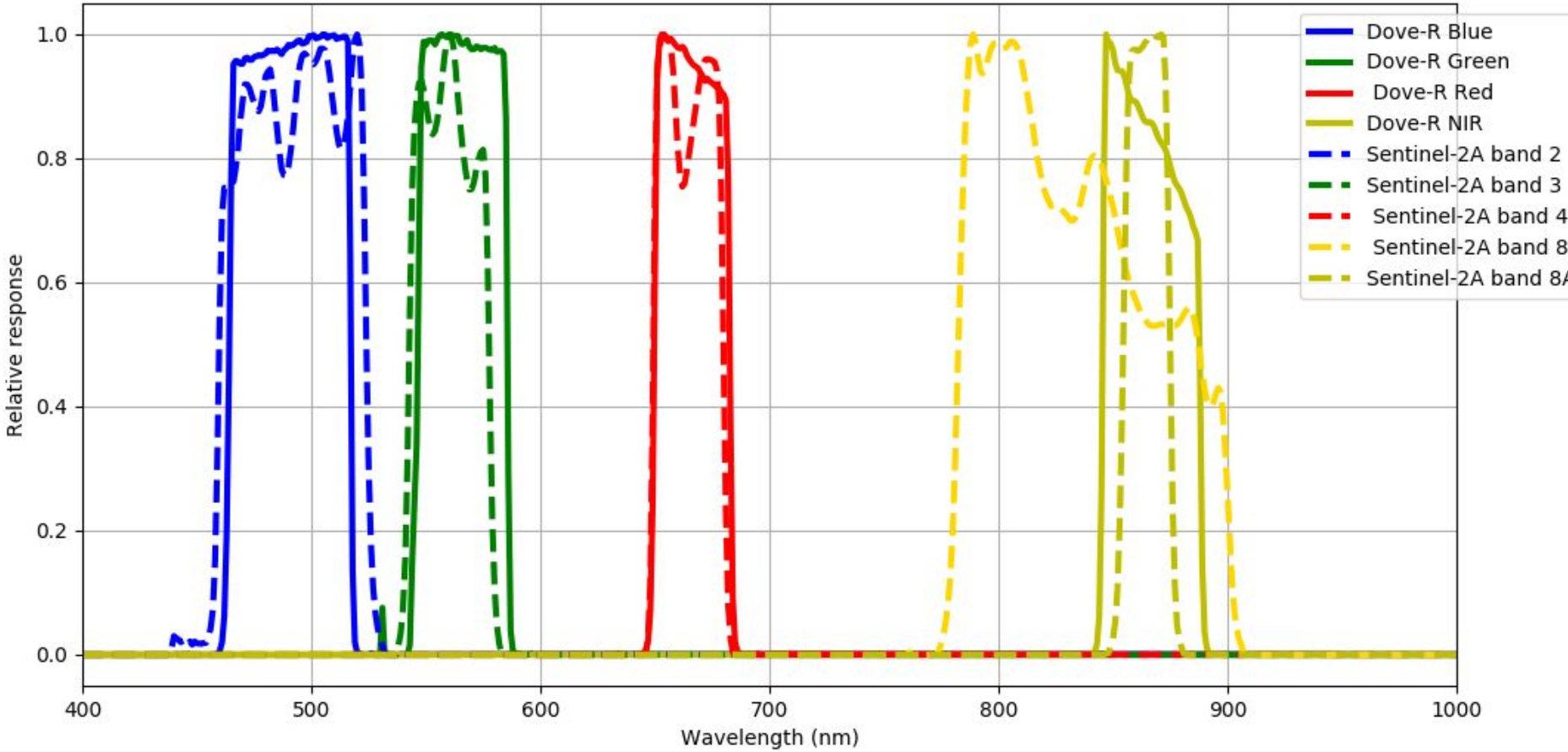


- This is the layout of a Dove-R
  - The four bands are arranged vertically across the sensor
  - Multiple images are taken in rapid succession so that the same point on the Earth is imaged by all the filters as the satellite orbits
  - Subsequent frames are composited together in a structure from motion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

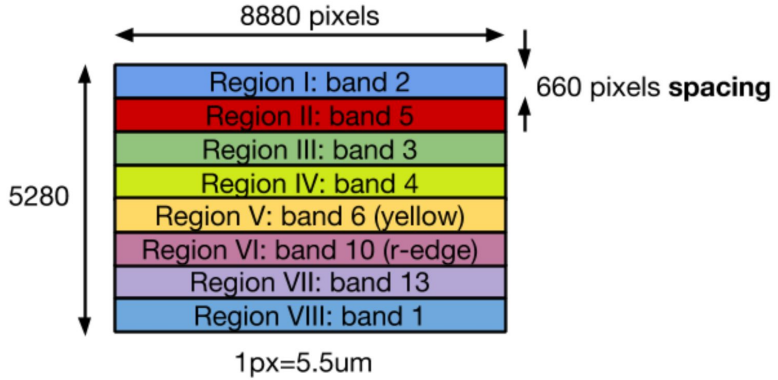
Typical Dove-R RSR (from manufacturer data)



RSR compared to Sentinel-2A



SuperDove 8-band sensor layout



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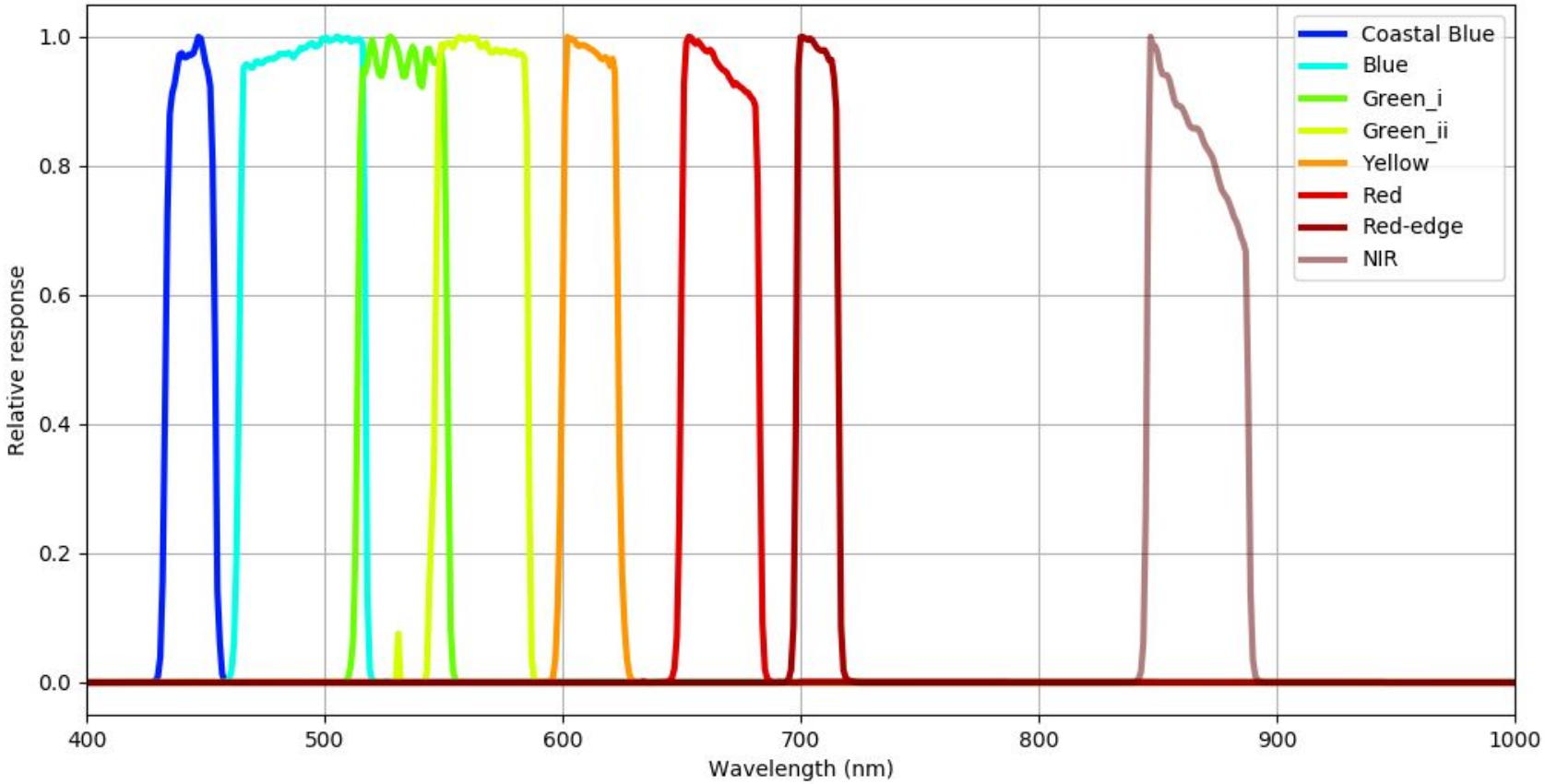
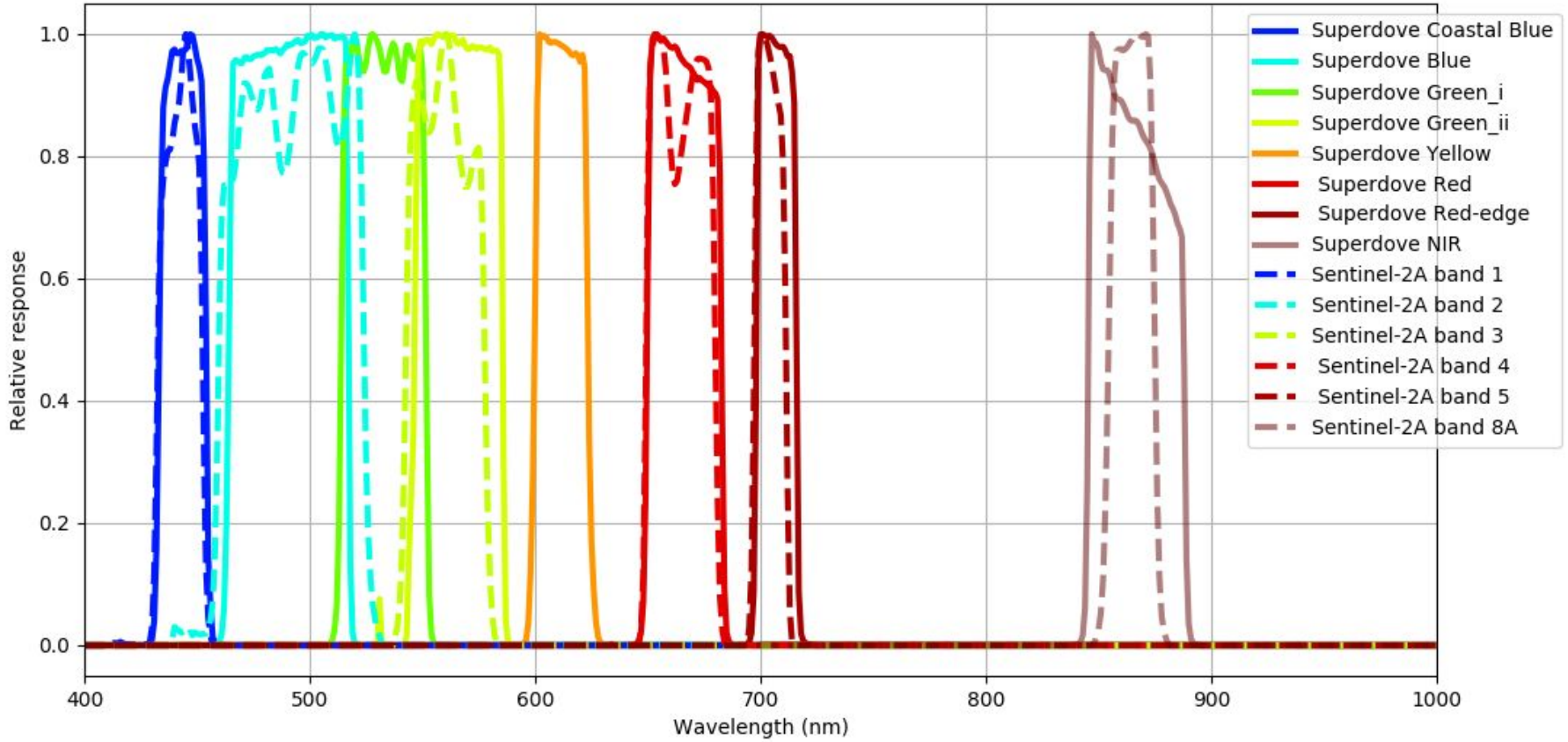
Patent Pending (US20180098014A1)

Superdove RSR (from manufacturer data)



RSR comparison with Sentinel-2



Methodology

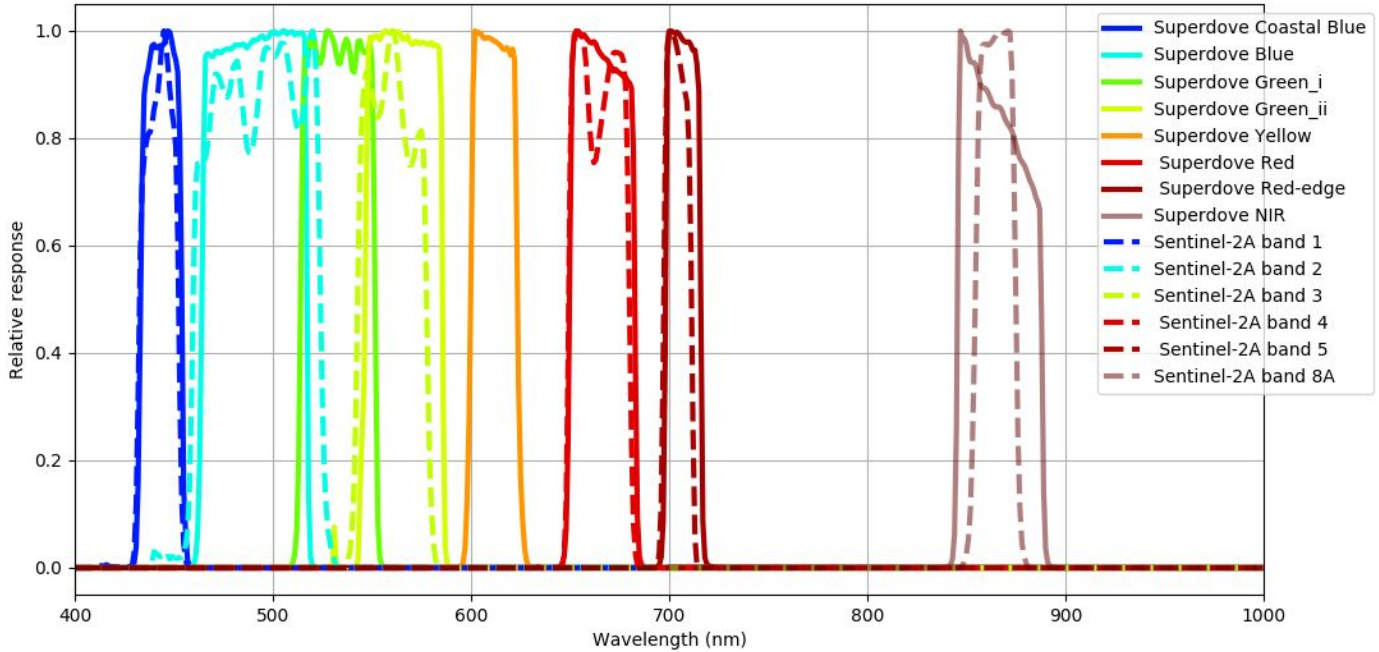
Lake Tuborg, Canada – May 30, 2015

Overview

- The current calibration methodology is based on gathering a dataset of near **simultaneous crossovers with a reference satellite**
  - We use Sentinel-2A and Sentinel-2B as the reference satellites
  - Previously for Dove Classics and Dove-Rs, we used the RapidEye satellites but we are currently changing the reference for those satellites to the Sentinel-2 satellites as well for consistency
- The assumption was made that for the **six shared bands between Sentinel-2 and SuperDoves**, an SBAF was **unnecessary** since their RSRs were so similar
- This allows us to move **away** from well-characterised calibration sites and do a **global search** for near simultaneous crossovers
  - A global search means that a **wider range of terrain types** are captured in the calibration dataset, from **dark sites, vegetation sites to the cryosphere**
- It also means that the calibration dataset for each satellite is **much larger** and a valid calibration dataset can be generated **rapidly** after launch

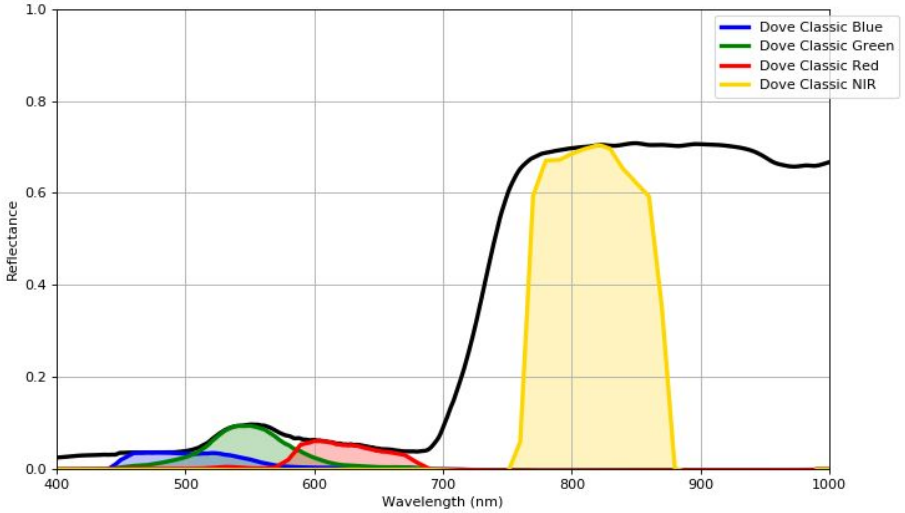
Differences in RSRs

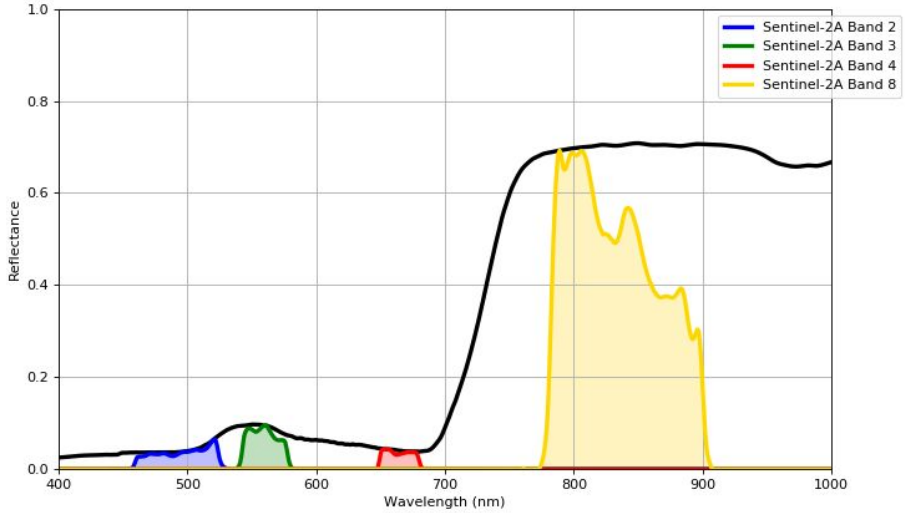
- The assumption was made that the RSRs of the Sentinel-2 satellites are so similar to the SuperDove satellites that well-characterised calibration sites and SBAFs are unnecessary



Effects of Differing Responses: **Dove Classic**

A lawn grass spectrum from a spectral library



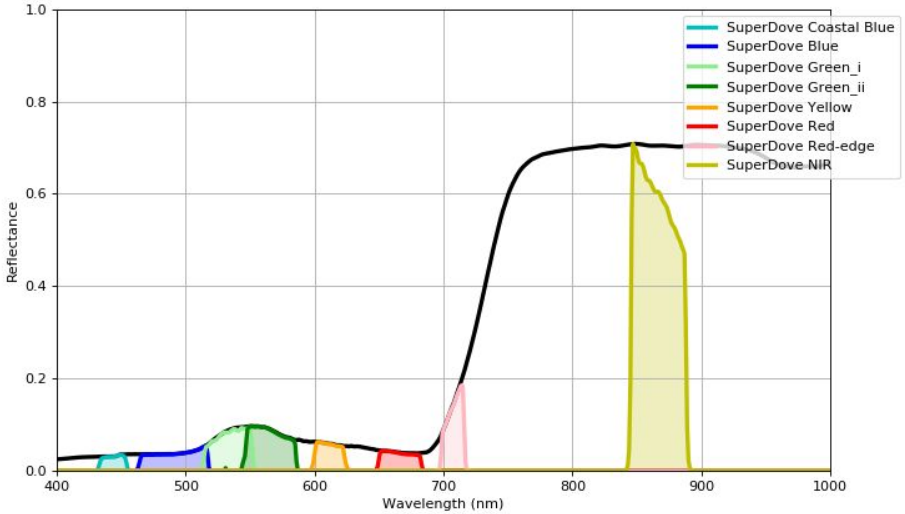


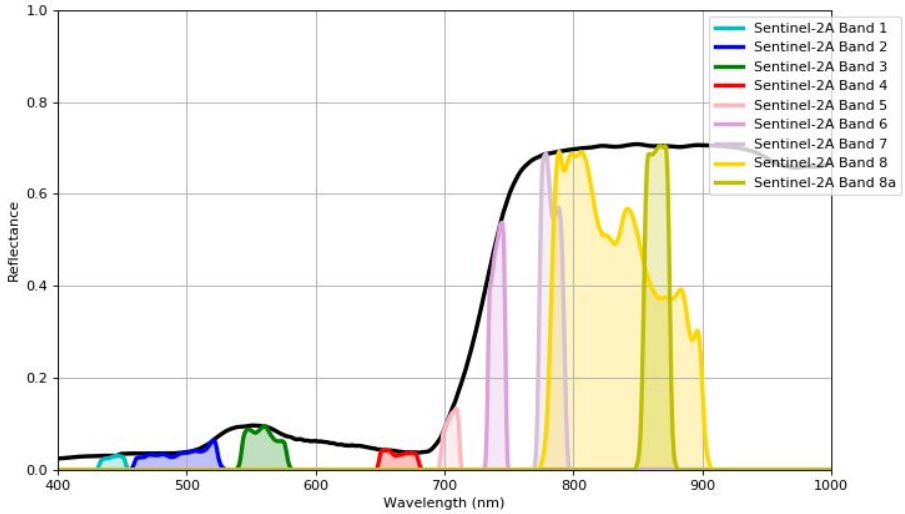
SBAF Corrections *Dove Classic → Sentinel-2*	Blue to Band 2	Green to Band 3	Red to Band 4	NIR to Band 8
	1.034	1.415	0.851	0.943

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

Effects of Differing Responses: **SuperDove**

A lawn grass spectrum from a spectral library





SBAF Corrections *SuperDove → Sentinel-2*	Coastal Blue to Band 1	Blue to Band 2	Green_ii to Band 3	Red to Band 4	Red-edge to Band 5	NIR to Band 8a
	0.992	1.019	1.053	0.9524	0.846	1.000

Calculating the spectral band adjustment factors between Sentinel-2 and SuperDove

Differences in RSRs

- To validate this assumption, the USGS Spectral Library v7 [1] was used to perform a study on the SBAFs to between SuperDove and Sentinel-2 for the six common bands

[1] Kokaly, R.F., Clark, R.N., Swayze, G.A., Livo, K.E., Hoefen, T.M., Pearson, N.C., Wise, R.A., Benzel, W.M., Lowers, H.A., Driscoll, R.L., and Klein, A.J., 2017, USGS Spectral Library Version 7: U.S. Geological Survey Data Series 1035, 61 p., https://doi.org/10.3133/ds1035.

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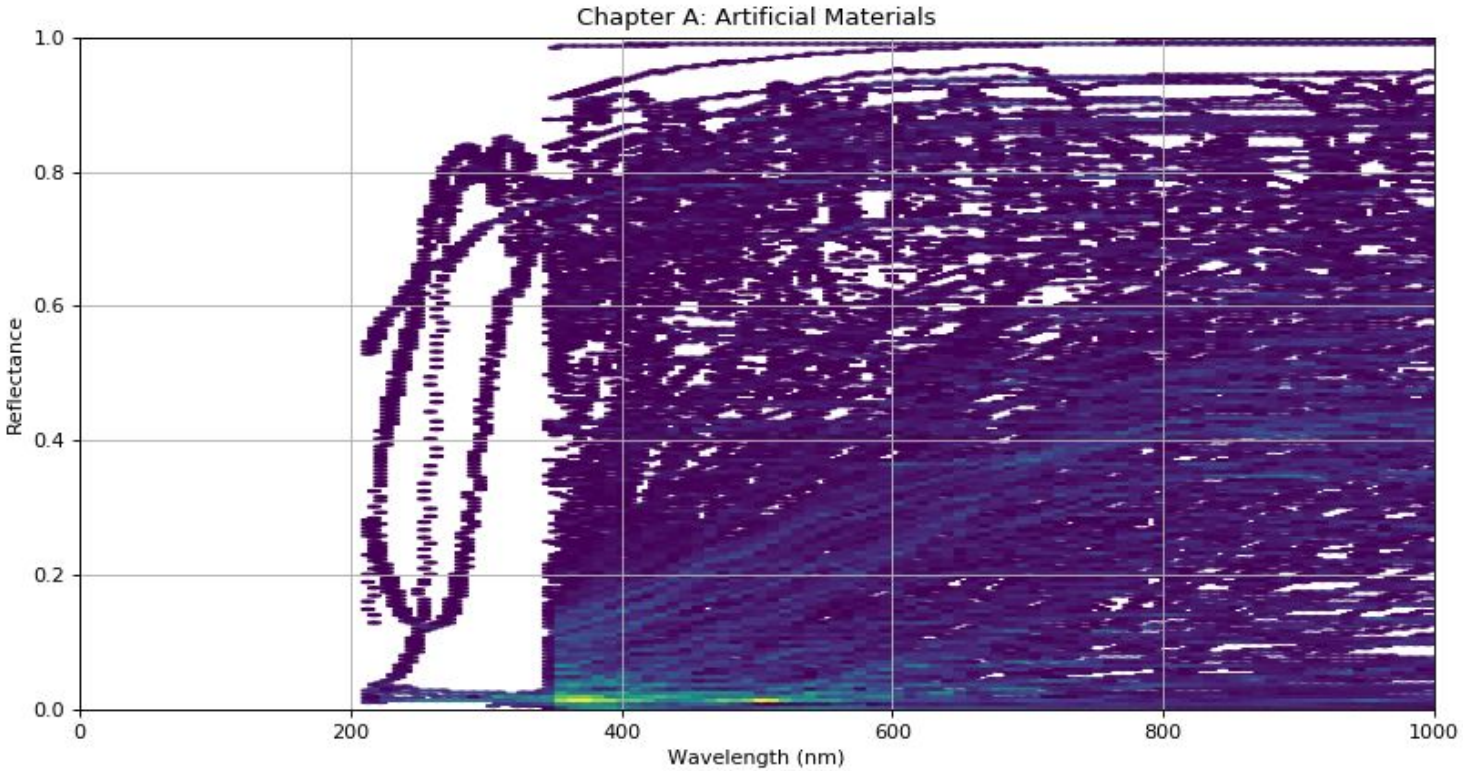
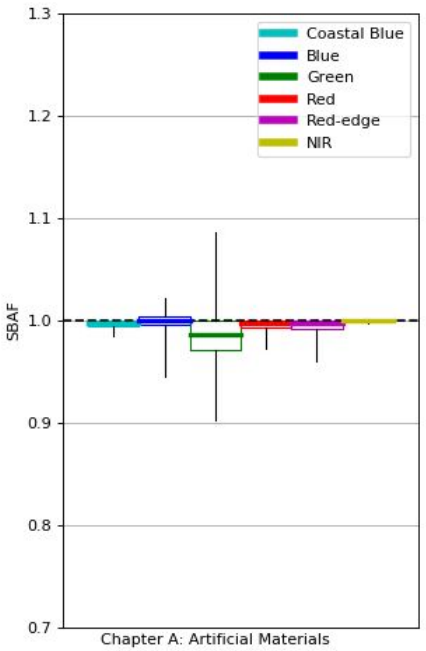
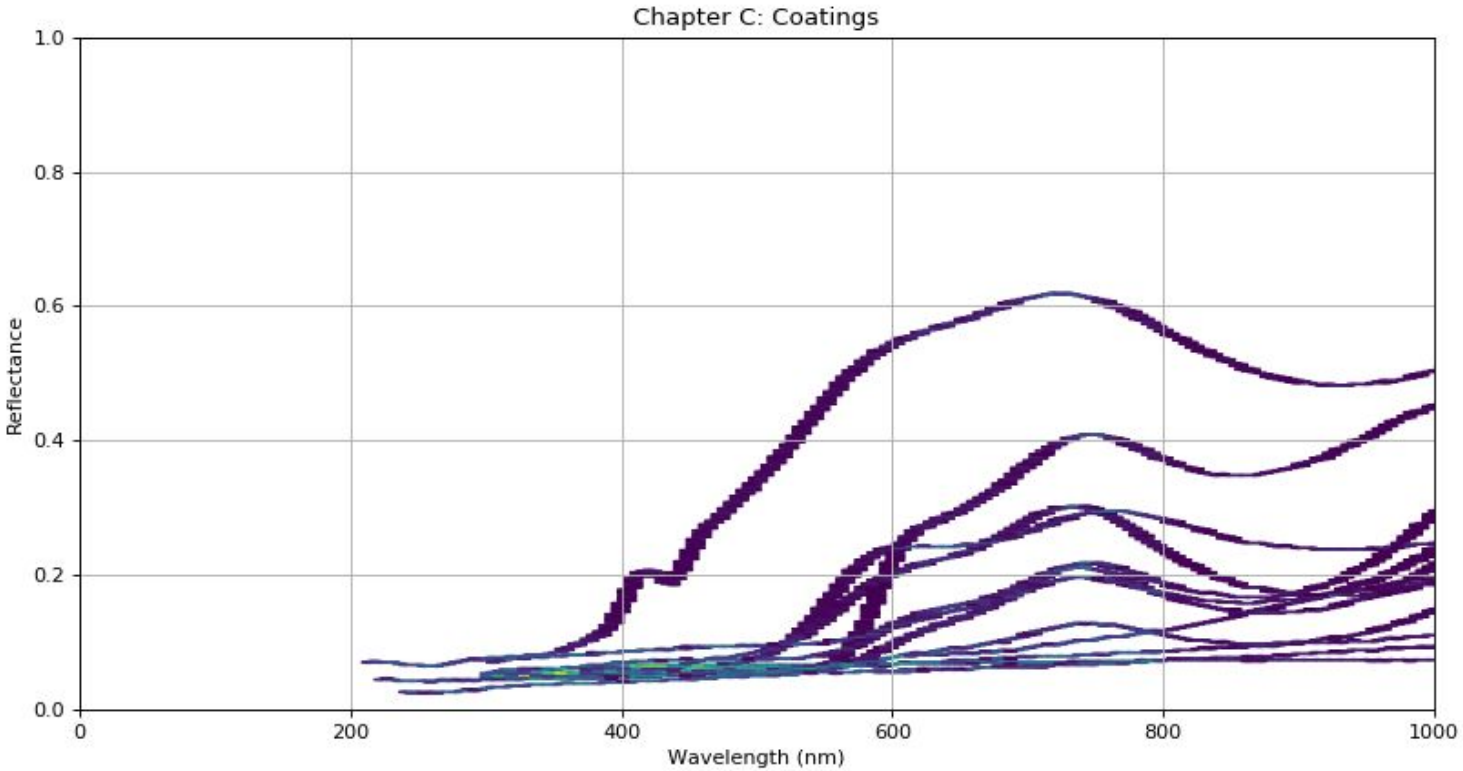
Chapter A - Artificial Materials (275 spectra)

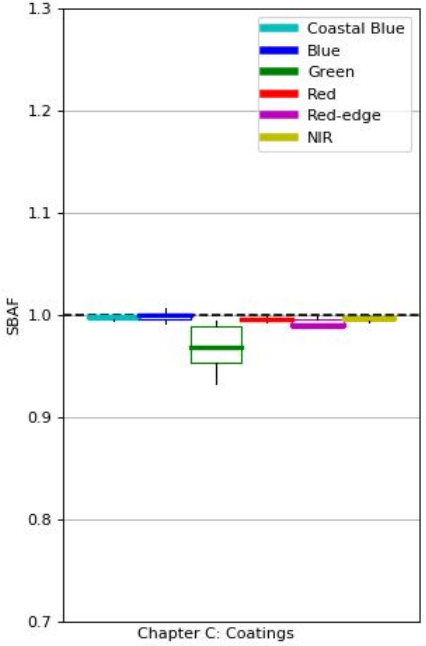




A density plot showing the range of spectra in this chapter

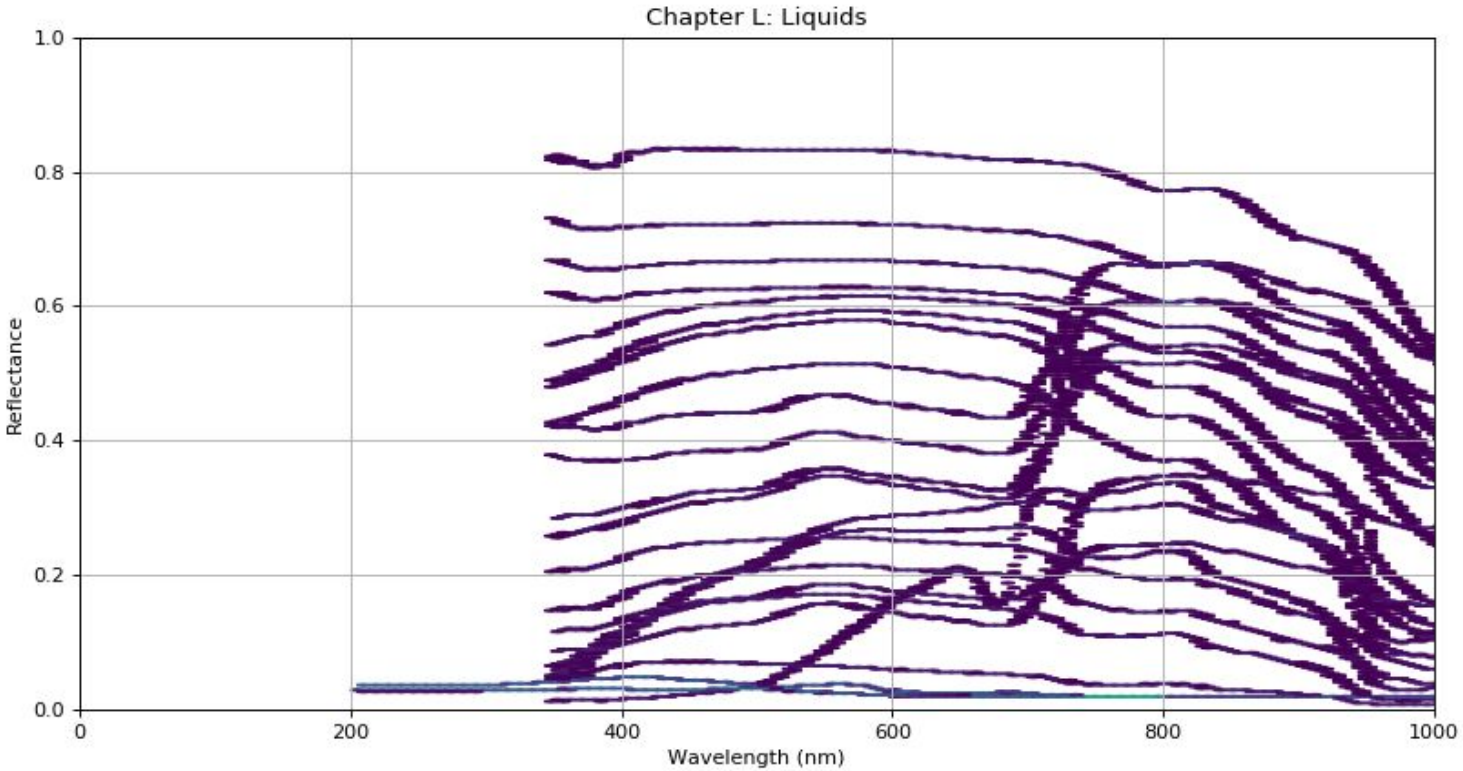
Chapter C - Coatings (12 spectra)

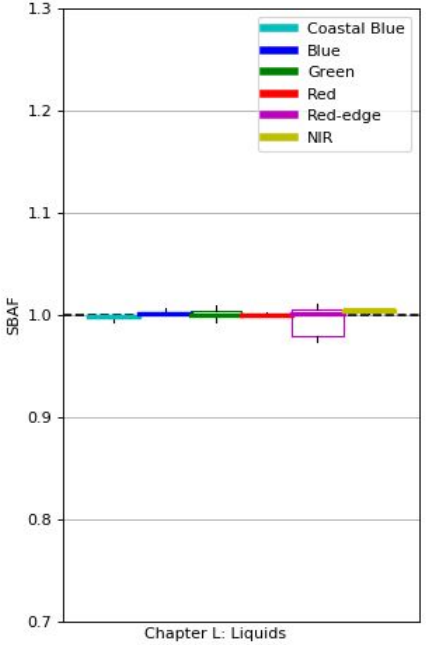




A density plot showing the range of spectra in this chapter

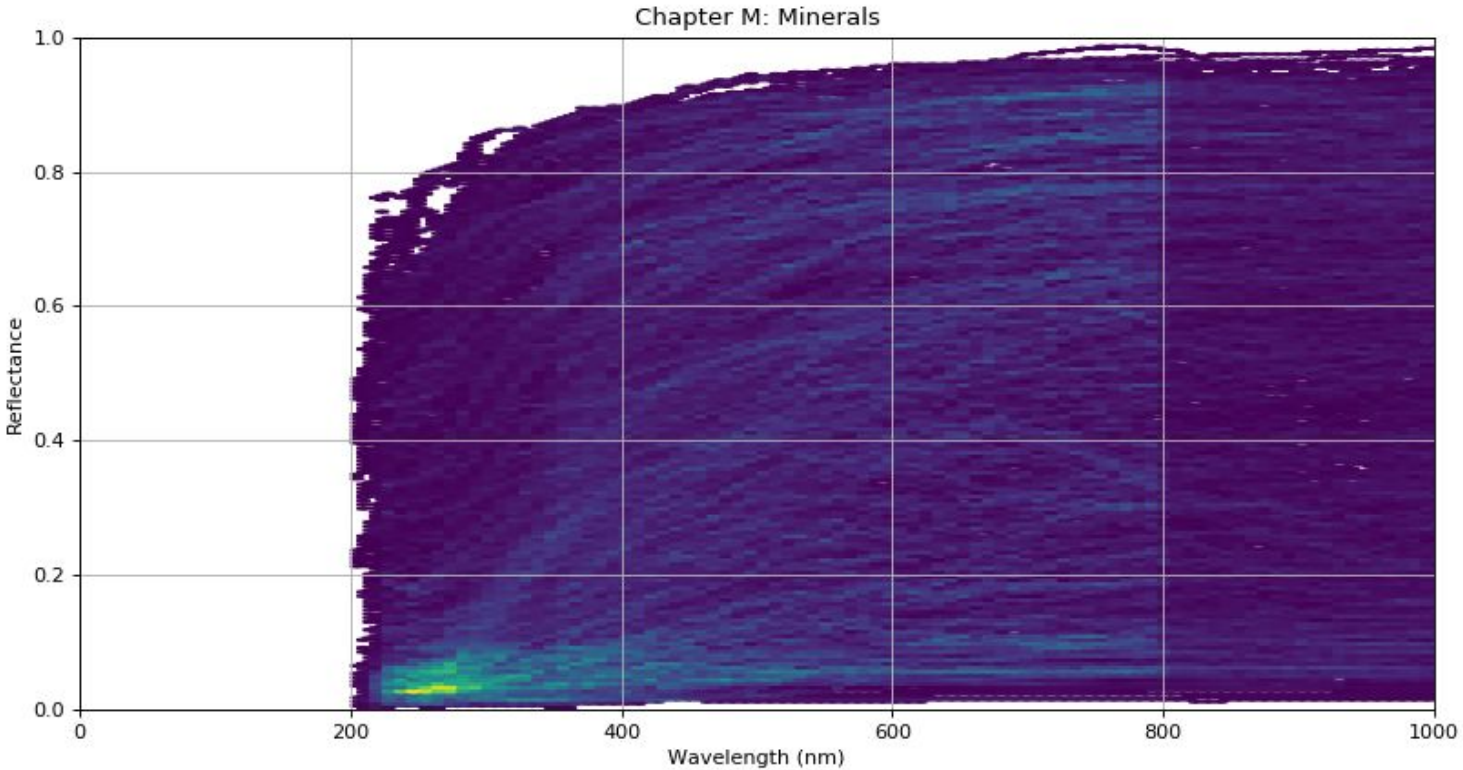
Chapter L - Liquids (23 spectra)

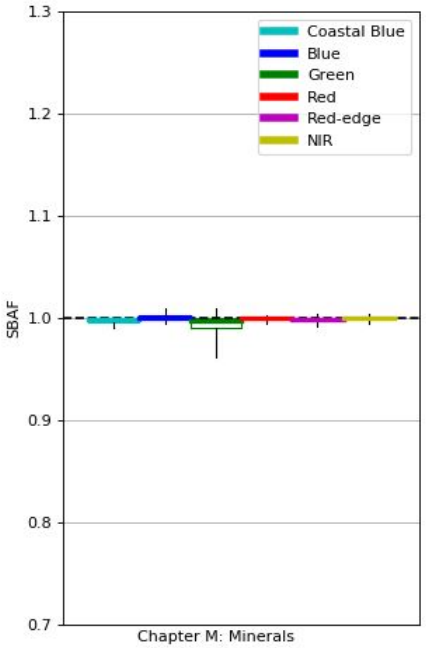




A density plot showing the range of spectra in this chapter

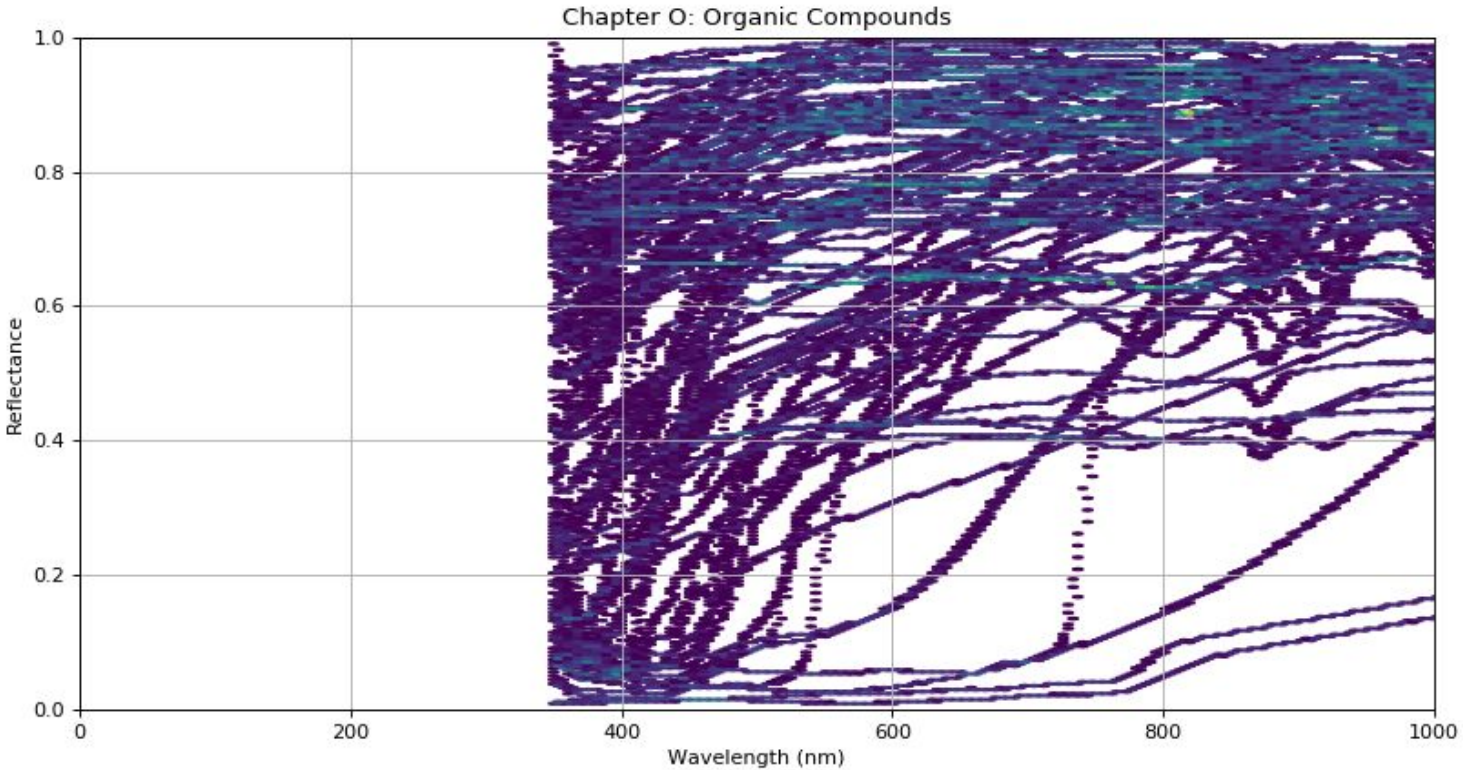
Chapter M - Minerals (855 spectra)

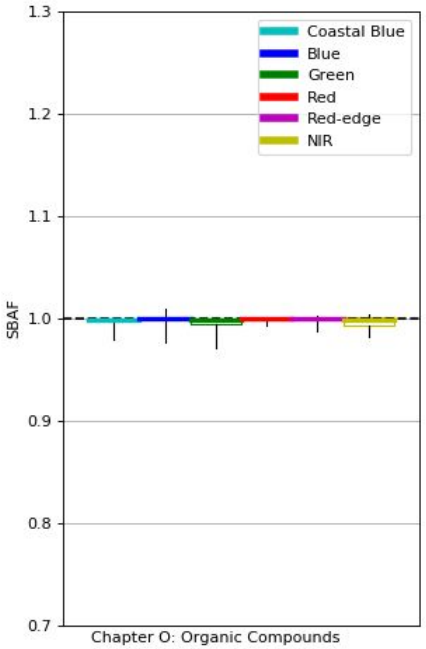




A density plot showing the range of spectra in this chapter

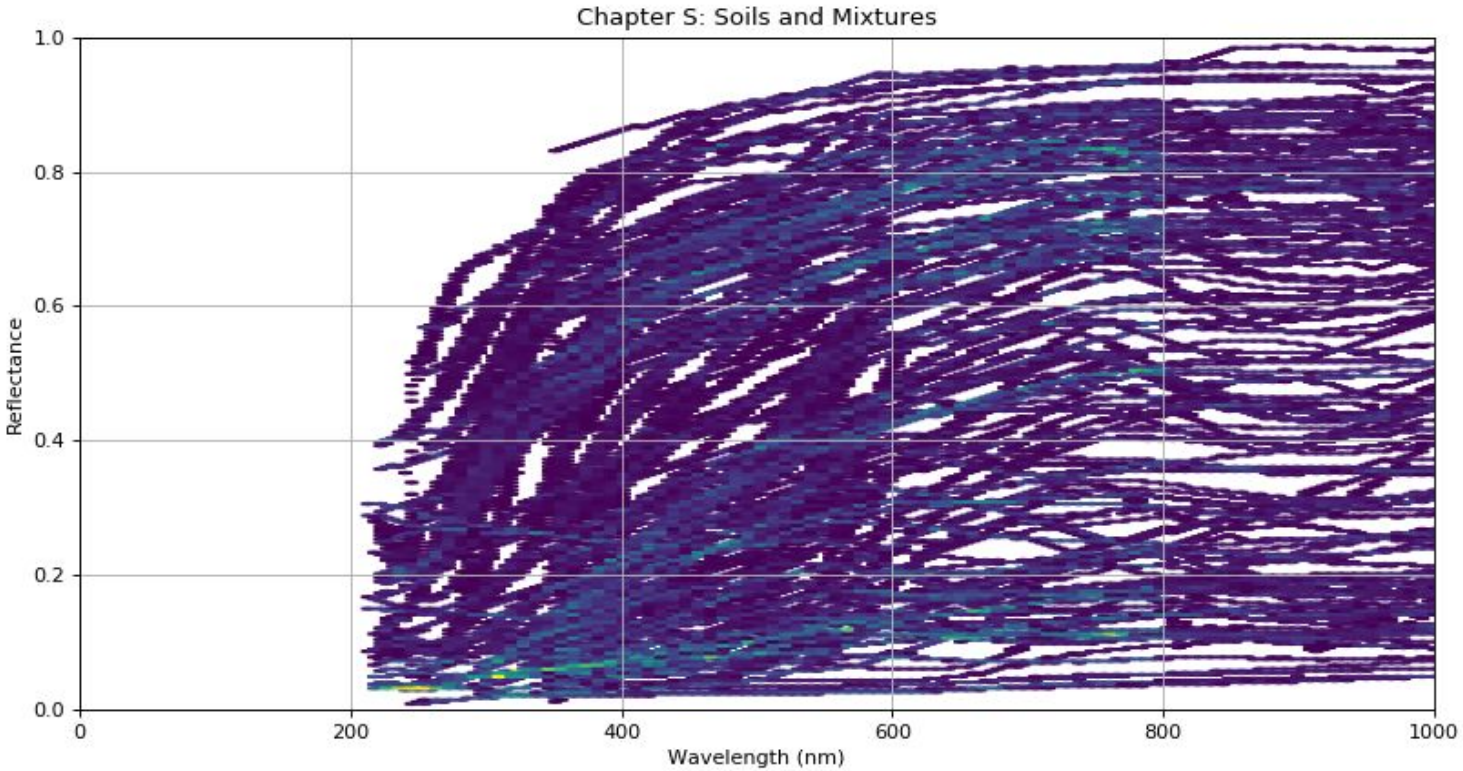
Chapter O - Organic Compounds (113 spectra)

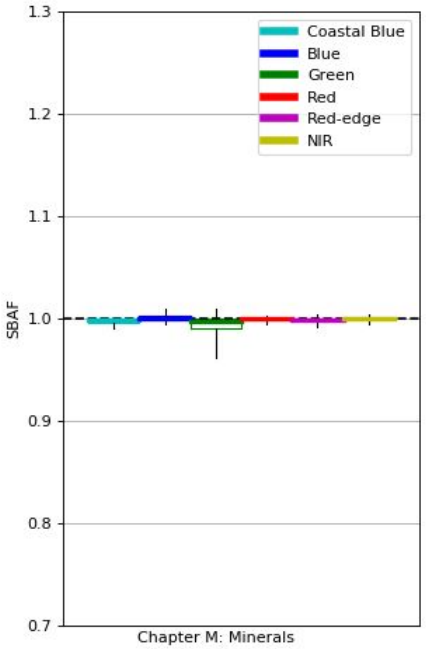




A density plot showing the range of spectra in this chapter

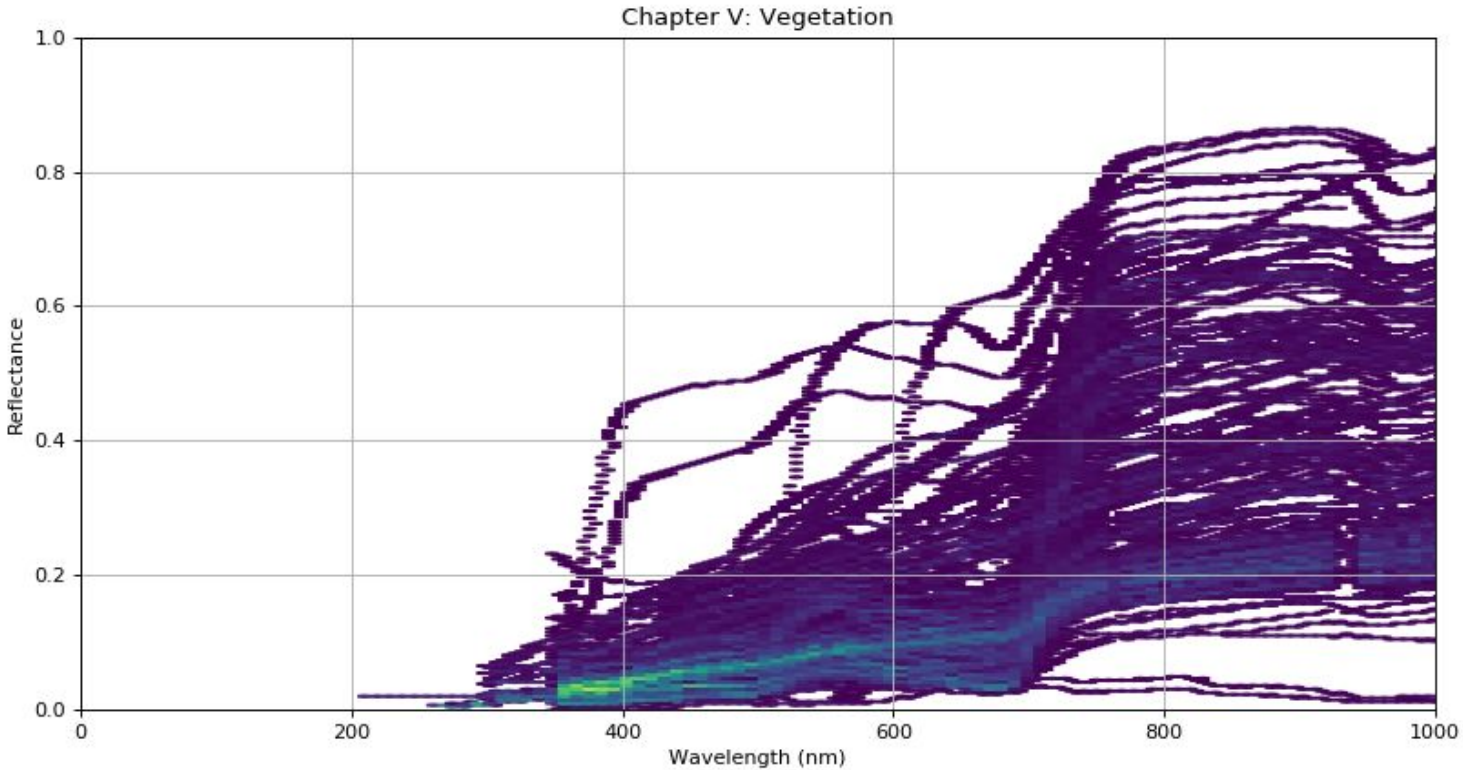
Chapter S - Soils and Mixtures (167 spectra)

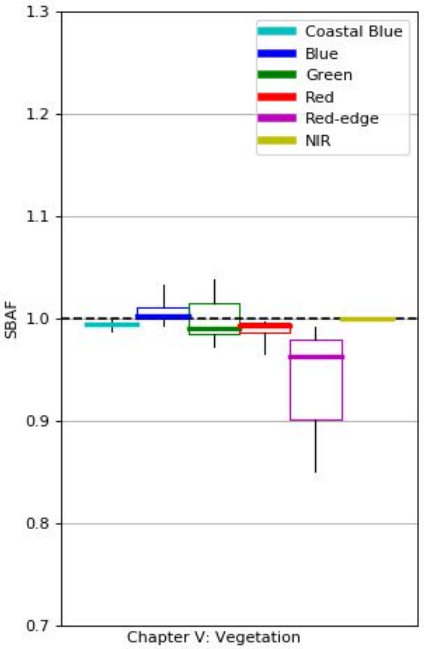




A density plot showing the range of spectra in this chapter

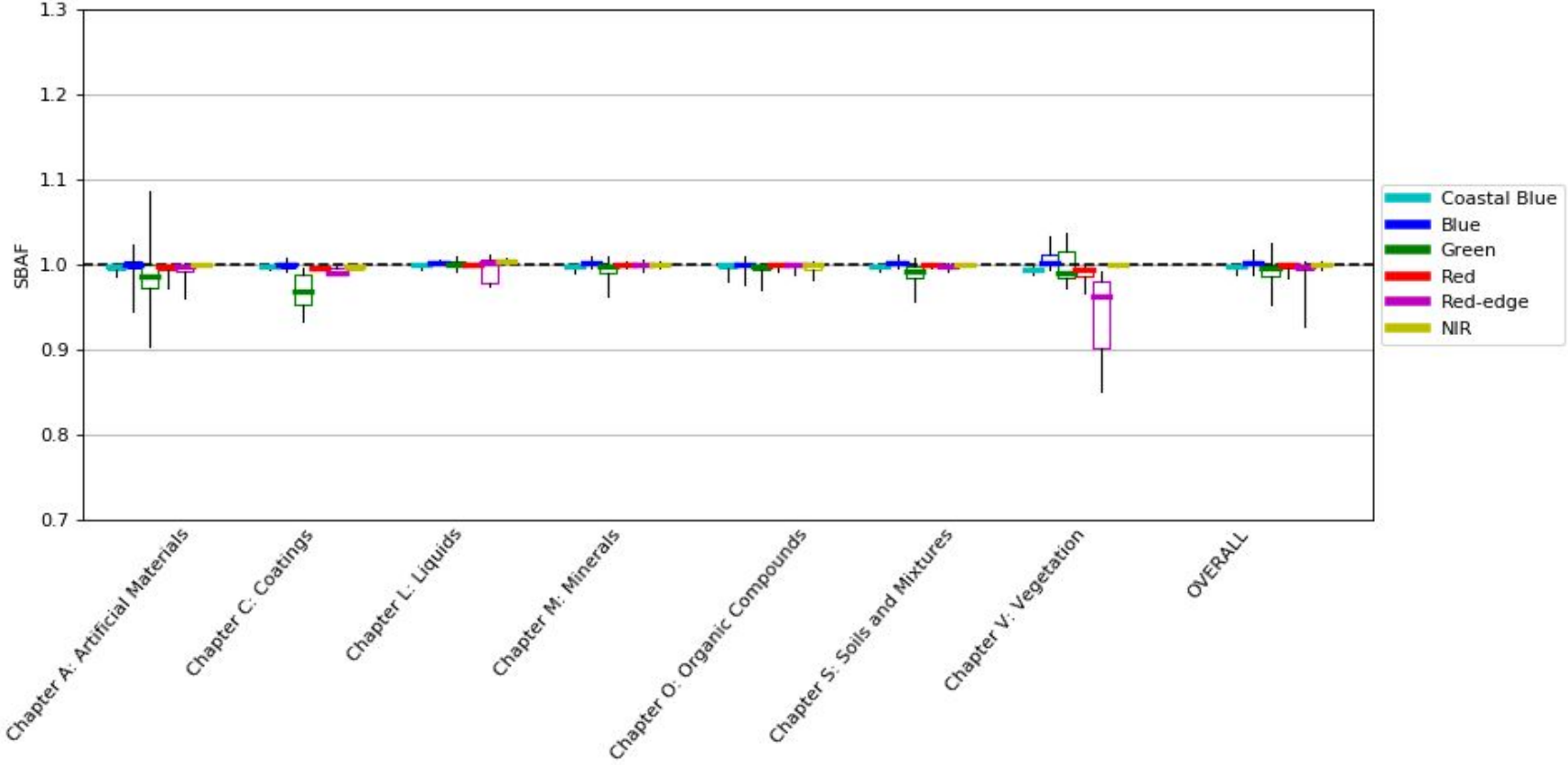
Chapter V - Vegetation (238 spectra)





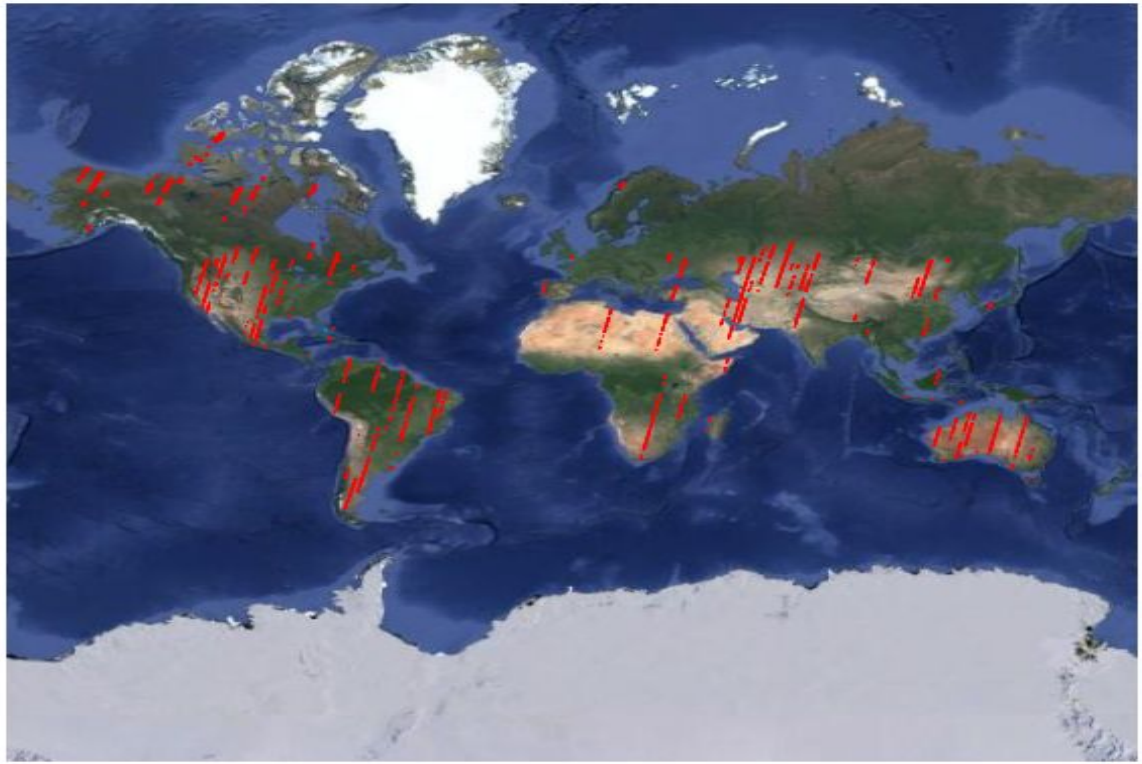
A density plot showing the range of spectra in this chapter

Average SBAFs divided up by chapter



An example of the results of a global search

- This is a **single SuperDove (222c)** ‘s near simultaneous crossovers with Sentinel-2A and Sentinel-2B for the **first week of September 2020**
  - There was **less than two hours difference** between a Sentinel-2 image and a Superdove
  - Just that one week produced **1969 crossover orthotiles**

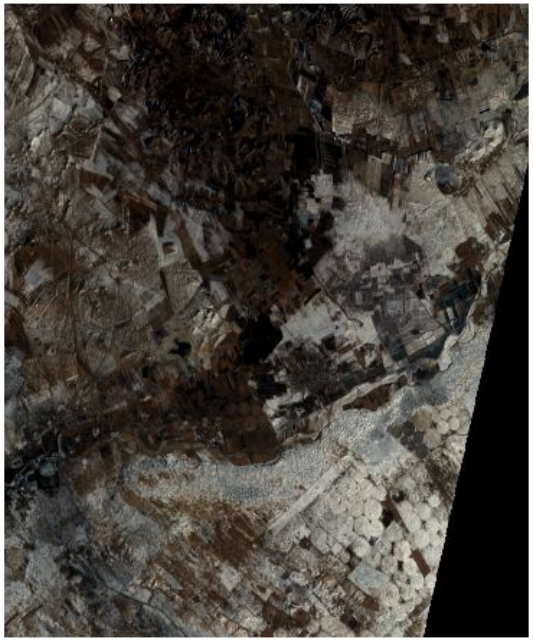


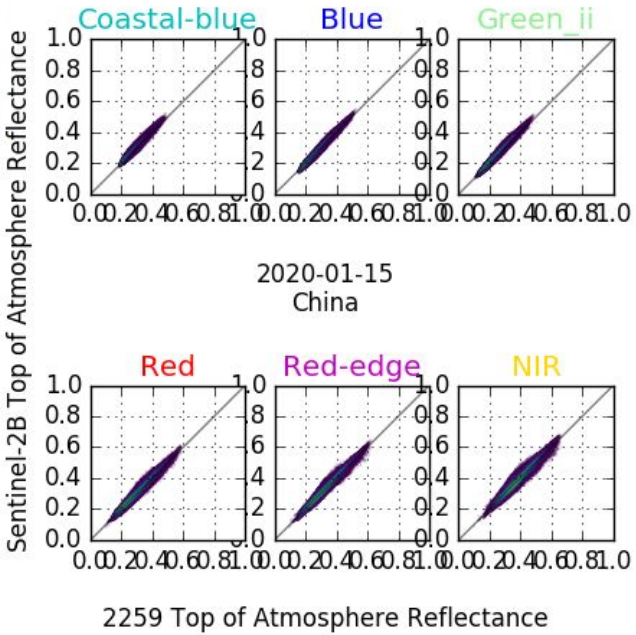
Examples of crossovers

- The crossovers are processed to **Top of Atmosphere Reflectance at 30m per pixel**
- **Orthotiles** are used (based on 25km square tiles within the UTM coordinate system) to divide up the crossover dataset
  - Only the orthotiles with joint crossover pixels that **cover more than 25% of the orthotile** area are used to exclude tiny slithers
- Below are some **examples** of the crossovers

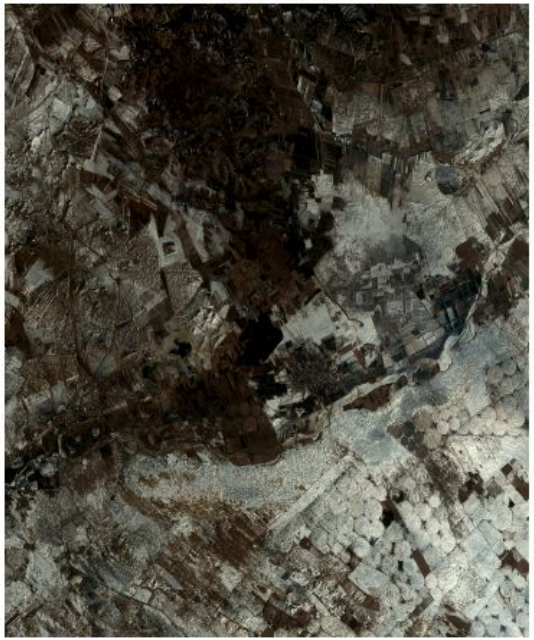
China - 2020-01-15

2259



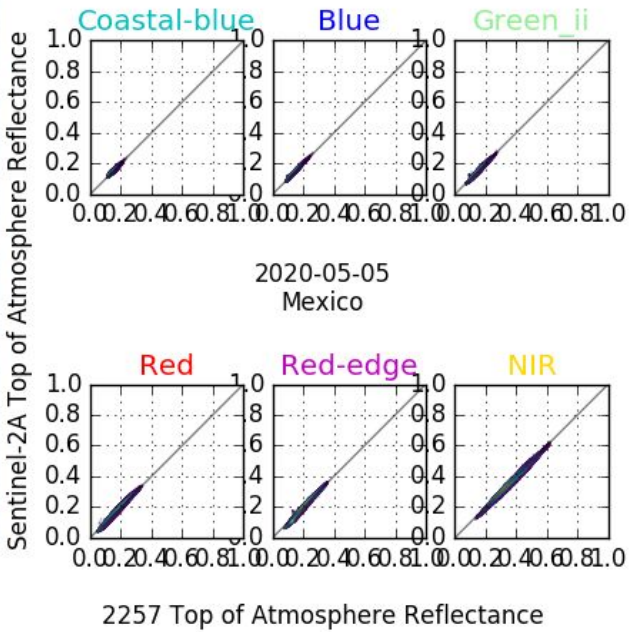


Sentinel-2B



Mexico - 2020-05-05

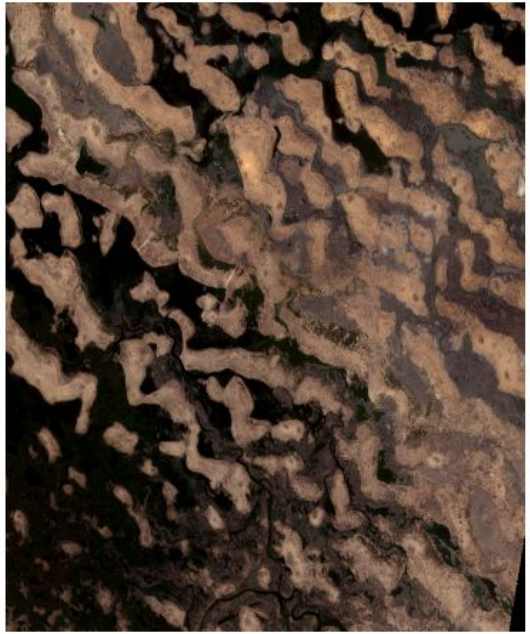
2257

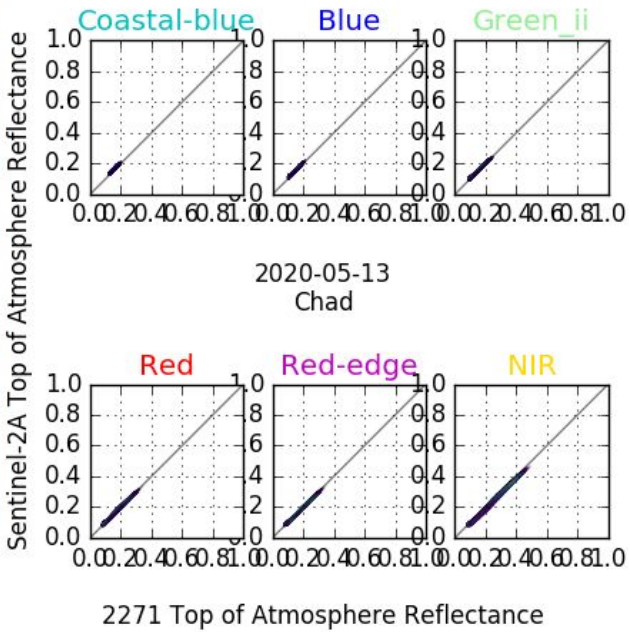


Sentinel-2A

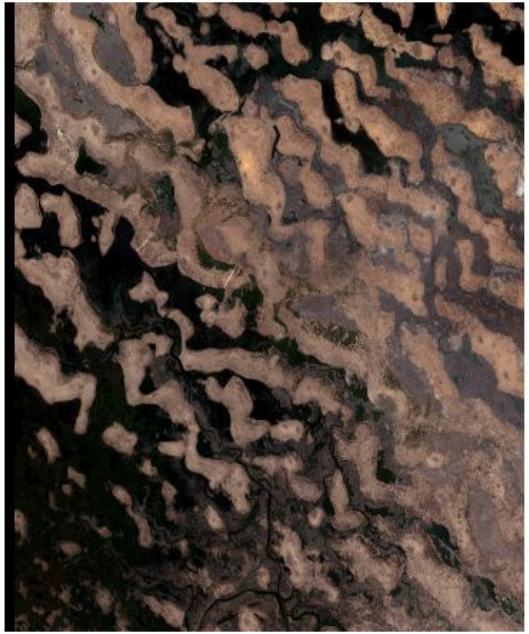
Chad - 2020-05-13

2271





Sentinel-2A



Collecting statistics

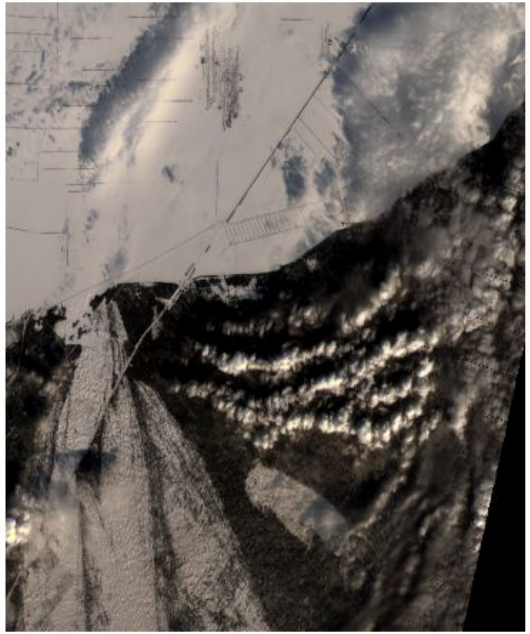
- From each orthotile crossover, **statistics** are gathered:
  - The **joint mode of the candidate and reference pixels** of the orthotile
  - The **RANSAC linear fit** of the candidate and reference pixels and the **R^2 score of the fit**
  - The min, median, mean, max and standard deviation of the candidate pixel distribution and the reference pixel distribution
- These are then **collated** for all the orthotile crossovers

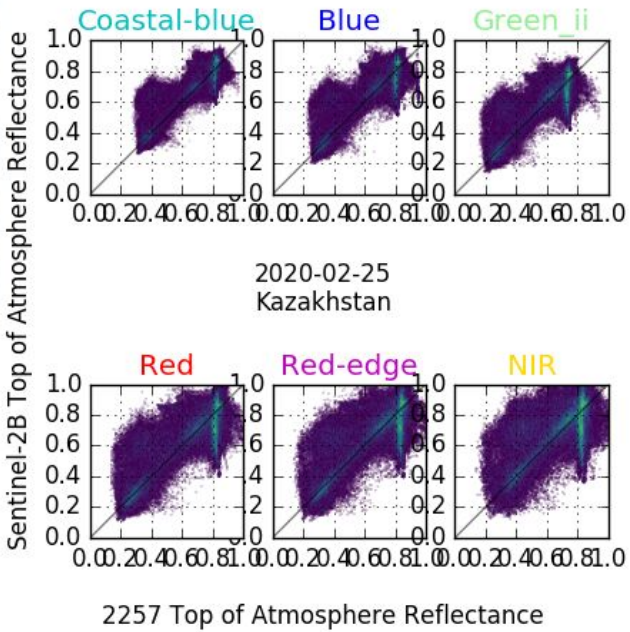
More examples of crossovers

- Since we take all the crossovers blindly, there could be **changes in cloud cover or atmospheric conditions** in some of the crossovers
  - The **R^2 score of the fit** between the reference pixels and the candidate pixels could be used to filter them out
  - But instead, the **joint mode of the candidate and reference pixel distribution for each orthotile** is used. This will be explained in more detail later
- Below are some examples of the crossovers have a **poor R^2 score**

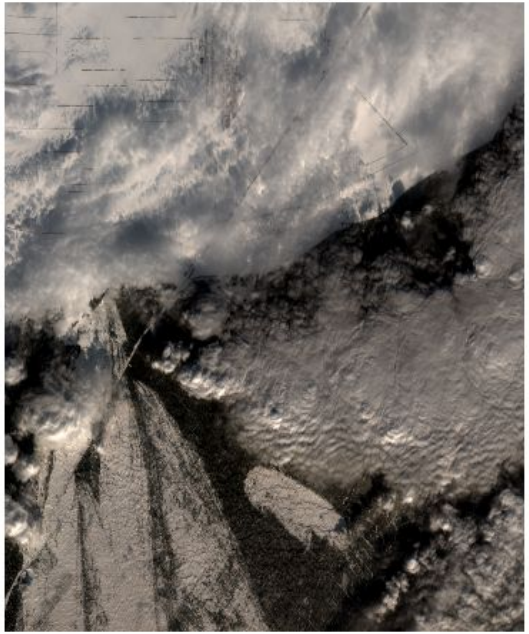
Kazakhstan - 2020-02-25

2257



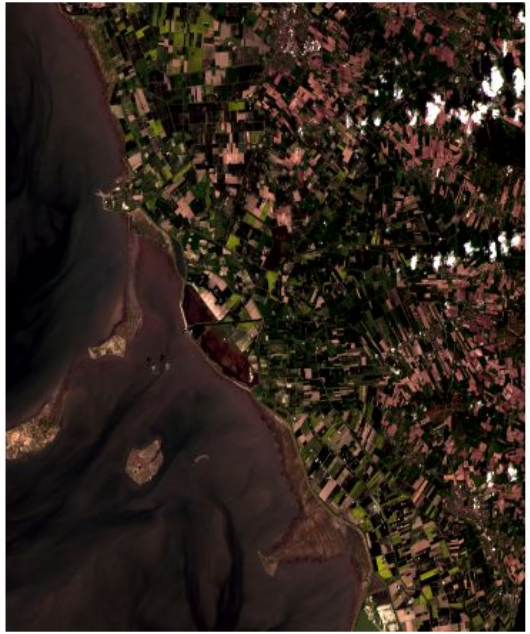


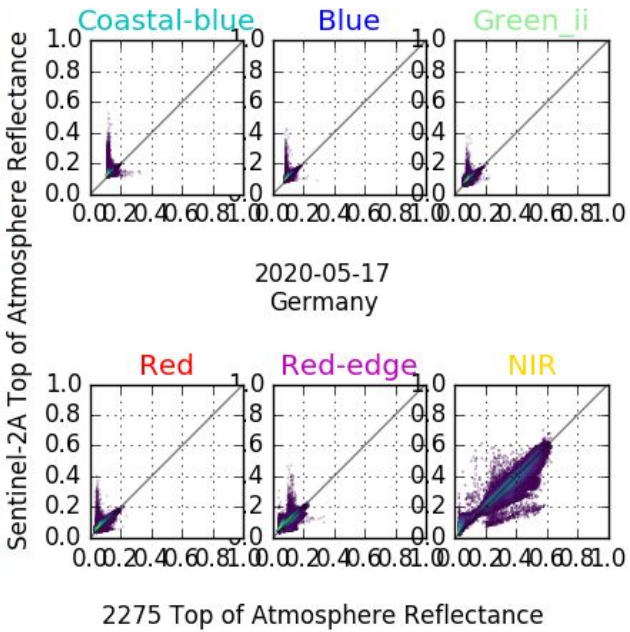
Sentinel-2B



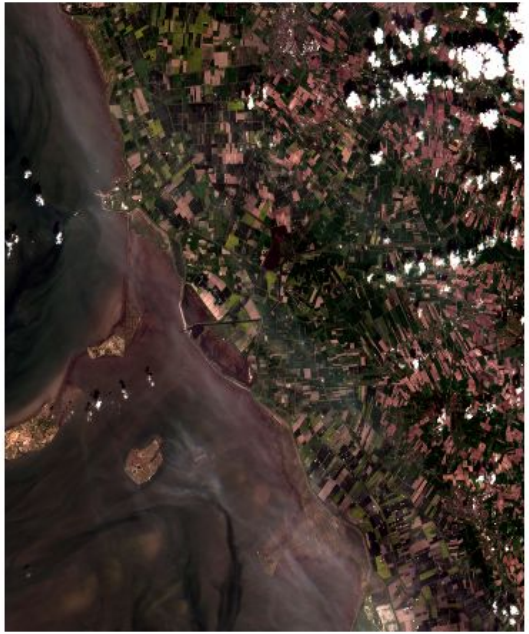
Germany - 2020-05-17

2275



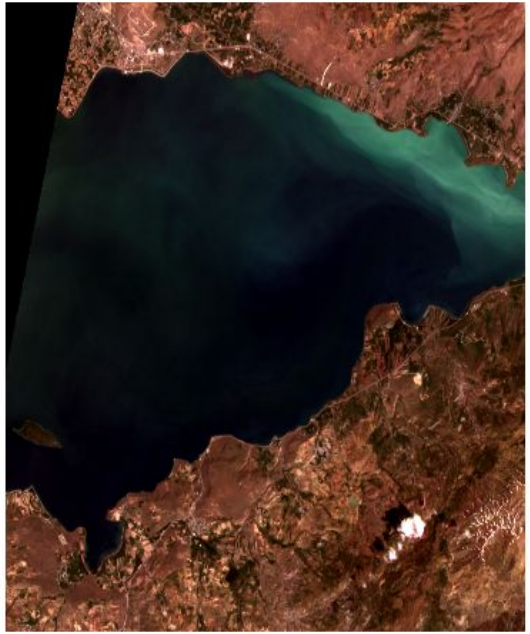


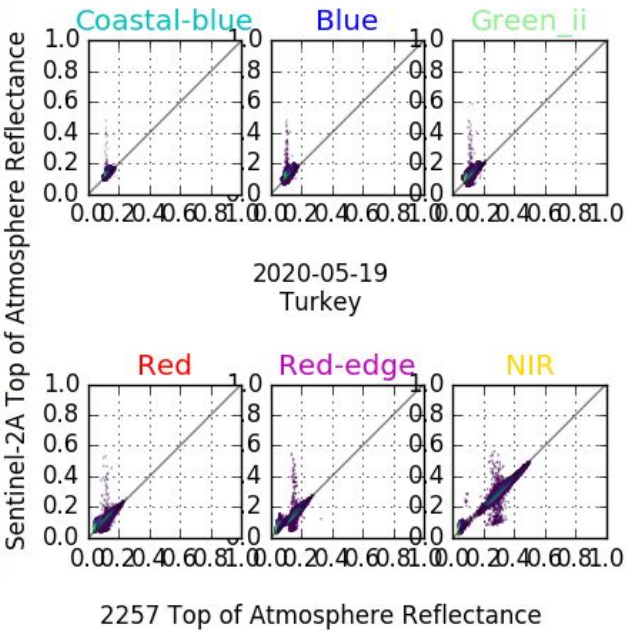
Sentinel-2A



Turkey - 2020-05-19

2257



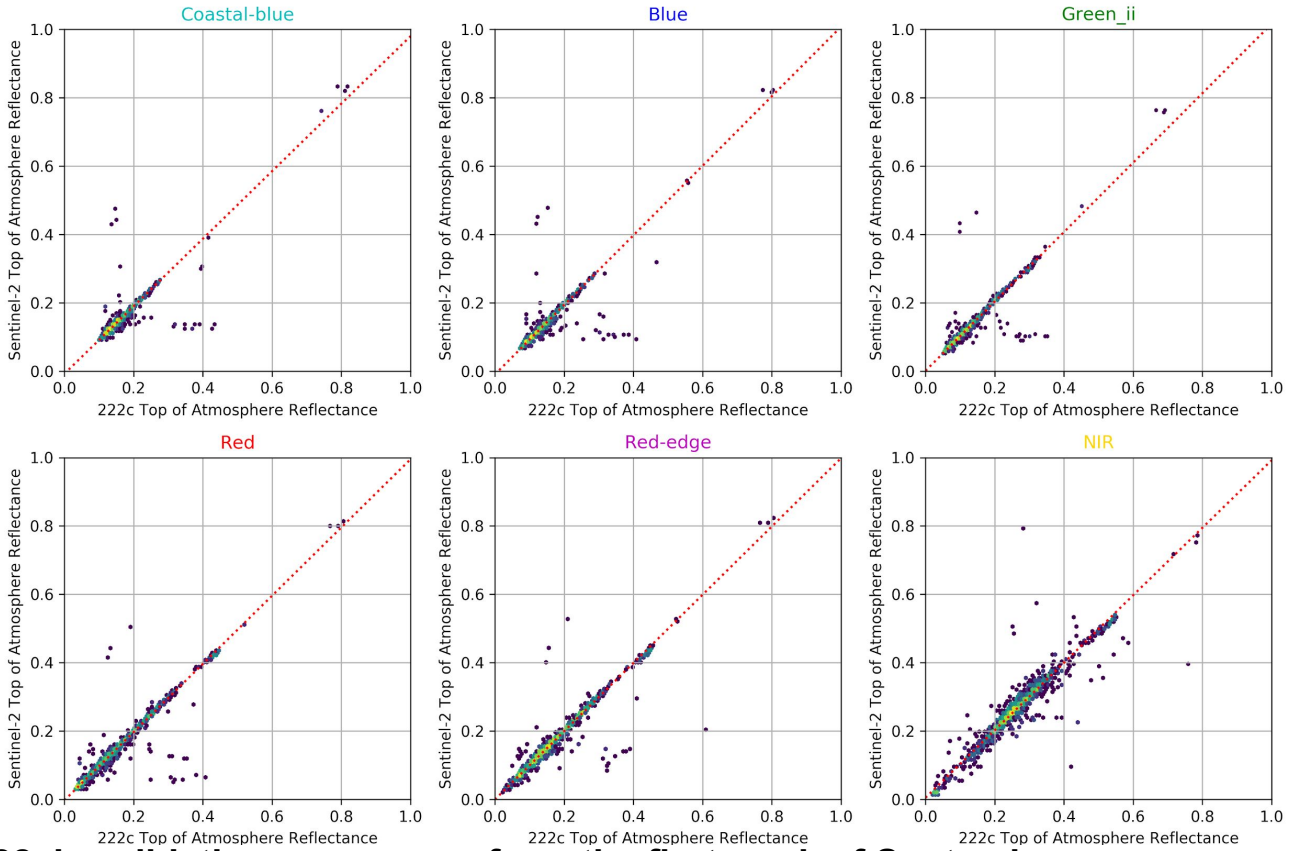


Sentinel-2A

Calibration

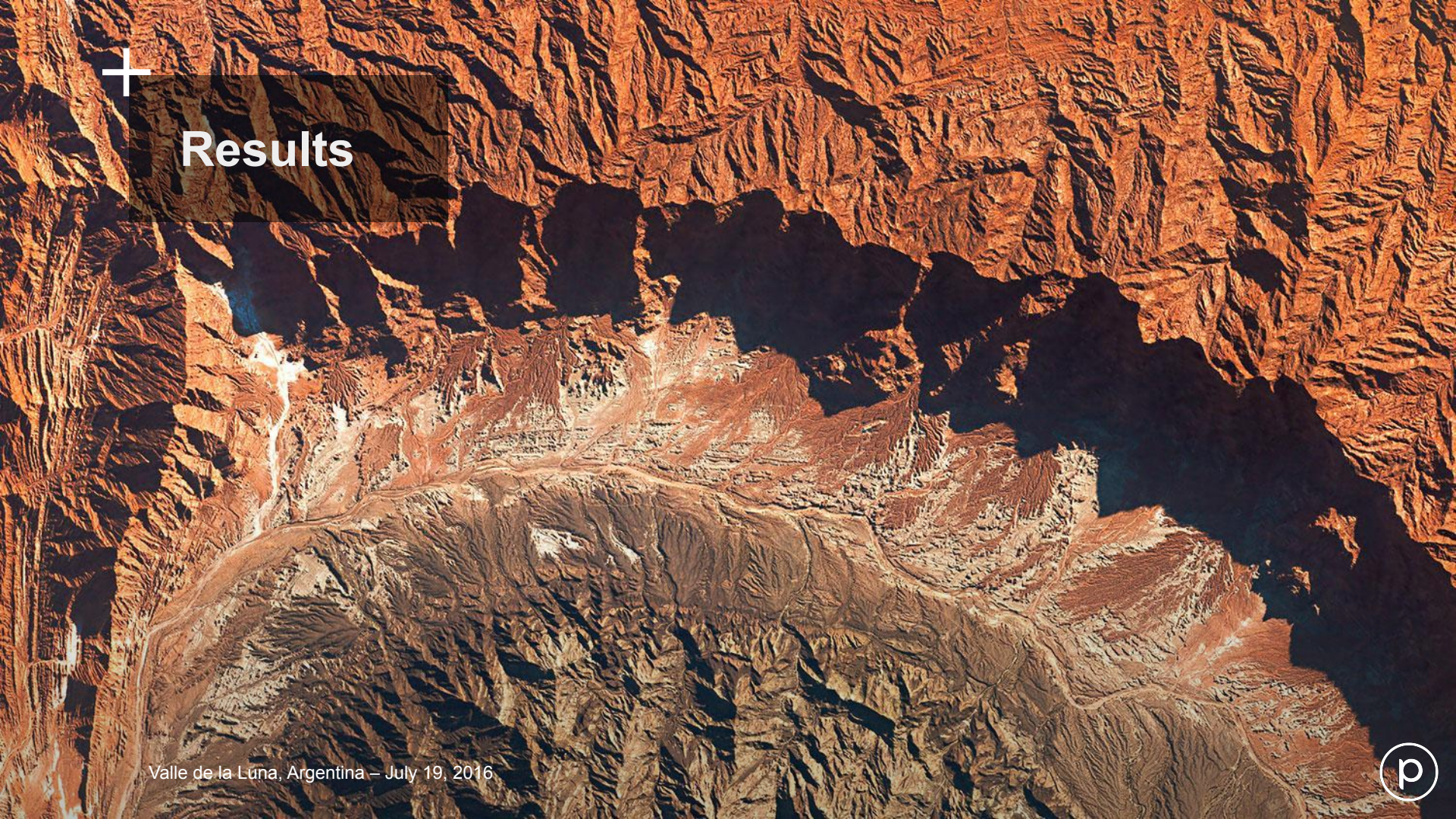
- The **joint mode** of each of the orthotiles is used to create the final calibration fit
  - The joint mode of an orthotile is **not as affected by changes in cloud cover** and other changes as long as the changes do not make up the majority of a scene
  - In the event that cloud cover makes up the majority of the orthotiles and **the joint mode is just random noise**, with a large enough data set, these noisy data points should make up the minority of the data set and be rejected in the **RANSAC fit**
- These are all collected together and a **RANSAC linear fit** is used to create the calibration model

Calibration



The results of 222c's validation crossovers from the first week of September

Results



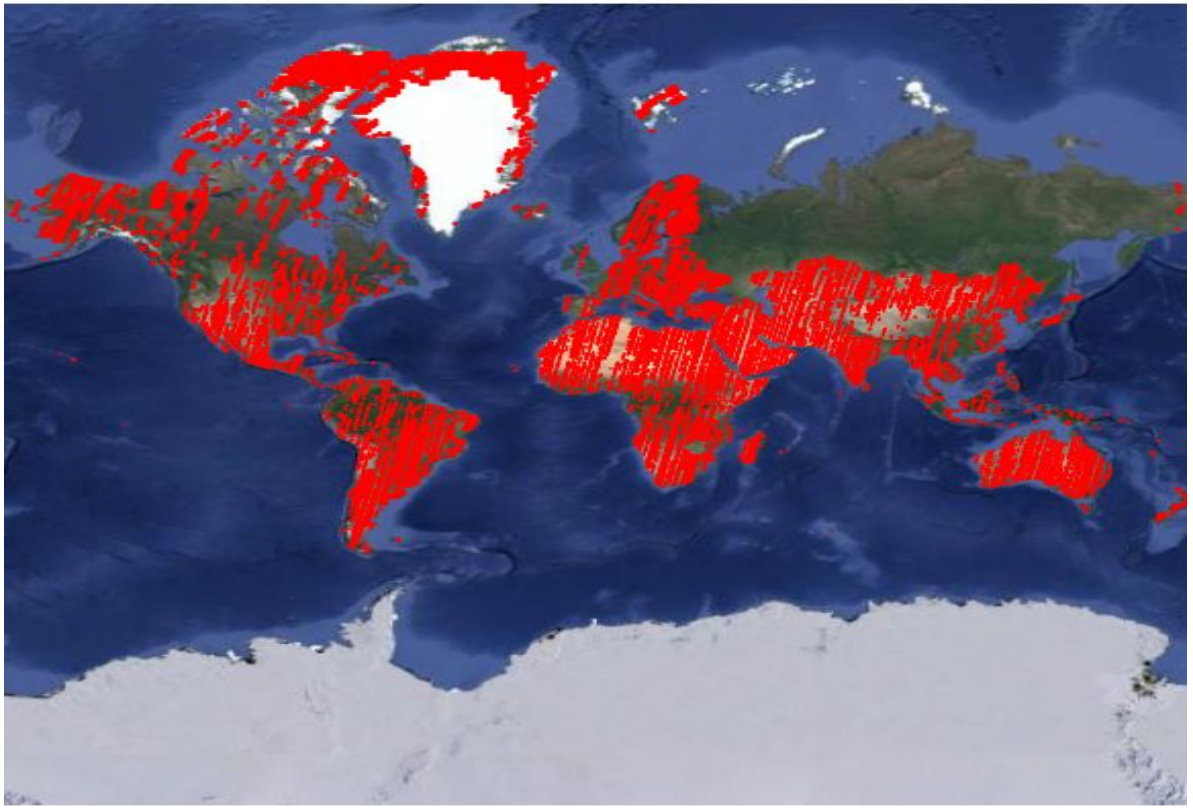
Valle de la Luna, Argentina – July 19, 2016

Results

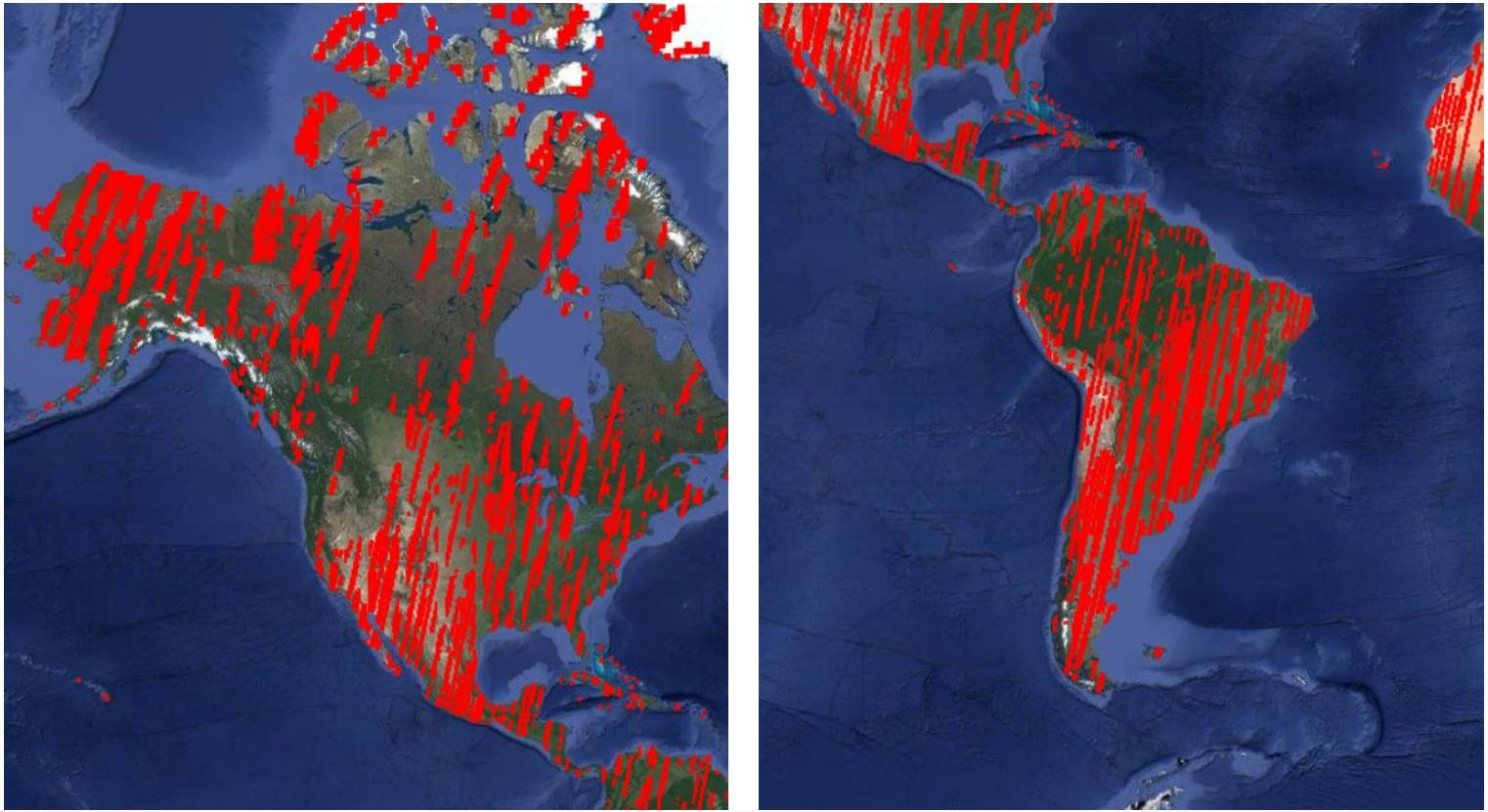
- A **single SuperDove's** crossovers will be examined in detail
  - **2257** was chosen from Flock 4p
  - This was launched on a PSLV on the **26th of November 2019**
  - It was **calibrated using crossovers in January 2020** and has not had an updated calibration yet
- **All crossovers** from the **1st of January 2020 to 1st of September 2020** were polled and processed

Global crossovers between a Superdove (2257) and Sentinel-2 for 2020

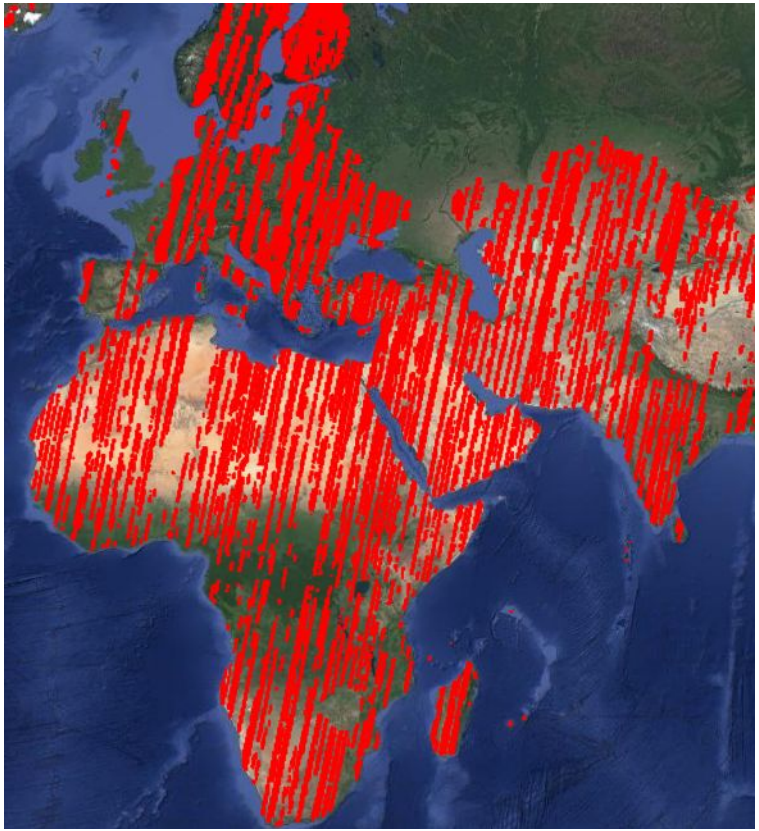
- These are all the crossover orthortiles for a single Superdove (2257)

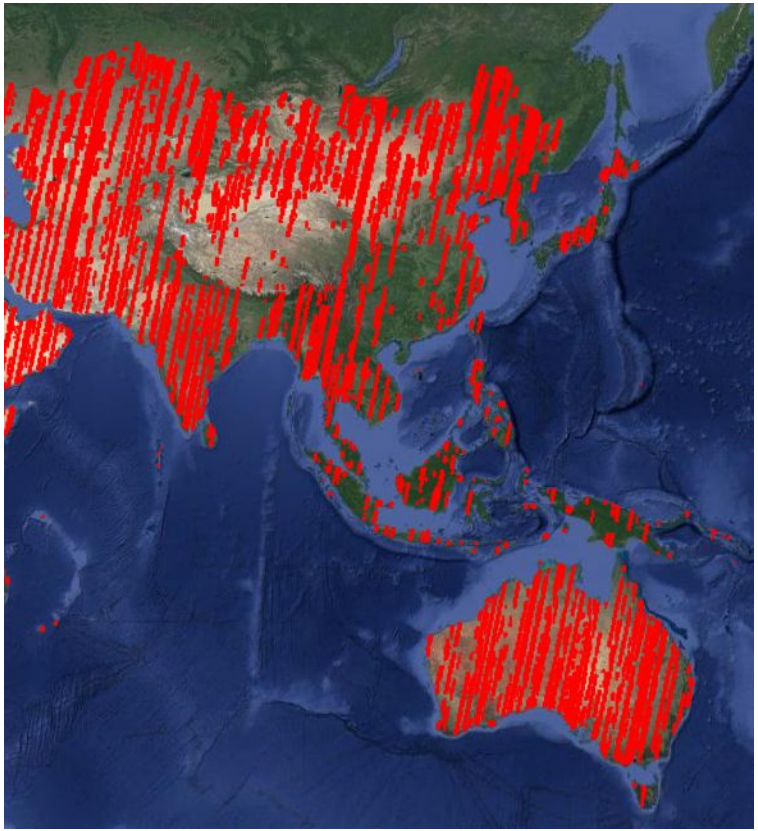


Global crossovers between a Superdove (2257) and Sentinel-2 for 2020

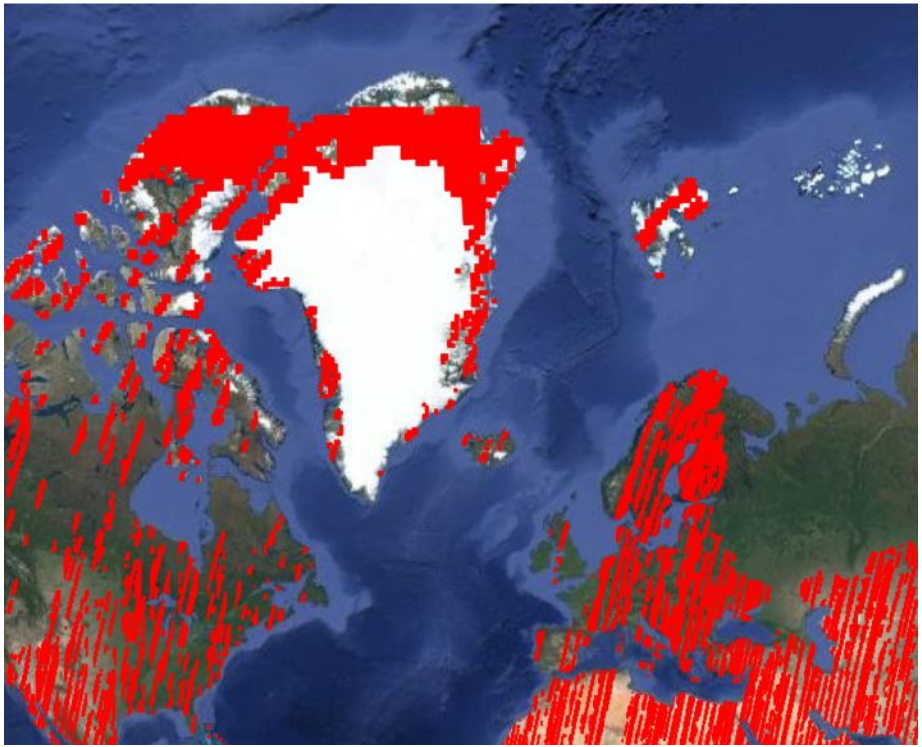


Global crossovers between a Superdove (2257) and Sentinel-2 for 2020

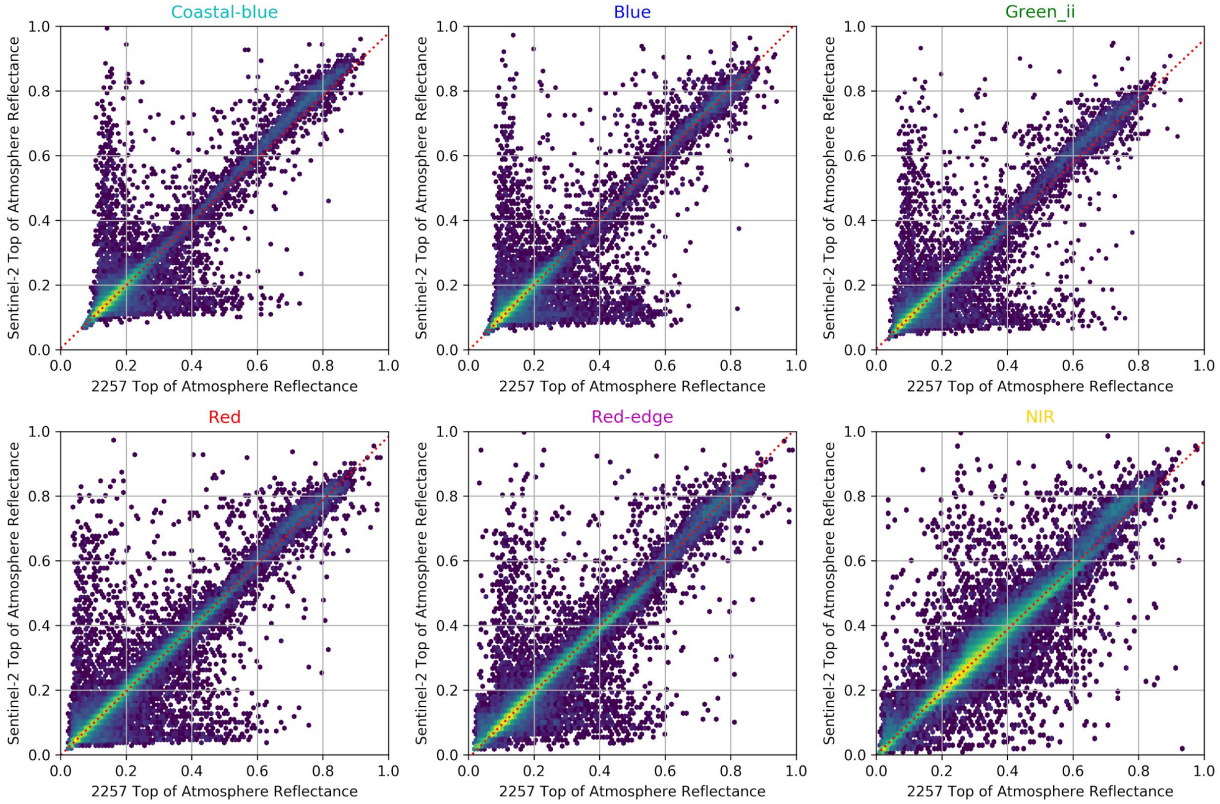




Global crossovers between a Superdove (2257) and Sentinel-2 for 2020

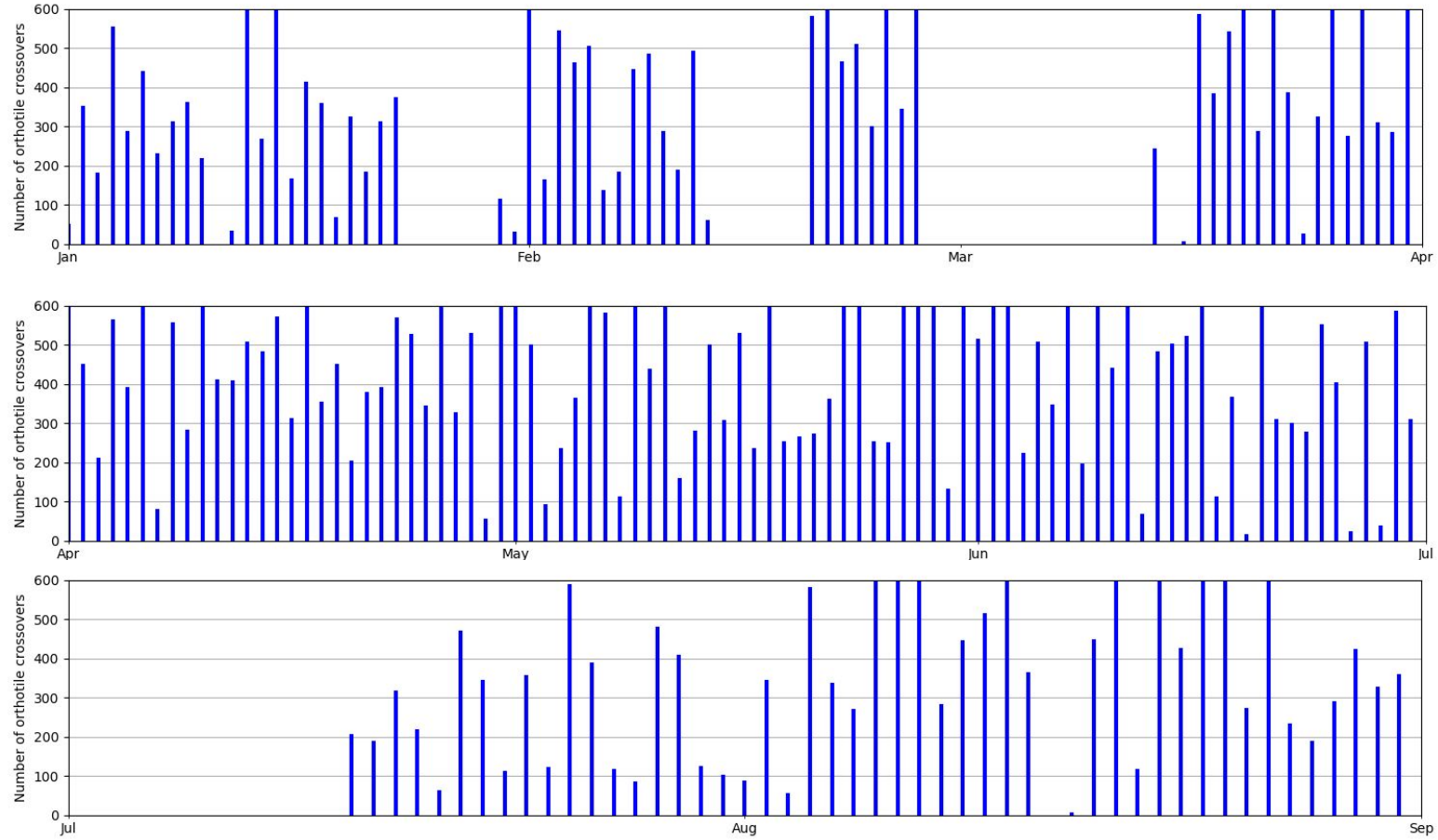


Global crossovers between a Superdove (2257) and Sentinel-2 for 2020



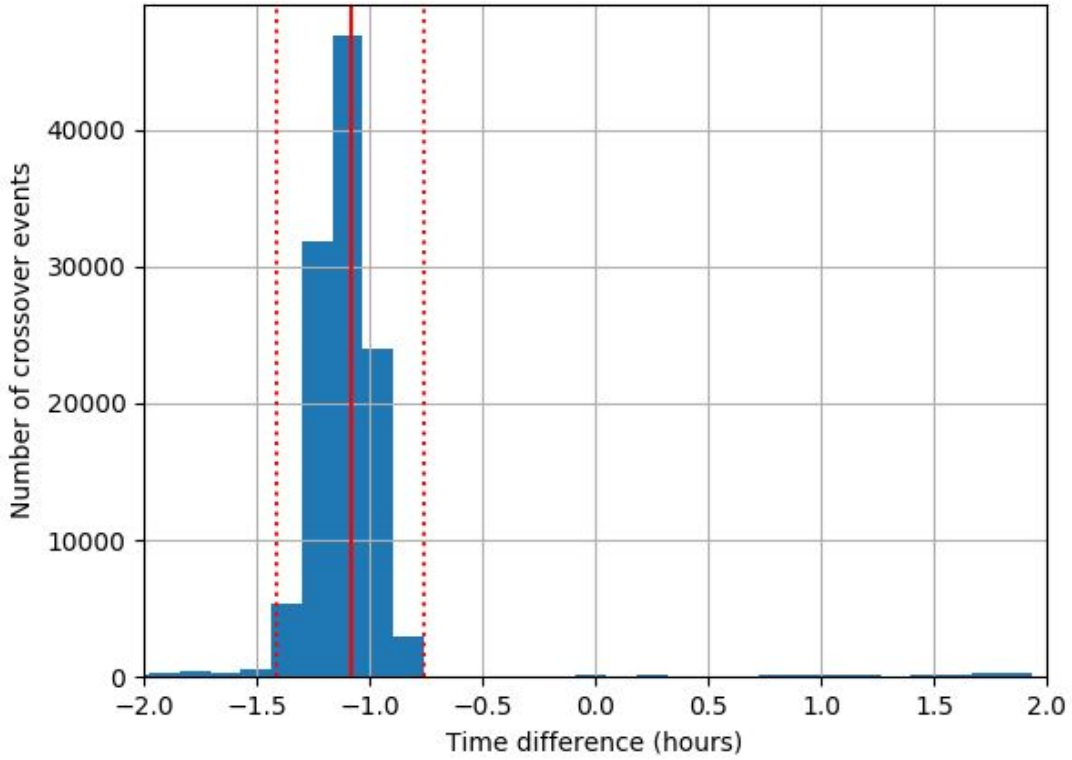
All 114,888 orthotile events between a Superdove and Sentinel-2 for 2020. Each data point in the density plot represents the joint mode of an orthotile

A timeline of the crossovers



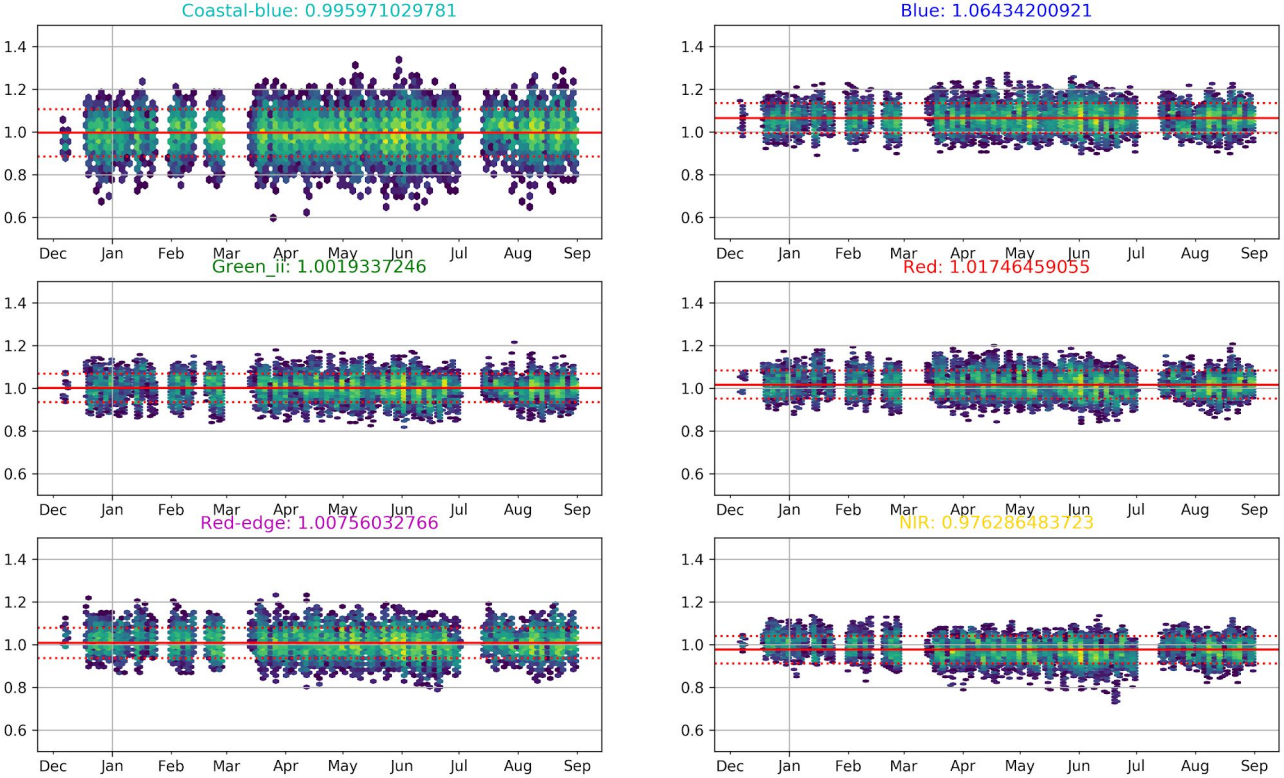
The number of crossover orthotiles for each day. The orthotiles were filtered so that only crossover events that overlapped over 25% of the orthotile.

The average time difference



Most of the crossover events had just over an hour time difference between the candidate and the reference scene.

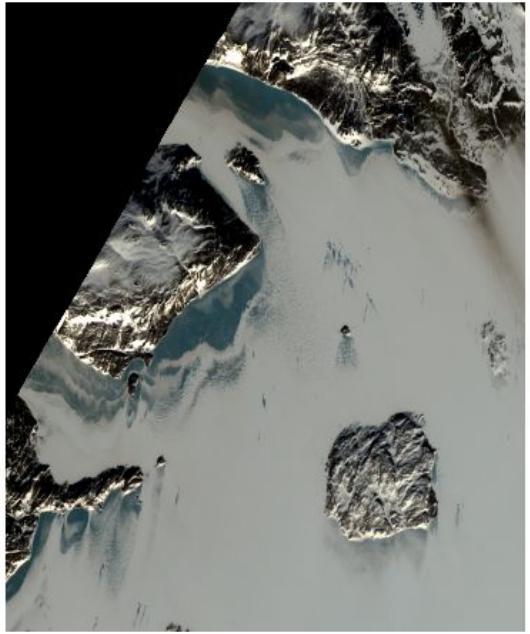
The fit of all the crossovers over time

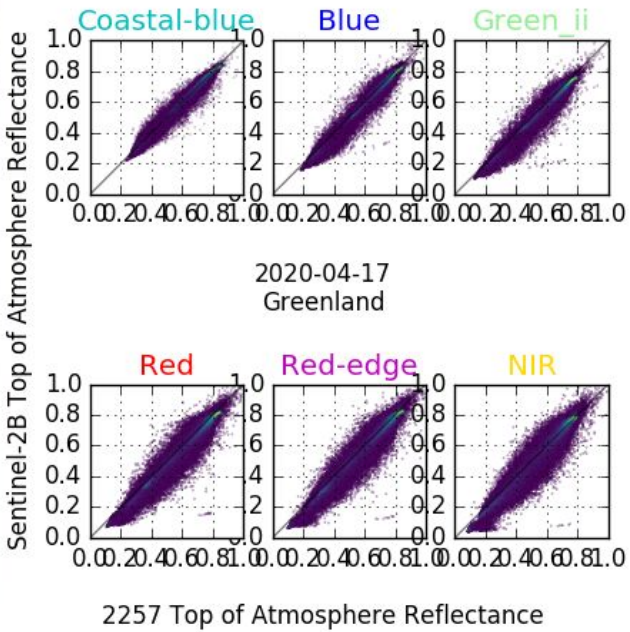


Showing the range of fits over time. The fit between the reference and candidate measurements for each orthotile crossover event is shown to investigate if there is any seasonal variation.

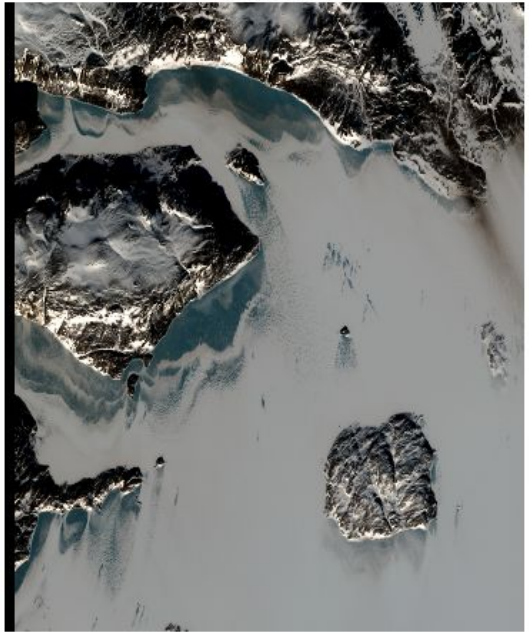
Greenland - 2020-04-17

2257



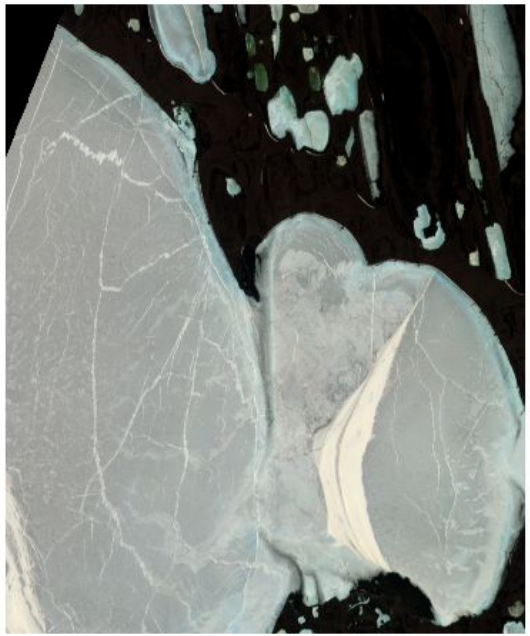


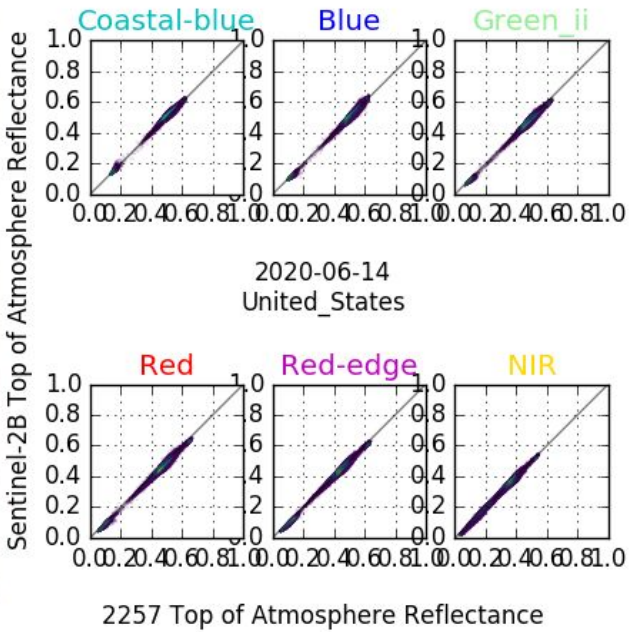
Sentinel-2B



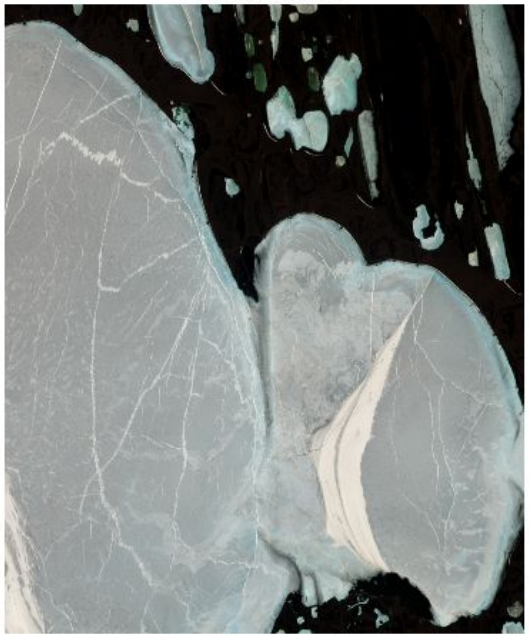
United States - 2020-06-14

2257



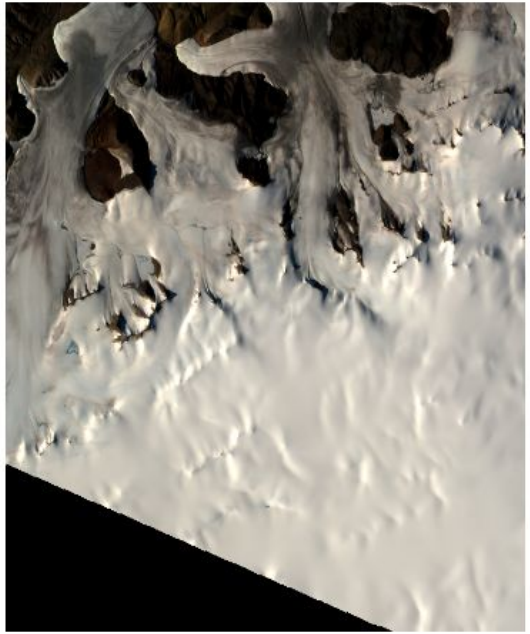


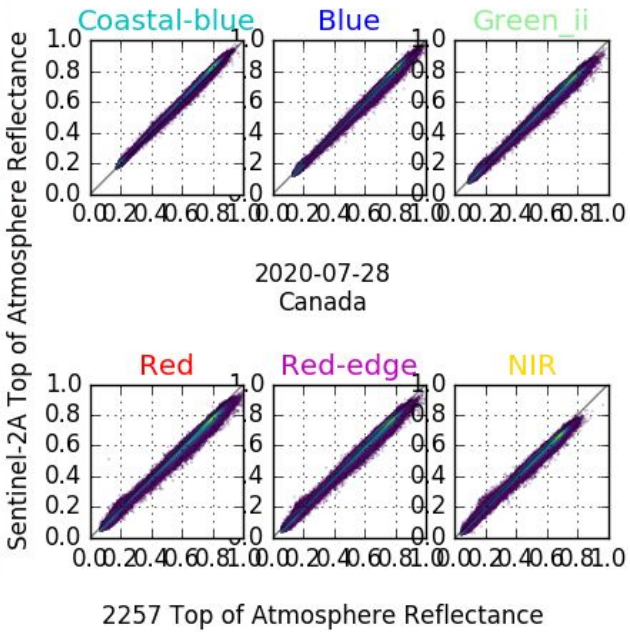
Sentinel-2B



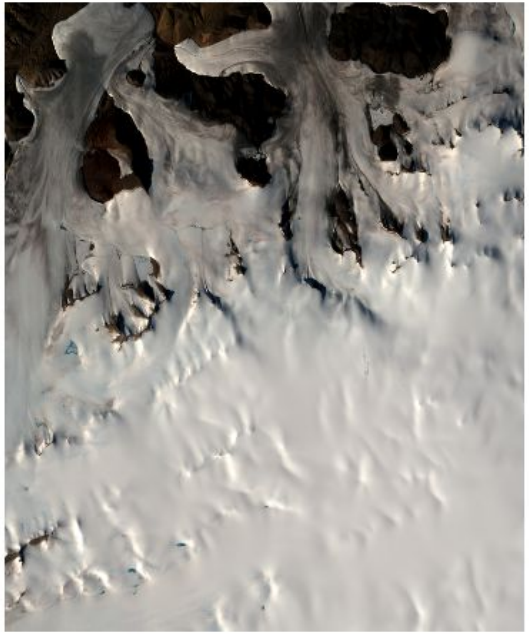
Canada - 2020-07-28

2257



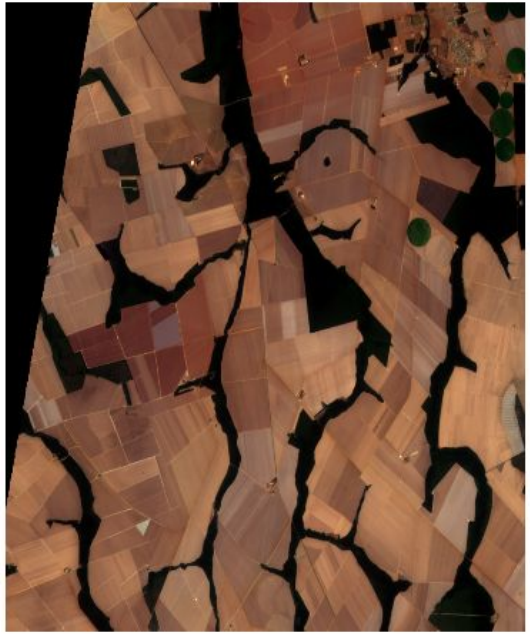


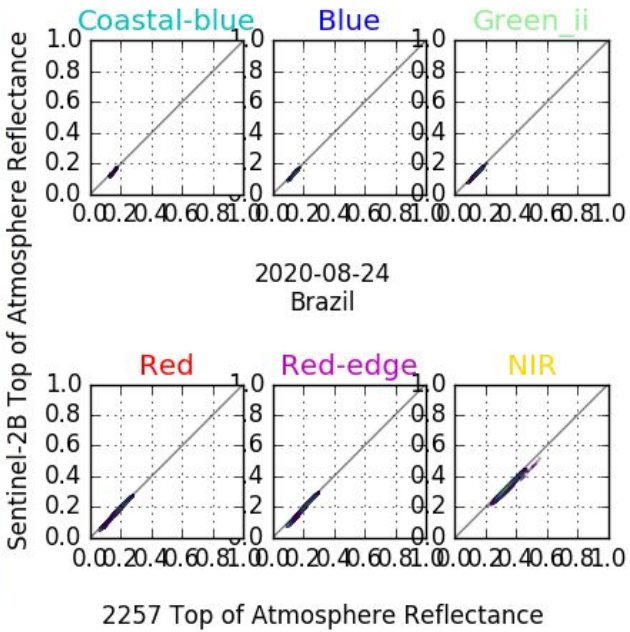
Sentinel-2A



Brazil - 2020-08-24

2257

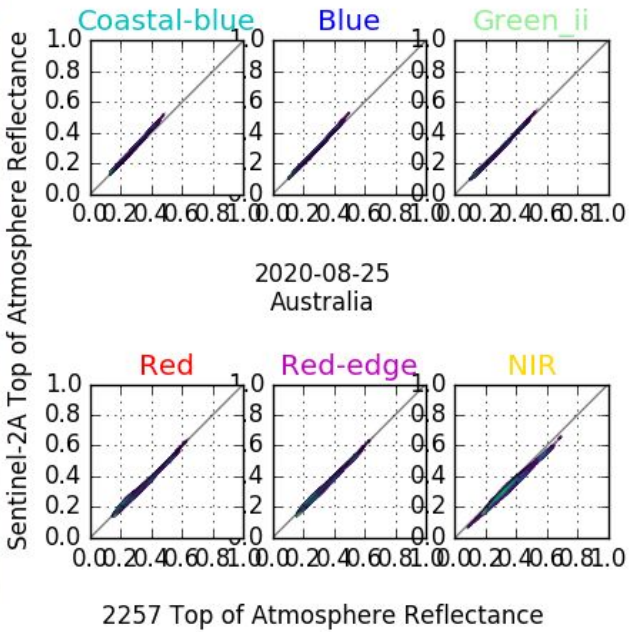




Sentinel-2B

Australia - 2020-08-25

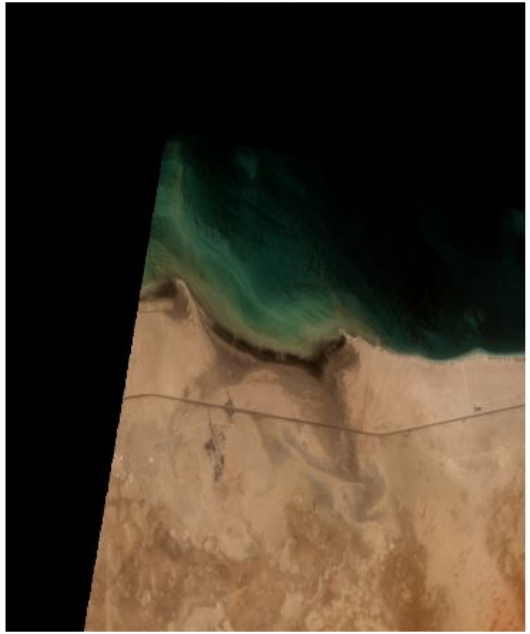
2257

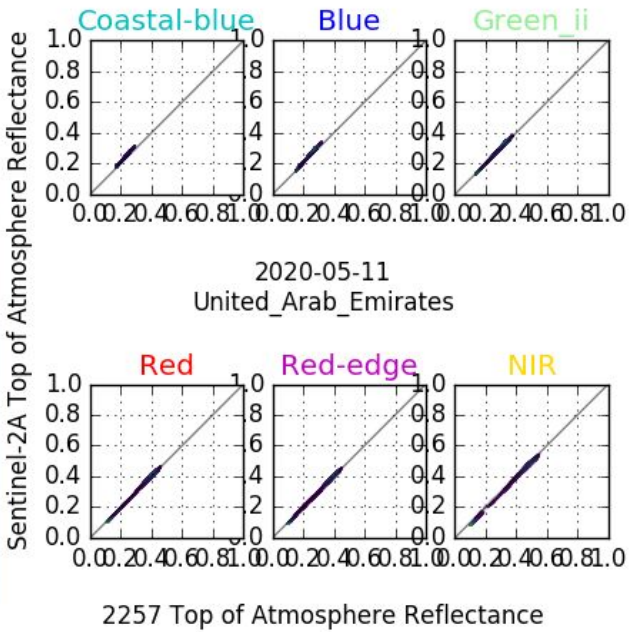


Sentinel-2A

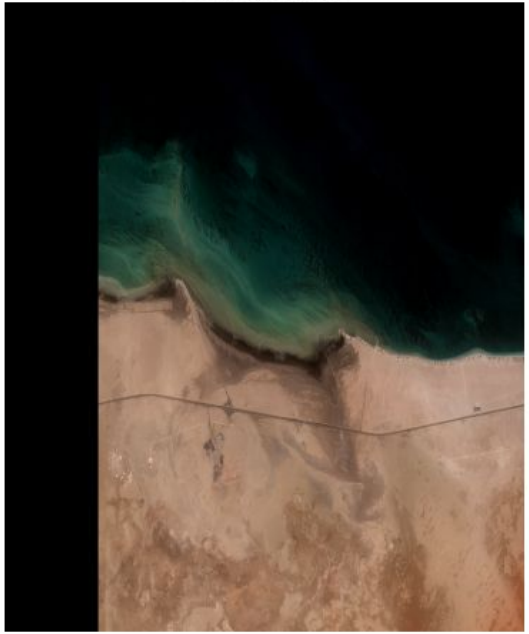
United Arab Emirates - 2020-05-11

2257

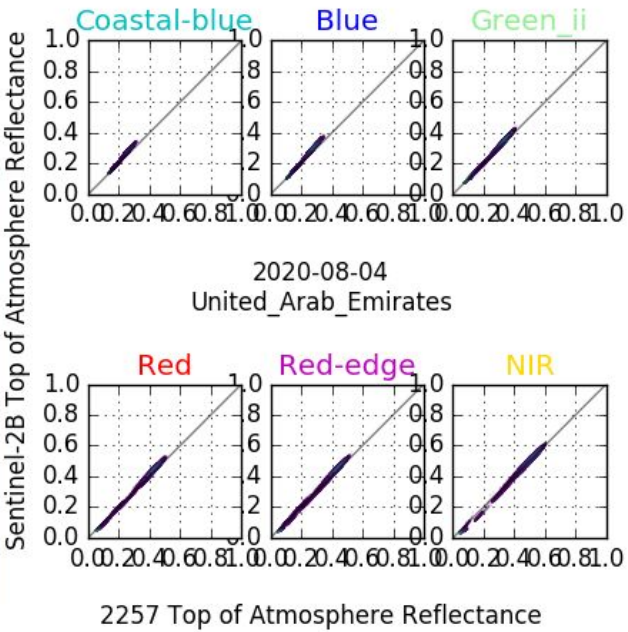




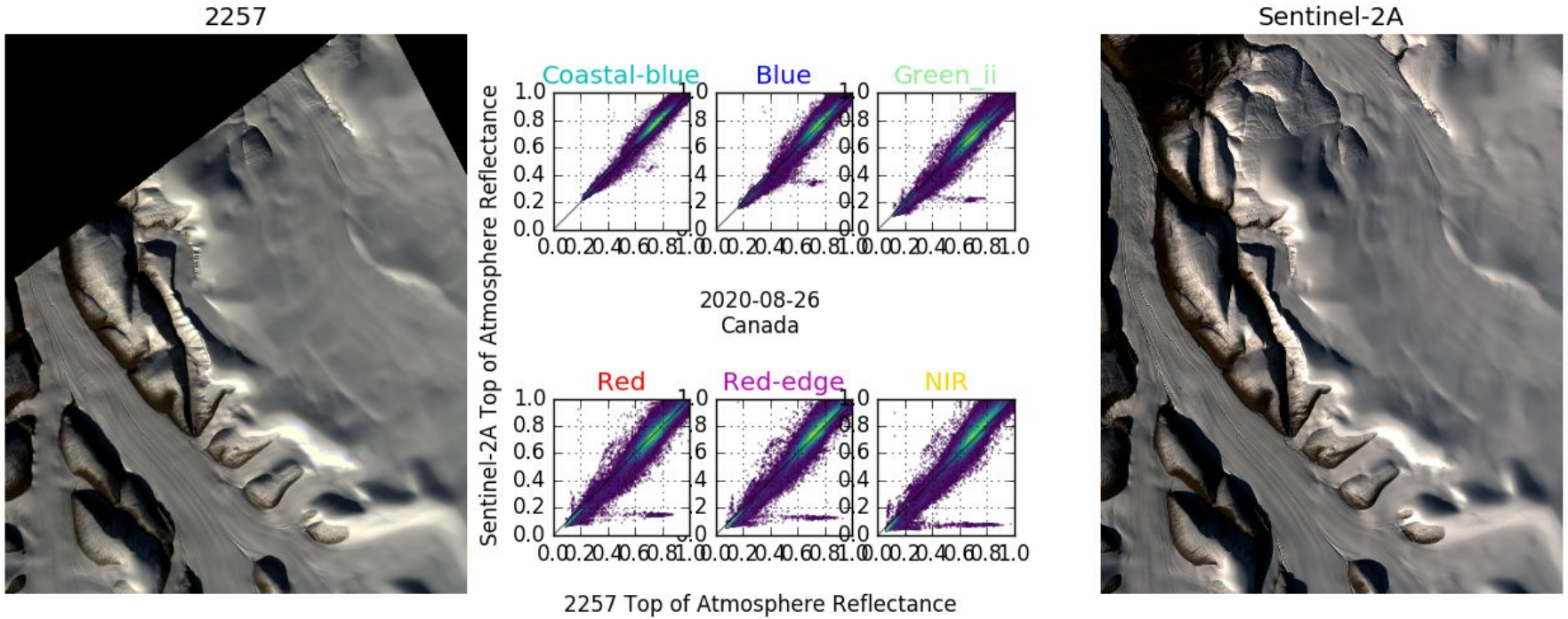
Sentinel-2A



United Arab Emirates - 2020-08-04

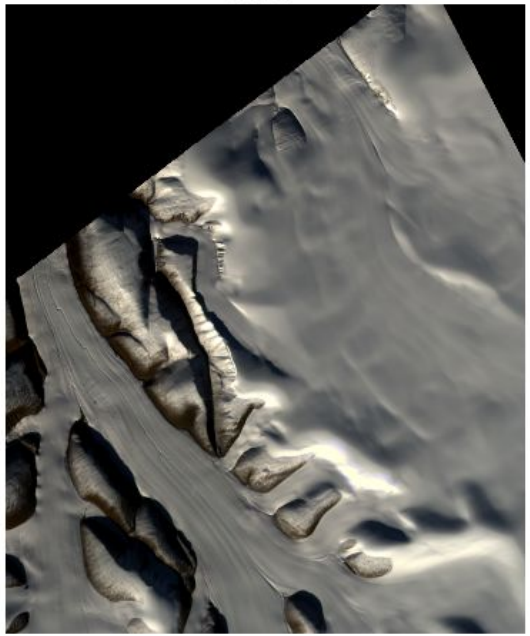


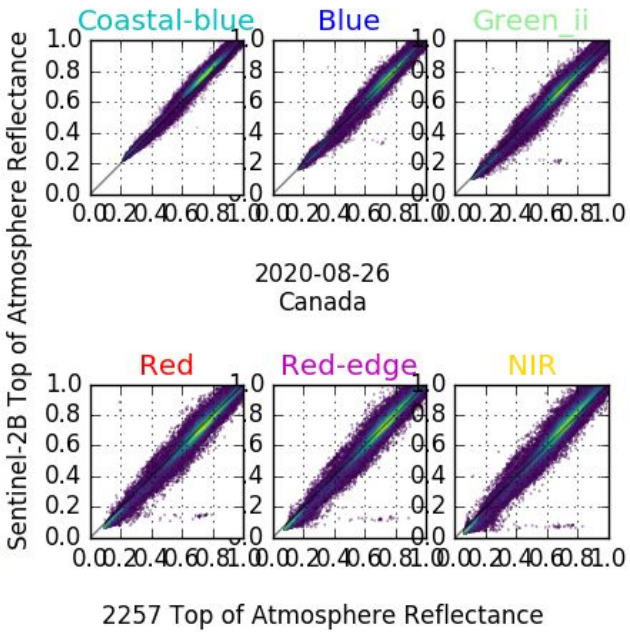
Canada - 2020-08-26



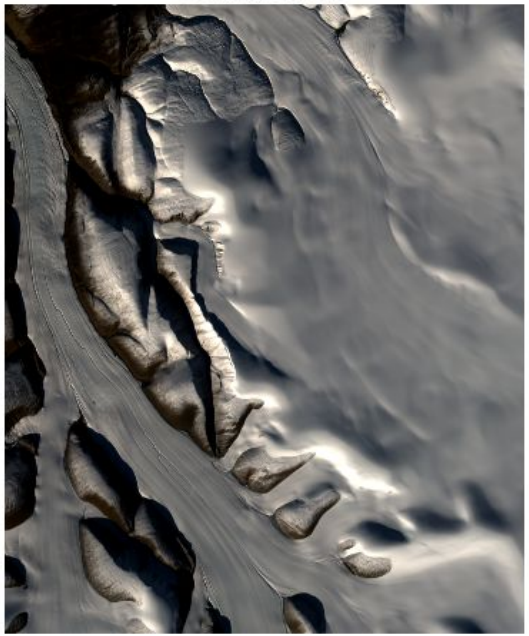
Canada - 2020-08-26

2257





Sentinel-2B



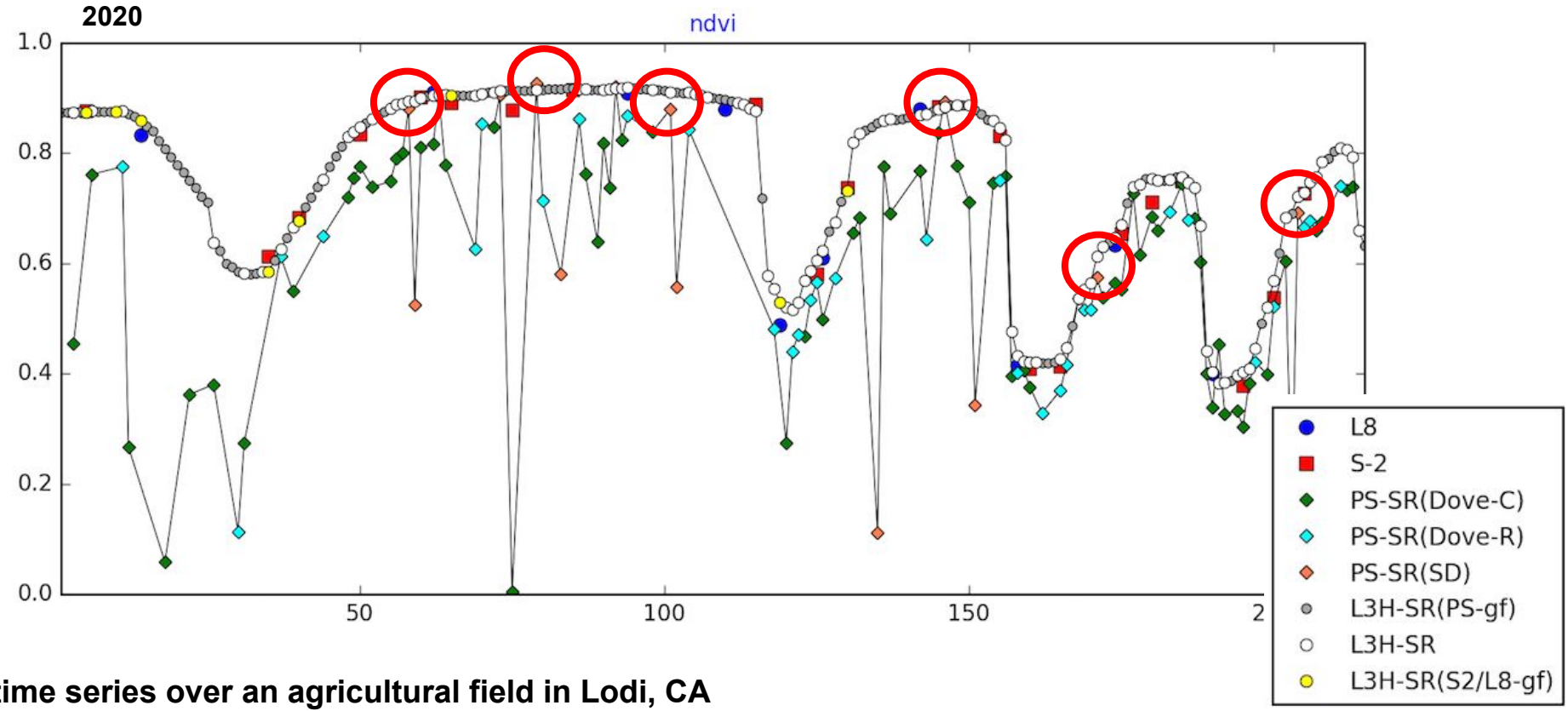
Summary

Iguazú National Park, Brazil – September 23, 2016

Summary

- This talk presented the **methodology** developed to calibrate the new SuperDove
- A study was performed using a **spectral library** to find the **variation of SBAFs** between the SuperDove and Sentinel-2
- Moving **away** from well characterised calibration sites has meant that a much more **varied calibration data set** is used to create the calibration model
  - There are scenes at multiple points along the **dynamic range**
  - Especially important are point on the **darker** end of the dynamic range and over **vegetation**
- The talk has concentrated on the **six bands** that are shared with the Sentinel-2 satellites
  - The **green_i** and **yellow calibration** will depend on a well characterised calibration sites and lunar calibration
  - The different spectral responses will need to be taken into account
- The **lack of SBAF correction assumption** depends on the **quality** of the filters and per satellite quality check
  - Accurate green_i and yellow calibration especially will depend on accurate **RSR measurements**, which is the subject of the next talk

SuperDove data is interoperable with Sentinel-2 data



A time series over an agricultural field in Lodi, CA

Questions?

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