# Assessment of Sensor Footprint Size and Comparison of Commercial Smallsat Images

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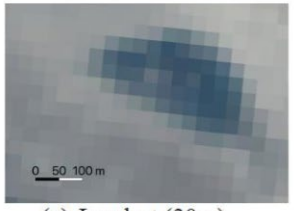
# Outline

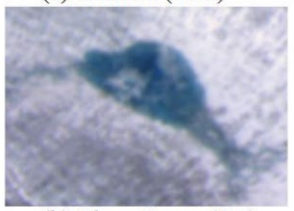
- Background
- Cal/Val Sites
- WorldView Assessment
- Planet’s Super Dove Assessment
- Black Sky Assessment
- Summary

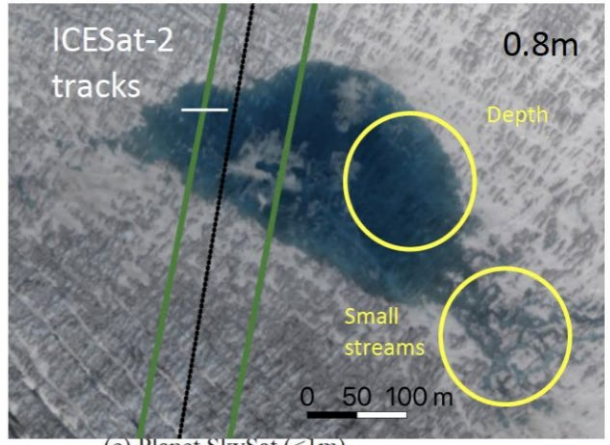
# Background

- Characterize sensor footprint size of satellite data for NASA's Commercial Smallsat Data Acquisition (CSDA) program.
- Sensor footprint size is a determining factor in scientific studies.
- Sensor footprint size is not always equivalent to image pixel size.



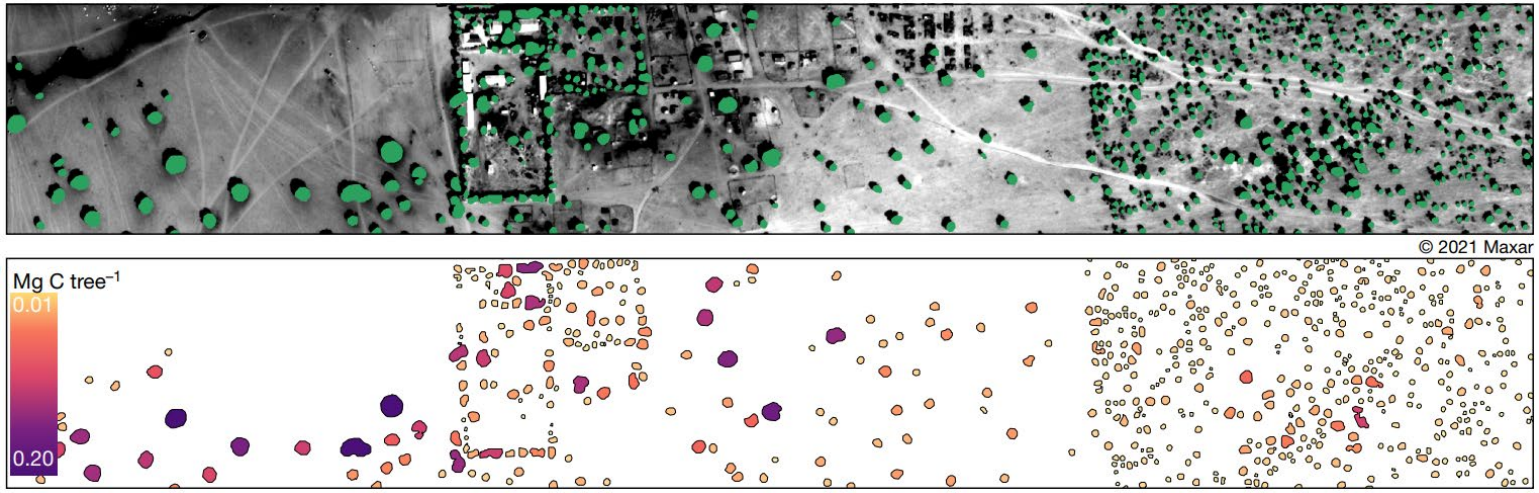
(a) Landsat (30m)


(b) PlanetScope (3m)



(c) Planet SkySat (<1m)

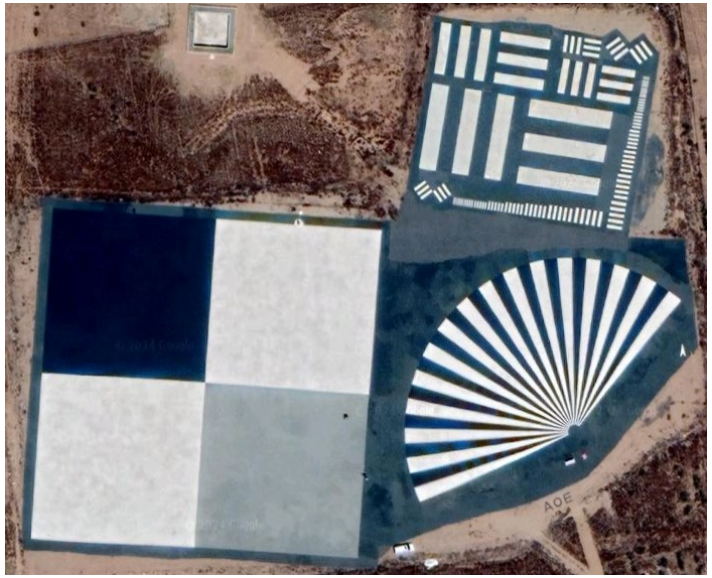
[1] Datta, 2019




[3] Tucker et al, 2023

# Cal/Val Sites

- Spatial Sites Catalog | EROS CalVal Center of Excellence (usgs.gov)
- Evaluated mostly at China site, supplemented with two other sites



Baotou, China
48 m slanted edges

Google Earth, 2024

Shadnagar, India
70 m slanted edges

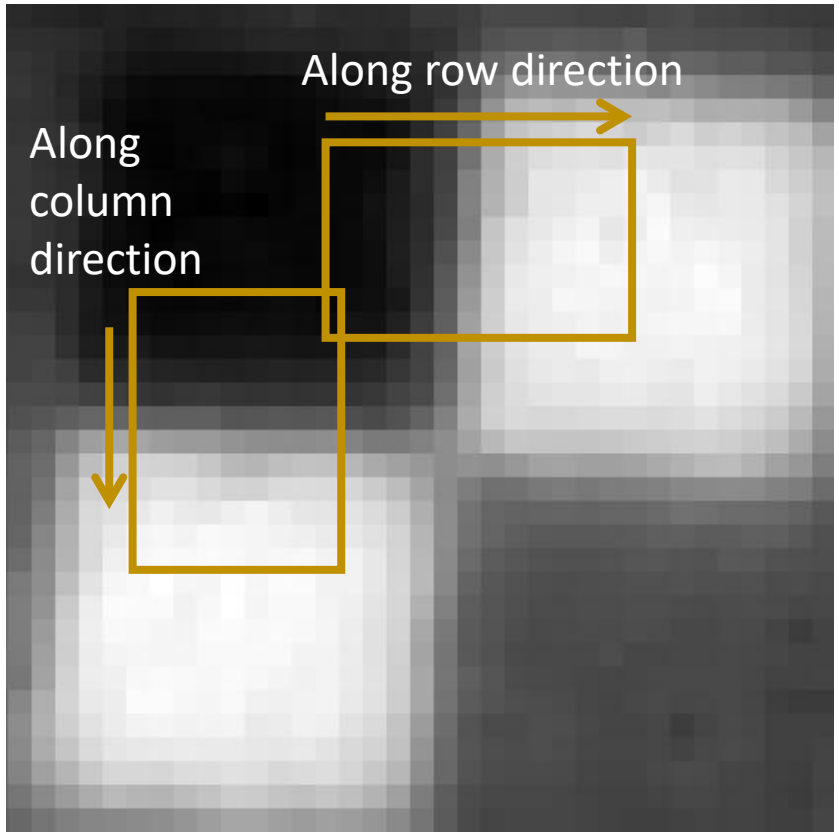
Google Earth, 2024

Google Earth, 2024

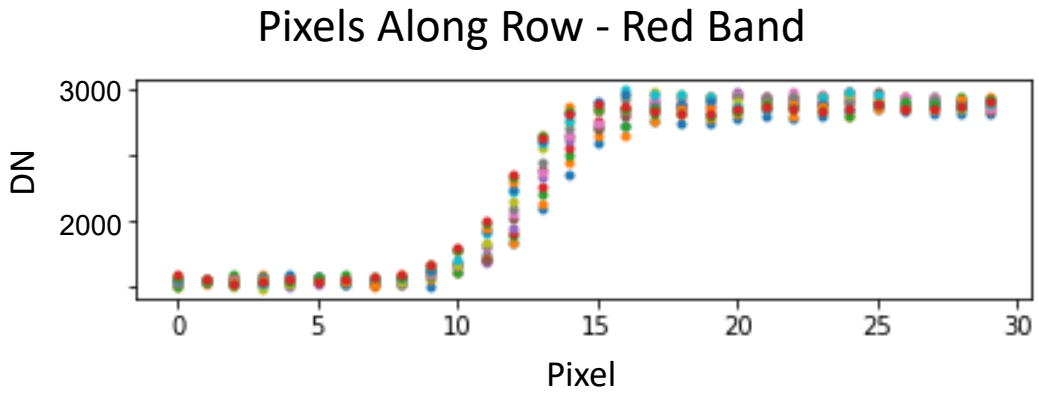
Big Spring, TX, USA
30 m slanted edges

# Methods: Extract Pixels

- Extract raw pixels along slanted black/white (B/W) transition.

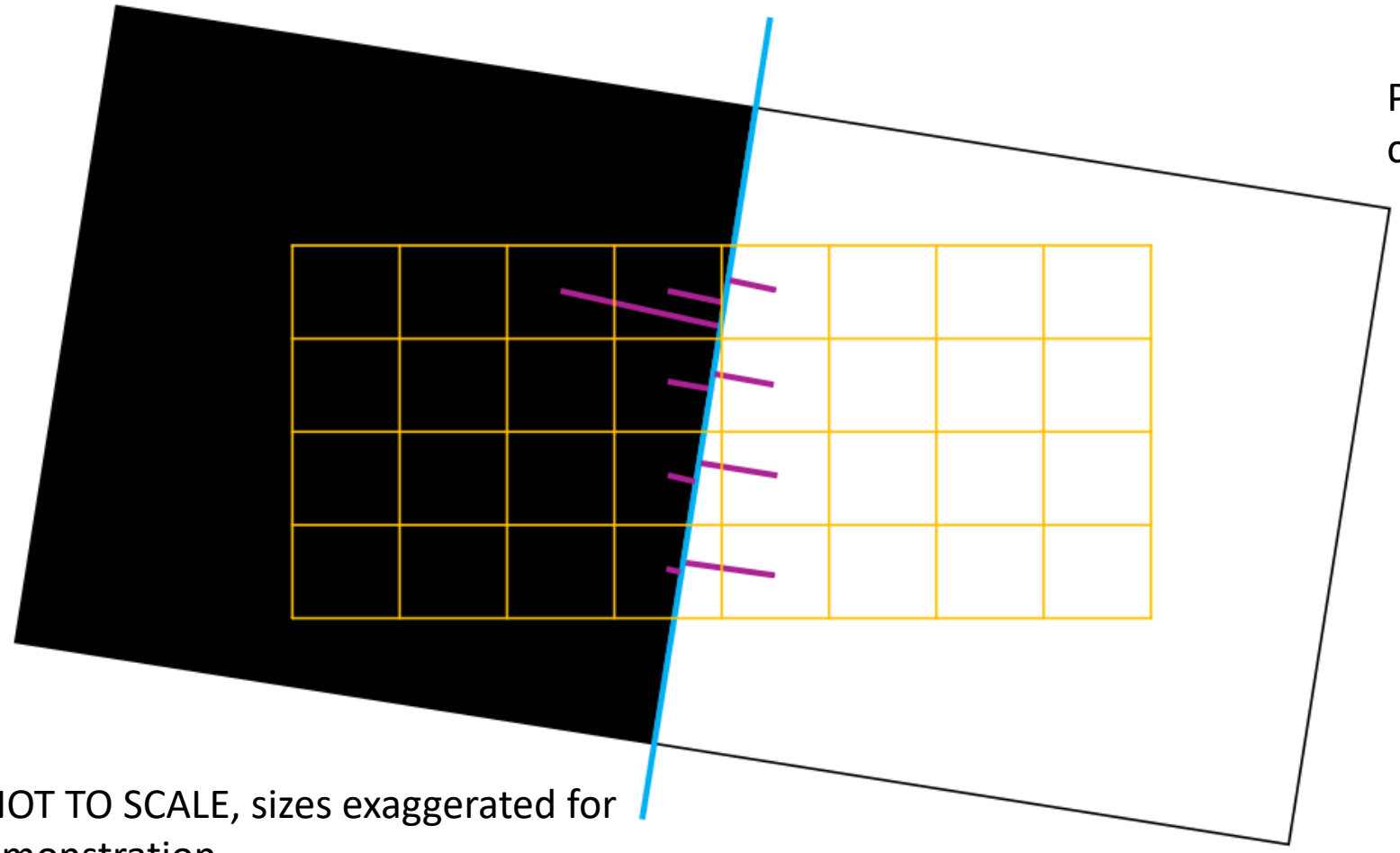


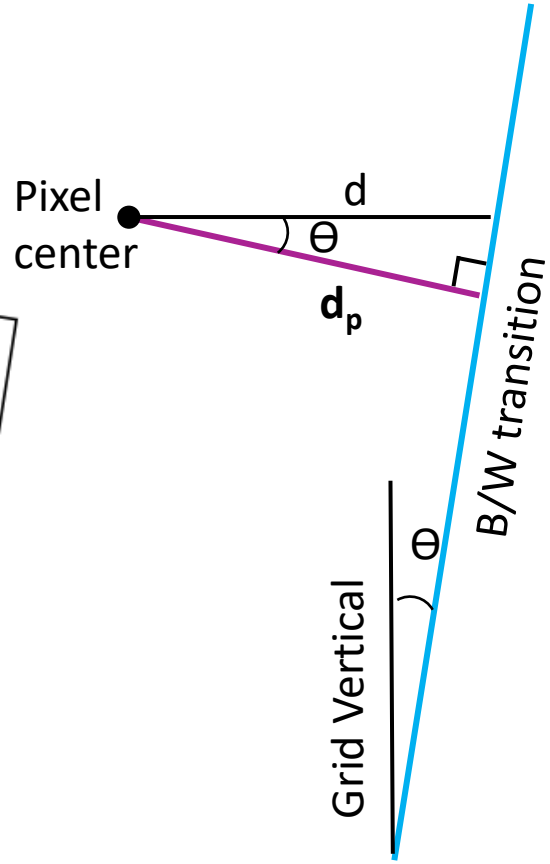

Site: China
Image ID: 20230312_022601_97_2423
Band: Red



# Methods: Transform into distance from B/W transition

1. Define a line as the transition from black to white (blue line in diagram)
2. Calculate perpendicular distance from pixel center to blue line (purple lines in diagram, $d_p$)
   $d_p = d*\cos(\Theta)$





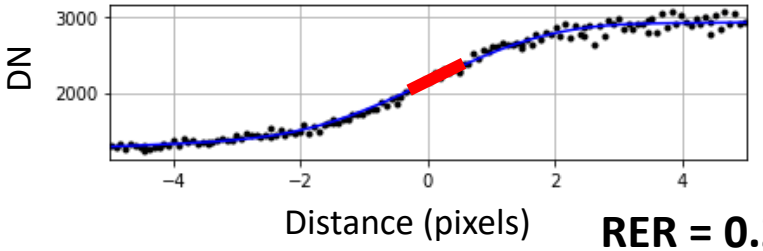

Θ = Angle between transition and image grid's vertical

*NOT TO SCALE, sizes exaggerated for demonstration

# Methods

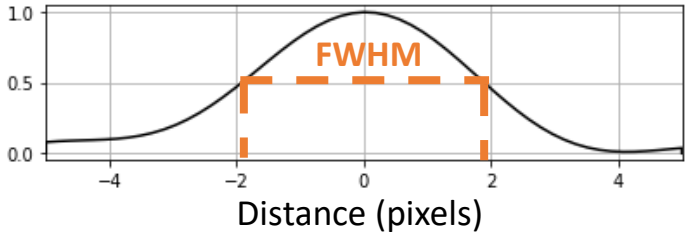
- Extract raw pixels along black/white (B/W) transition.
- Transform from pixel number to distance from B/W transition.
- Fit a function[2] to the transformed data to make Edge Spread Function (ESF). Find Relative Edge Response (RER) here.
- Calculate derivative of ESF to find Line Spread Function (LSF).
- Fourier transform the LSF to find Modulation Transfer Function (MTF).
- Find Ground Resolved Distance (GRD) where MTF(1/(2GRD)) = 0.5 .

Edge Spread Function (ESF) - Red Band



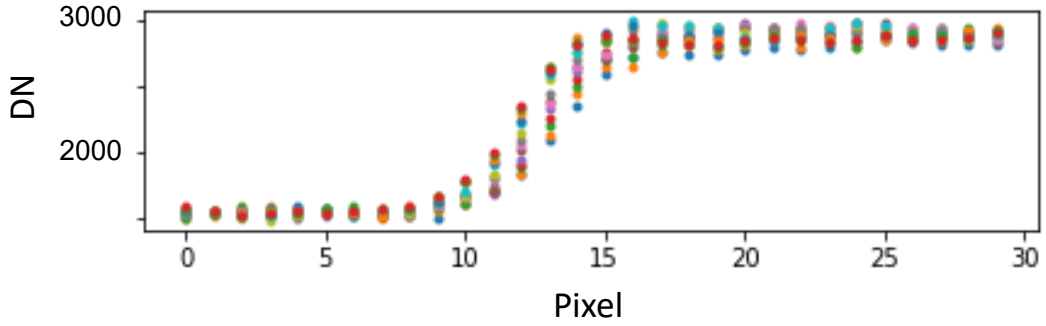

**RER = 0.20**

Line Spread Function (LSF) - Red Band

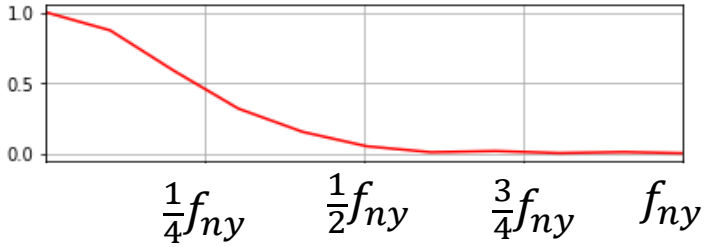



**FWHM = 3.8 pixels**

Pixels Along Row - Red Band




Modulation Transfer Function (MTF) - Red Band

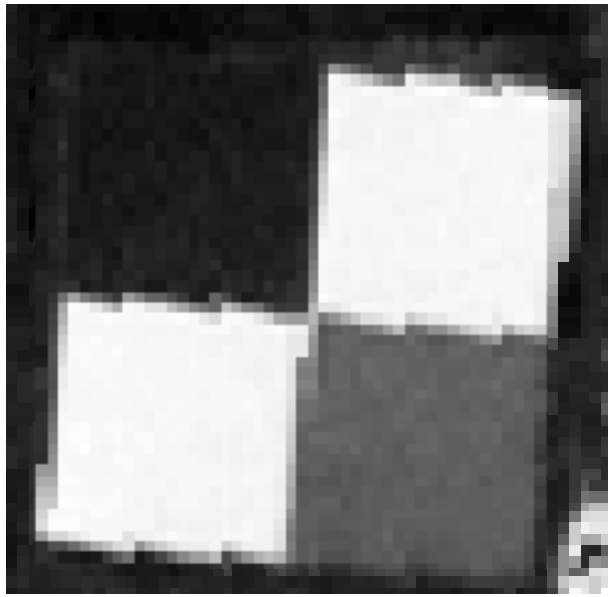



**MTF @ $f_{ny}$ = 0.004**

**GRD= 4.0 pixels**

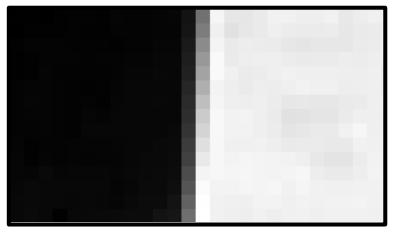
# Maxar's Worldview-2 Results

WV-2 (2.13 m)

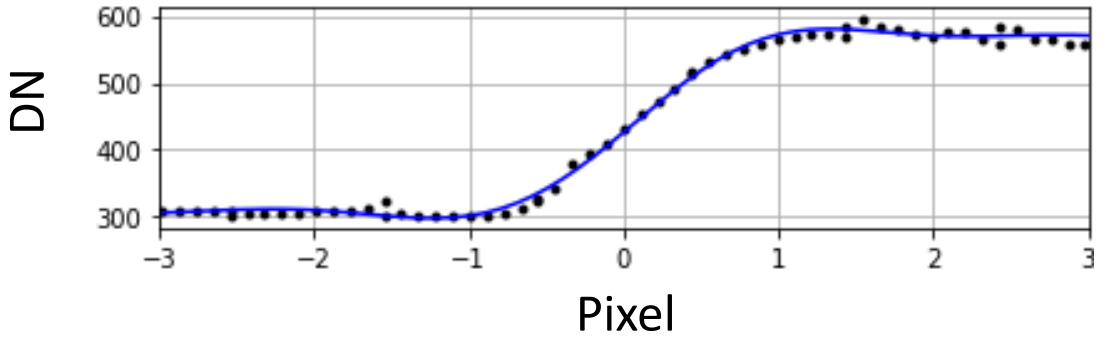


Cal/Val site: China
Image ID: 103001008D27CB00
Band: Red

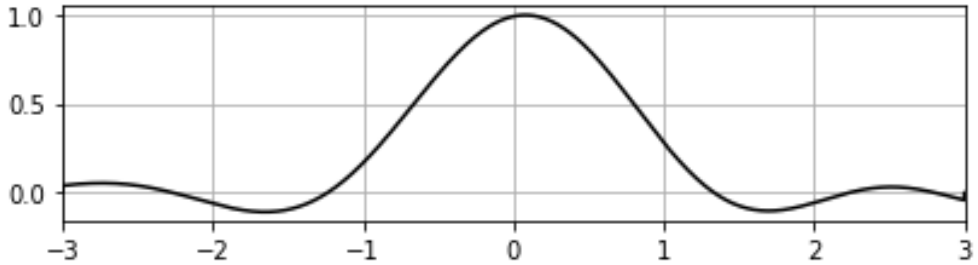
Edge



ESF - Red Band



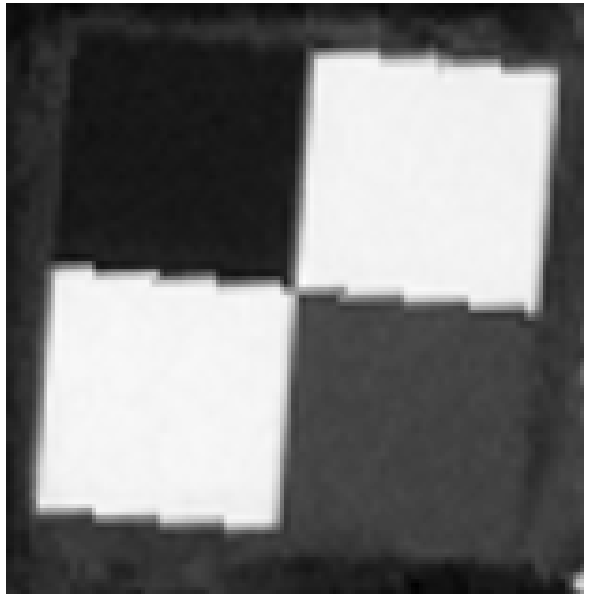

LSF - Red Band




**FWHM** = 1.5 pixels
**Footprint size** = 3.2 m

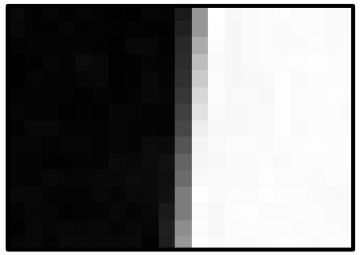
# Maxar's Worldview-3 Results

WV-3 (1.62 m)

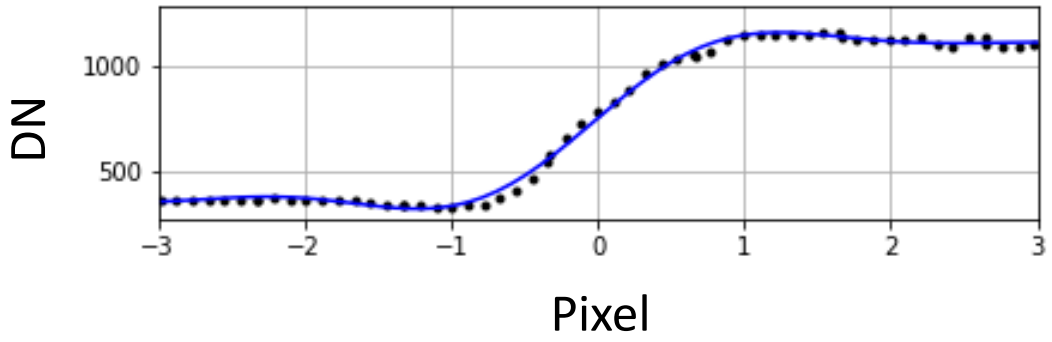


Cal/Val site: China
Image ID: 10400100690DF600
Band: Red

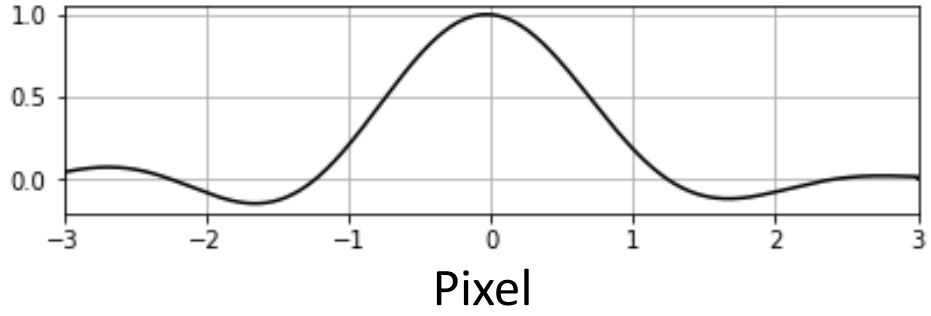
Edge



ESF - Red Band




LSF - Red Band




**FWHM** = 1.4 pixels
**Footprint Size** = 2.3 m

# Planet's SuperDove (SD) - Overview

- Planet has launched 6 'Flocks' of SD series satellites.
  - Flock4Q – 11/2023
  - Flock4Y – 1/2023
  - Flock4X – 1/2022
  - Flock4S – 1/2021
  - Flock4V – 9/2020
  - Flock4P – 11/2019

- We assessed RGB resolution for 1 sensor from each of Flocks P – X at two times;
  - 1st: soon after launch
  - 2nd: 1+ yrs after launch

- Assess both generational and temporal changes in 'Flocks'

# SuperDove RGB Resolution: Temporal Changes

- Oldest and newest pairs shown here, selected from the 9 assessments we performed.
- Both column and row assessments perform similarly, below are means of column and row results.
- Overall, SD sensor resolutions improve slightly after 1+ yrs in orbit

**Sensor: 2487 (03/22)**
RER = 0.23
FWHM = 3.10 pixels
Footprint Size = 9.3 m


**Sensor: 2487, 03/23**
RER = 0.23
FWHM = 3.10 pixels
Footprint Size = 9.3 m

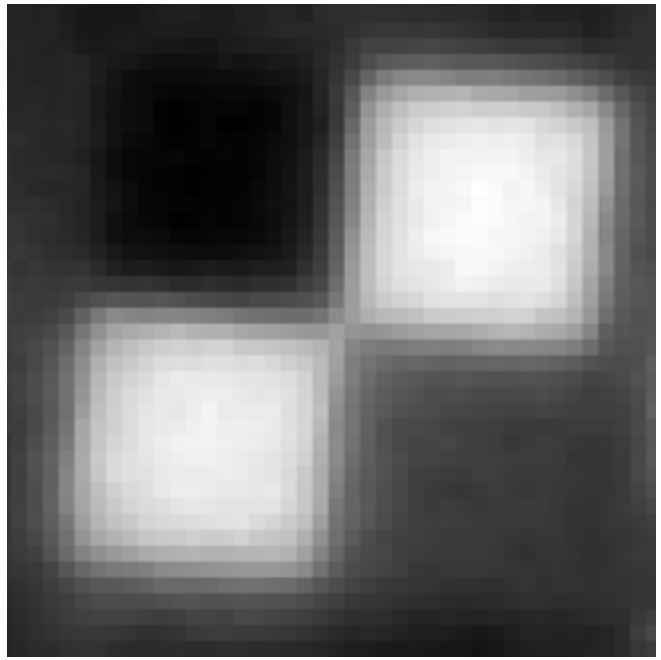
**Sensor: 2231, 09/20**
RER = 0.19
FWHM = 3.79 pixels
Footprint Size = 11.36 m


**Sensor: 2231, 08/22**
RER = 0.23
FWHM = 3.17
Footprint Size = 9.5 m

**Mean (all 9 assessments)**
RER = 0.22
FWHM = 3.33 pixels
Footprint Size = 9.9 m

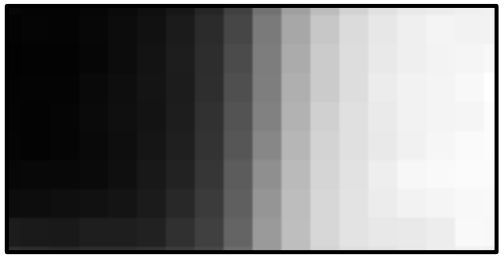
# Super Dove - Visual Mean

Displayed here is an evaluation of one image similar to the mean quality of SuperDove images.

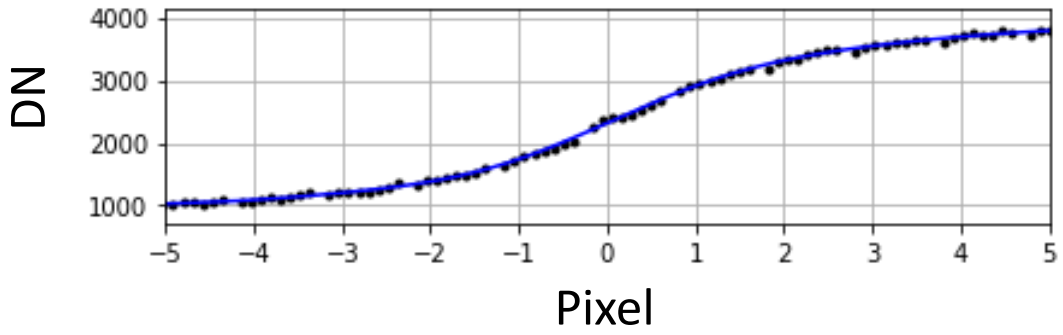


Cal/Val site: Baotou, China
Image ID: 20221005_031939_43_2254
Band: Red

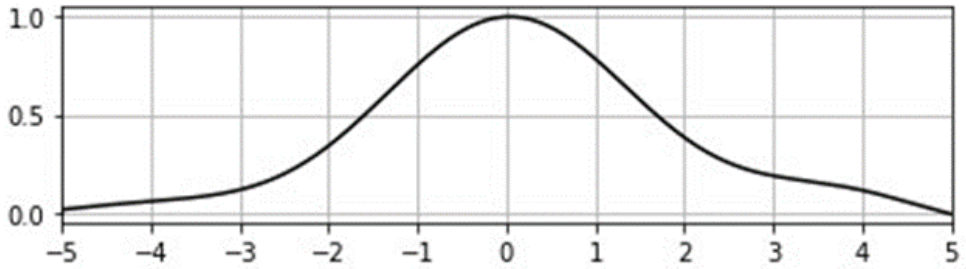
Edge



ESF - Red Band




LSF - Red Band




FWHM = 3.3 pixels
Footprint size = 9.9 m

# Black Sky Results

- At the time of this evaluation, Black Sky had 16 sensors in orbit. We acquired images from 12 different sensors.
- BlackSky's RGB images are pan-sharpened due to their extended Bayer color mosaic filter.
- Oldest (Global-4) and newest (Global-5) sensor results shown here, selected from the 12 assessments we performed.
- Both column and row assessments perform similarly, below are means of column and row results.
- Global-5 is a newer generation compared to Global-4, and shows improved image quality.

**Oldest Sensor: 4**
FWHM = 2.87 pixels
Footprint Size = 2.87 m

**Mean (all 12 assessments)**
FWHM = 2.55 pixels
Footprint Size = 2.55 m

**Newest Sensor: 5**
FWHM = 2.20 pixels
Footprint Size = 2.20 m

# Black Sky - Visual Mean

Displayed here is an evaluation of one image similar to the mean quality of BlackSky images.

BlackSky (0.93 m)

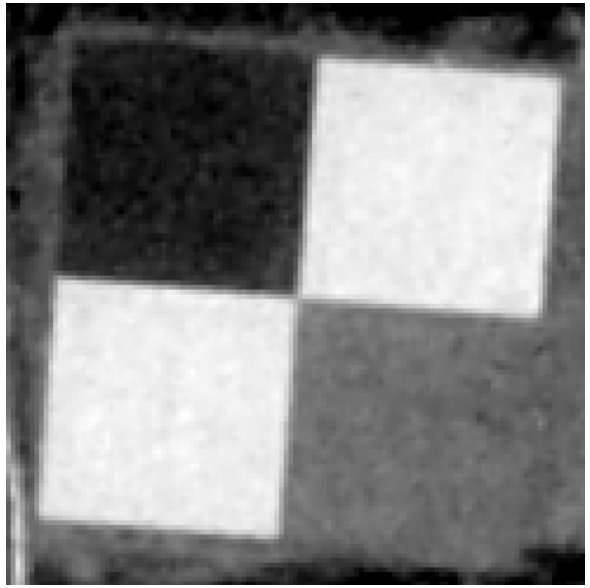
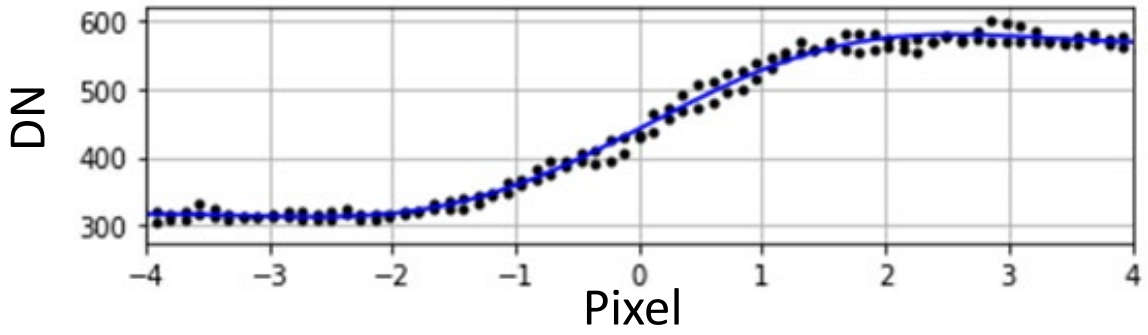


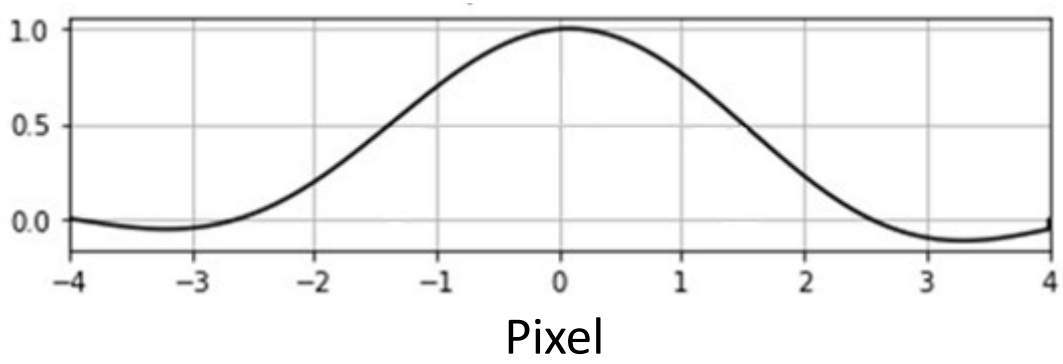
Image ID: BSG-115-20220220-001023-19247291
Band: Red

Edge

ESF - Red Band

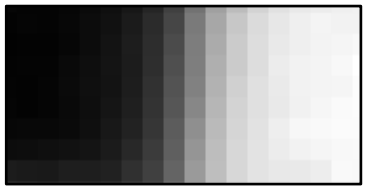
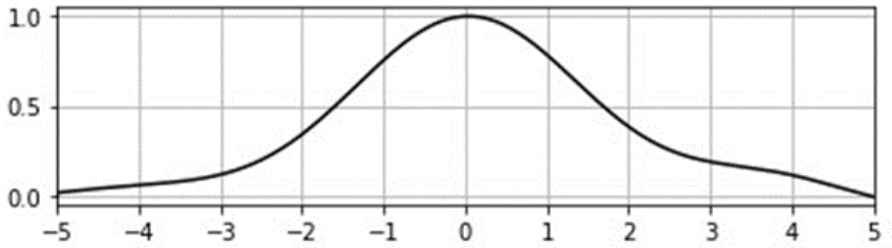
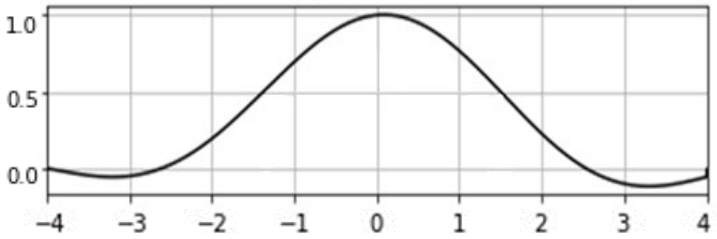
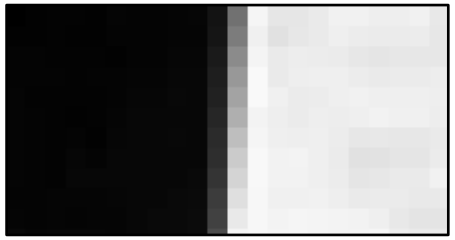
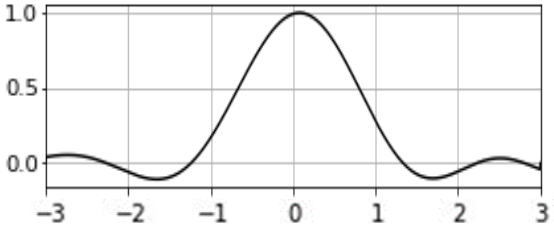
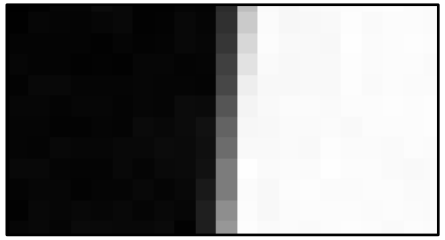
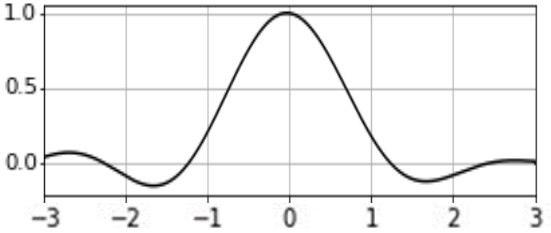



LSF - Red Band




FWHM = 2.7 pixels
Footprint size = 2.5 m

# Comparison of Commercial Sensors

| Sensor | Edge | LSF - Red Band | |
|---|---|---|---|
| SuperDove (typical) |  |  | FWHM = 3.3<br>Footprint = 9.9 m |
| BlackSky (typical) |  |  | FWHM = 2.7<br>Footprint = 2.5 m |
| WV-2 |  |  | FWHM = 1.5<br>Footprint = 3.2 m |
| WV-3 |  |  | FWHM = 1.4<br>Footprint = 2.3 m |

Pixel

# Summary

- Cal/Val sites have been used to successfully evaluate sensor footprint size for in-orbit sensors ranging from pixel size 0.33 - 3.0 m.
- Maxar's WV-2 sensor FWHM is 1.5 pixels (3.2 m), and WV-3 sensor FWHM is 1.4 pixels (2.3 m).
- Planet's SD sensor performance (RER, FWHM, GRD) slightly improves with time.
- SD average performance in both row and column direction is RER = 0.22, FWHM = 3.33 pixels (9.9 m). It is the most oversampled of those evaluated here.
- BlackSky's average sensor performance is better than expected. Mean spatial response in both directions is FWHM = 2.53 pixels (2.53 m).

# References


[1] Datta, R. (2019). Meltwater on the Greenland Ice Sheet. NASA CSDA Evaluation. https://www.earthdata.nasa.gov/s3fs-public/imported/CSDAP-Pilot-Tri-Datta.pdf -

[2] Li, T., & Feng, H. (2009). Comparison of different analytical edge spread function models for MTF calculation using curve-fitting. In *MIPPR 2009: Remote Sensing and GIS Data Processing and Other Applications* (Vol. 7498, pp. 395-402). SPIE. https://doi.org/10.1117/12.832793

[3] Tucker C., Brandt M., Hiernaux P., Kariryaa A., Rasmussen K., Small J., Igel C., Reiner F., Melocik K., Meyer J., Sinno S. (2023) Sub-continental-scale carbon stocks of individual trees in African drylands. *Nature* (Vol 615, pp 80-86.Mar 2;615(7950):80-6. https://doi.org/10.1038/s41586-022-05653-6