Determining True Sensor Spatial Resolution of Very High Resolution Optical Imagery

Alana Semple[1,2]

Bin Tan[1,2]

Guoqing (Gary) Lin[2]

1. Science Systems and Applications, Inc., Lanham, MD

2. NASA Goddard Space Flight Center, Greenbelt, MD

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Outline

- Background

- Cal/Val & Bridge Sites

- Bridge Simulations

- Commercial Assessments
  - WV-2/3
  - BlackSky
  - SuperDove

- Public Sensor Assessments
  - Landsat 8/9
  - Sentinel-2

- Summary

Image Grid (pixel size) vs Sensor Resolution

- Image grid pixel size is not always the sensor resolution.

- This can cause misinformation and confusion among data users.
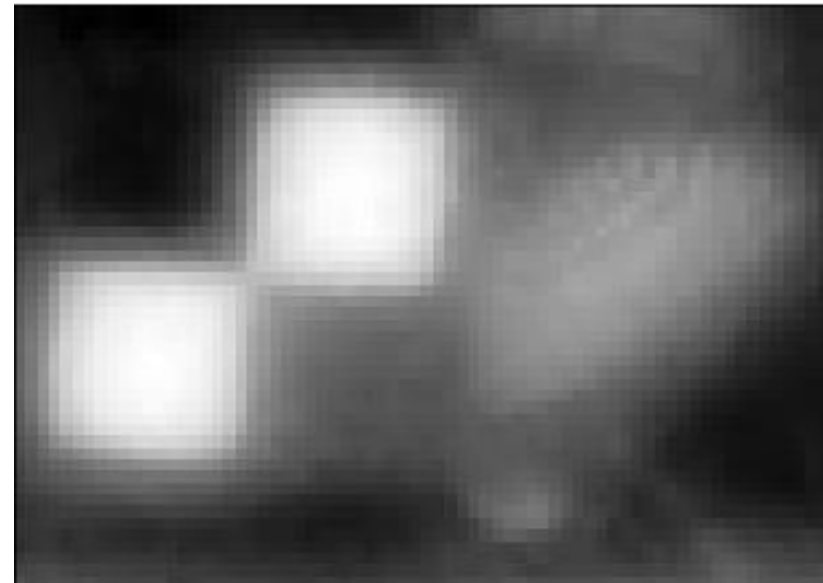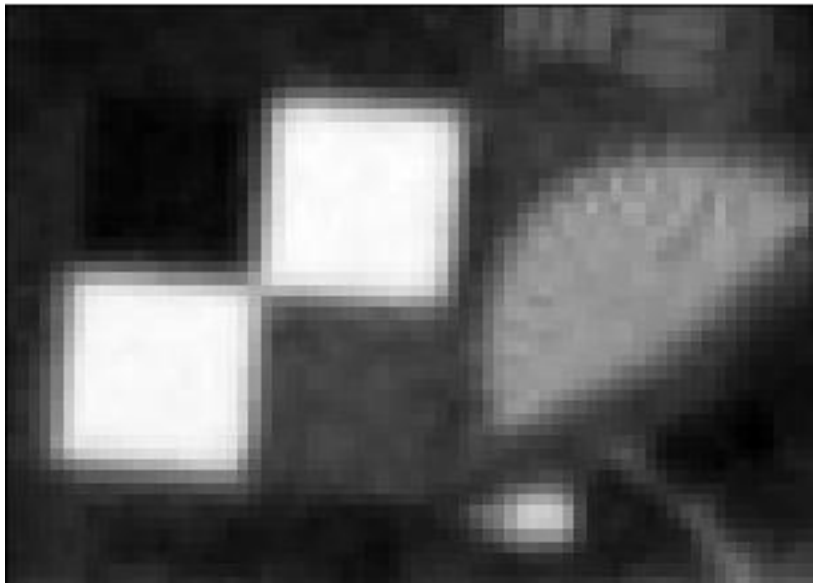
- These two images have the same pixel size, but different sensor resolutions.

- Sharper transitions across edges indicate better quality images, they provide more detailed information on the image grid.
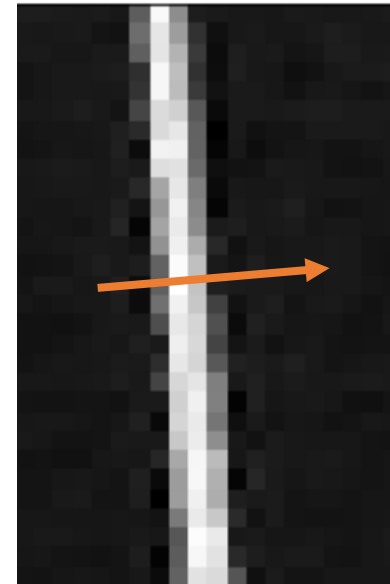
Determining Sensor Resolution - Find transitions

- Current Cal/Val sites for <6m pixels

- Local (skinny) bridges for ~10m pixels

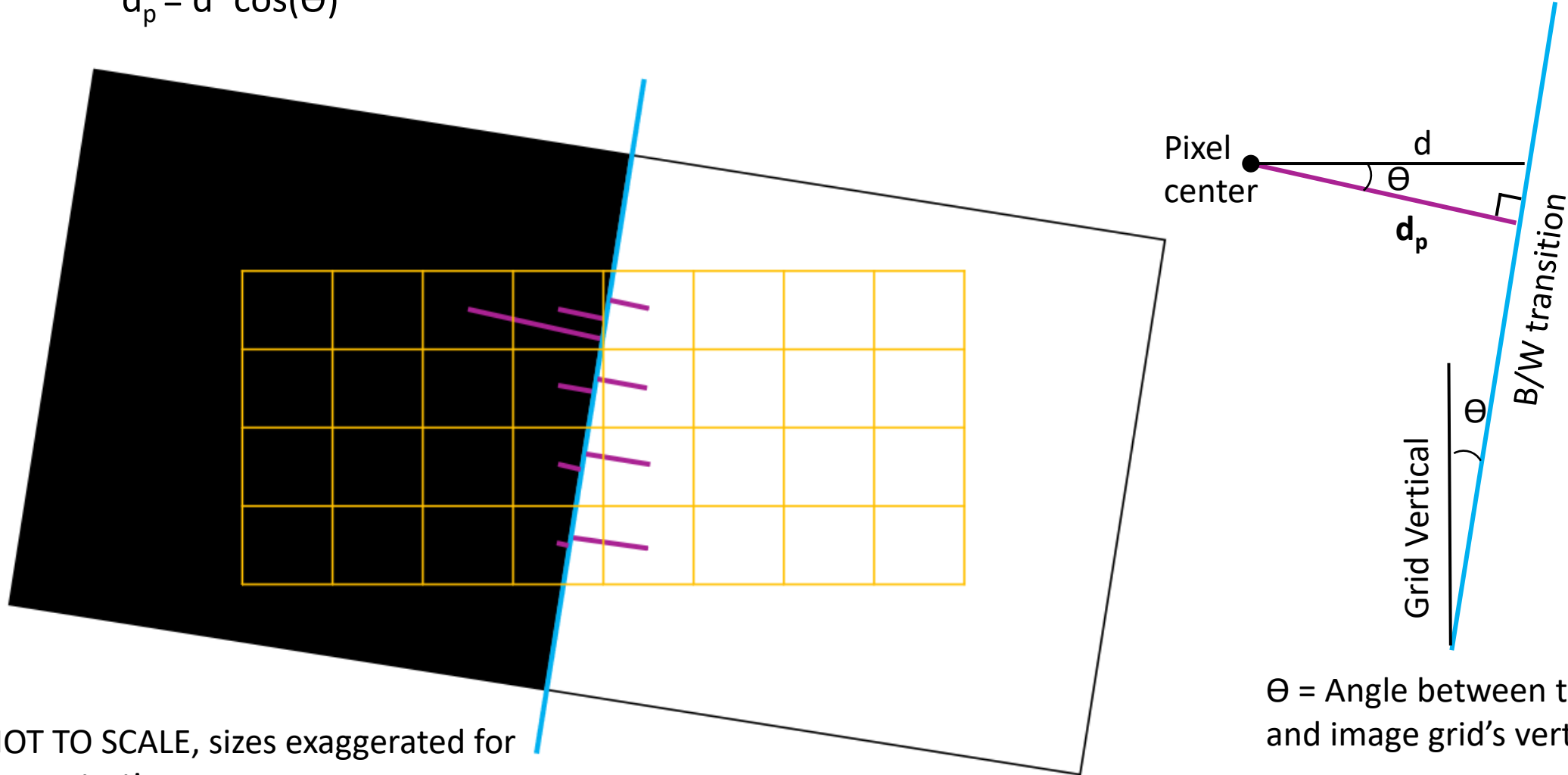- Wide bridges over water for >30m pixels

Cal/Val sites
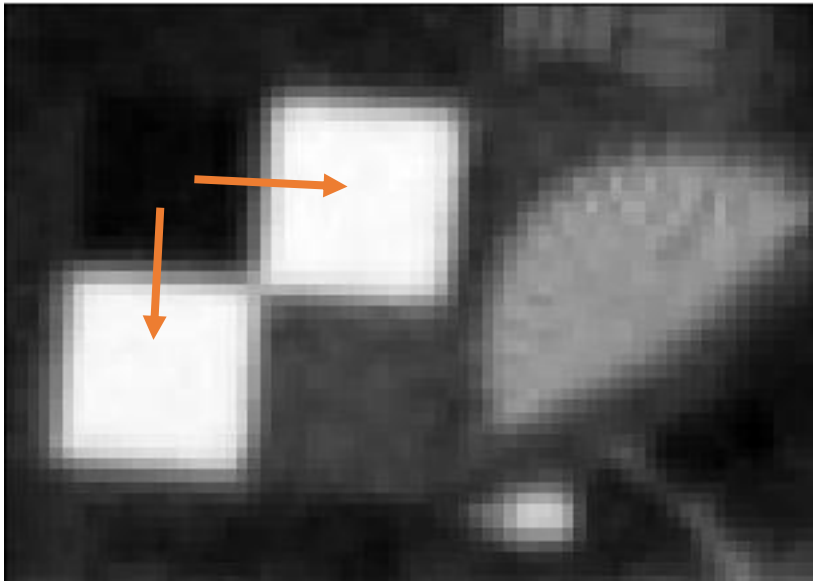
Bridges

Slanted Edge 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)
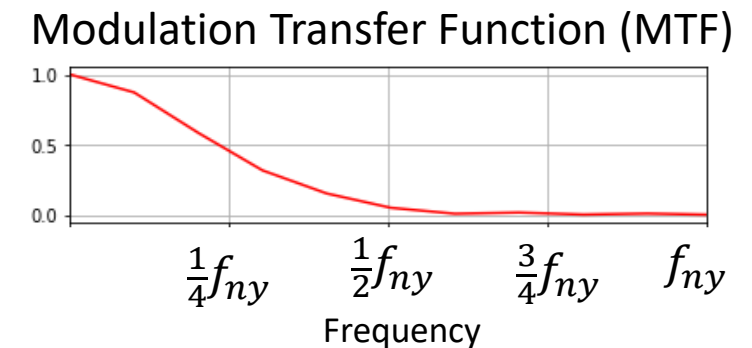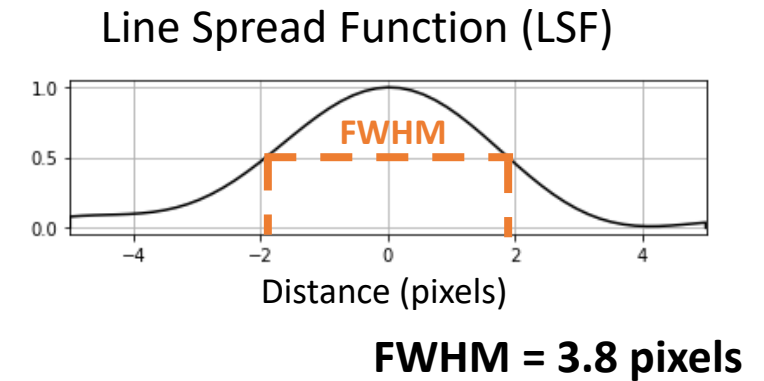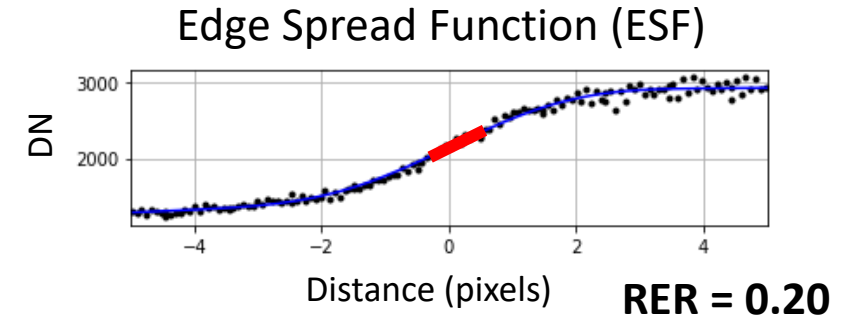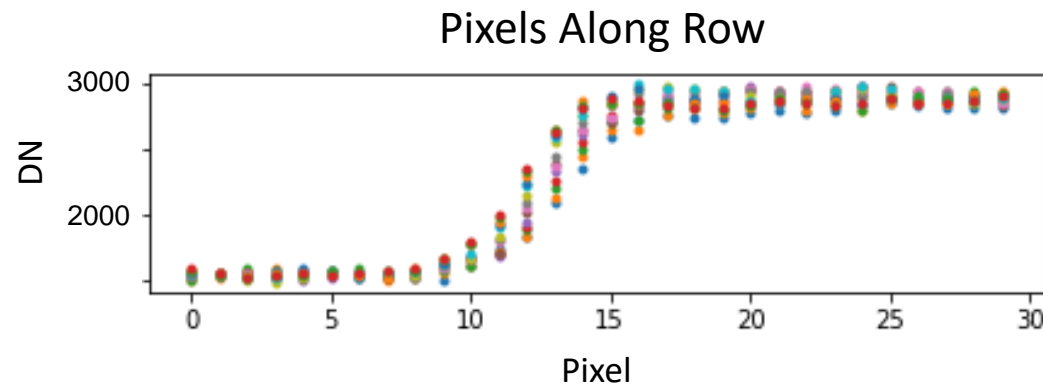
   $d_p = d*\cos(\Theta)$

*NOT TO SCALE, sizes exaggerated for demonstration

Θ = Angle between transition and image grid's vertical

Slanted Edge Methods

- Extract 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 construct 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).

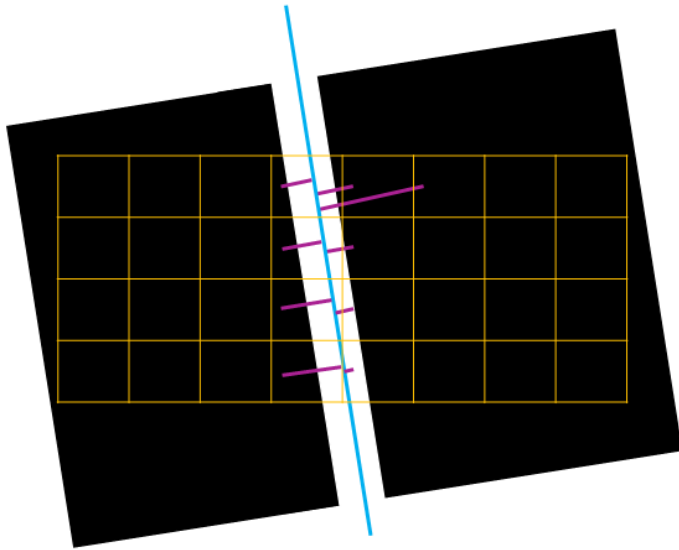- Find Ground Resolved Distance (GRD) where MTF(1/(2GRD)) = 0.5 .

Edge Spread Function (ESF)

RER = 0.20

Line Spread Function (LSF)

FWHM

FWHM = 3.8 pixels

Modulation Transfer Function (MTF)

$\frac{1}{4}f_{ny}$ $\frac{1}{2}f_{ny}$ $\frac{3}{4}f_{ny}$ f_{ny}

Frequency

MTF @ f_{ny} = 0.004
GRD= 4.0 pixels

Pixels Along Row

DN

Pixel

Bridge "Slit" Methods

- Extract pixels along the bridge.

- Transform from pixel number to distance from bridge center.

- Fit a line to it, and this is the Line Spread Function (LSF).

- Fourier transform the LSF to find Modulation Transfer Function (MTF).

Line Spread Function (LSF)

FWHM

Distance (pixels)

FWHM = 3.8 pixels

Modulation Transfer Function (MTF)

$\frac{1}{4}f_{ny}$ $\frac{1}{2}f_{ny}$ $\frac{3}{4}f_{ny}$ f_{ny}

Frequency

MTF @ f_{ny} = 0.004

*NOT TO SCALE, sizes exaggerated for demonstration
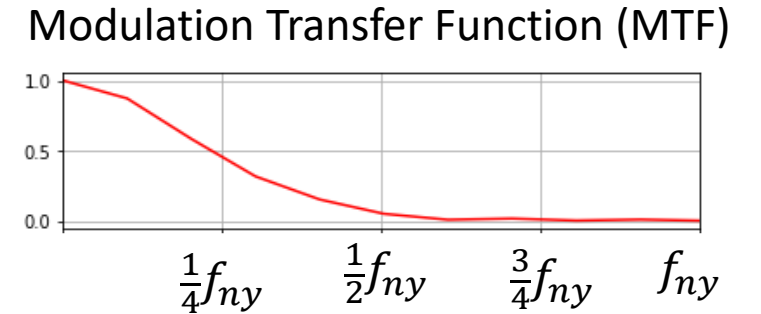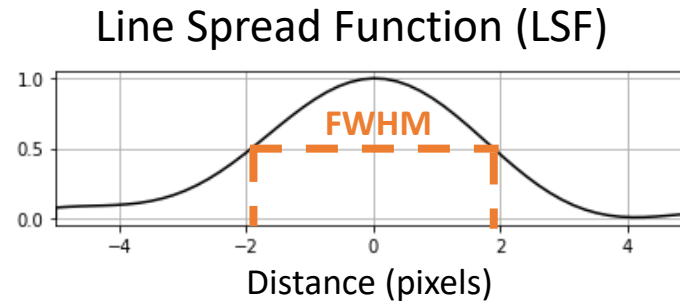
Bridge Simulations

- Simulate impacts of bridge width on LSF estimation.
  - Gaussian LSF is applied to an idealized white 'bridge' on a black background
  - Difference in returned apparent LSF FWHM and applied Gaussian FWHM is determined.
  - Various combinations of $\frac{Bridge\ width}{Pixel\ size}$ ratios are tested and an empirical relationship established.
- Use simulation results to remove impacts of bridge width on LSFs retrieved from bridge images.

Simulation Samples

Ideal
Bridge

Gaussian
LSF applied
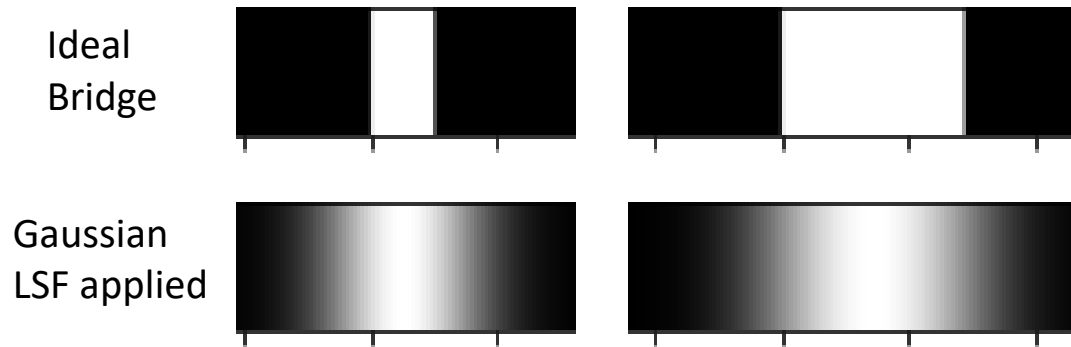
Same Gaussian LSF applied, different apparent FWHM returned due to different $\frac{Bridge\ width}{Pixel\ size}$ ratios
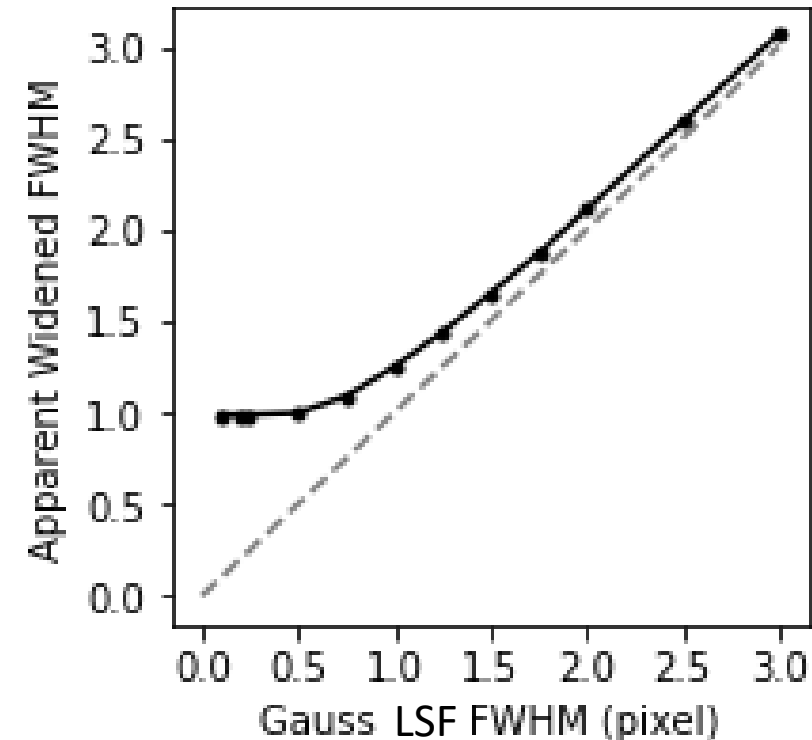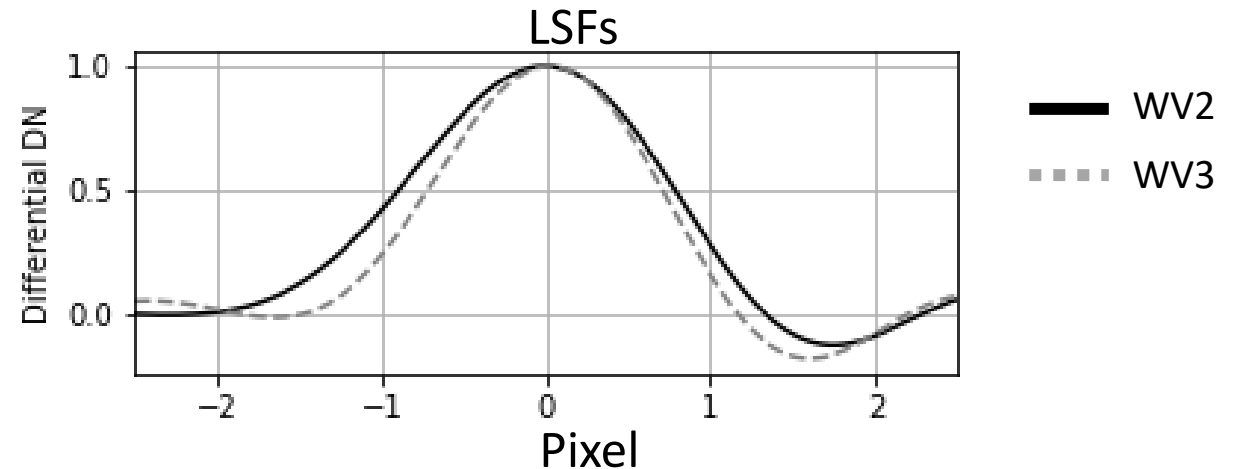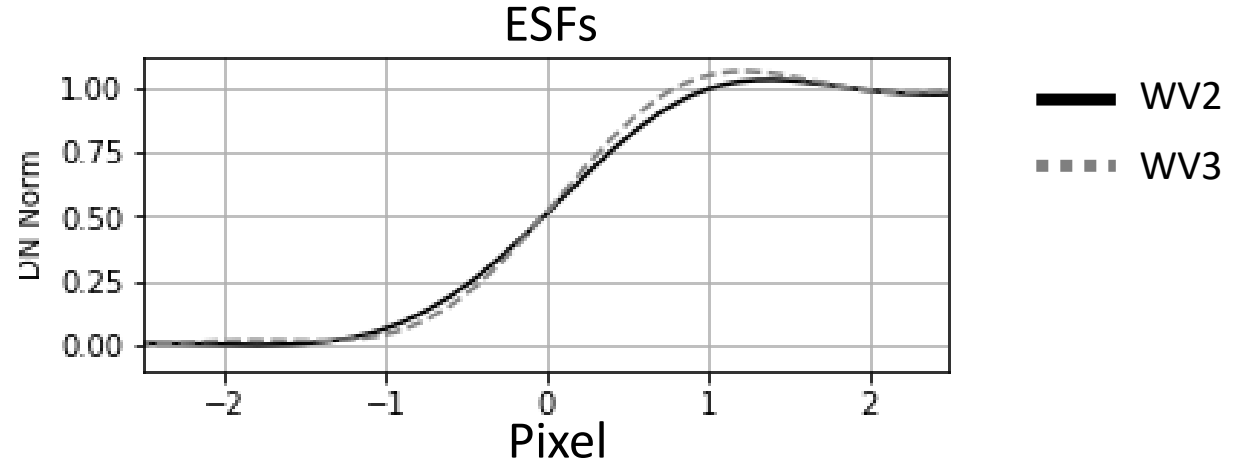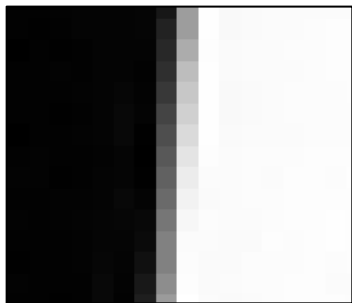
Maxar's Worldview-2/-3 Results

Results for all four images examined for WV-2 (0.46m Pan, 1.84m multi band pixel size) and WV-3 (0.31m Pan, 1.25 VNIR bands pixel size).

WV-2 (China Site)
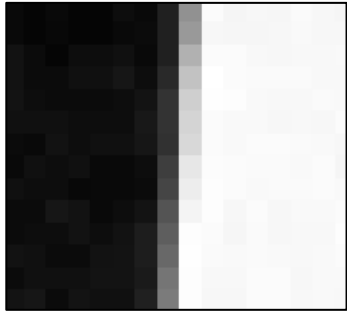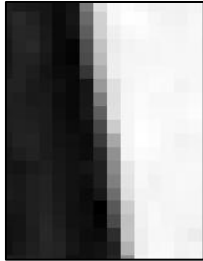

WV-3 (China Site)

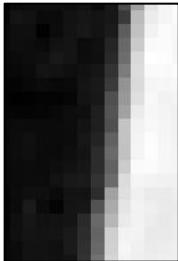**FWHM** = 1.4, 1.5 pixels

Black Sky - Quality Range

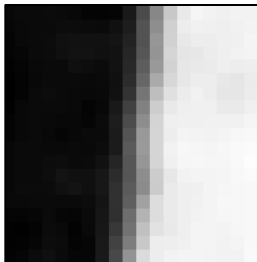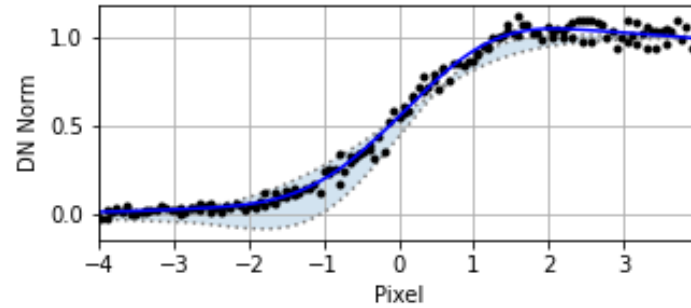The range of BlackSky (~1 m pixel size) image quality from 12 sensors.
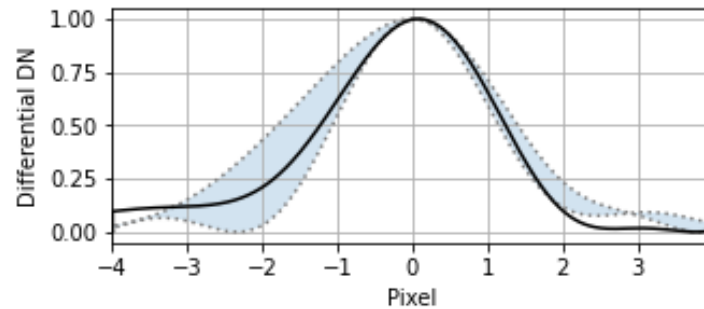
Narrowest BSG LSF

ESF

Mean BSG LSF

LSF

Widest BSG LSF

FWHM = 2.7 pixels
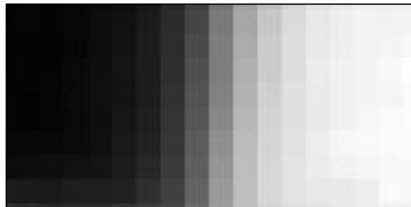Footprint size = 2.5 m

Planet's SuperDove - Quality Range

The range of SuperDove (~3m pixel size) image quality from 10 images.
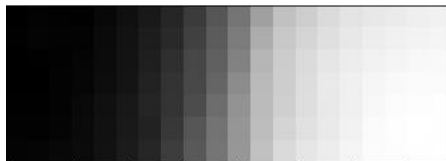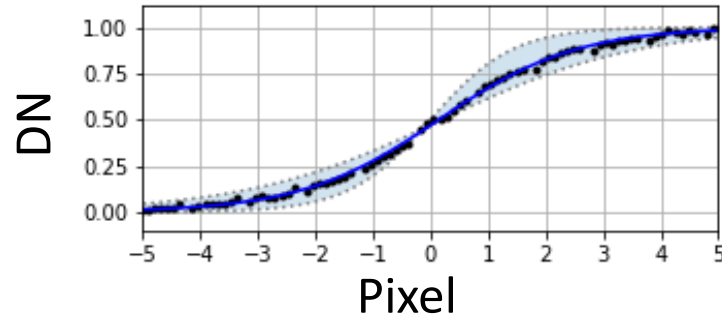
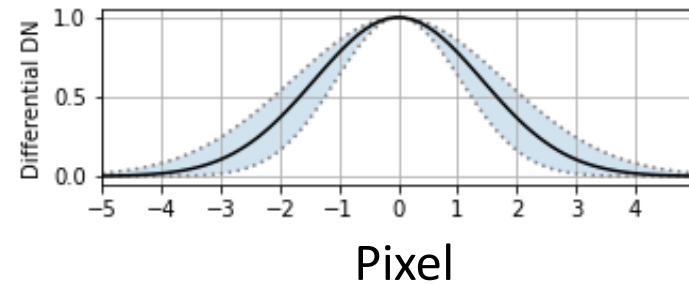Edge

Narrowest SD LSF

Mean SD LSF

Widest SD LSF

ESF

LSF

Mean FWHM = 3.3 pixels
Footprint size = 9.9 m

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

1 yr in orbit →

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

2 yrs in orbit →

Sensor: 2231, 08/22
RER = 0.23
FWHM = 3.17
Footprint Size = 9.5 m
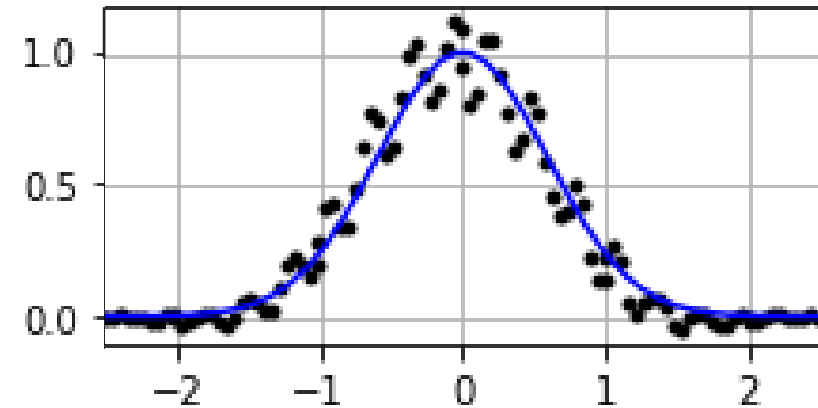
Mean (all 9 assessments)
RER = 0.22
FWHM = 3.33 pixels
Footprint Size = 9.9 m

Landsat-8/9 assessment

- 15m Pan band assessed at India Cal/Val site.
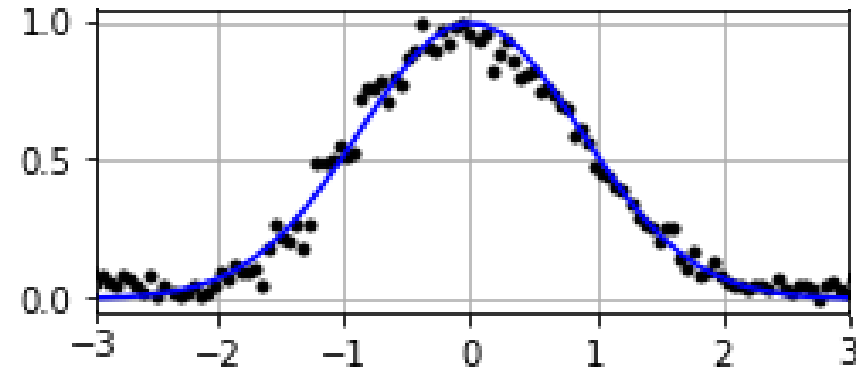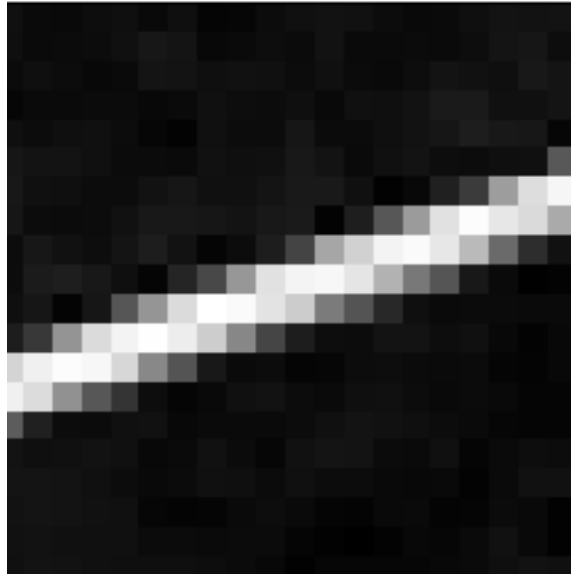- 30m bands assessed at bridges.

Apparent FWHM = 1.3 pixels
Adjusted FWHM = 1.0 pixels

Sentinel-2 Assessment

10 m bands assessed at India Cal/Val site.
20+ m bands assessed at bridges.

Apparent FWHM = 2.0 pixels
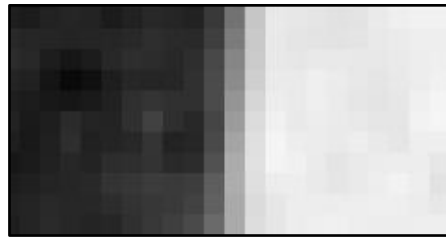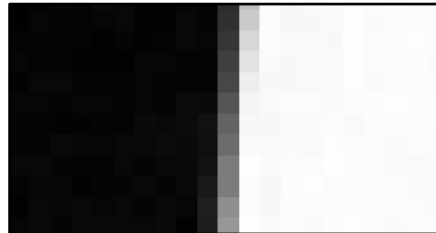Adjusted FWHM = 1.8 pixels
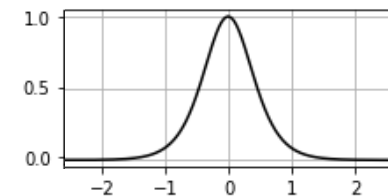
Comparison of All Sensors

Edge — Typical LSF

Sensor		
SuperDove (typical)		Mean FWHM = 3.3 Footprint = 9.9 m
BlackSky (typical)		Mean FWHM = 2.7 Footprint = 2.5 m
WV-3		FWHM ~ 1.4 Footprint = 2.3 m
Sentinel-2		FWHM = 1.4 Footprint = 14 m
Landsat-8		FWHM ~ 1.0 Footprint = 15 m
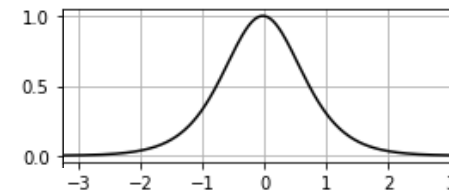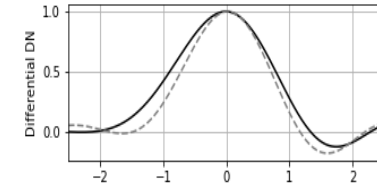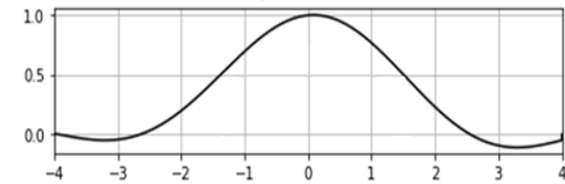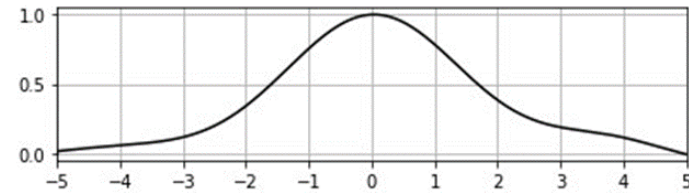
Pixel

Summary

- Cal/Val sites have been used to successfully evaluate sensor footprint size for in-orbit sensors ranging from pixel size 0.33 - 10 m.

- Bridge modeling has improved certainty of retrieved FWHM from bridge analysis.

- Best to poorest performance of the gridded images analyzed here is: Landsat8/9, WV-2/3, Sentinel-2, BlackSky, Planet's SuperDove

- SD is the most oversampled at FWHM = 3.3 pixels (~10m). The true resolution is more similar to Sentinel-2's 10m band than its gridded pixel size.