An Automated Tool to Estimate the Spatial Resolution of Products Acquired by High Spatial Resolution Remote Sensing Imaging Systems

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Image Formation

- An image can be considered the convolution of a point spread function (PSF) with an input scene that is sampled

$$I_o(x,y) = \int_{-\infty}^{\infty}\int I_i(x',y')PSF(x'-x,y'-y)dx'dy'$$

where $I_o(x,y)$ is the output image

$I_i(x',y')$ is the input object

PSF is the system's impulse response and is assumed to be a slow varying function

Image Formation Example I

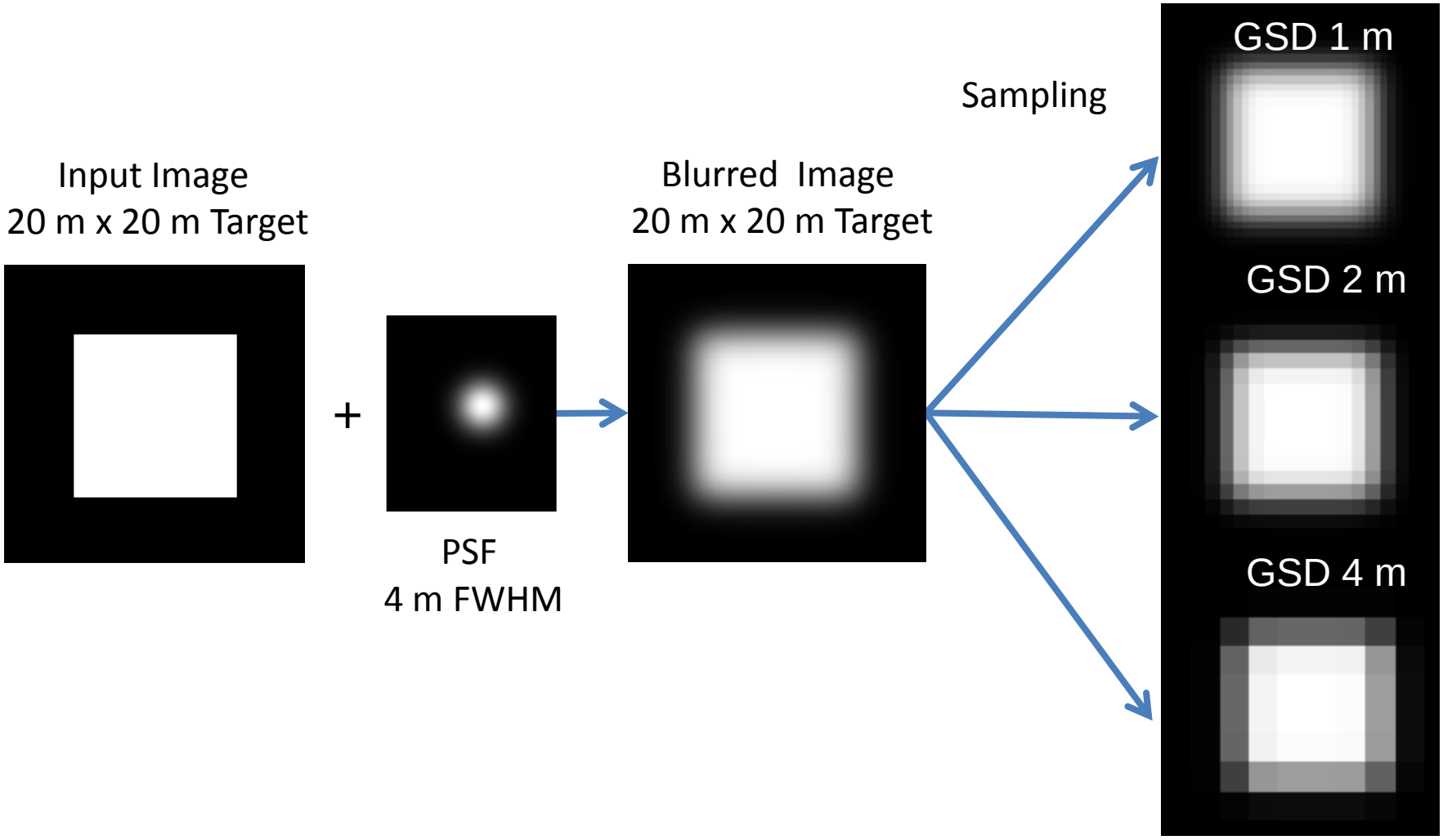
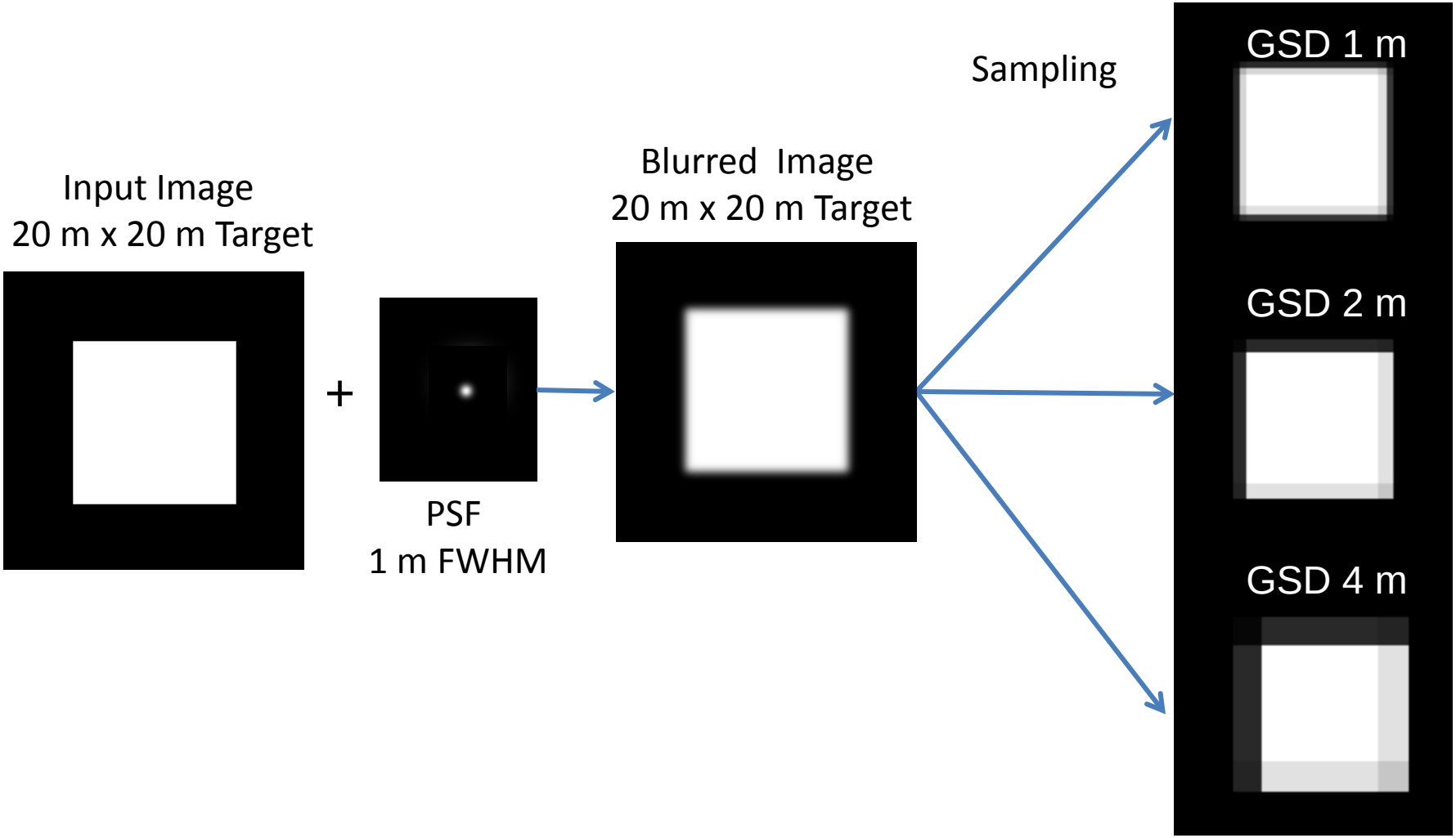


Image Formation Example II



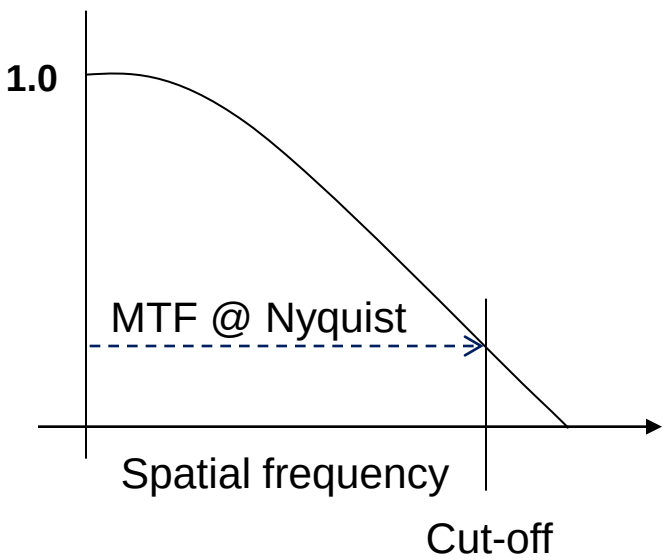
Spatial Resolution Characterization Considerations

- Point Spread Function (PSF) or Optical Transfer Function (OTF) are desired but difficult to determine fully in practice
- Edge and pulse targets allow for partial evaluation of PSF and OTF
  - One dimensional evaluations

Common Spatial Resolution Metrics

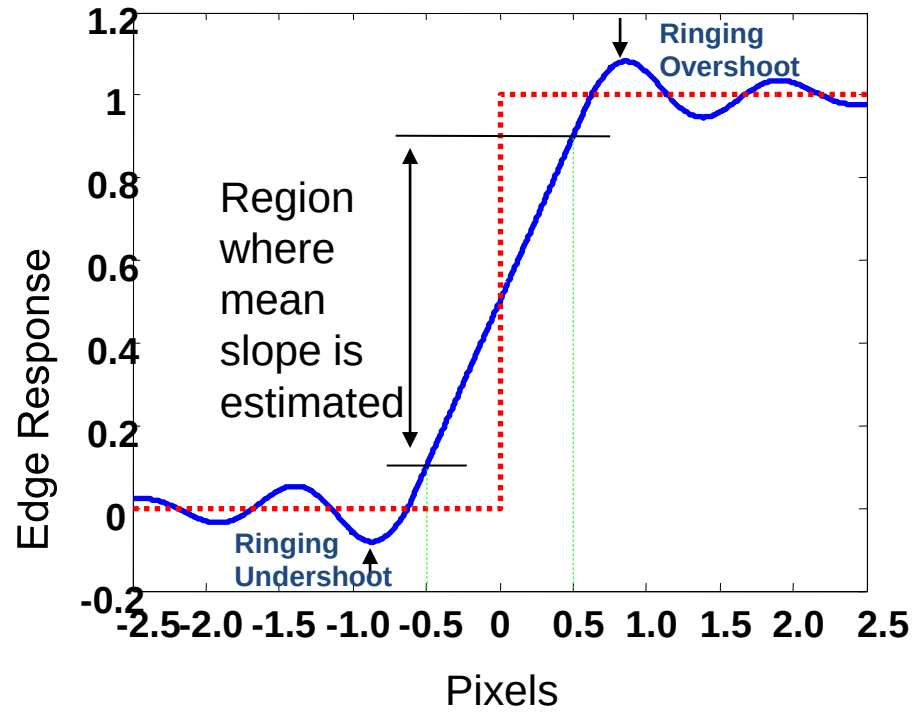
Frequency Domain

- Modulation Transfer Function (MTF)
  - MTF at Nyquist typical parameter



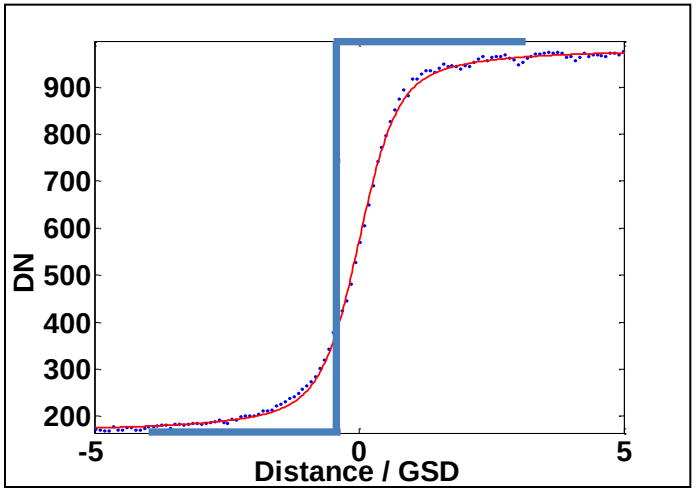
Spatial Domain

- Relative Edge Response (RER)

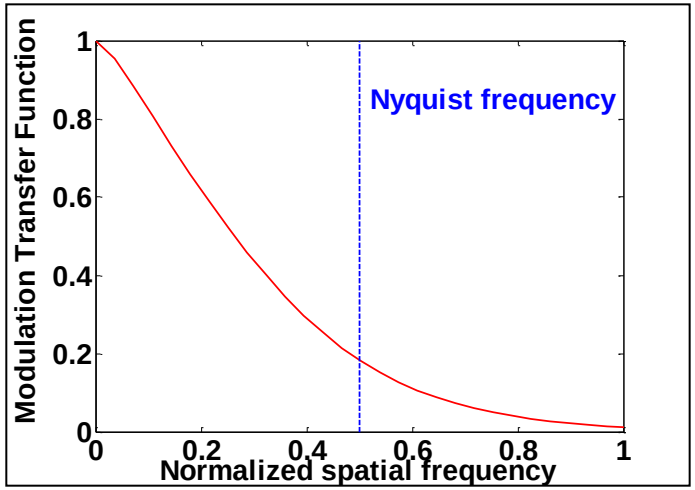


MTF Estimation

Edge Response

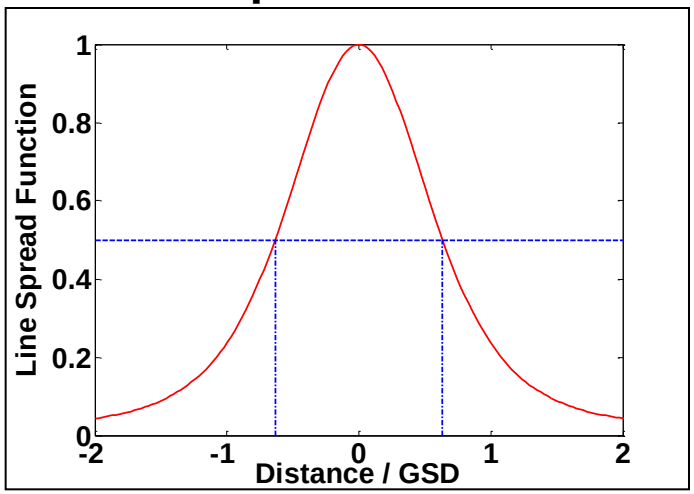


MTF

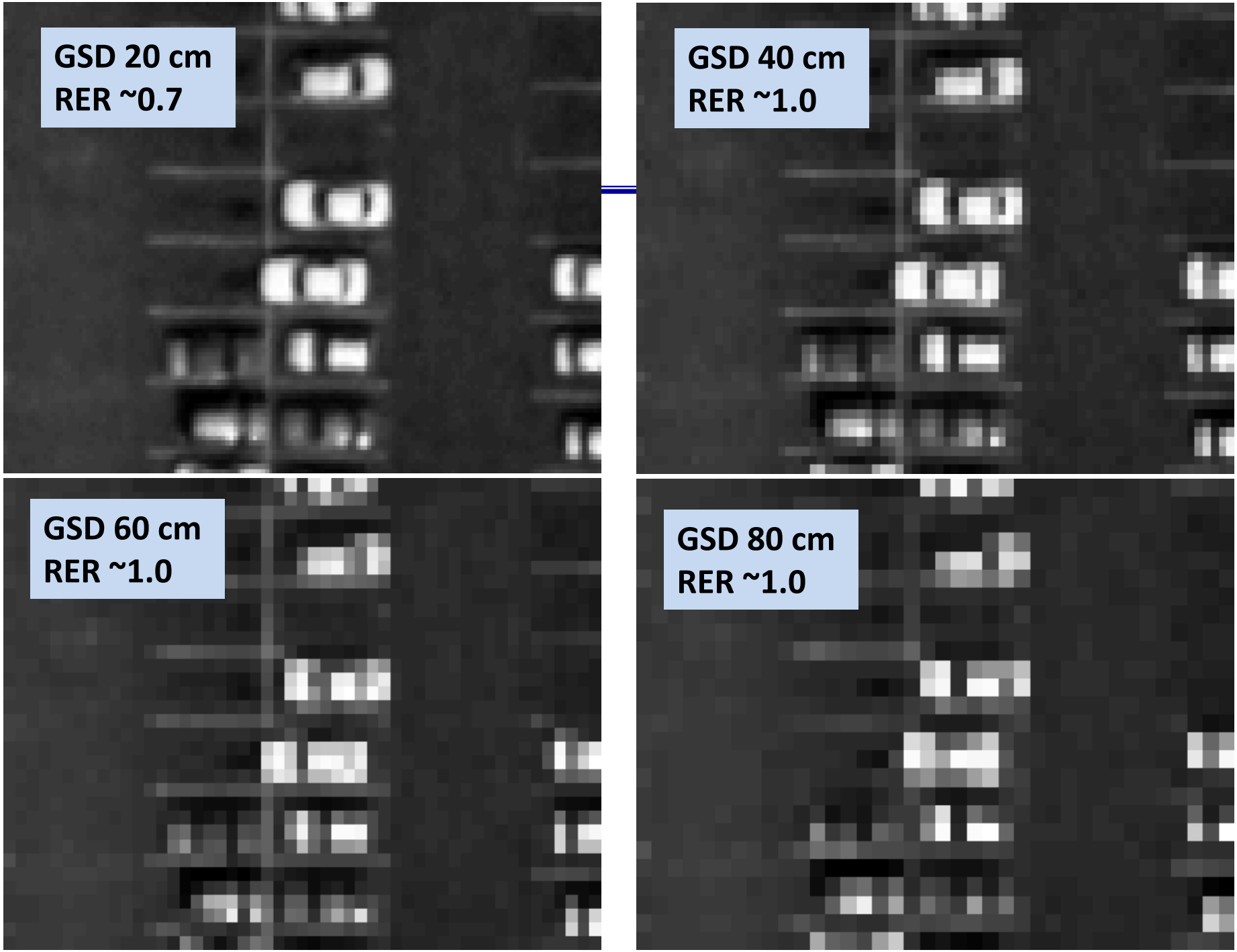


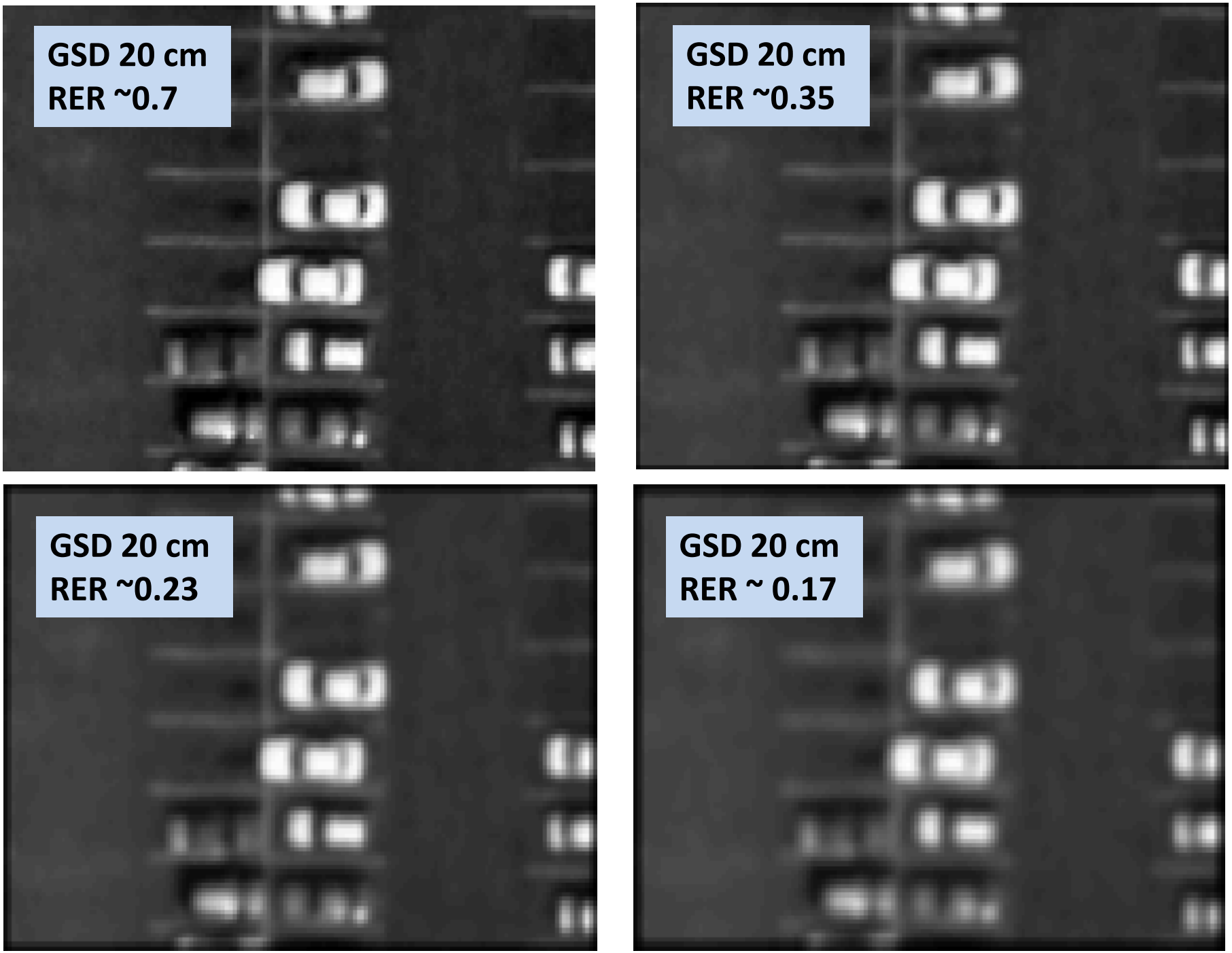
Differentiate

Line Spread Function



Fourier Transform


GSD 20 cm
RER ~0.7
GSD 40 cm
RER ~1.0
GSD 60 cm
RER ~1.0
GSD 80 cm
RER ~1.0

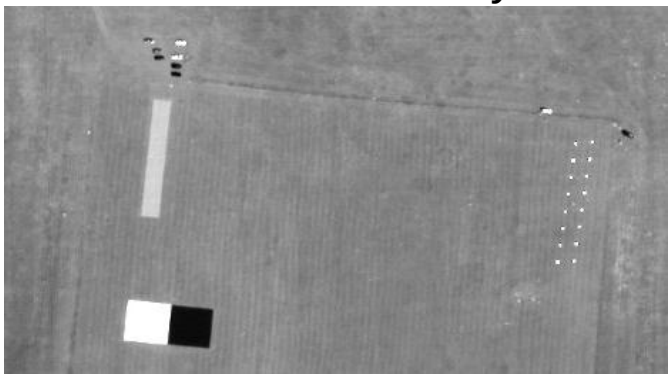

GSD 20 cm
RER ~0.7
GSD 20 cm
RER ~0.35
GSD 20 cm
RER ~0.23
GSD 20 cm
RER ~ 0.17

Problem…

Most commonly used estimation techniques require engineered targets (deployed or fixed)

Traditional Spatial Resolution Targets

Deployable targets at the South Dakota State University site



NASA SSC painted concrete radial target

NASA SSC painted concrete edge target

Digital Globe provided satellite imagery

Traditional Spatial Resolution Targets

These types of targets however, will not generally be available in the imagery to validate spatial resolution

Big Spring
TX, USA

Pong Hu, Taiwan

Salon de
Provence, France

Digital Globe provided satellite imagery

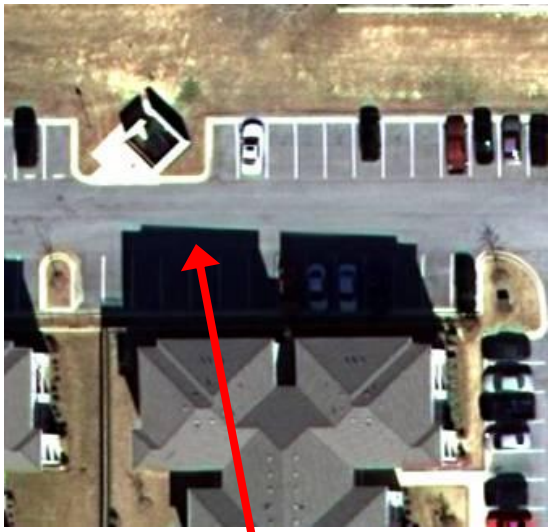
Natural Edge Target Spatial Resolution Estimation

- Exploit features in nominal imagery
- Edge response estimation without dedicated targets
- Developing automated process
  - Identify edges
  - Construct resulting edge response
  - Calculate MTF and RER

“Natural” Edge Targets Examples

- Natural edge targets within the imagery can be used

Street center lines
(pulse targets)



Building Shadows

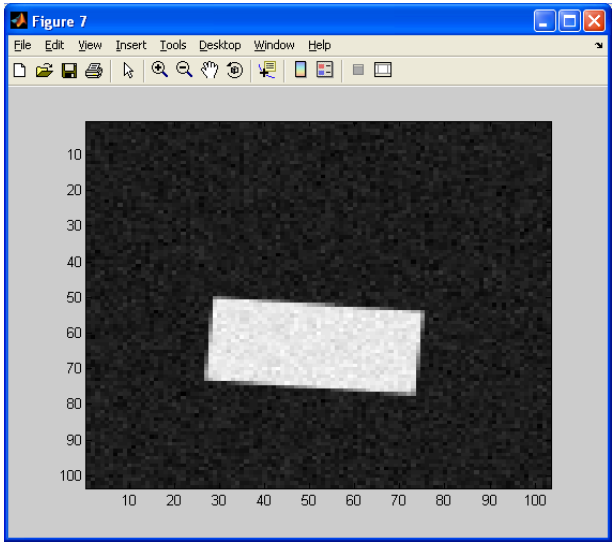
Rooflines

Automated Spatial Resolution Algorithm Flowchart

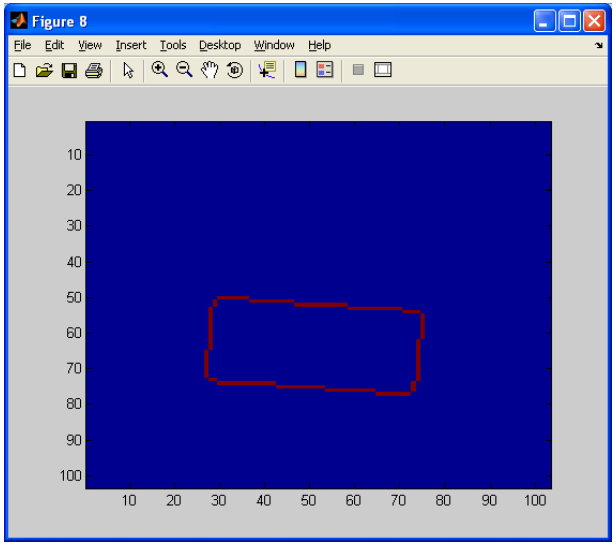
Image	
Edge Detection	Sobel edge detection returns points where gradient of image is maximum.
Edge Screening	Signal-to-Noise Ratio of near horizontal or near vertical edges
Edge Response	Edges plotted and curve-fit using LOESS or Sigmoidal functions. Curves are set to even spacing.
MTF Estimation	Smoothed edge response is differentiated to estimate LSF Fourier transform of LSF gives MTF at Nyquist
RER Estimation	Difference of edge response at +/-0.5 pixel.

Finding Edges and Generating Edge Response

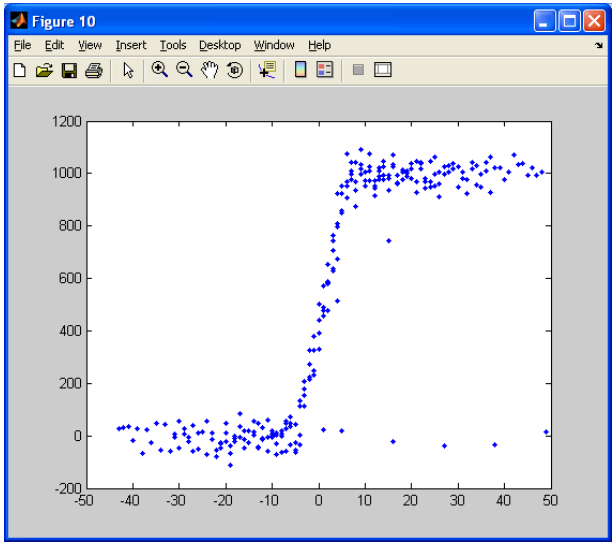
- Algorithm developed for automated edge detection and analysis using scene data



Simulated image with noise

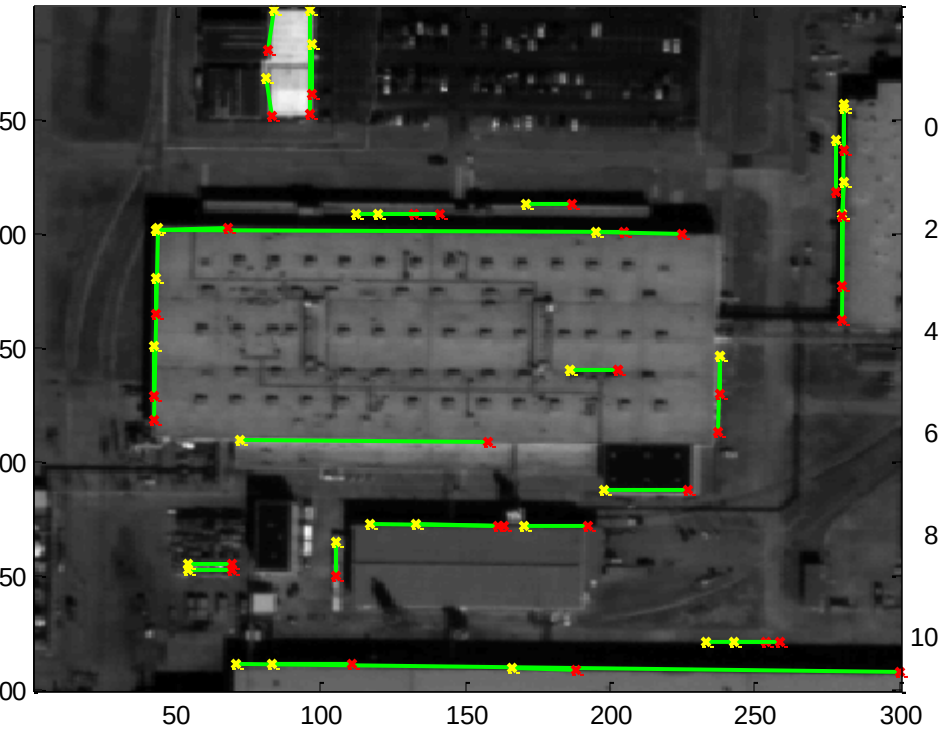


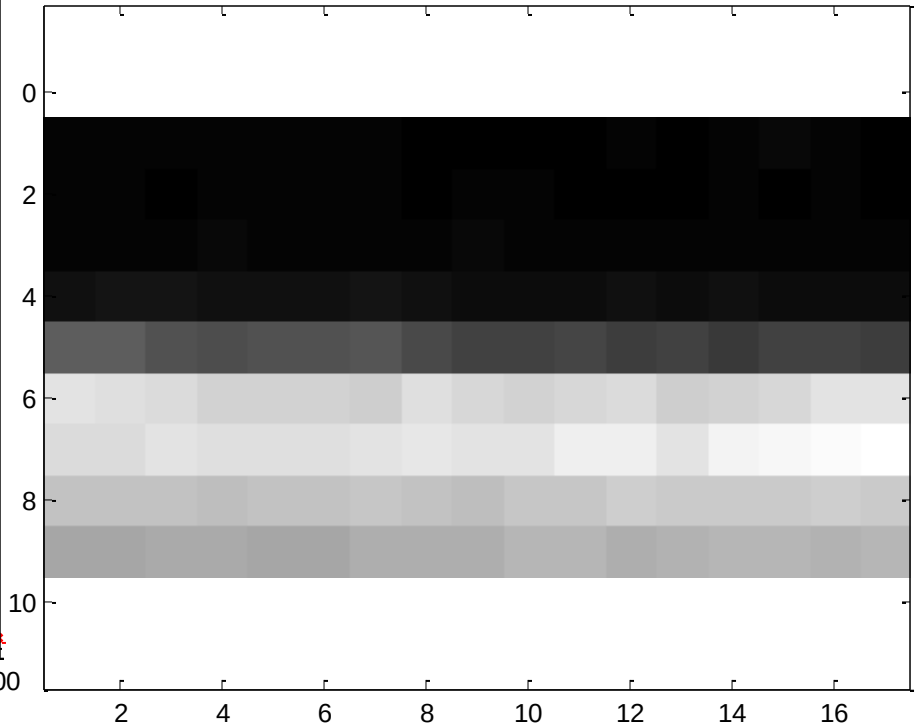
Edge found with Sobel method



Data points across the edge to estimate edge response

Natural Edges at SSC



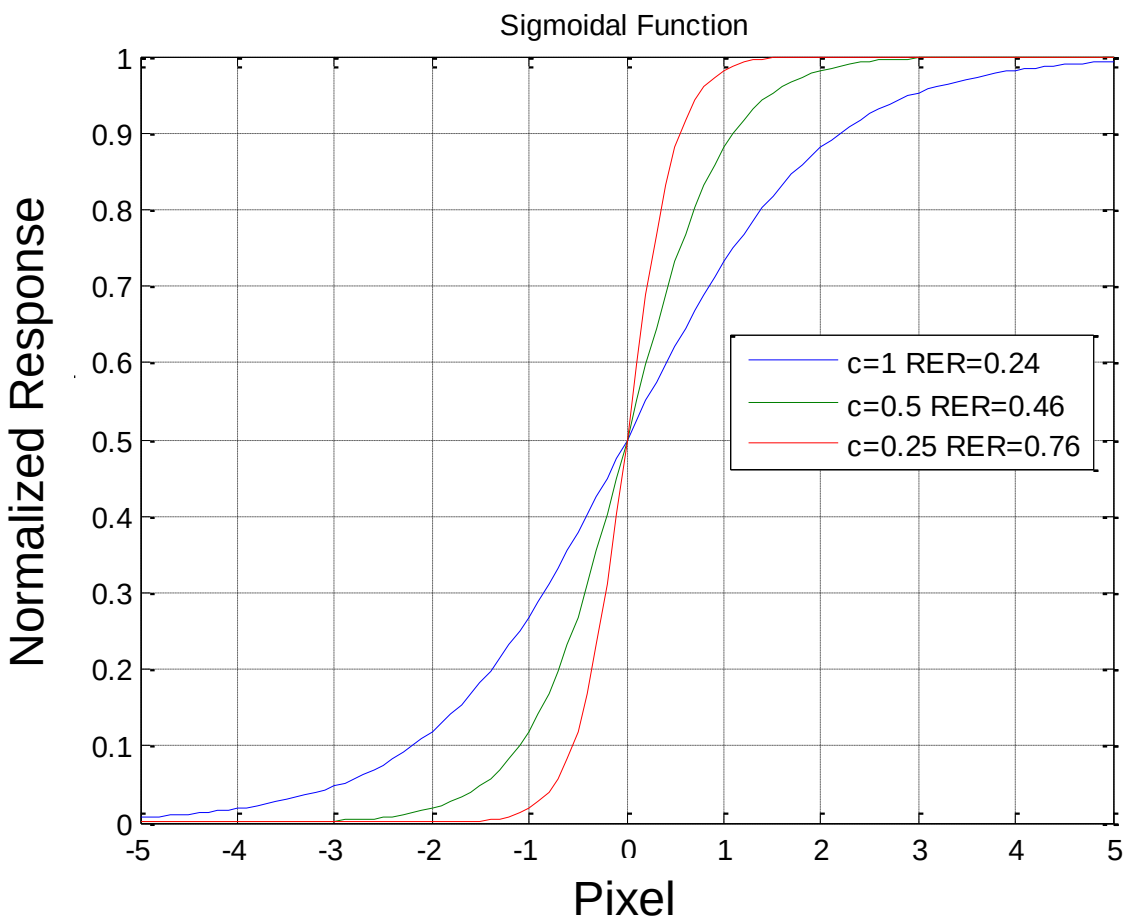


Edge Response Processing Option I

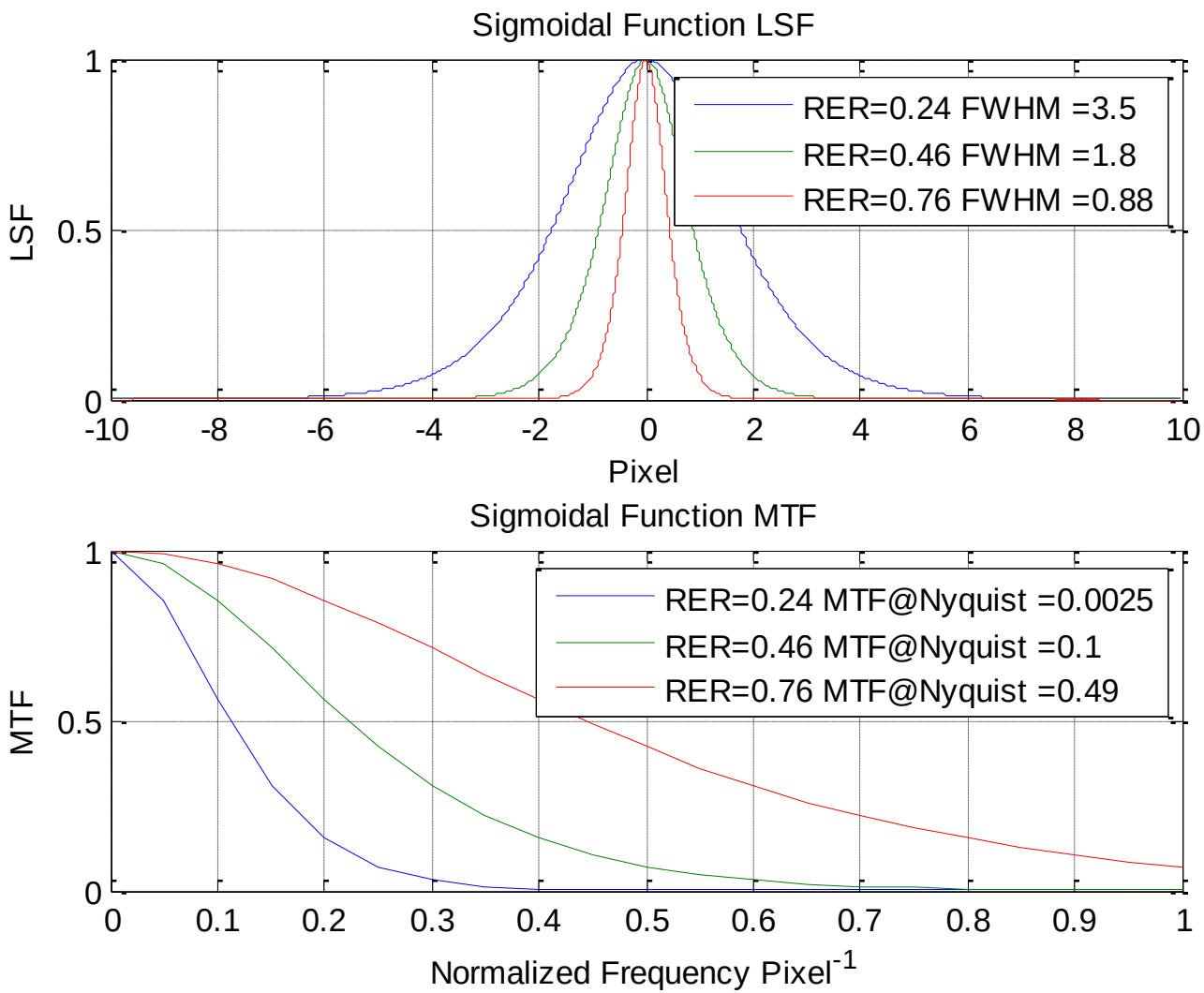
- Parametric
  - Edge response is fitted to a function whose characteristic shape is “representative” of the measured edge
  - Addresses SNR associated with numerical derivative of edge response
  - Sigmoidal function or superposition of Sigmoidal functions commonly used
    - Previous SSC work used superposition of several Sigmoidal functions to account for MTFC ringing
  - Can breakdown at low MTF@Nyquist values

Parametric Sigmoidal Function

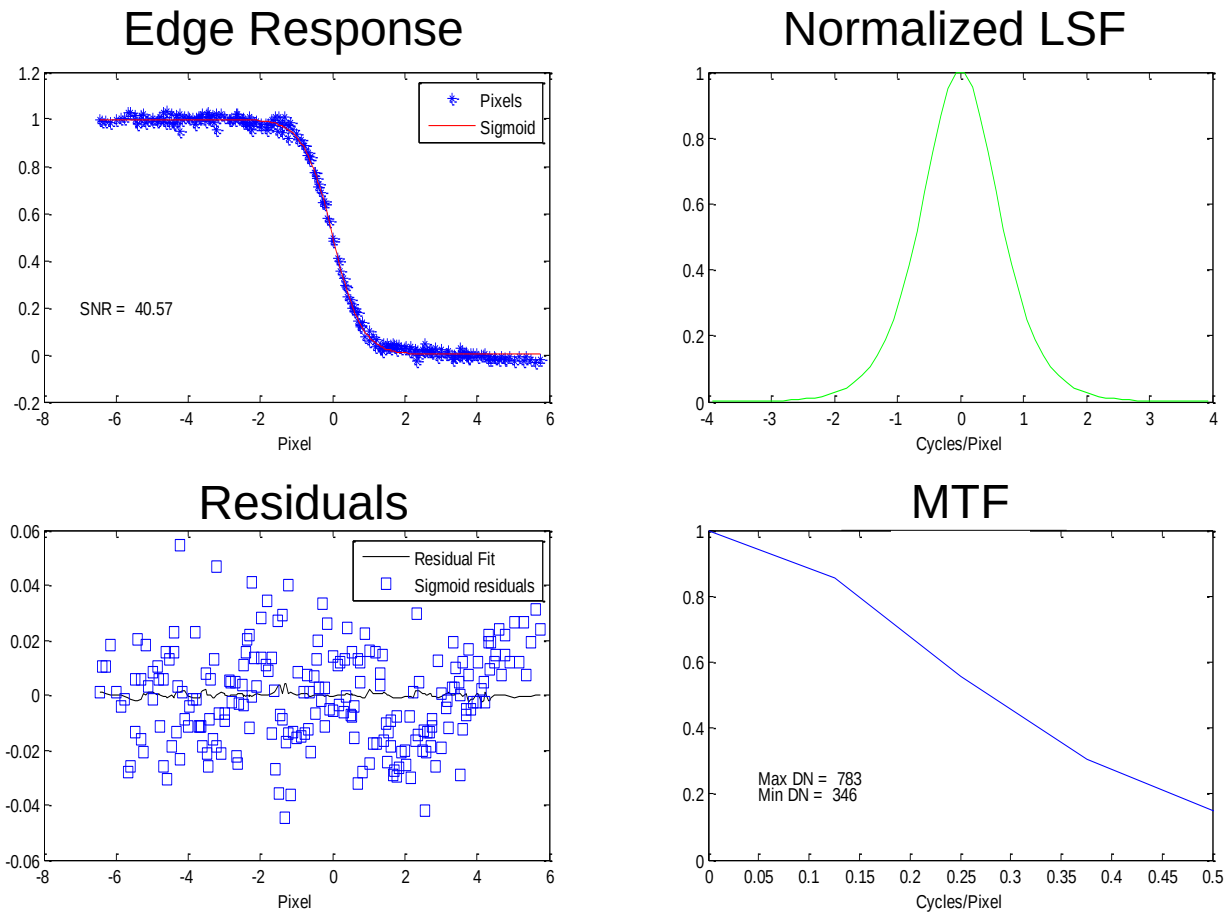
$$S(x) = a\,/(1 + \exp\left[\frac{x - b}{c}\right])$$



Parametric Sigmoidal Function (cont.)



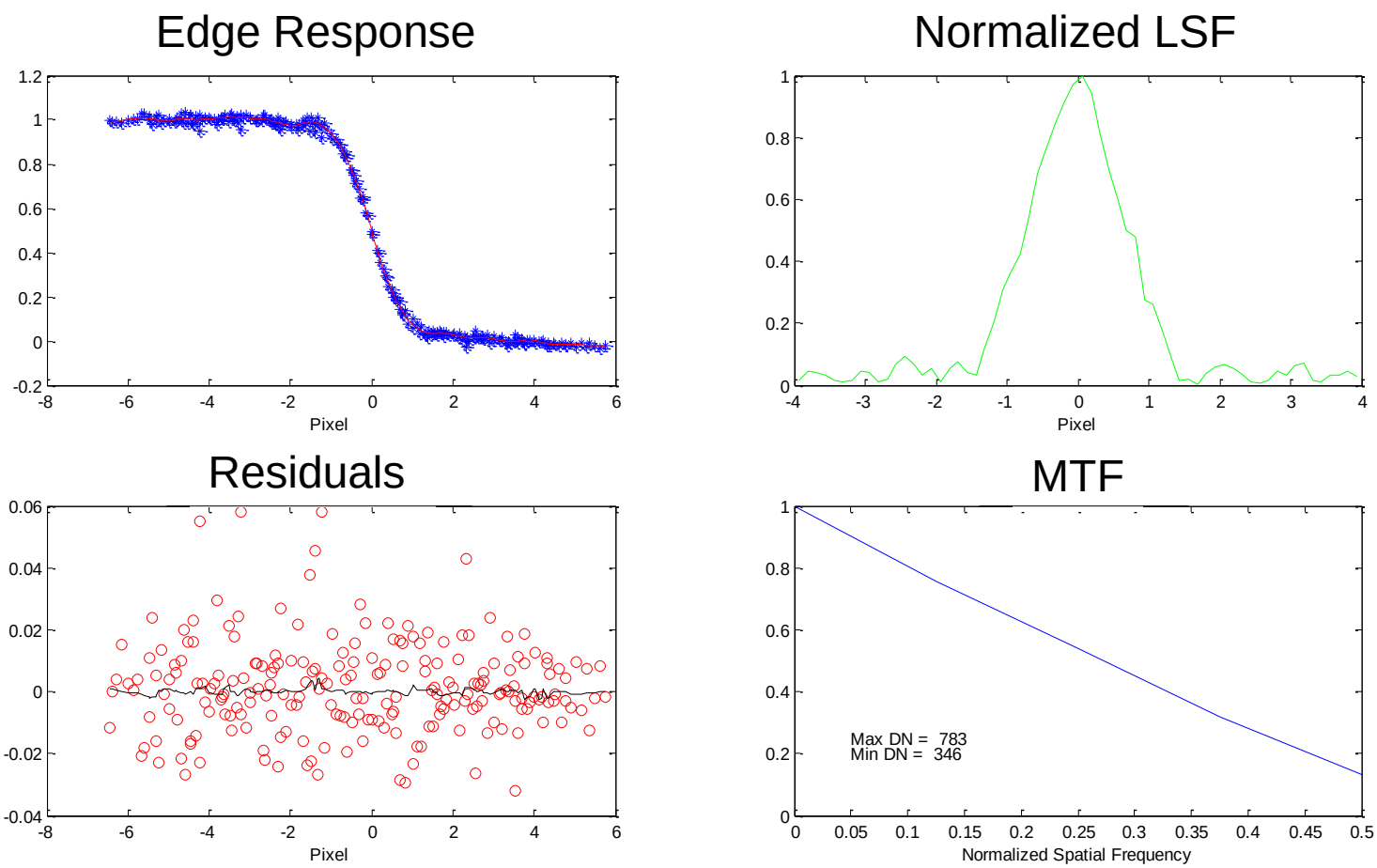
Sigmoidal Fit Example



Edge Response Processing Option II

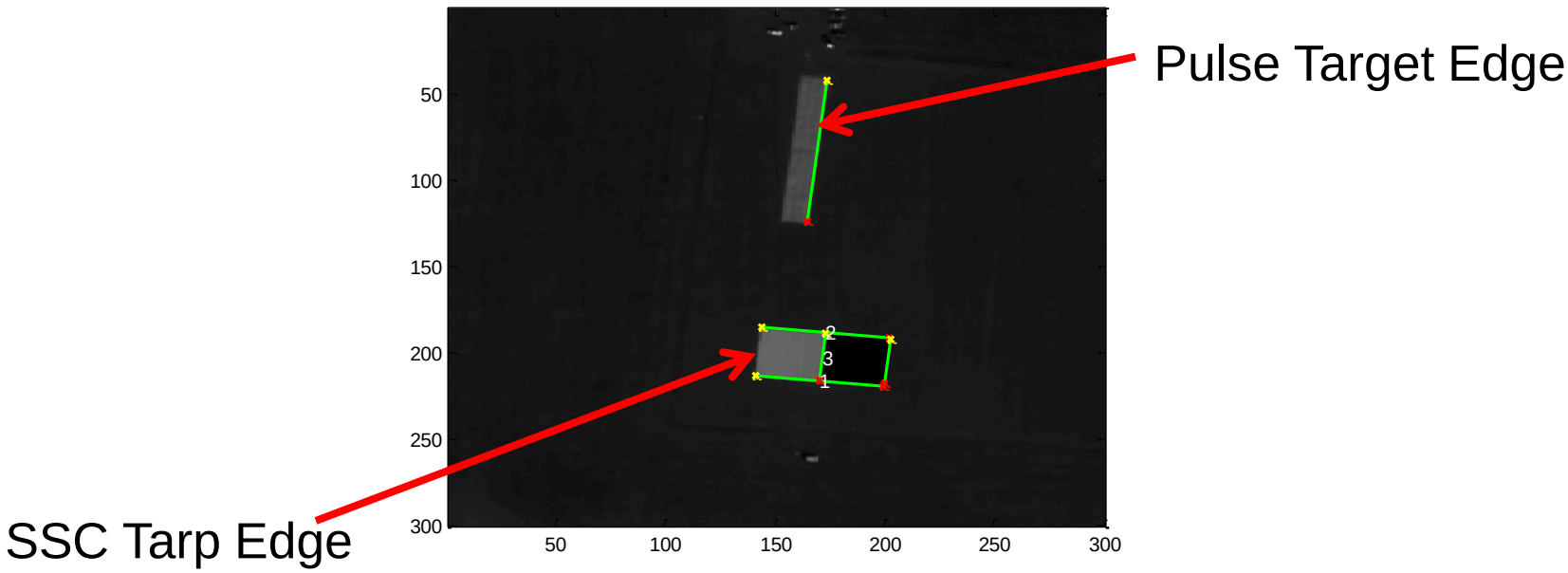
- Non-parametric
  - Minimal assumptions about underlying edge response shape
- Local Weighted Regression (LOWESS or LOESS)
  - Smoothes curve and produces an equally distributed sampling for FFT processing
  - Only partially addresses the SNR issues associated with taking numerical derivatives

LOESS Example



Validation

- Used several years of IKONOS and Quickbird SSC tarp data to estimate MTF and RER using automated algorithm and comparing results with traditional method



Comparison of Automated Method with SSC Traditional Methods

RER comparisons using tarp edge

Sensor	Processing	Date	Location	Orientation	Tarp RER	LOESS	SIG	% Diff (L)	% Diff (S)
IKONOS	MTFC Off/CC	1/15/2002	Stennis	Easting	**0.51**	**0.51**	**0.51**	-0.5%	0.9%
		2/17/2002	Stennis	Northing	**0.54**	**0.55**	**0.54**	-1.6%	-0.4%
		7/22/2002	Brookings	Easting	**0.46**	**0.45**	**0.47**	1.5%	-1.7%
		12/15/2004	Stennis	Northing	**0.47**	**0.47**	**0.49**	0.6%	-4.7%
		3/24/2005	Wiggins	Easting	**0.53**	**0.53**	**0.53**	0.2%	0.7%
		4/15/2005	Stennis	Northing	**0.49**	**0.48**	**0.48**	2.0%	1.7%
	MTFC Off/NN	7/22/2002	Brookings	Easting	**0.43**	**0.42**	**0.44**	1.5%	-1.3%
QuickBird	CC	7/20/2002	Brookings	Easting	**0.56**	**0.54**	**0.55**	4.2%	2.4%
		8/25/2002	Brookings	Easting	**0.55**	**0.55**	**0.55**	0.0%	-0.7%
		9/7/2002	Brookings	Easting	**0.58**	**0.54**	**0.55**	6.4%	4.4%
		11/14/2002	Stennis	Easting	**0.53**	**0.50**	**0.55**	6.0%	-4.0%
		9/15/2003	Brookings	Easting	**0.51**	**0.49**	**0.49**	4.0%	3.9%
		1/10/2004	Stennis	Easting	**0.53**	**0.52**	**0.56**	2.4%	-4.8%
		3/12/2005	Stennis	Northing	**0.52**	**0.52**	**0.52**	-0.5%	0.3%
		6/22/2005	Brookings	Northing	**0.51**	**0.48**	**0.52**	5.7%	-2.8%

Comparison of Automated Method with SSC Traditional Methods

MTF at Nyquist comparisons using tarp edge

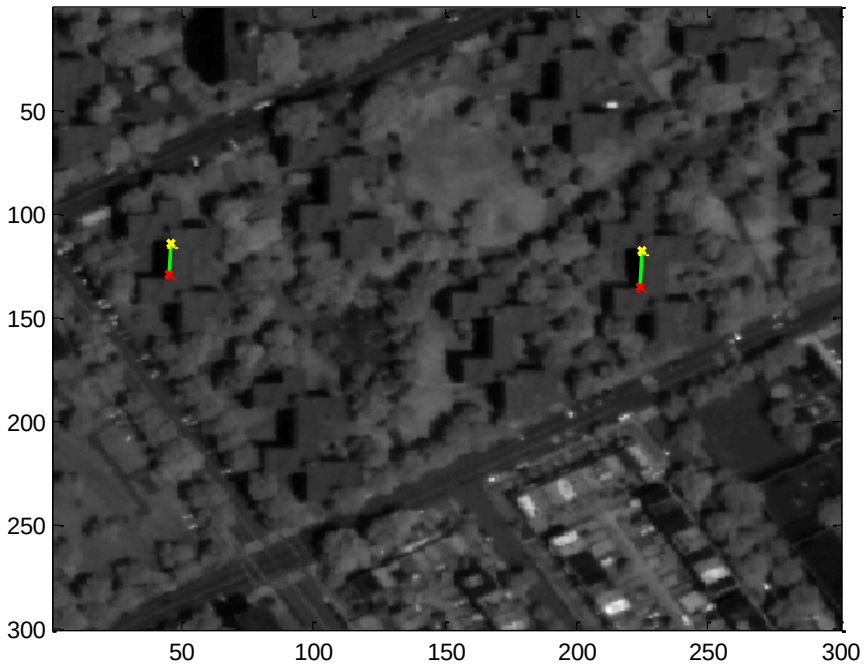
Sensor	Processing	Date	Location	Orientation	Tarp MTF	LOESS	SIG	% Diff (L)	% Diff (S)
IKONOS	MTFC Off/CC	1/15/2002	Stennis	Easting	**0.13**	**0.13**	**0.10**	-1.1%	19.5%
		2/17/2002	Stennis	Northing	**0.18**	**0.20**	**0.14**	-10.8%	22.9%
		7/22/2002	Brookings	Easting	**0.07**	**0.11**	**0.07**	-58.2%	-6.6%
		12/15/2004	Stennis	Northing	**0.14**	**0.09**	**0.09**	34.5%	33.3%
		3/24/2005	Wiggins	Easting	**0.14**	**0.12**	**0.12**	16.5%	12.0%
		4/15/2005	Stennis	Northing	**0.14**	**0.10**	**0.08**	30.6%	39.3%
	MTFC Off/NN	7/22/2002	Brookings	Easting	**0.12**	**0.09**	**0.05**	21.5%	54.8%
QuickBird	CC	7/20/2002	Brookings	Easting	**0.15**	**0.15**	**0.14**	1.1%	4.4%
		8/25/2002	Brookings	Easting	**0.17**	**0.15**	**0.15**	11.0%	11.2%
		9/7/2002	Brookings	Easting	**0.21**	**0.15**	**0.15**	27.8%	28.0%
		11/14/2002	Stennis	Easting	**0.15**	**0.03**	**0.15**	79.2%	1.5%
		9/15/2003	Brookings	Easting	**0.14**	**0.14**	**0.09**	-1.0%	34.6%
		1/10/2004	Stennis	Easting	**0.14**	**0.07**	**0.15**	47.1%	-8.9%
		3/12/2005	Stennis	Northing	**0.14**	**0.13**	**0.12**	4.3%	17.1%
		6/22/2005	Brookings	Northing	**0.06**	**0.06**	**0.12**	-1.3%	-102.5%

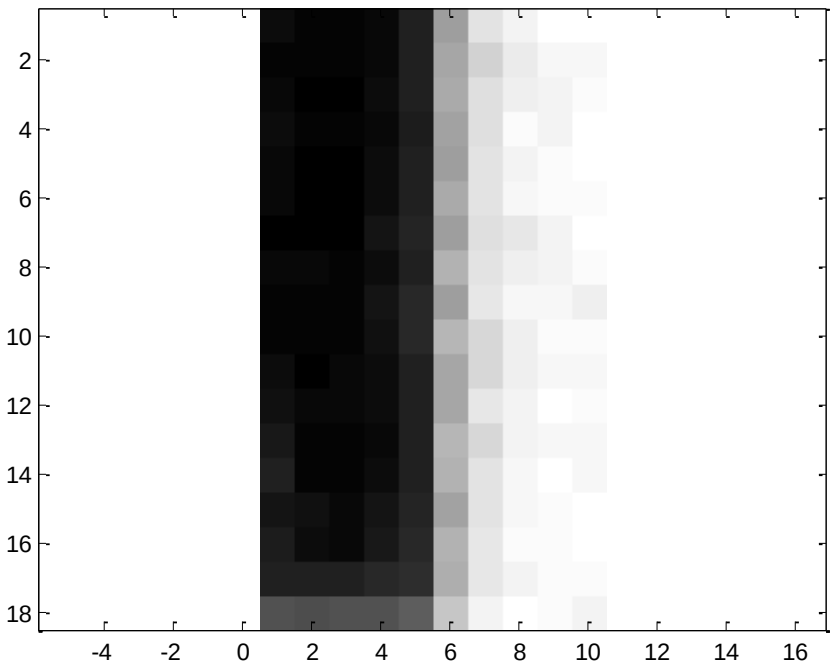
Validation Study Summary

- Algorithm produce similar results as traditional SSC approach using tarp targets
- RER and MTF @ Nyquist results comparable with high contrast target

Sensor	Traditional Method		LOESS		Sigmoidal	
	MTF	RER	MTF	RER	MTF	RER
IKONOS MTFC Off/CC	0.15±0.04	0.54±0.03	0.11±0.05	0.52±0.03	0.13±0.02	0.54±0.02
QuickBird CC	0.13±0.04	0.50±0.03	0.13±0.04	0.50±0.04	0.10±0.03	0.50±0.03

New York City Imagery Example





IKONOS Imagery acquired 5/31/2001

NYC Example

Location	LOESS		Sigmoidal	
	MTF	RER	MTF	RER
r01c10e1s1	0.09	0.42	0.03	0.38
r06c07e1s1	0.31	0.63	0.17	0.57
r06c11e1s1	0.16	0.44	0.10	0.50
r07c13e1s1	0.22	0.56	0.10	0.50
r08c04e1s1	0.28	0.58	0.12	0.52
r08c08e1s1	0.14	0.47	0.08	0.47
r08c22e1s1	0.06	0.32	0.01	0.35
r09c14e1s1	0.34	0.68	0.24	0.63
r09c14e2s1	0.29	0.59	0.15	0.55
r12c08e1s1	0.43	0.60	0.13	0.53
mean	0.23	0.53	0.11	0.50
stddev	0.12	0.11	0.07	0.08

Summary

- Automated tool finds edges and estimates spatial resolution
- MTF and RER has been tested and validated
- Many edges are needed to produce good results
- Error and uncertainty analysis need to be developed