Innovative Imaging & Research

An Automated Method to Estimate In-flight Image Quality Parameters from High Spatial Resolution Imagery

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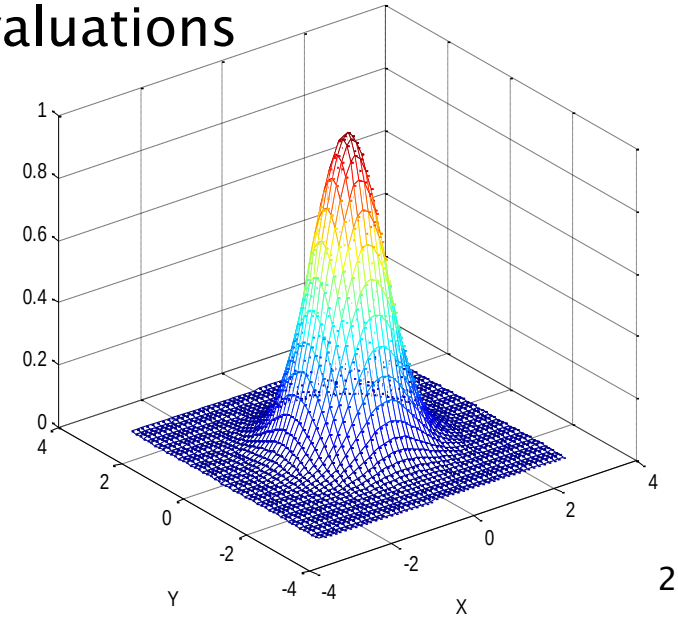
Spatial Resolution Characterization Considerations

- Spatial resolution is not ground sample distance
  - Depends on Point Spread Function (PSF) or Modulation Transfer Function (MTF)
- PSF and MTF are difficult to fully determine in practice
- Edge targets placed within a scene can be used to partially evaluate PSF and MTF
  - One dimensional cross-sectional evaluations



Example 2D PSF

Image Formation Example I

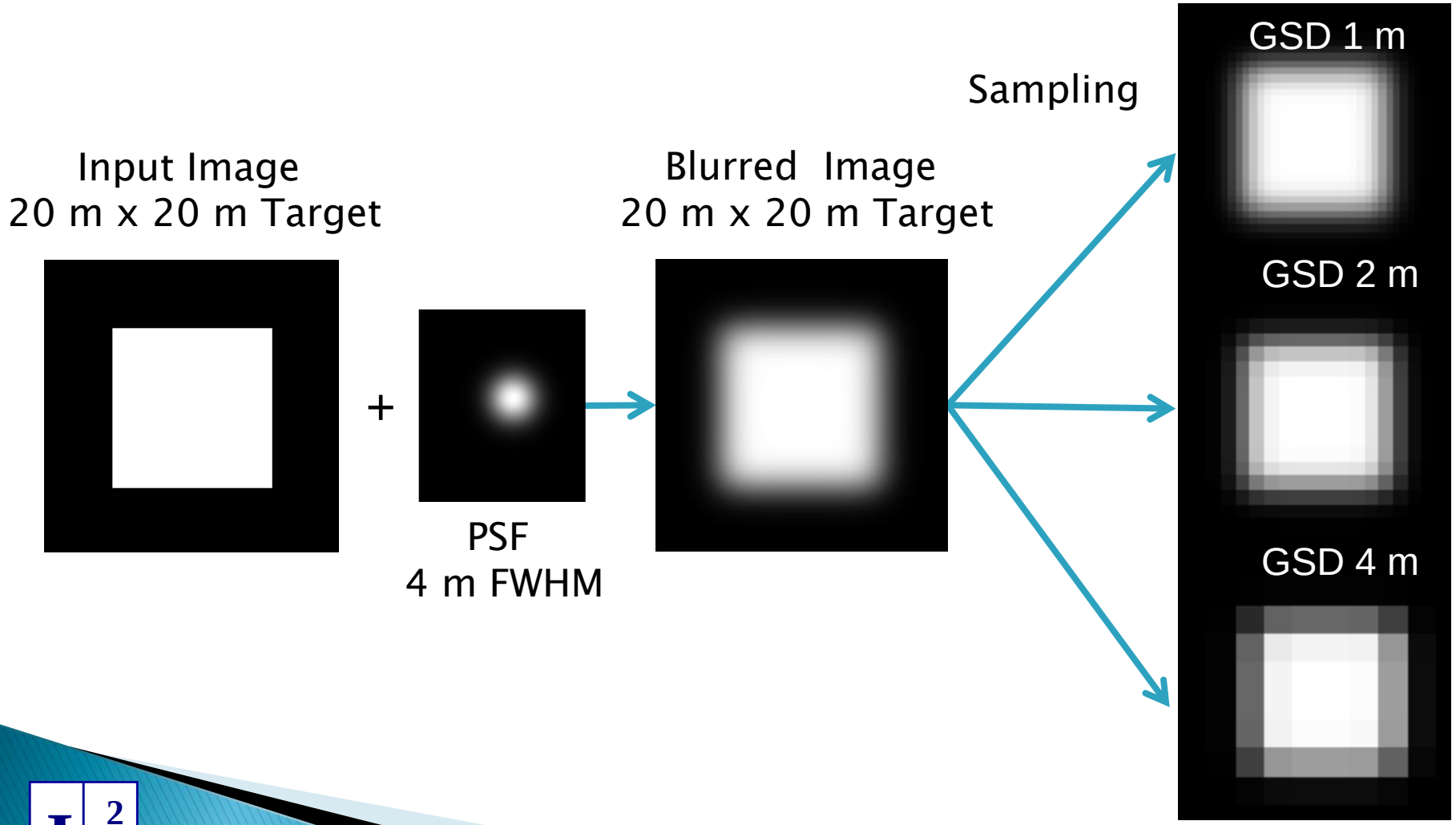
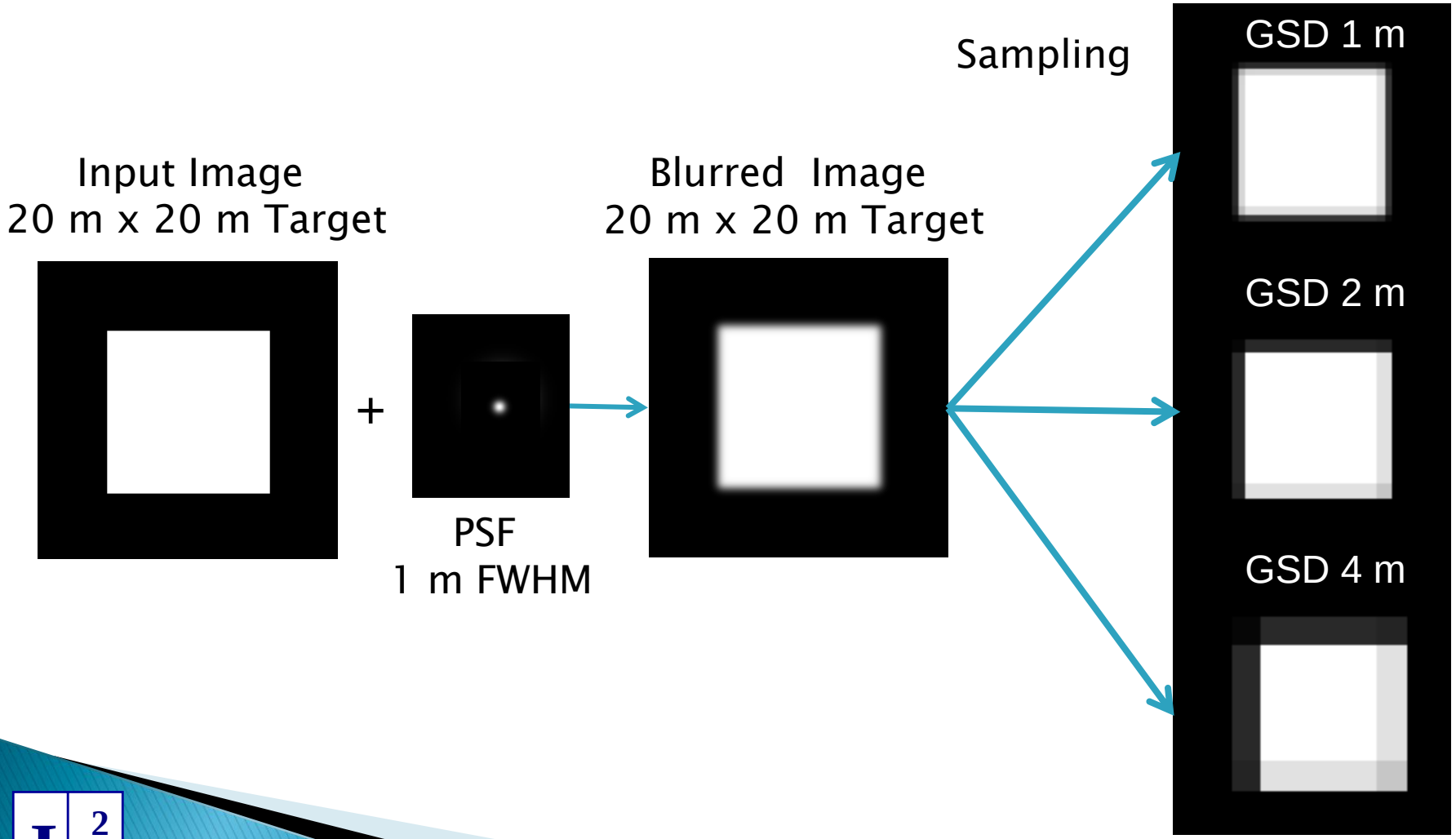


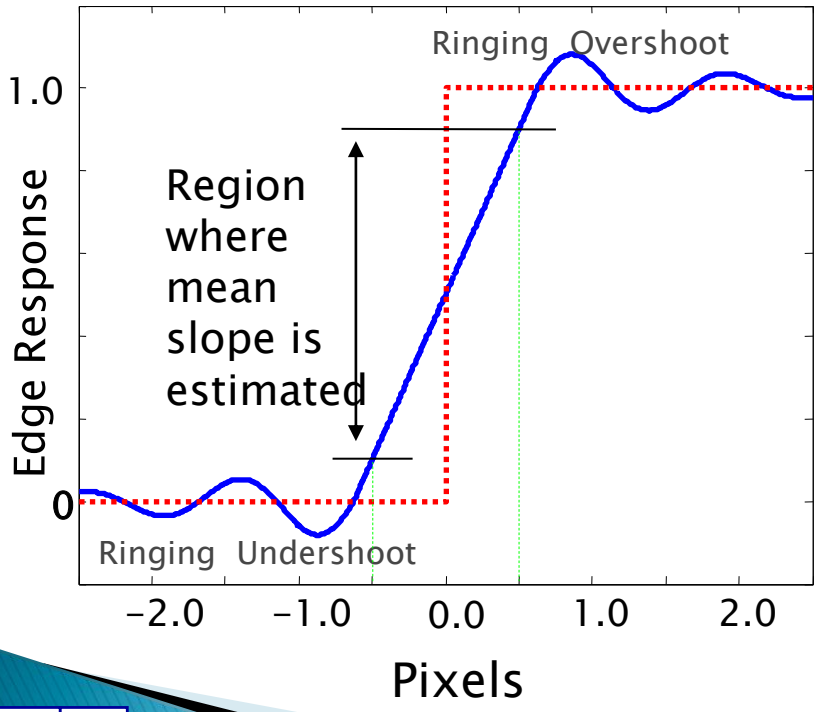
Image Formation Example II



Common Spatial Resolution Metrics

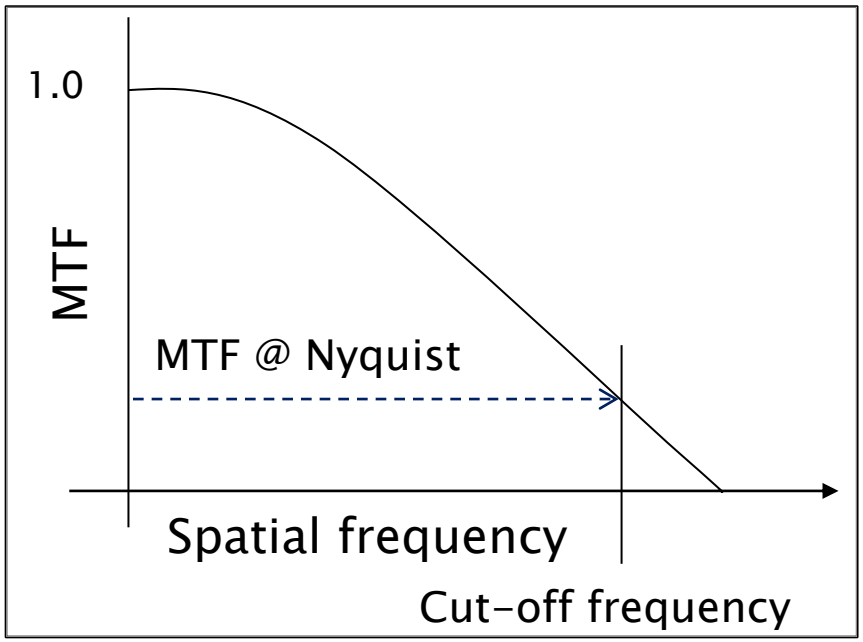
Spatial Domain

- Relative Edge Response (RER)



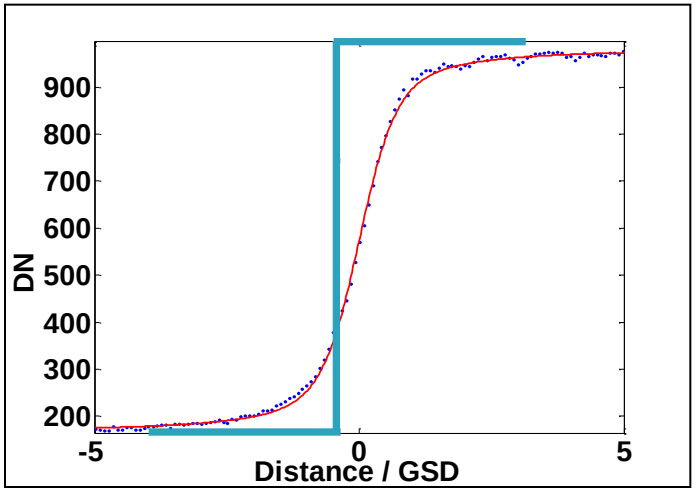
Frequency Domain

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

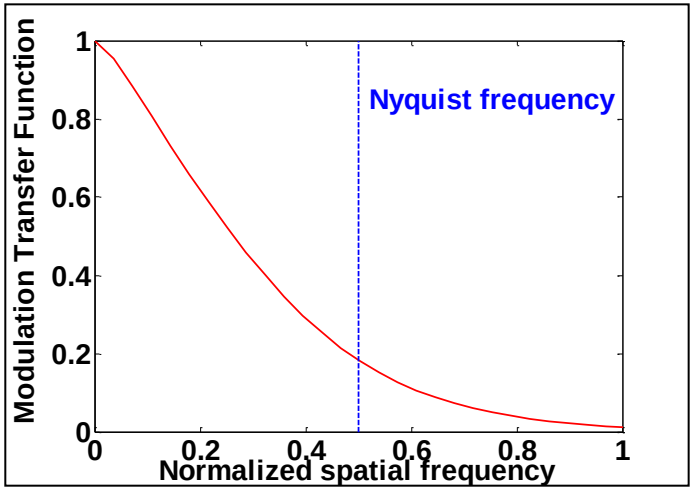


MTF Estimation

Edge Response

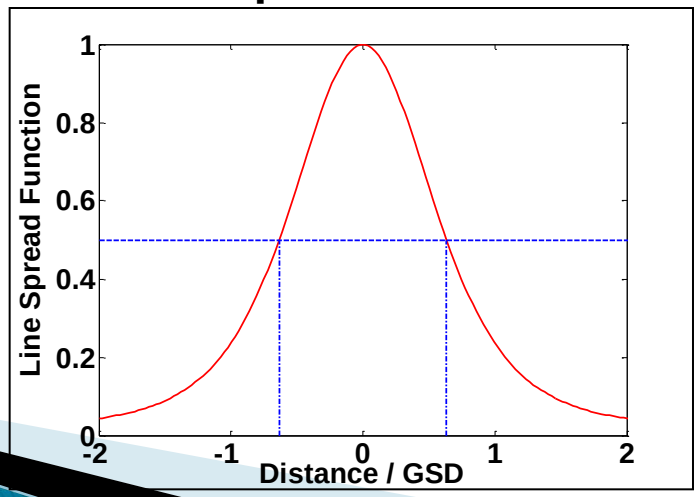


MTF



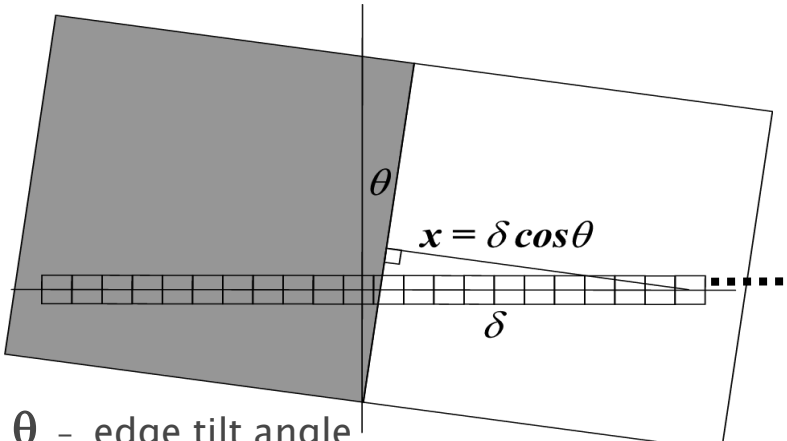
Differentiate

Line Spread Function



Fourier Transform

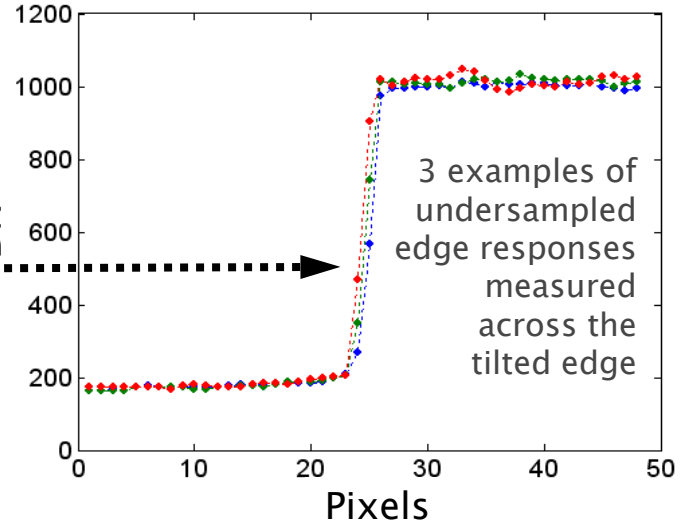
Tilted Edge Technique



θ – edge tilt angle

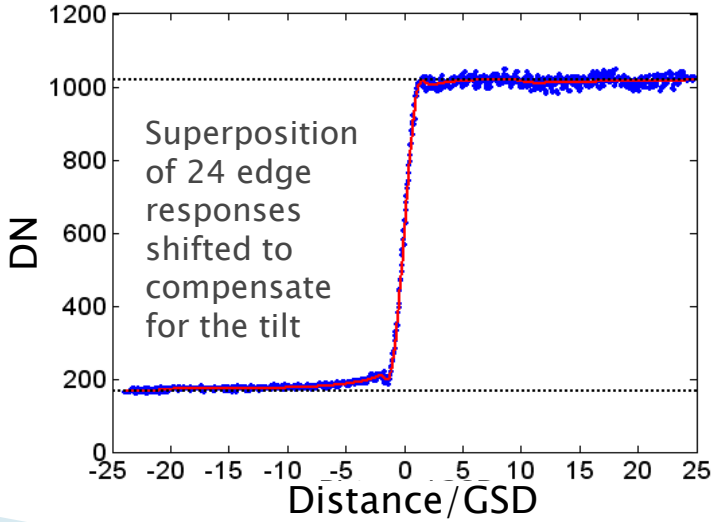
δ – pixel index

x – pixel's distance from edge (in GSD)



Problem: Digital cameras undersample edge target

Solution: Image tilted edge to improve sampling



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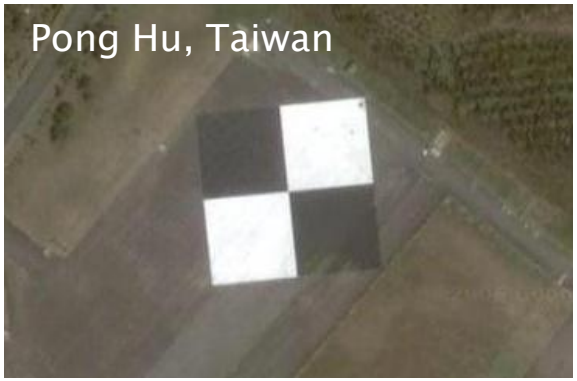
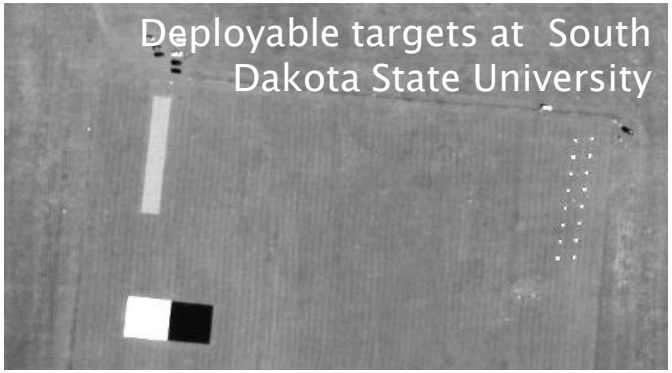
Problem…

- Most commonly used spatial resolution estimation techniques require engineered targets (deployed or fixed)
- Target size scales with GSD
  - Edge targets are typically uniform edges 10-20 pixels long and ~10 pixels tilted a few degrees relative to pixel grid (improve sampling)
  - Increasing GSD increases difficulty
    - Moderate resolution systems such as Landsat use pulse targets

Traditional Engineered Spatial Resolution Targets

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

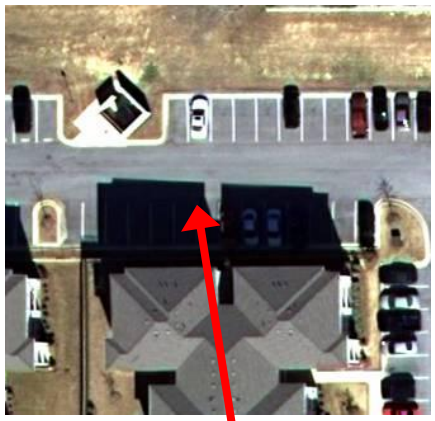




Digital Globe provided satellite imagery

Spatial Resolution Estimation Using In-Scene Edges

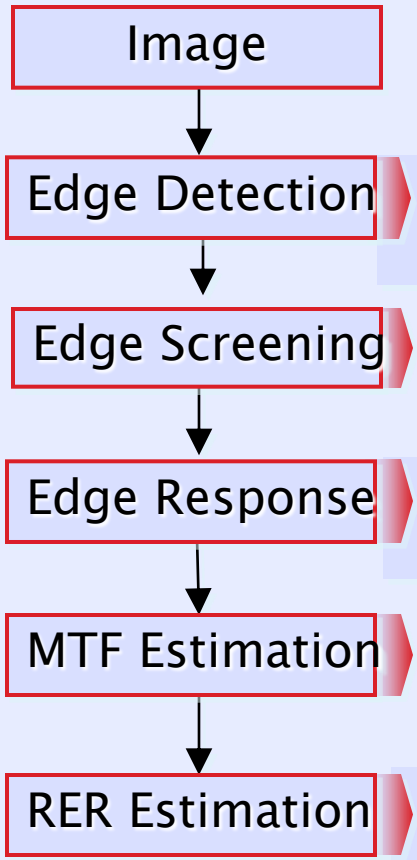
- Exploit edge features in nominal imagery
  - Edge response estimation is performed without dedicated engineered targets
- Automated process after algorithm optimization
  - Identifies edges and screens them
  - Constructs resulting edge response
  - Calculates MTF and RER



Building Shadows

Rooflines

Automated Spatial Resolution Algorithm Flowchart



Edge detection returns points where gradient of image is maximum.

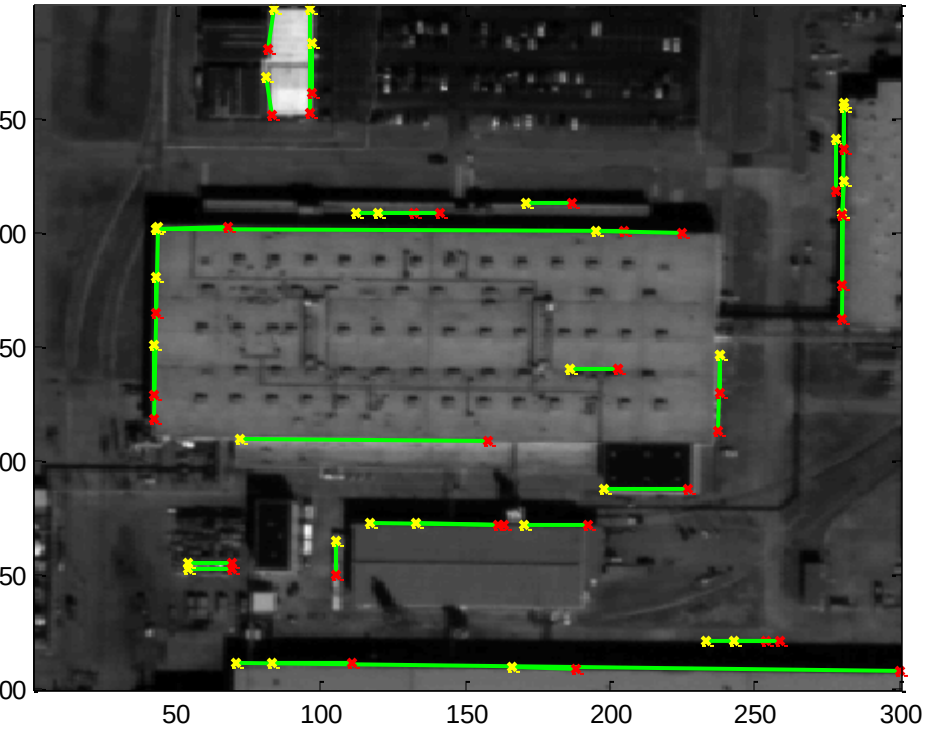
Signal-to-Noise Ratio of near horizontal or near vertical edges

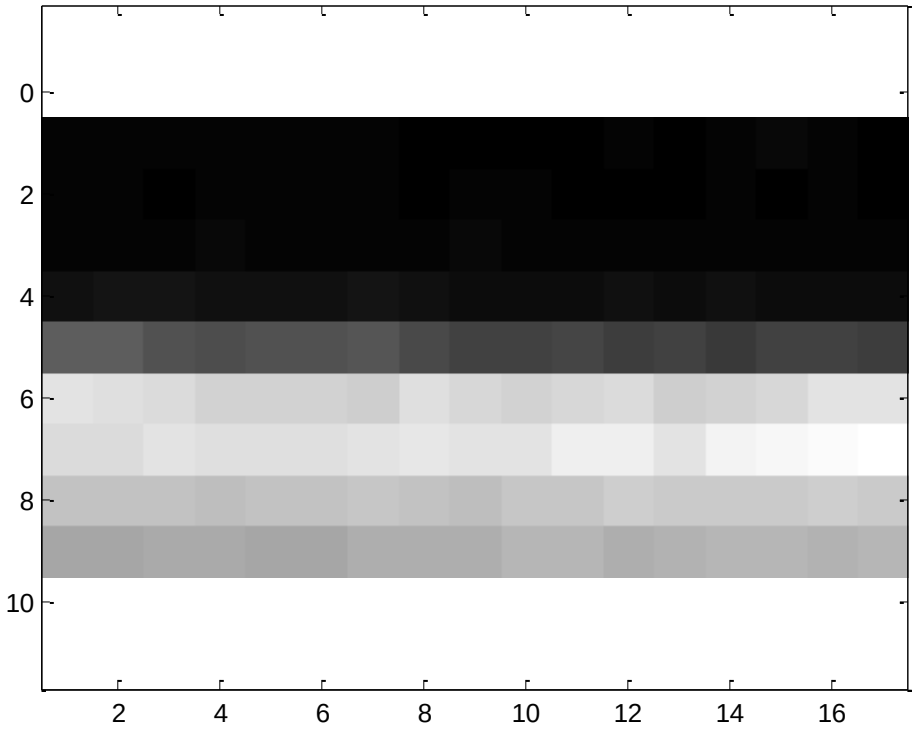
Edges plotted and curve-fit using Sigmoidal functions. Curves are set to even spacing.

Smoothed edge response is differentiated to estimate LSF
Fourier transform of LSF gives MTF at Nyquist

Difference of edge response at +/-0.5 pixel.

In-Scene Edge Detection Example

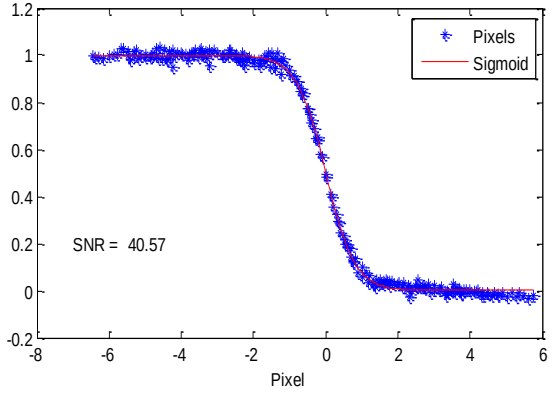




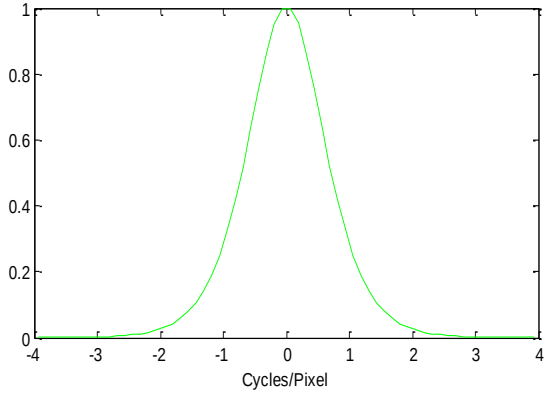
Satellite image: Digital Globe

Edge Response Fit and Analysis Example

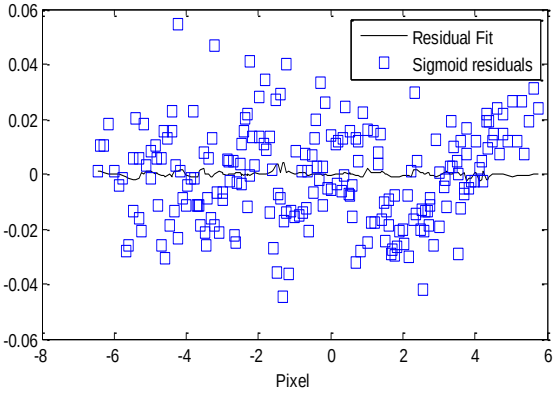
Edge Response



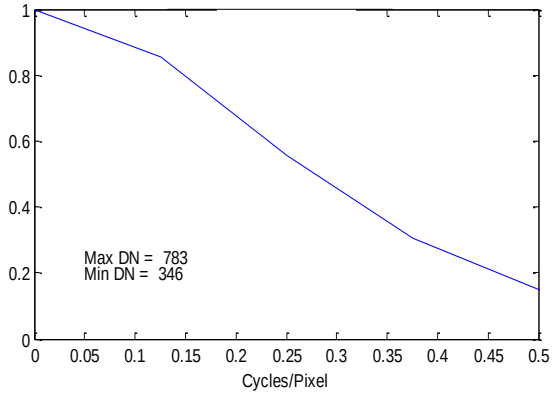
Normalized LSF



Residuals

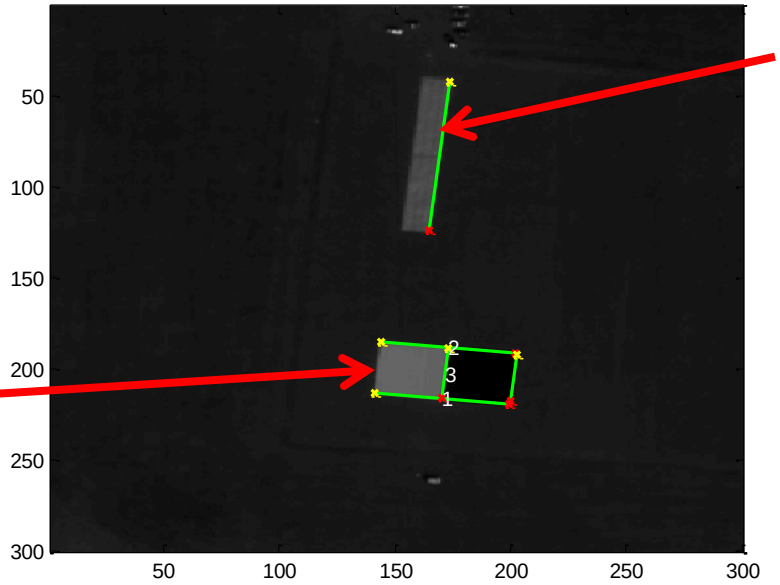


MTF



Automated Algorithm Validation

- Automated algorithm was validated using several years of IKONOS and Quickbird imagery of engineered targets by comparing automated algorithm results with traditional method



Validation Study Summary

- Automated algorithm reproduces results obtained using traditional approaches employing engineered targets
  - GSD scales approx. 1 m
  - Values combine cross track and in-track assessments

Sensor	Traditional Method		Automated Algorithm	
	MTF	RER	MTF	RER
QuickBird CC	0.14±0.04	0.52±0.03	0.13±0.03	0.53±0.03
IKONOS MTFC Off/CC	0.13±0.04	0.50±0.03	0.10±0.03	0.50±0.03

RapidEye Analysis

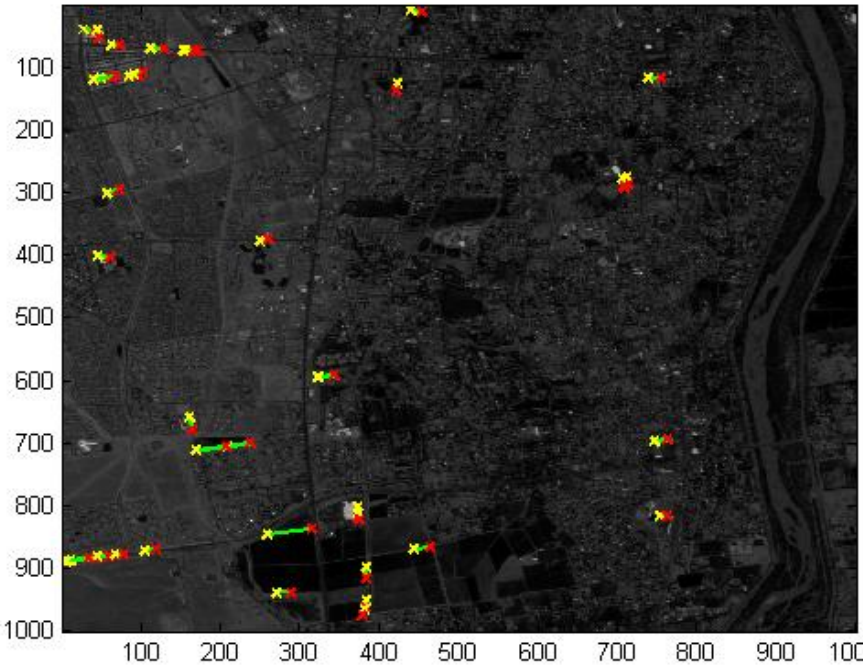
- RapidEye sensors
  - 5 bands in the visible-NIR
    - blue (440-510), green (520-590), red (630-685), red edge (690-730), NIR (760-850)
  - IFOV GSD 6.5m and orthorectified resampled GSD 5m
- RapidEye provided I2R several Level1R scenes from RapidEye-5 (radiometrically corrected but not band aligned)
  - Four Cities
    - Albuquerque, NM
    - Dallas Fort Worth, TX
    - Nellis Air Force Base, NV
    - Denver, CO

Albuquerque, NM

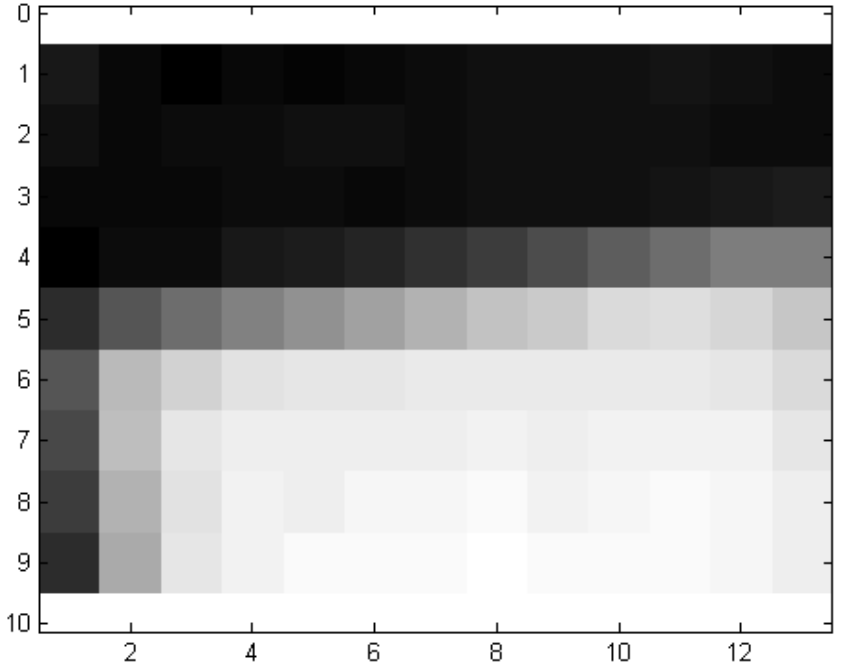
RapidEye-5 L1R
27 July 2010
6.7 deg view angle

Albuquerque Band 3 Example Edge

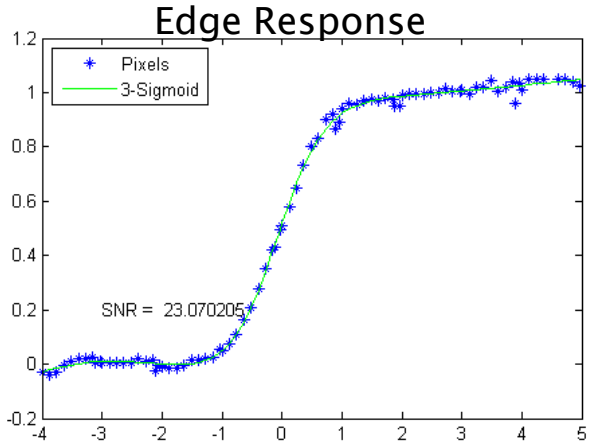
Automated edge detection

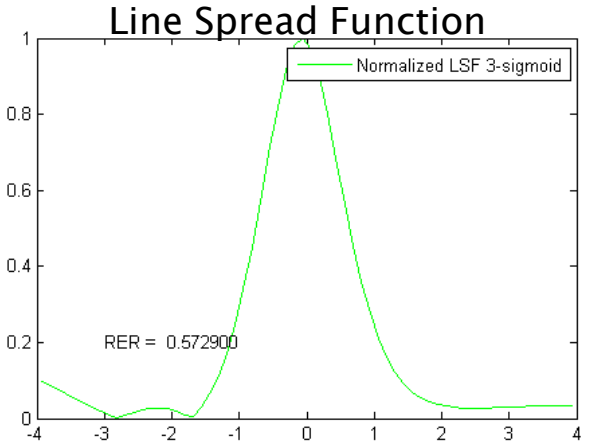


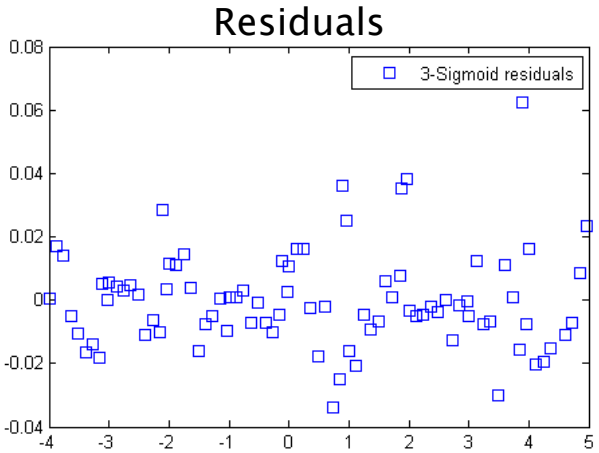
Horizontal edge

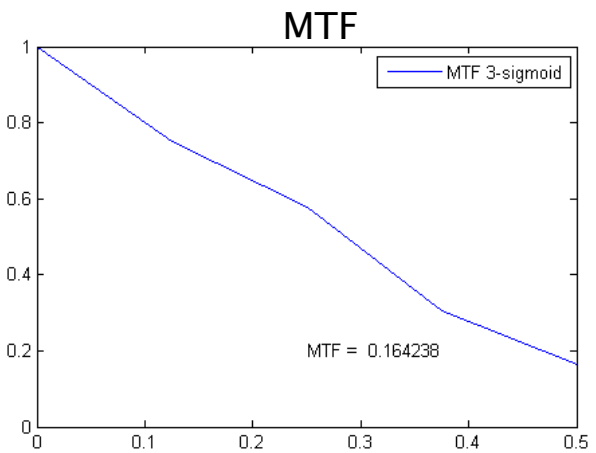


Albuquerque Band 3Edge Assessment

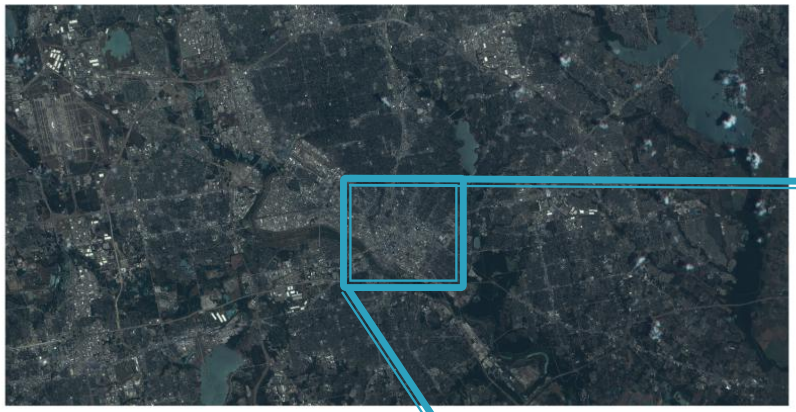




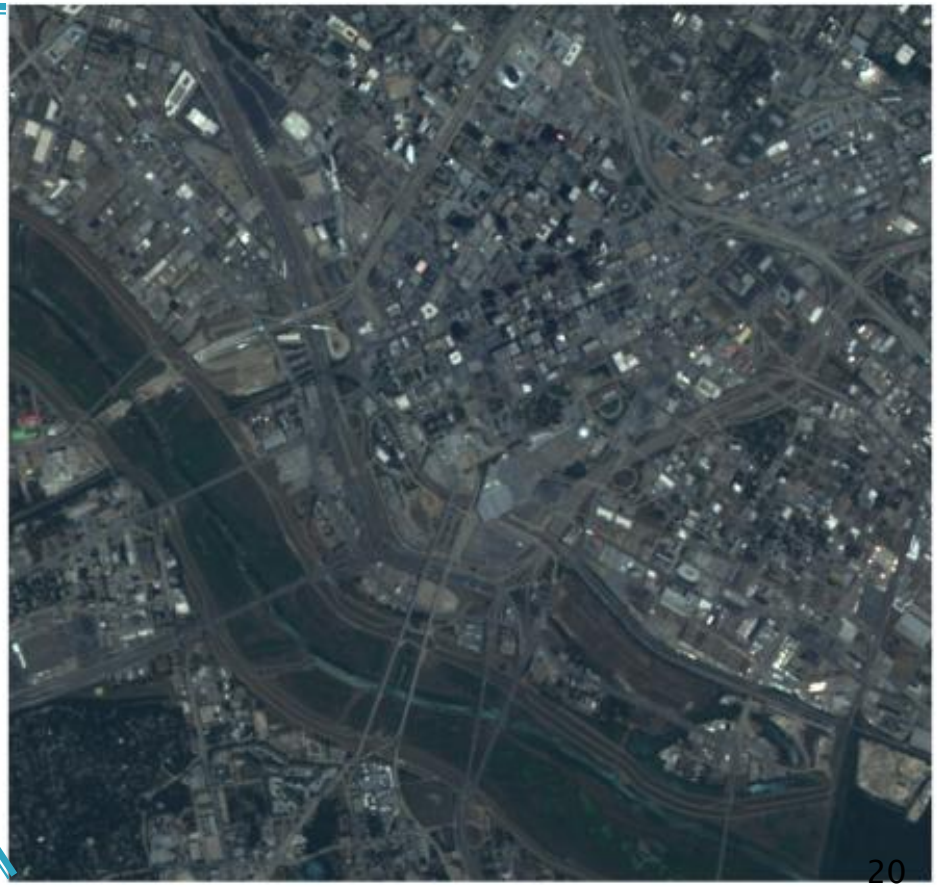




Dallas/Fort Worth, TX

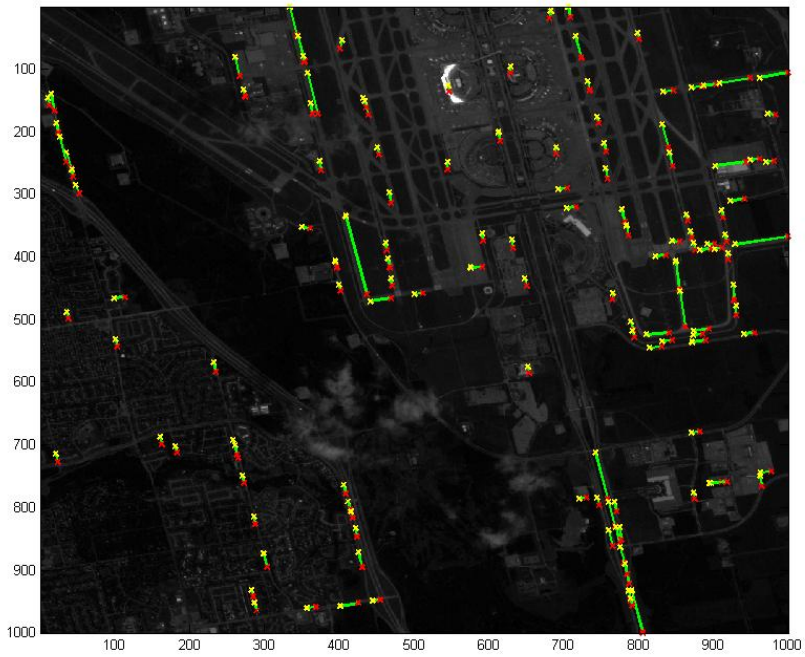


RapidEye-5 L1R
22 June 2010
6.7 deg view angle

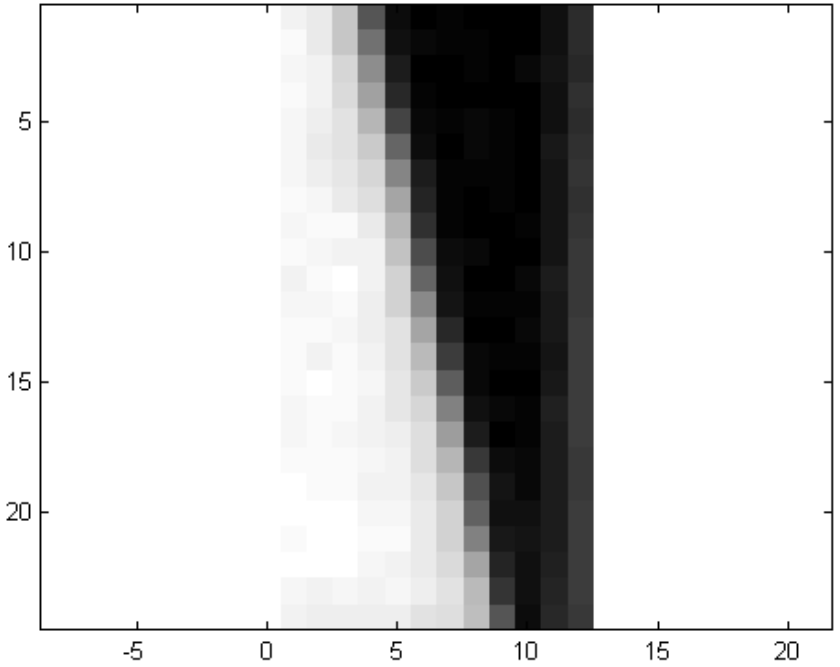


Dallas Band 1Example Edge

Automated edge detection

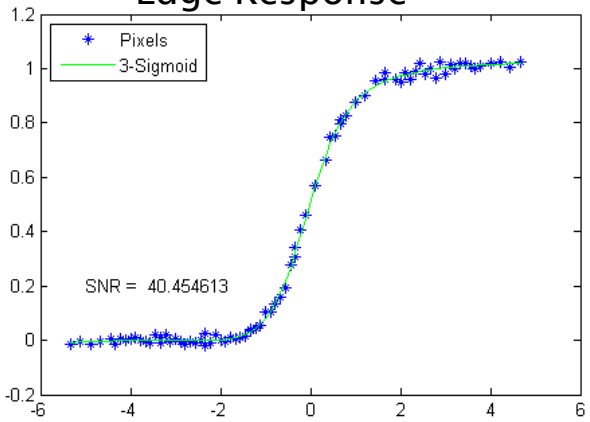


Vertical edge

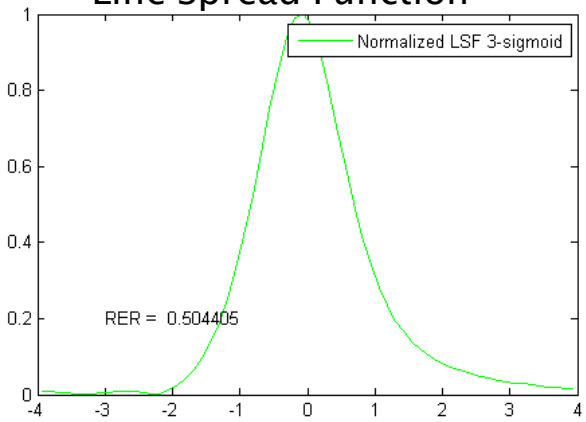


Dallas Band 1 3Edge Assessment

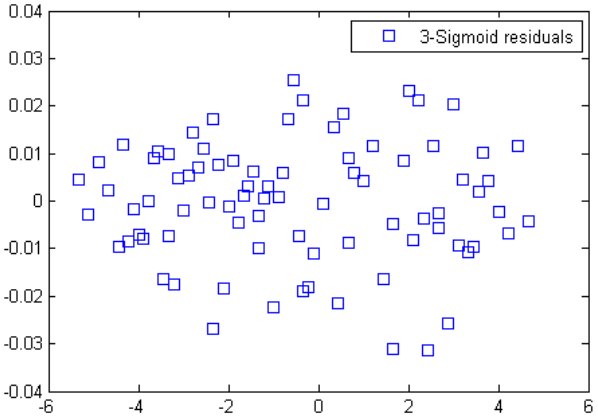
Edge Response



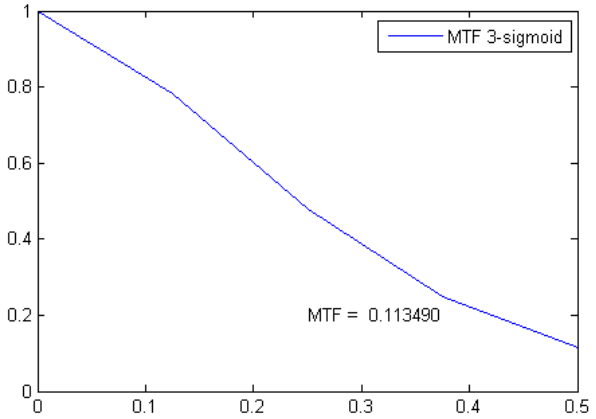
Line Spread Function



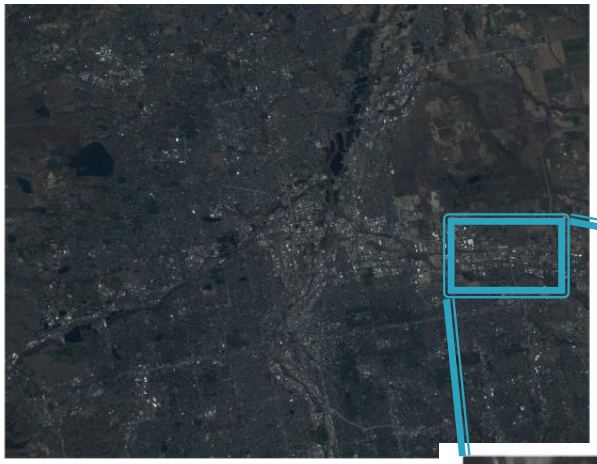
Residuals



MTF



Denver, CO



RapidEye-5 L1R
15 August 2010
6.7 deg view angle

Nellis Air Force Base, NV

RapidEye-5 L1R
Band 3 (red)

04 May 2010
6.7 deg view angle

RapidEye 5 In-Track MTF

Level1R

	Albequerque			Dallas			Denver			Nellis		
	MTF	STD	Num Edges	MTF	STD	Num Edges	MTF	STD	Num Edges	MTF	STD	Num Edges
Band 1	0.12	0.09	46	0.12	0.07	132	0.12	0.06	68	0.16	0.09	45
Band 2	0.11	0.06	45	0.12	0.06	132	0.13	0.09	70	0.15	0.08	43
Band 3	0.12	0.09	45	0.14	0.06	131	0.12	0.06	79	0.14	0.07	52
Band 4	0.11	0.07	45	0.15	0.07	131	0.13	0.07	91	0.15	0.08	52
Band 5	0.13	0.09	46	0.15	0.07	128	0.17	0.08	135	0.14	0.07	62
Weighted Mean	0.12	0.03		0.14	0.03		0.13	0.03		0.15	0.03	

Band Average MTF@ Nyquist 0.13 +/- 0.02

RapidEye 5 In-Track RER

Level1R

	Albequerque			Dallas			Denver			Nellis		
	RER	STD	Num Edges	RER	STD	Num Edges	RER	STD	Num Edges	RER	STD	Num Edges
Band 1	0.45	0.15	48	0.51	0.07	128	0.49	0.09	69	0.58	0.12	44
Band 2	0.50	0.13	47	0.53	0.05	128	0.53	0.07	67	0.58	0.09	45
Band 3	0.49	0.13	46	0.55	0.06	127	0.53	0.06	78	0.56	0.07	52
Band 4	0.50	0.13	47	0.56	0.07	128	0.54	0.08	90	0.58	0.07	51
Band 5	0.50	0.13	47	0.56	0.07	131	0.58	0.06	129	0.57	0.07	58
Weighted Mean	0.49	0.06		0.54	0.03		0.54	0.03		0.57	0.04	

Band Average RER 0.54 +/- 0.02

RapidEye 5 Cross Track MTF

Level1R

	Albequerque			Dallas			Denver			Nellis		
	MTF	STD	Num Edges	MTF	STD	Num Edges	MTF	STD	Num Edges	MTF	STD	Num Edges
Band 1	0.06	0.05	16	0.18	0.09	145	0.10	0.05	73	0.15	0.08	37
Band 2	0.07	0.06	16	0.16	0.08	147	0.11	0.06	75	0.14	0.07	38
Band 3	0.14	0.09	33	0.17	0.08	146	0.12	0.06	75	0.14	0.04	37
Band 4	0.16	0.09	33	0.17	0.08	145	0.12	0.06	100	0.14	0.06	38
Band 5	0.13	0.08	32	0.15	0.07	145	0.11	0.06	104	0.10	0.05	36
Weighted Mean	0.09	0.03		0.16	0.04		0.11	0.03		0.13	0.02	

Band Average MTF@ Nyquist 0.12 +/- 0.01

RapidEye Cross Track RER

Level1R

	Albequerque			Dallas			Denver			Nellis		
	RER	STD	Num Edges	RER	STD	Num Edges	RER	STD	Num Edges	RER	STD	Num Edges
Band 1	0.37	0.11	17	0.55	0.10	148	0.49	0.08	73	0.50	0.12	38
Band 2	0.42	0.14	17	0.56	0.08	150	0.51	0.07	71	0.54	0.07	37
Band 3	0.53	0.07	34	0.56	0.07	147	0.50	0.07	76	0.55	0.05	37
Band 4	0.54	0.07	33	0.56	0.08	145	0.52	0.06	103	0.55	0.06	37
Band 5	0.51	0.07	33	0.55	0.06	142	0.50	0.05	103	0.50	0.06	38
Weighted Mean	0.50	0.04		0.56	0.03		0.50	0.03		0.53	0.03	

Band Average RER 0.52 +/- 0.02

RapidEye L1R Summary

- No significant differences in MTF or RER were found between bands in L1R data
- In-Track results
  - Band Average MTF@ Nyquist 0.13 +/- 0.02
  - Band Average RER 0.54 +/- 0.02
- Cross Track results
  - Band Average MTF@ Nyquist 0.12 +/- 0.01
  - Band Average RER 0.52 +/- 0.02

RapidEye Level 3 Product Quick Look Assessment

- Single full scene
  - Las Vegas
    - 04 May 2010
    - 6.7 deg
- Resampled
  - Cubic convolution
  - MTF
  - Nearest neighbor

Band 5 CC

RapidEye Level3 Product MTF

		LasVegas_83805_CC			LasVegas_83806_MTF			LasVegas_83807_NN		
		MTF	**StdDev**	**NumEdges**	**MTF**	**StdDev**	**NumEdges**	**MTF**	**StdDev**	**NumEdges**
Band 1	Horizontal	0.11	0.06	57	0.17	0.07	19	0.15	0.07	86
Band 1	Vertical	0.12	0.06	30	0.24	0.09	8	0.16	0.07	66
Band 2	Horizontal	0.13	0.07	126	0.2	0.06	21	0.14	0.07	85
Band 2	Vertical	0.11	0.06	77	0.22	0.08	8	0.17	0.07	81
Band 3	Horizontal	0.11	0.07	133	0.21	0.1	25	0.11	0.05	110
Band 3	Vertical	0.11	0.06	95	0.2	0.09	19	0.14	0.07	85
Band 4	Horizontal	0.11	0.06	133	0.22	0.06	27	0.13	0.07	125
Band 4	Vertical	0.11	0.06	95	0.23	0.1	30	0.14	0.07	88
Band 5	Horizontal	0.11	0.06	131	0.18	0.07	28	0.13	0.06	162
Band 5	Vertical	0.08	0.05	108	0.19	0.08	29	0.12	0.06	111
Weighted Mean		**0.11**	**0.03**		**0.20**	**0.03**		**0.14**	**0.03**	

RapidEye Level3 Product RER

		LasVegas_83805_CC			LasVegas_83806_MTF			LasVegas_83807_NN		
		RER	StdDev	NumEdges	RER	StdDev	NumEdges	RER	StdDev	NumEdges
Band 1	Horizontal	0.54	0.07	59	0.6	0.05	18	0.56	0.07	85
Band 1	Vertical	0.57	0.05	30	0.71	0.13	8	0.57	0.07	68
Band 2	Horizontal	0.56	0.07	123	0.63	0.05	21	0.57	0.06	86
Band 2	Vertical	0.54	0.06	77	0.67	0.06	8	0.58	0.06	81
Band 3	Horizontal	0.53	0.06	133	0.64	0.07	25	0.54	0.05	108
Band 3	Vertical	0.54	0.05	93	0.62	0.09	18	0.55	0.06	84
Band 4	Horizontal	0.54	0.05	131	0.67	0.08	28	0.55	0.07	123
Band 4	Vertical	0.53	0.05	96	0.64	0.08	30	0.55	0.06	88
Band 5	Horizontal	0.54	0.06	133	0.63	0.08	28	0.55	0.06	160
Band 5	Vertical	0.5	0.04	106	0.63	0.08	29	0.51	0.06	110
Weighted Mean		**0.54**	**0.02**		**0.64**	**0.04**		**0.55**	**0.03**	