



# On-orbit Modulation Transfer Function (MTF) Measurement of QuickBird

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# Introduction

- Modulation Transfer function (MTF)
  - A method of evaluating the spatial resolution of an imaging system.
  - MTF is a measure of the spatial frequency response.
  - MTF is often calculated from the point spread function (PSF).
  - Nyquist frequency is the maximum resolution in digital imaging system, which is one-half cycle per pixel.

$$H(\omega_x, \omega_y) = \mathfrak{F}\{PSF(x, y)\}$$

$$MTF(\omega_x, \omega_y) = \frac{|H(\omega_x, \omega_y)|}{|H(0,0)|}$$

Often 1 dimensional functions are used:

- 1-D PSF is the line spread function (LSF).
- LSF can be obtained by differentiation of the edge spread function (ESF).

# Method Description

- Edge Method (MTF estimation method)
  - Sub-pixel edge locations were found by Fermi function fit.
  - A least-square error line was calculated through the edge locations.
  - Savitzky-Golay Helder-Choi filtering was applied on each line
  - The filtered profile was differentiated to obtain LSF
  - MTF calculated by applying Fourier transform to LSF.

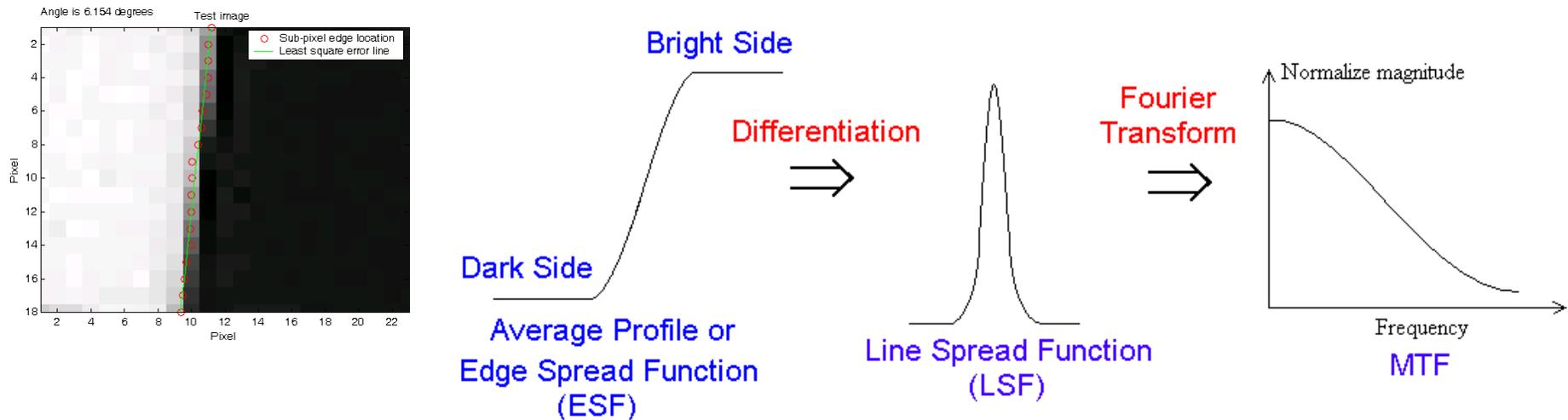


Fig 1. Edge Method

- Pulse method

- A pulse input is given to an imaging system.
- Output of the system is the resulting image.
- Edge detection and SGHC filtering was applied to get output profile.
- Take Fourier transform of the input and output.
- MTF is calculated by dividing output by input.

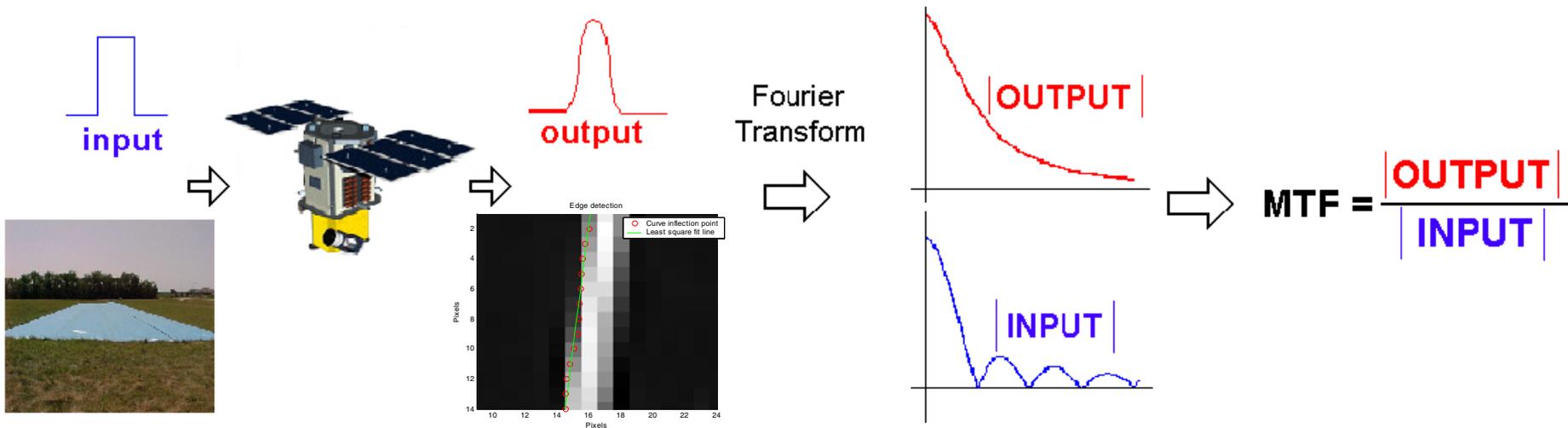


Figure 2. Pulse method

- Parametric Edge Detection

- A model based parametric method was applied to detect sub-pixel edge locations.
- The Fermi function was chosen to fit this function to the ESF for improved edge angle estimation.
- Sub-pixel edge locations were calculated on each line by finding best fitting curve's value 'b' .

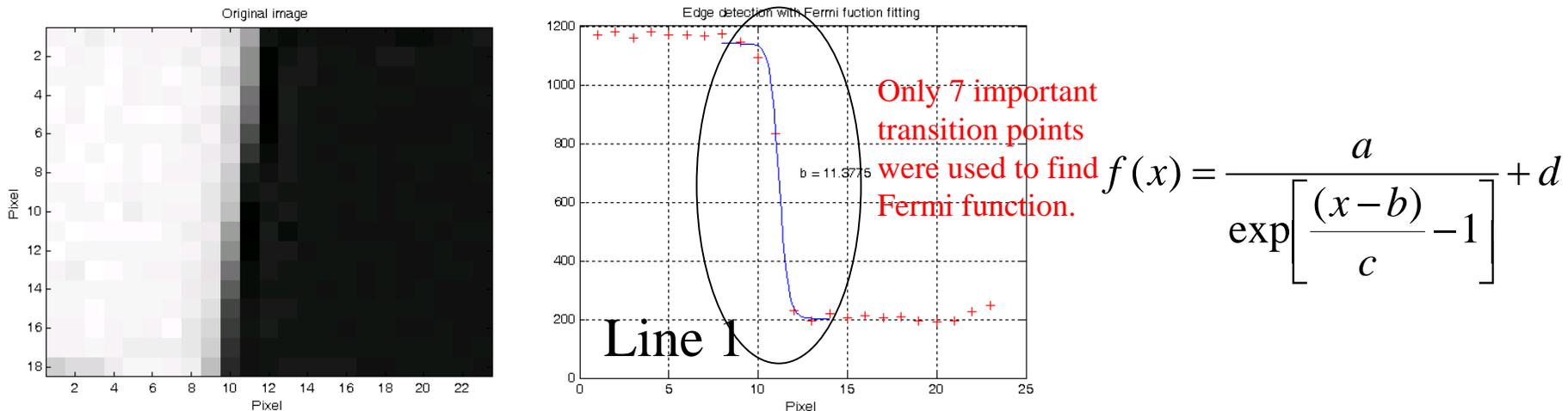


Figure 3. Parametric edge detection

- Savitzky-Golay Helder-Choi (SGHC) Filtering
  - Unlike normal FIR filters, SGHC filter is applicable to randomly spaced data.
  - By using the original concept, best fitting 2<sup>nd</sup> order polynomial was calculated within 1-pixel window using Matlab fminsearch function.

- Filter output found by evaluating fitting polynomial at the center of window.
- The next value was evaluated by shifting the window with sub-pixel resolution.
- The shifting step determines output resolution.

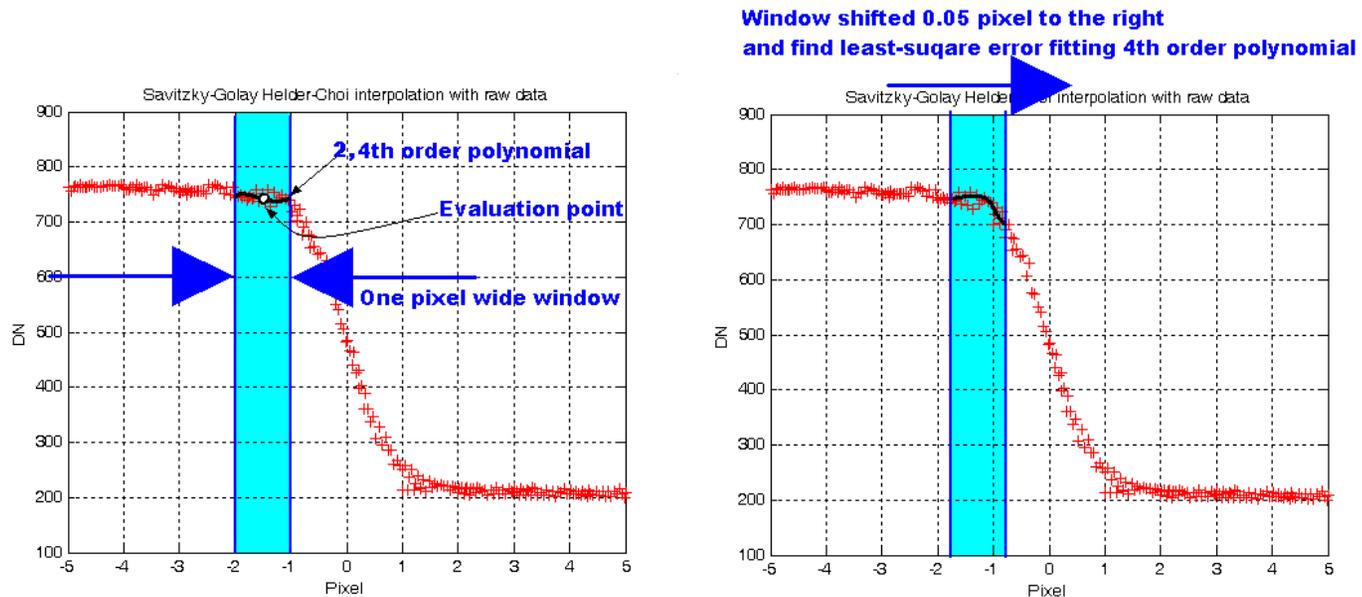


Figure 4. Parametric edge detection

# Target Description

- Target Area

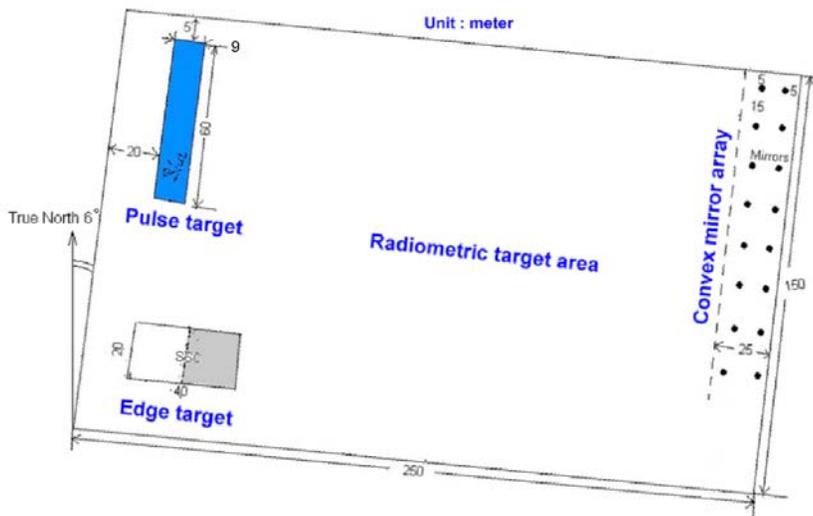


Figure 5. Brookings site plan and QuickBird image on September 7, 2002

- Blue Tarp
  - Pulse width was determined to be 3-pixel wide in multispectral bands.
  - There was two degrees difference between desired edge angle and actual angle in image.
  - All the grommets were aligned by a transit to maintain straight edges.

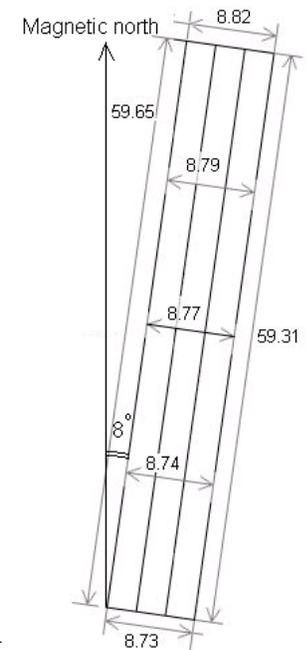
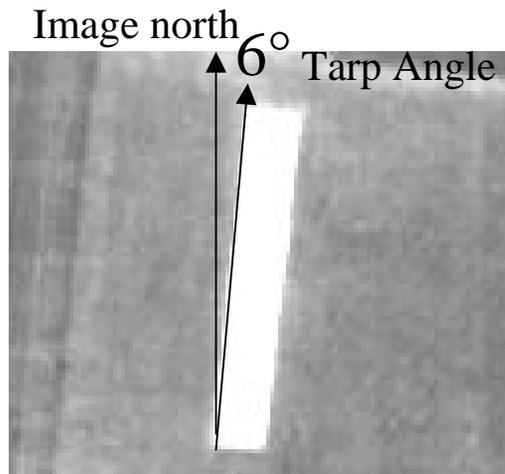


Figure 6. Blue tarp physical layout on June 20, 2002

- Stennis tarp (MTL Systems product)
  - Edge angle was parallel to the tarp.
  - Radiometrically and spectrally stable target with a large DN difference between 3.6% and 52.1% reflectance panel.
  - At least two horizontal pixels were covered by the edge line in panchromatic band.

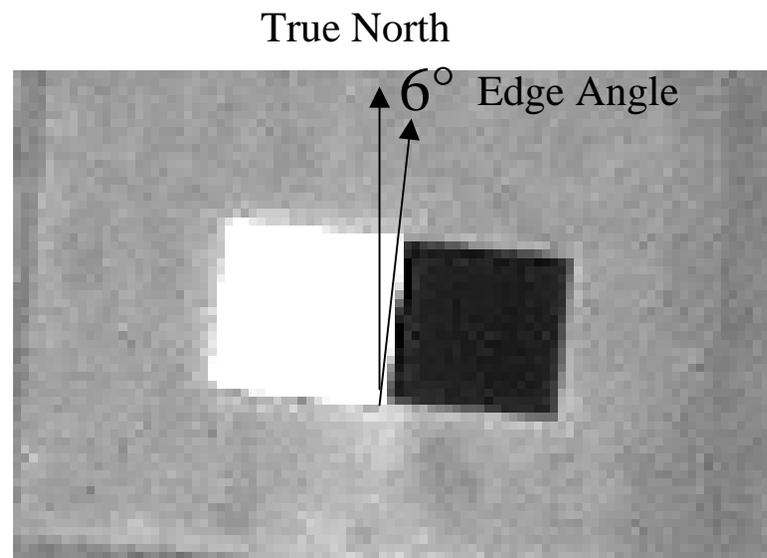


Figure 8. Stennis tarp.

- Tarp Angle
  - Dashed lines are projections of ground sample interval (GSI) points.
  - Resolution of sub-pixel profile is determined by the edge angle.
  - At least two horizontal pixels were covered by the edge line in multispectral bands.

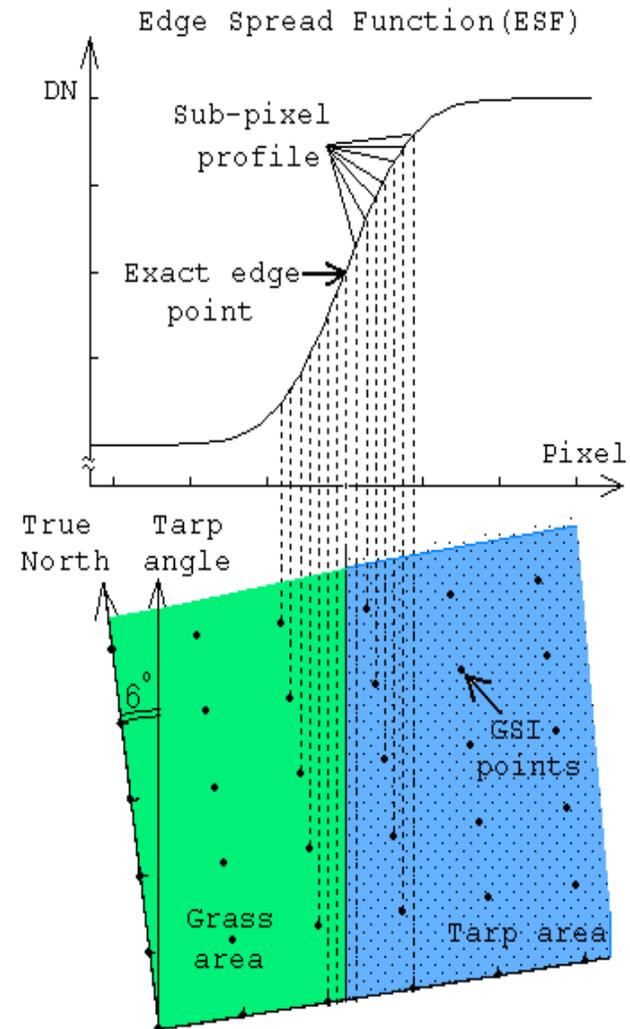


Figure 7. ESF projection from angled GSI points.

# Results

- Brookings image information
  - Stennis tarp was available after July 20, 2002
  - No target was deployed on August 7, 2002

Acquired	Original Order Item	Processed	Order ADP Version	Resampling Kernel & (Note)	Cat ID
6/27/2002	17544	1-Jul-02	ADP 1.5.1	CC	1010010000AEDC02
	37889	1-Feb-03	ADP 2.0	CC	
7/20/2002	17833	22-Jul-02	ADP 1.6	CC	1010010000D4CD01
	37896	1-Feb-03	ADP 2.0	CC	
8/7/2002	20637	8-Aug-02	ADP 1.6	CC	1010010000F33601
	37897	1-Feb-03	ADP 2.0	CC	
8/25/2002	25370	13-Sep-02	ADP 1.7	CC (No Pan.)	10100100011190
	31073	11-Nov-02	ADP 1.8	CC	
	38318	6-Feb-03	ADP 2.0	MTF	
9/7/2002	25378	13-Sep-02	ADP 1.7.1	CC (No Pan.)	1010010001280C01
	31089	11-Nov-02	ADP 1.8	CC	
	38321	6-Feb-03	ADP 2.0	MTF	
	38335	11-Mar-03	ADP 2.0	CC (orthorectified)	
	38450	8-Feb-03	ADP 2.0	CC (full size)	

- Procedure plots for pulse method

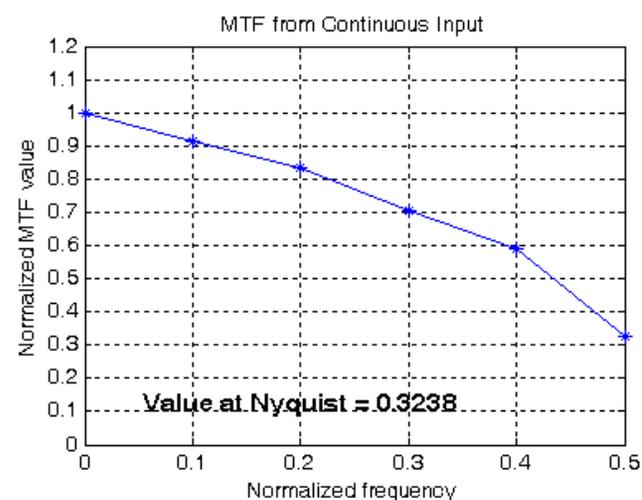
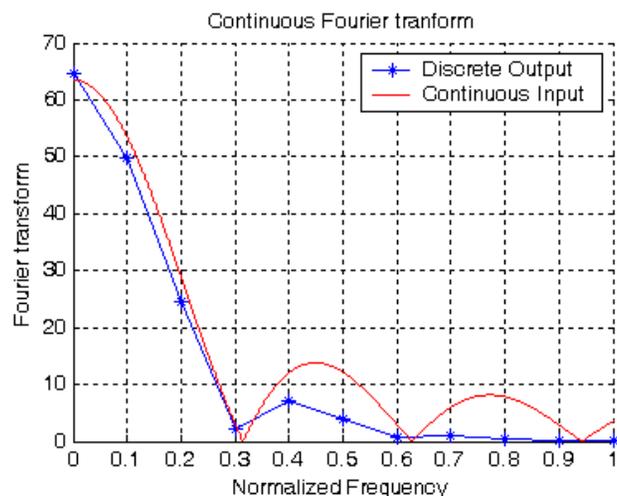
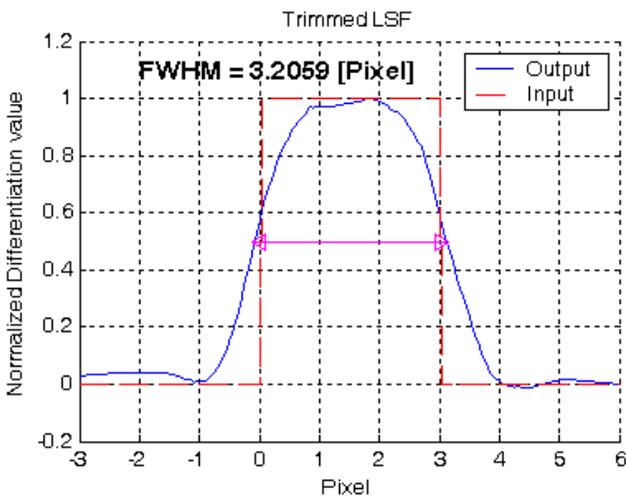
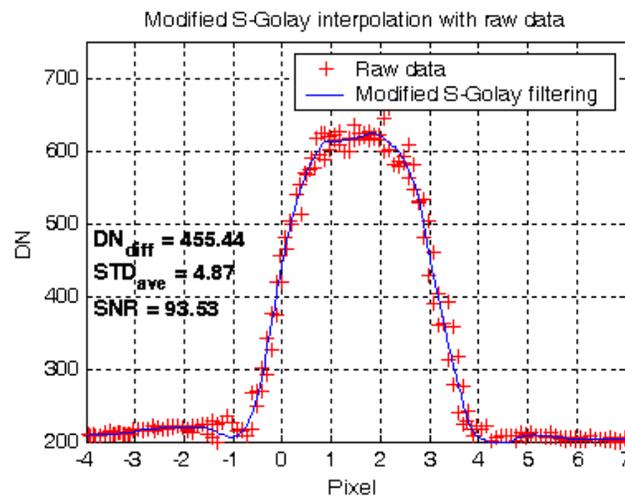
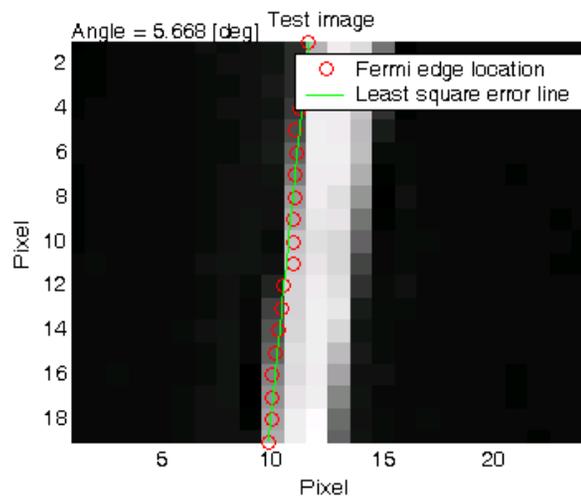


Figure 9. Blue band tarp target on August 25, 2002  
(ADP Version 1.8, Cubic Convolution)

Sensor	Band		Target		Method			
QuickBird	Blue		Blue Tarp		Pulse			

Date	6/27/02	6/27/02	7/20/02	7/20/02	8/25/02	8/25/02	9/7/02	9/7/02
Resamp.	CC	CC	CC	CC	CC	MTF	CC	MTF
ADP Ver.	1.5.1	2.0	1.6	2.0	1.8	2.0	1.8	2.0
FWHM	4.1247	4.1680	3.1502	3.1525	3.2059	3.1746	3.2102	3.0981
MTF	0.0816	0.3227	0.2957	0.3333	0.3238	0.6107	0.3687	0.6169
SNR	56.0	57.7	65.0	62.2	93.5	95.6	95.8	93.5

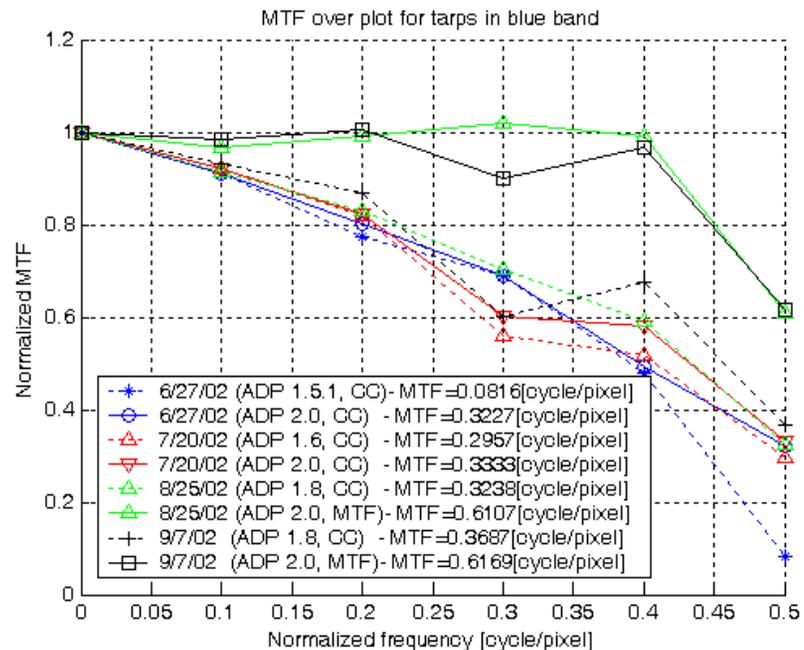
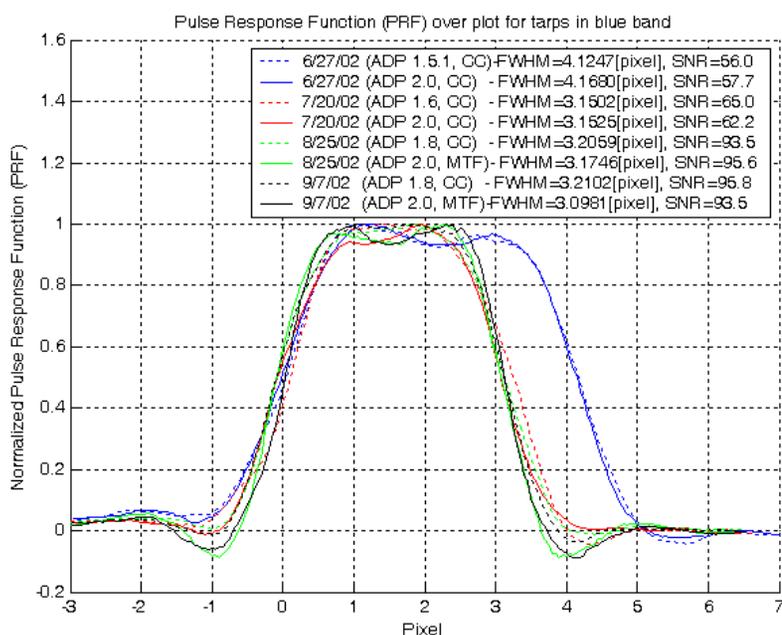
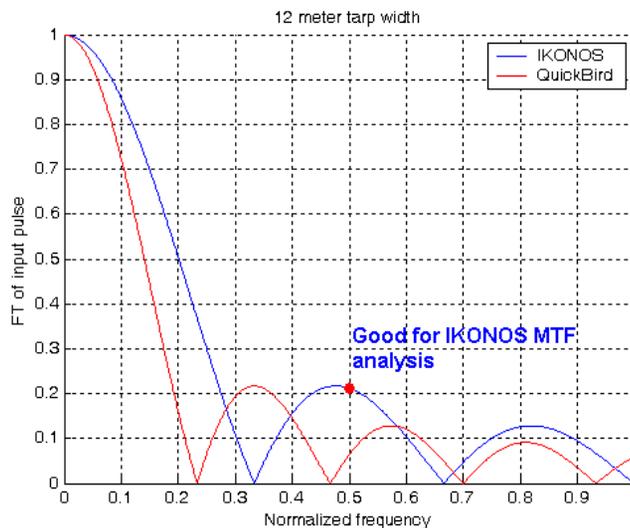


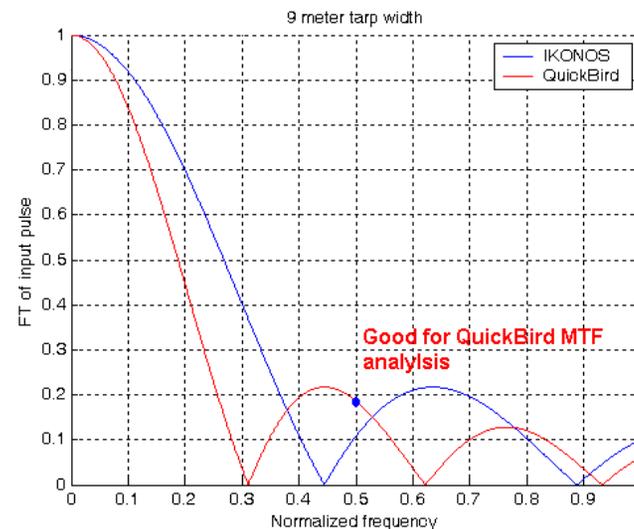
Figure 10. Over plots of blue band of blue tarp target

## – Tarp Width vs. Zero Crossing Points

- Because we focused on the IKONOS satellite on June 27 2002, 2×4 pattern (12m × 60m) was used.
- The close Nyquist frequency position of input sinc function to second zero-crossing point made the MTF value at Nyquist unstable.



(a) 12 meter target



(a) 9 meter target

- Procedure plots for edge method

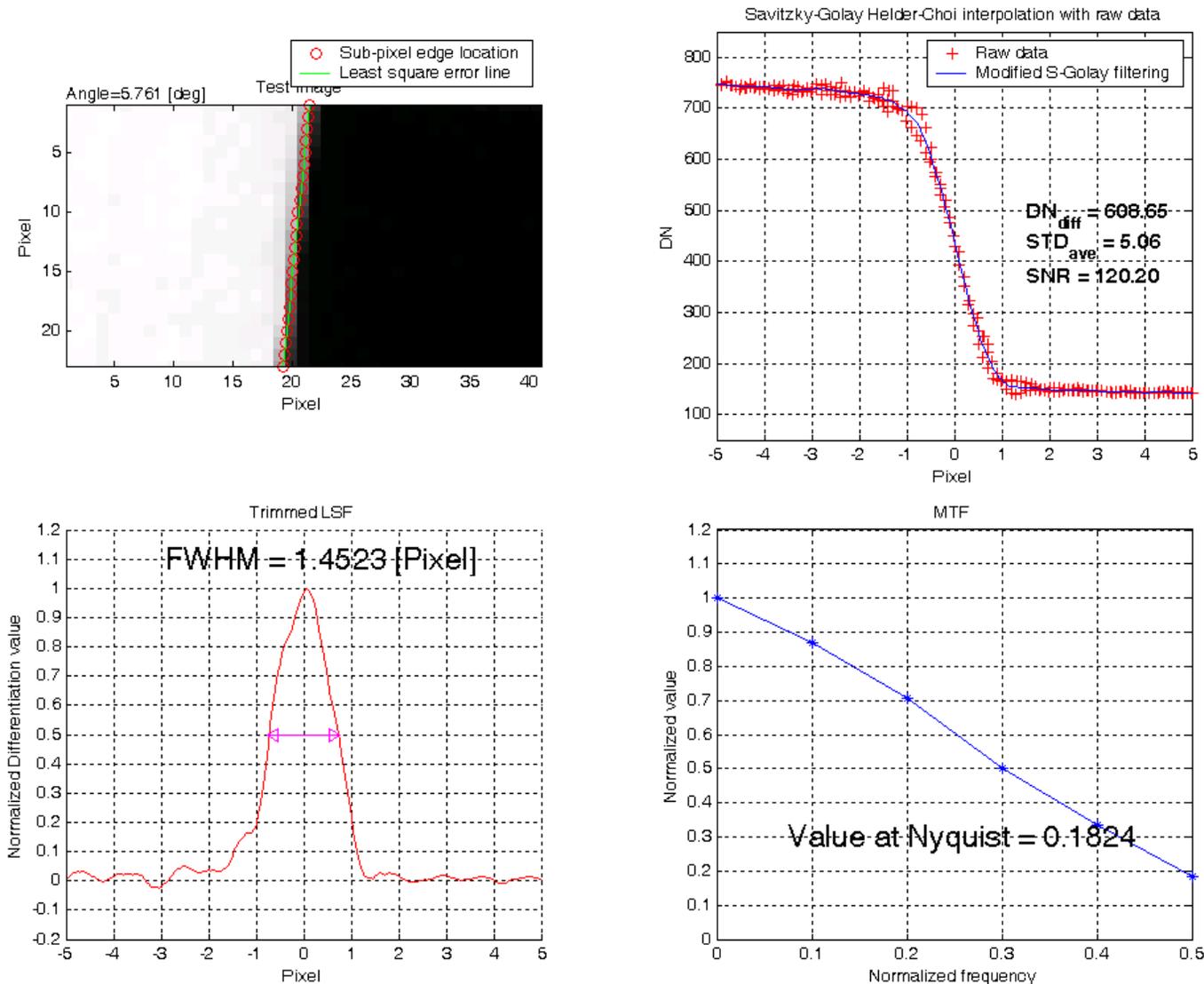


Figure 14. Panchromatic band analysis of Stennis tarp on July 20, 2002 (ADP Version 1.8, Cubic Convolution)

Sensor	Band	Target	Method
QuickBird	Pan	Stennis	Edge

Date	7/20/02	7/20/02	8/25/02	8/25/02	9/7/02	9/7/02
ADP, Interpolator	1.6, CC	2.0, CC	1.8, CC	2.0, <b>MTF</b>	1.8, CC	2.0, <b>MTF</b>
FWHM	1.5706	1.4560	1.4355	<b>1.2579</b>	1.4523	<b>1.1325</b>
MTF	0.1316	0.1559	0.1639	<b>0.3683</b>	0.1824	<b>0.6040</b>
SNR	137.6	100.1	100.5	<b>53.7</b>	141.3	<b>67.2</b>

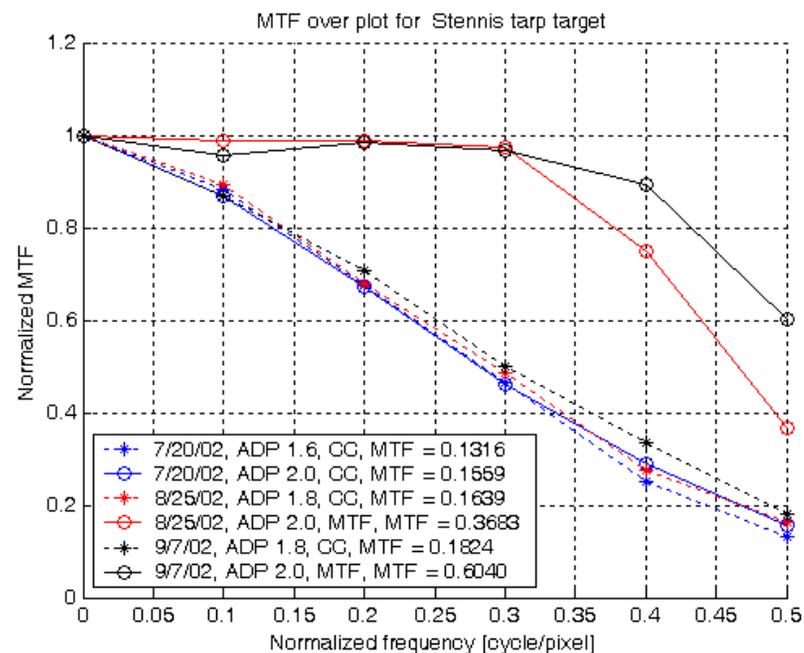
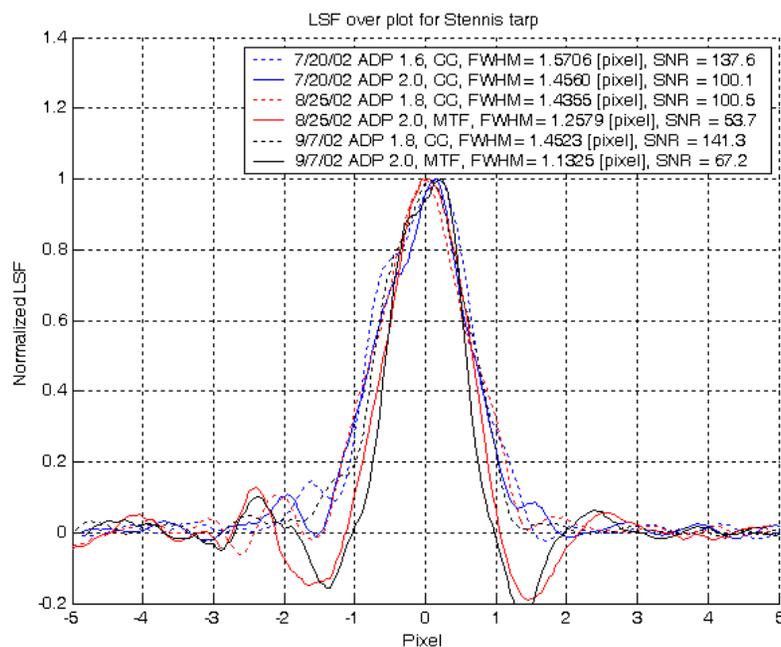


Figure 15. Over plots of panchromatic band Stennis tarp target

- Product MTF Comparison on Sept 7, 2002 Scenes.
  - With MTF resampling kernel, MTF value was higher and SNR was less than than CC kernel.
  - Basic1B product had small MTF value and angle problems.
  - Ortho-rectified product had artifact in the LSF plot.

Original Order Item	Processed	Order ADP Version	Resampling Kernel	Image Descriptor	MTF	SNR	FWHM
31089	11-Nov-02	ADP 1.8	CC	Standard2A	0.1824	141.3	1.4523
38321	6-Feb-03	ADP 2.0	MTF	Standard2A	0.6040	67.2	1.1325
38335	11-Mar-03	ADP 2.0	CC	OrthoRectified3E	0.1027	152.2	1.6227
38450	8-Feb-03	ADP 2.0	CC	Basic1B (Full Scene)	0.0247	130.2	1.9648

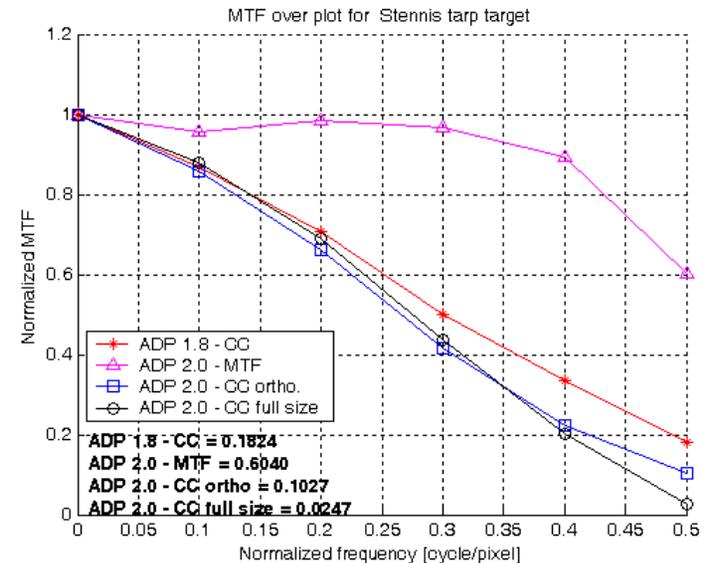
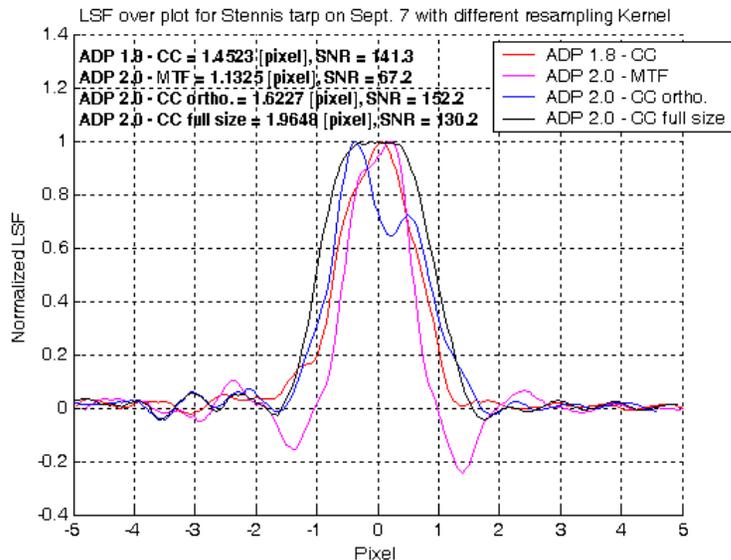
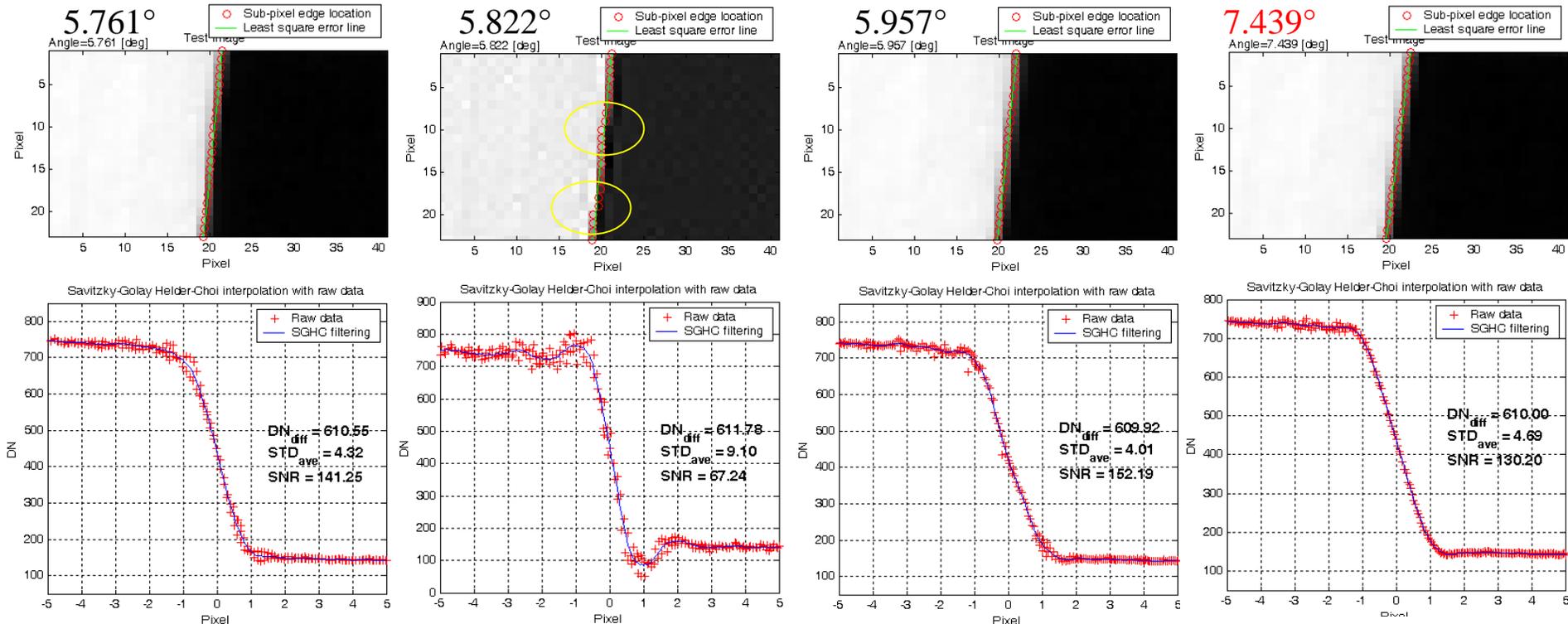


Figure 16. Result over plots of different products on Sept 7, 2002

# – Visual inspection



(a) Standard2A, CC

(b) Standard2A, MTF

(c) Orthorectified, CC

(d) Basic1B, CC

- Noisy, discontinuous transition along the edge.

- Artifact in LSF

- Full scene, about 1.5° of angle difference.

Figure 17. Visual inspection of different products on Sept 7, 2002

- Specification Comparison

- Latest version of ADP with cubic convolution interpolated images were used.

Values \ Sensor	Panchromatic Band	Blue band
# of Scenes	3	4
ADP Versions	2.0, 1.8, 1.8	2.0, 2.0, 1.8, 1.8
MTF $\pm 1\sigma$	0.16 $\pm 0.01$	0.34 $\pm 0.02$
FWHM $\pm 1\sigma$	1.45 $\pm 0.01$	3.19 $\pm 0.03^*$
SNR $\pm 1\sigma$	113.97 $\pm 23.67$	77.30 $\pm 20.14$
SDP Spec.	0.09	0.20
Spec. Margin	0.07	0.14

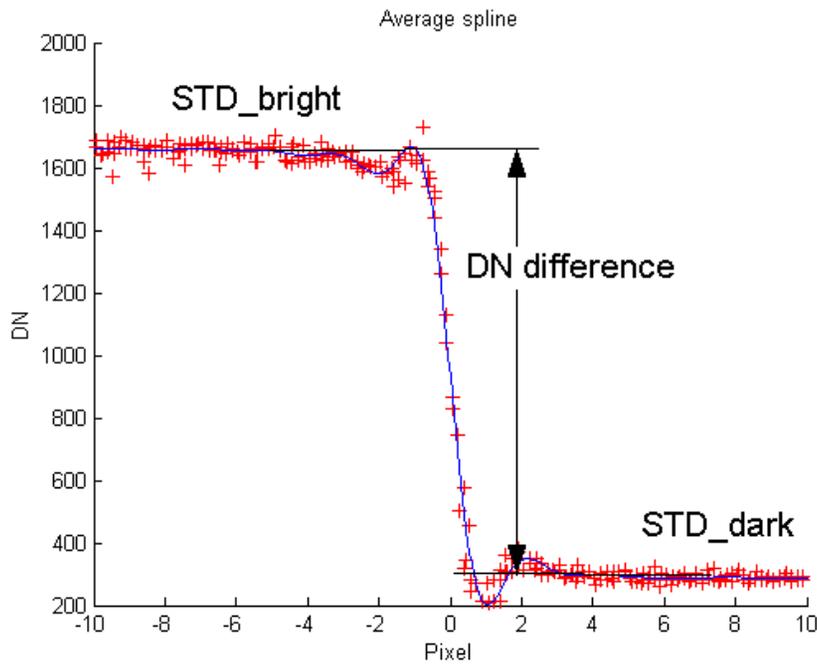
\* 6/27/2002 result was excluded because of larger blue tarp width.

# Conclusions

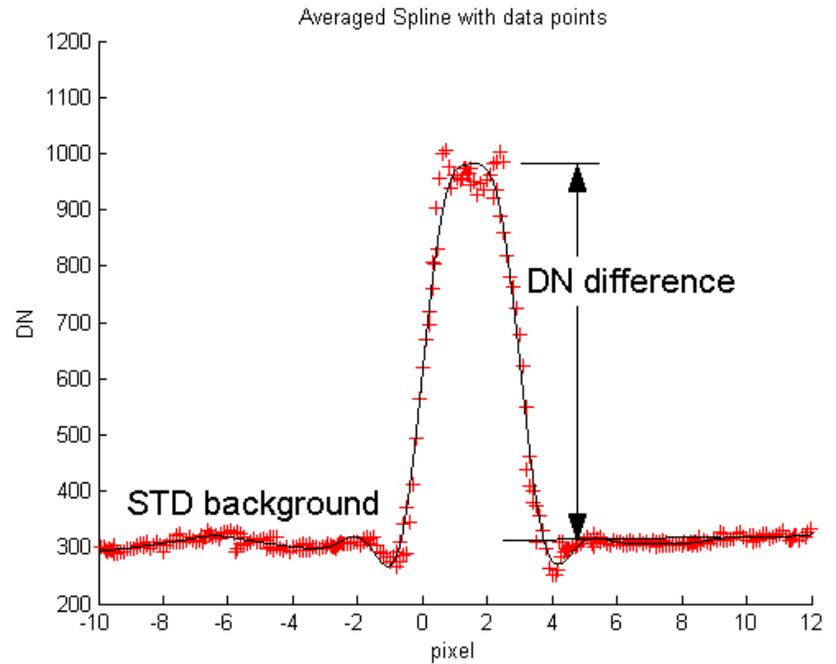
- Physical layout was extremely important for a high-resolution sensor.
- Parametric edge detection and SGHC filtering produced accurate MTF results when  $\text{SNR} > 60$ .
- Stennis tarp provided panchromatic band results at average of 0.16 MTF value at Nyquist.
- The most reliable Blue band MTF value at Nyquist was an average of 0.34.
- Significant tradeoff exists between MTF and SNR.
- QuickBird imagery met the SDP spatial quality specification.

Back up slides

# SNR Calculation



$$\text{SNR} = \frac{\text{DN difference}}{(\text{STD\_bright} + \text{STD\_dark}) / 2}$$



$$\text{SNR} = \frac{\text{DN difference}}{\text{STD background}}$$

Figure 18. SNR definition

Sensor	Band	Target	Method
QuickBird	Green	Blue Tarp	Pulse

Date	6/27/02	6/27/02	7/20/02	7/20/02	8/25/02	8/25/02	9/7/02	9/7/02
Resamp.	CC	CC	CC	CC	CC	MTF	CC	MTF
ADP Ver.	1.5.1	2.0	1.6	2.0	1.8	2.0	1.8	2.0
FWHM	4.1442	4.1479	3.2138	3.1926	3.1993	3.1590	3.2050	3.0680
MTF	0.1430	0.2144	0.3038	0.3124	0.3533	0.6219	0.3904	0.5692
SNR	32.7	31.9	42.1	43.0	76.7	71.0	35.7	36.3

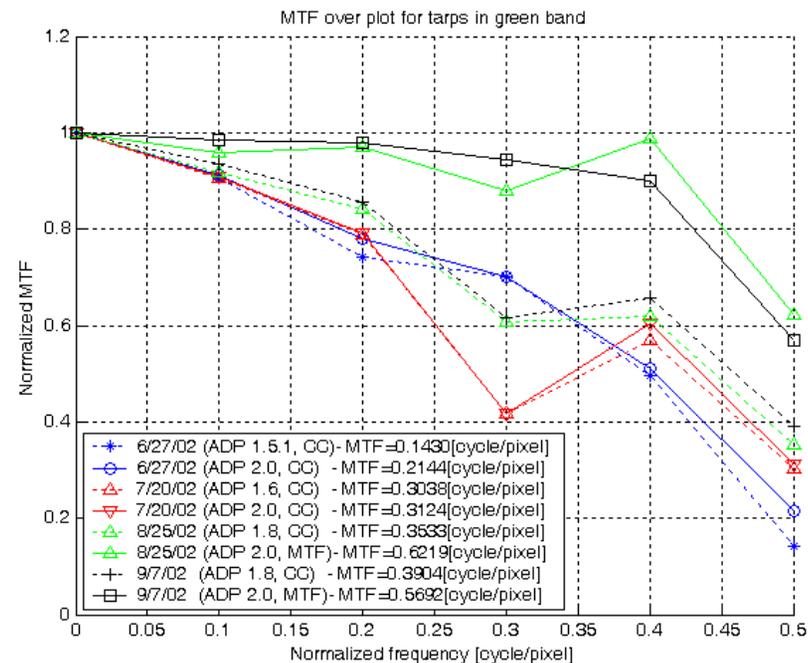
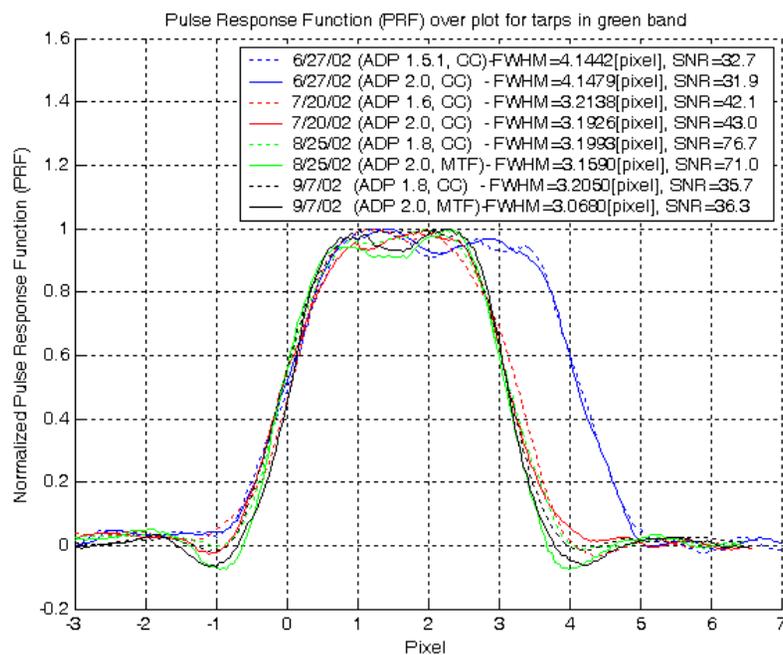


Figure 19. Over plots of green band of blue tarp target

Sensor	Band		Target	Method
QuickBird	NIR		Blue Tarp	Pulse

Date	6/27/02	6/27/02	7/20/02	7/20/02	8/25/02	8/25/02	9/7/02	9/7/02
Resamp.	CC	CC	CC	CC	CC	MTF	CC	MTF
ADP Ver.	1.5.1	2.0	1.6	2.0	1.8	2.0	1.8	2.0
FWHM	4.1750	4.2097	3.2367	3.1998	3.2589	3.2082	3.4007	3.3649
MTF	0.4582	0.4327	0.2988	0.2204	0.2606	0.4673	0.1851	0.2276
SNR	28.1	28.9	45.8	48.7	38.4	35.0	9.3	11.8

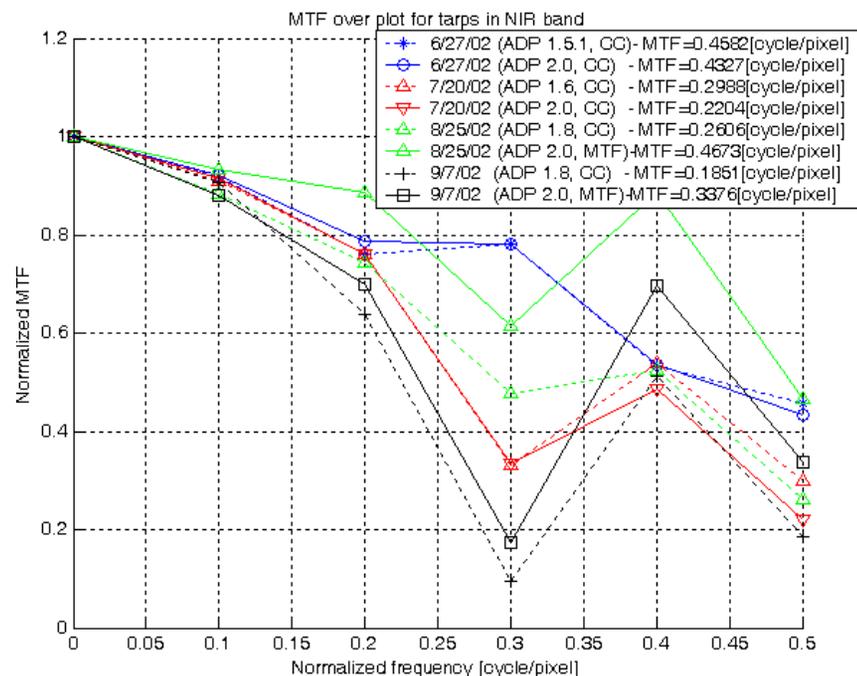
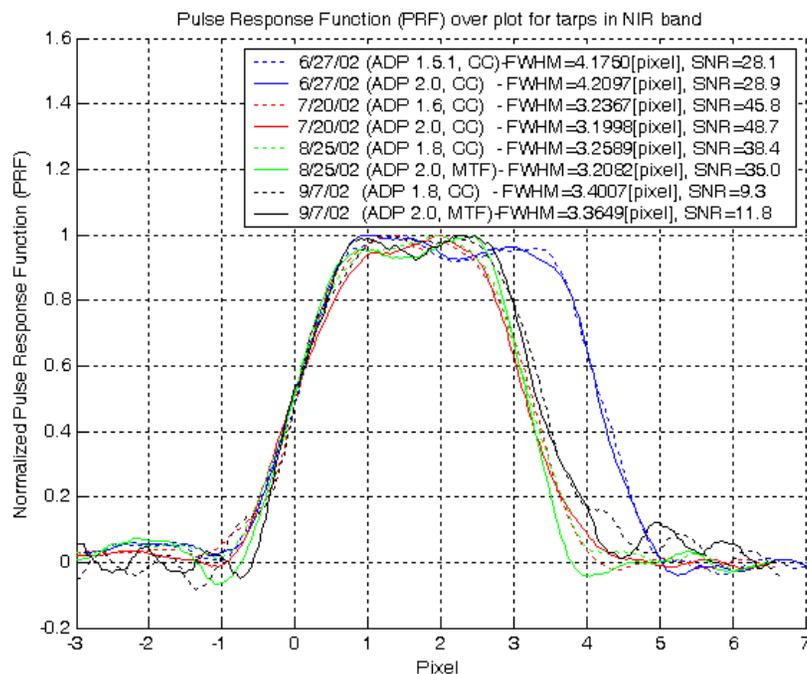


Figure 20. Over plots of NIR band of blue tarp target