

On-orbit Modulation Transfer Function (MTF) measurement of QuickBird

Presented by

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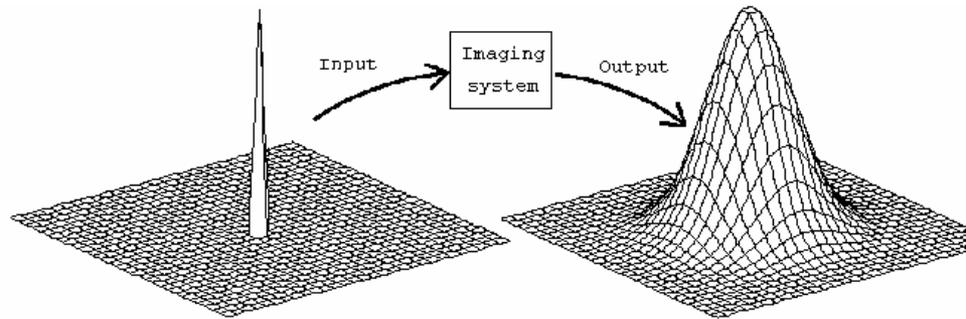
Outline

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 - Edge Method
- Target Description
- Results
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Introduction

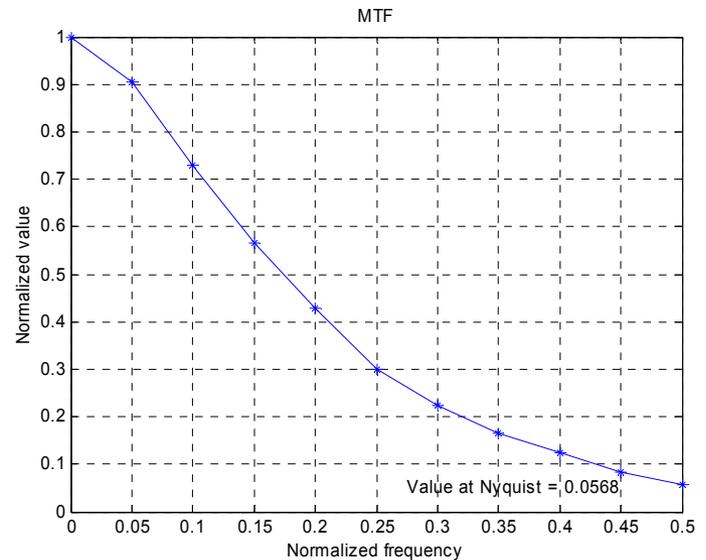
- Point Spread Function

- A method of evaluating the spatial resolution of an imaging system.
- A measure of the spread of a single point of light.



- Modulation Transfer function (MTF)

- MTF is a measure of the spatial frequency response.
- MTF is often calculated from the point spread function (PSF).
- System response at the Nyquist frequency (or 0.5 cycle/pixel) is often used as a figure of merit.



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

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

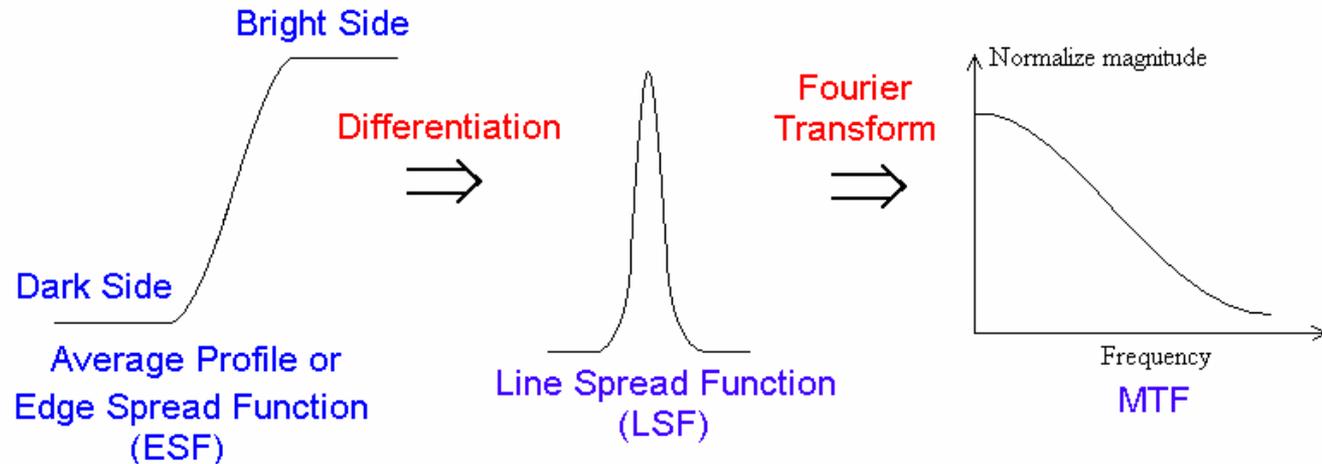
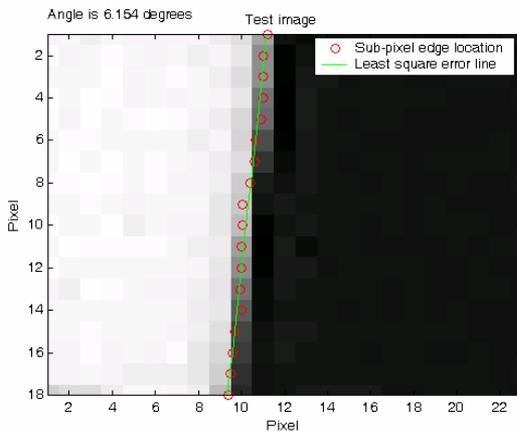
- 2-dimensional PSF and MTF are difficult to obtain.
- Often 1 dimensional functions are used:
 - 1-D PSF is the line spread function (LSF).
 - LSF can be obtained by differentiation of the edge spread function (ESF).

NASA Science Data Purchase (SDP) Specification

- Edge quality associated with the panchromatic band will provide a MTF of 0.09 or greater at the Nyquist frequency.
- Edge quality associated with each multispectral band will provide a MTF of 0.20 or greater at the Nyquist frequency.

Method Description

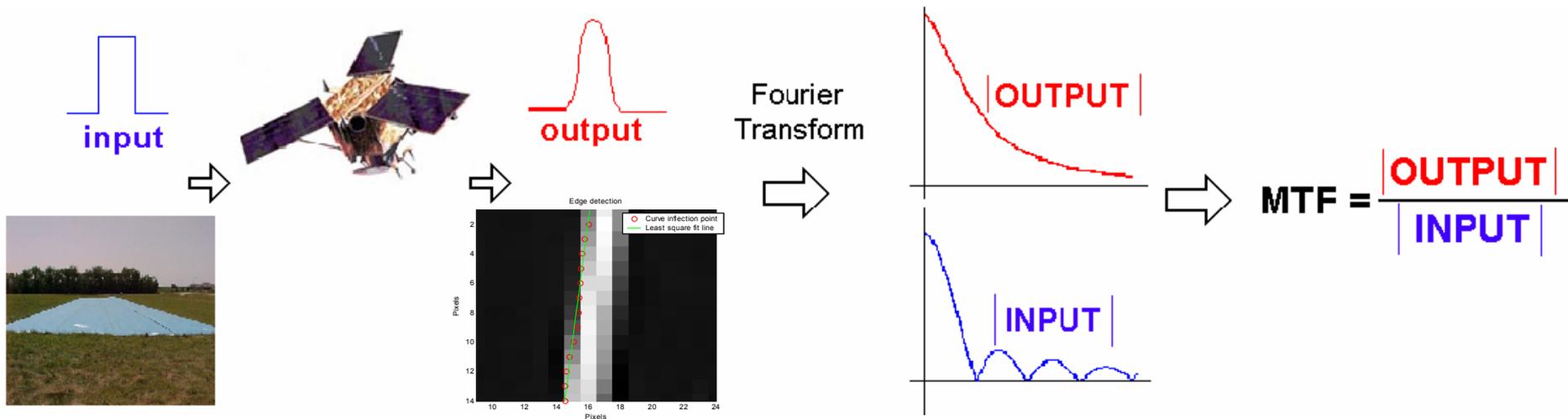
- Edge Method
 - Sub-pixel edge locations were found by Fermi function fit.
 - A least-square error line was calculated through the edge locations.
 - Modified Savitzky-Golay filtering was applied on each line.
 - The filtered profile was differentiated to obtain LSF
 - MTF calculated by applying Fourier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



Edge Method

- Pulse method

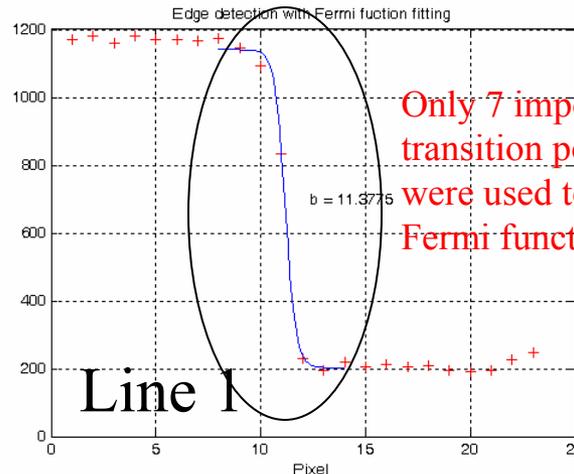
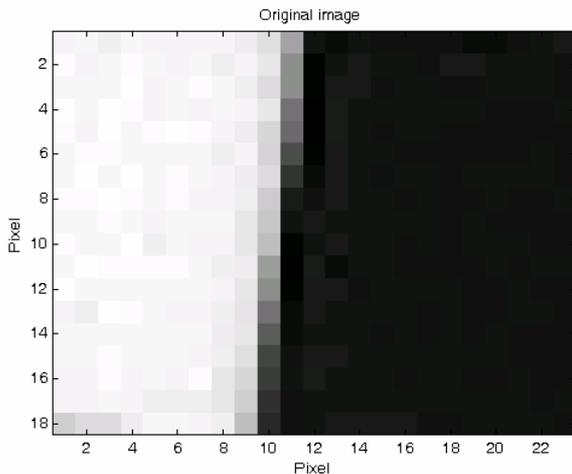
- A pulse input is given to the imaging system.
- Output of the system is the resulting image.
- Edge detection and mSG filtering was applied to obtain output profile.
- Take Fourier transform of the input and output.
- MTF is calculated by dividing output by input and normalizing DC component to unity.



Pulse method

- Parametric Edge Detection

- A model-based parametric method was applied to estimate edge location to sub-pixel accuracy.
- The Fermi function was chosen as a parametric fit to locate the edge to sub-pixel accuracy.
- Parameter ‘b’ is the sub-pixel edge location estimate.

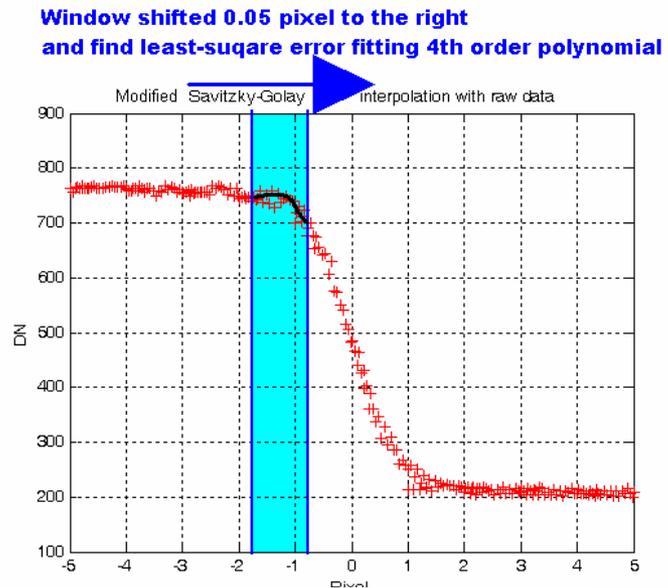
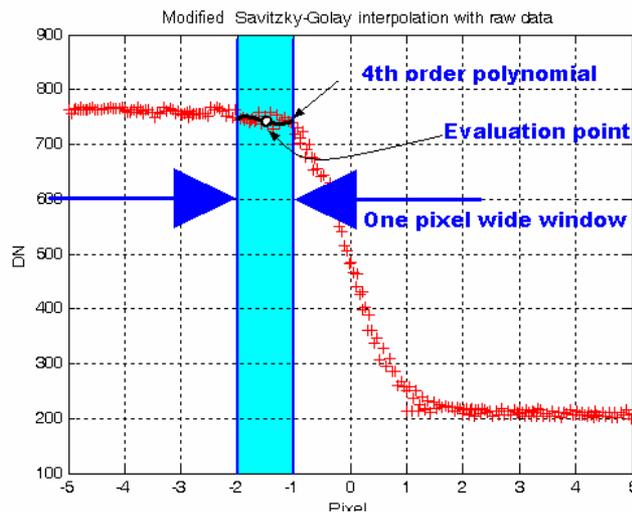


Only 7 important transition points were used to find Fermi function.

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

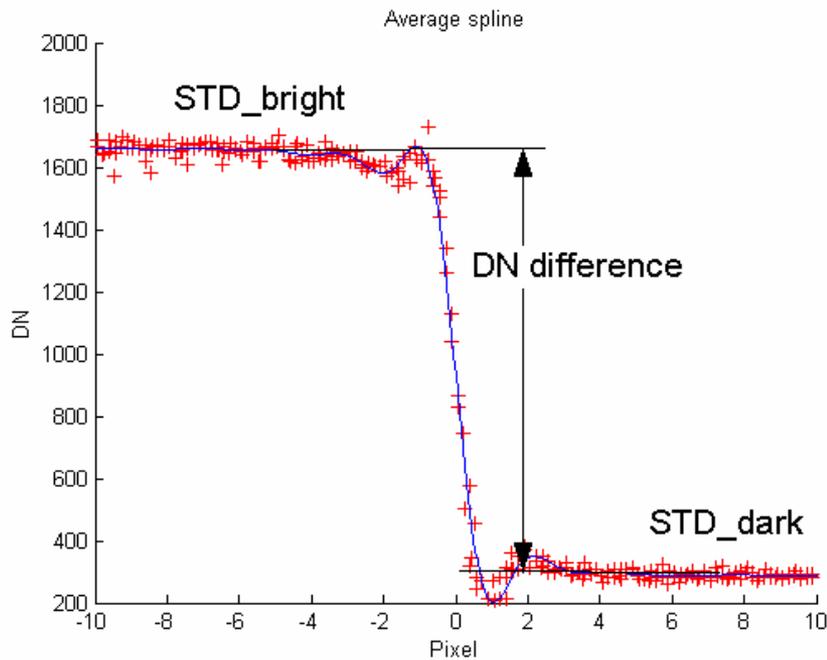
- Modified Savitzky-Golay (mSG) Filtering
 - Unlike normal Savitzky-Golay filtering, mSG filter is applicable to non-uniformly spaced data.
 - Using a least-square approach, a 4th order polynomial was fitted to the data in a 1-pixel wide window centered on each location where an output value was desired.

- One output in the window center is evaluated by the polynomial.
- The next value is evaluated by shifting the window at a sub-pixel scale. (typically 0.05 GSD)
- The shifting step determines output resolution.

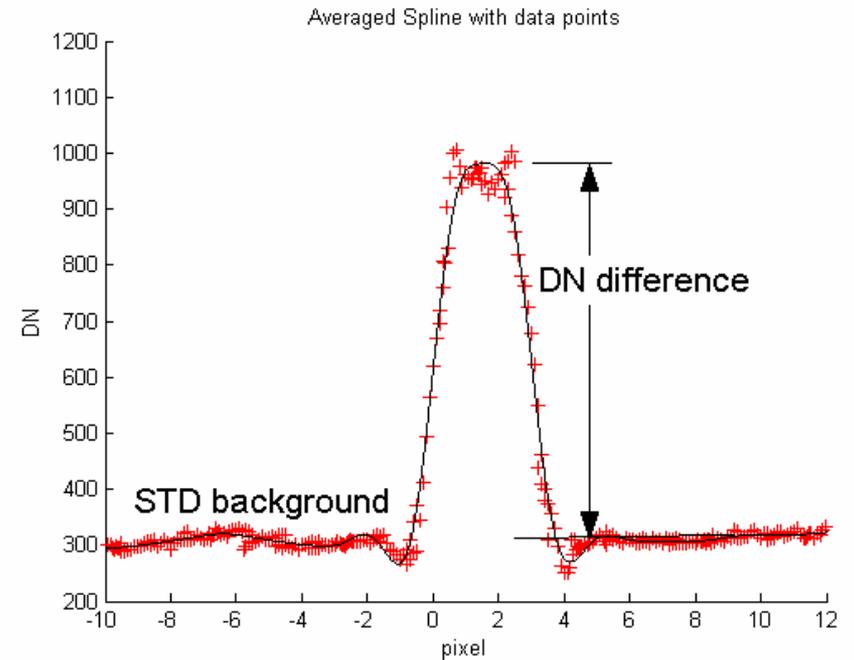


mSG filtering

SNR Calculation



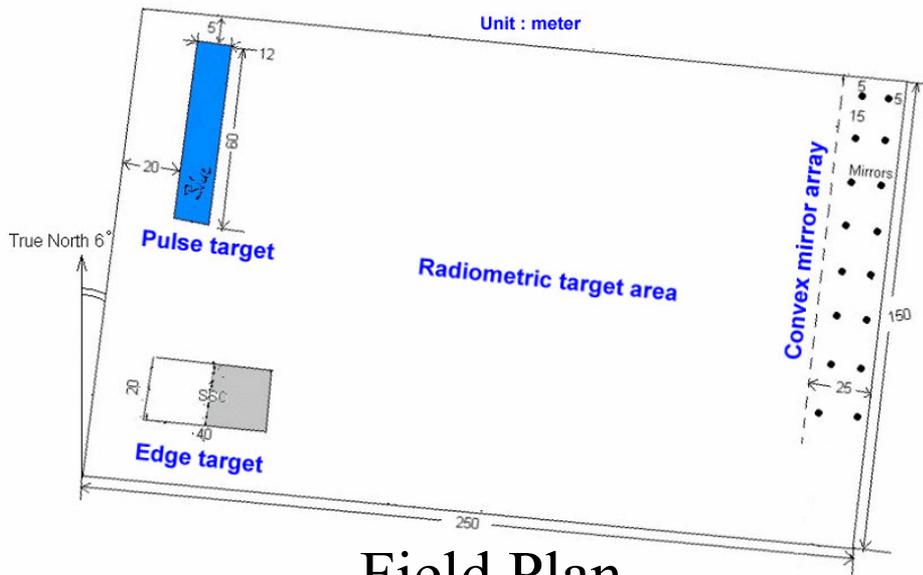
$$\text{SNR} = \frac{\text{DN difference}}{(\text{STD_bright} + \text{STD_dark}) / 2}$$



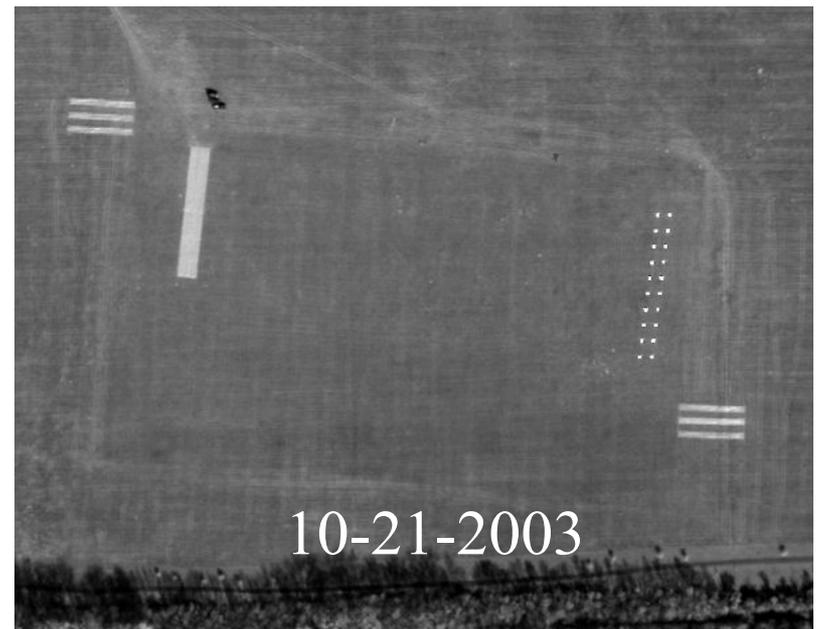
$$\text{SNR} = \frac{\text{DN difference}}{\text{STD background}}$$

SNR definition

Target Description



Field Plan



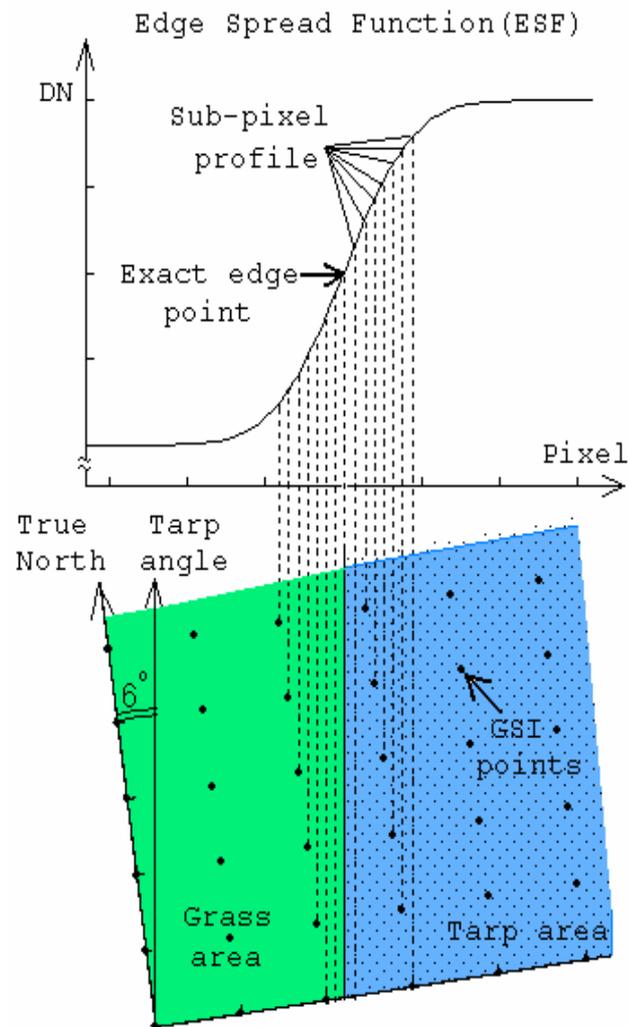
South to North view



North to South view



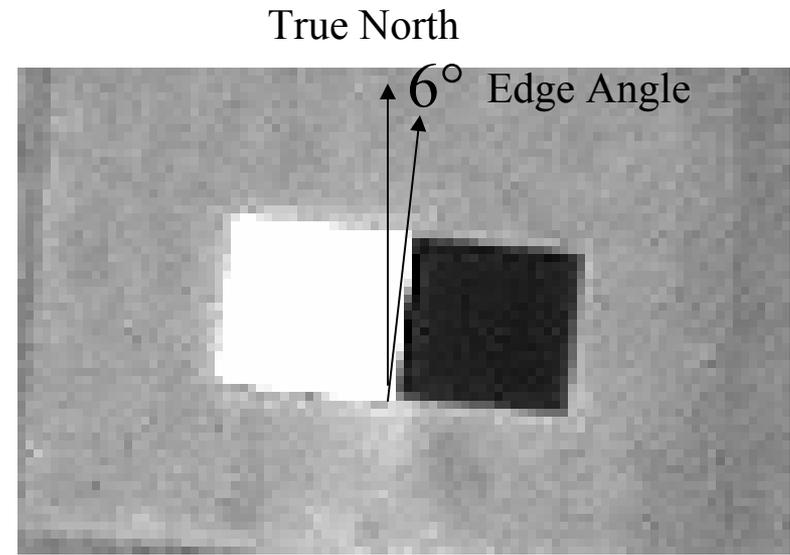
- Tarp Angle
 - Dashed lines are projections of ground sample interval (GSI) points.
 - Resolution of sub-pixel profile is determined by the edge angle.
 - At least two horizontal pixels were covered by the edge line in multispectral bands.



ESF projection from angled GSI points.

- NASA Stennis tarp

- Radiometrically and spectrally stable target with a large DN difference between 3.6% and 52.1% reflectance panels.
- Edge angle was parallel to the ‘blue’ tarps.
- At least two horizontal pixels were covered by the edge line in the panchromatic band.



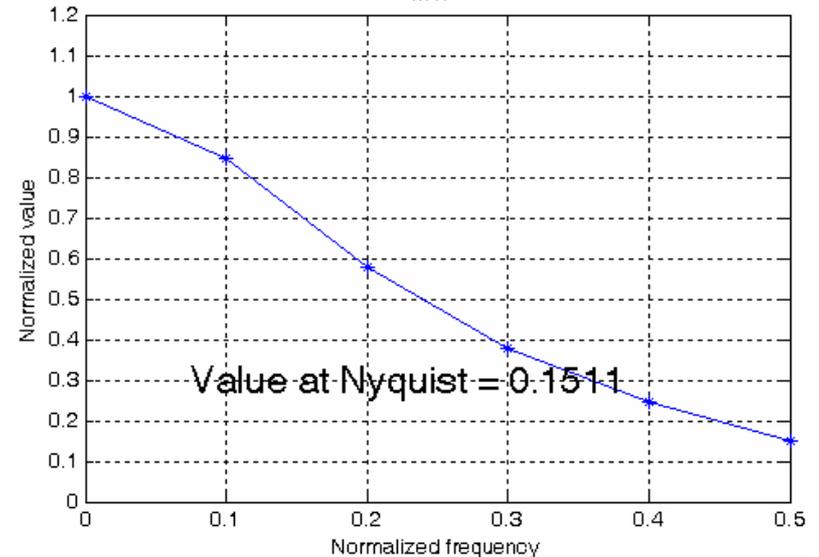
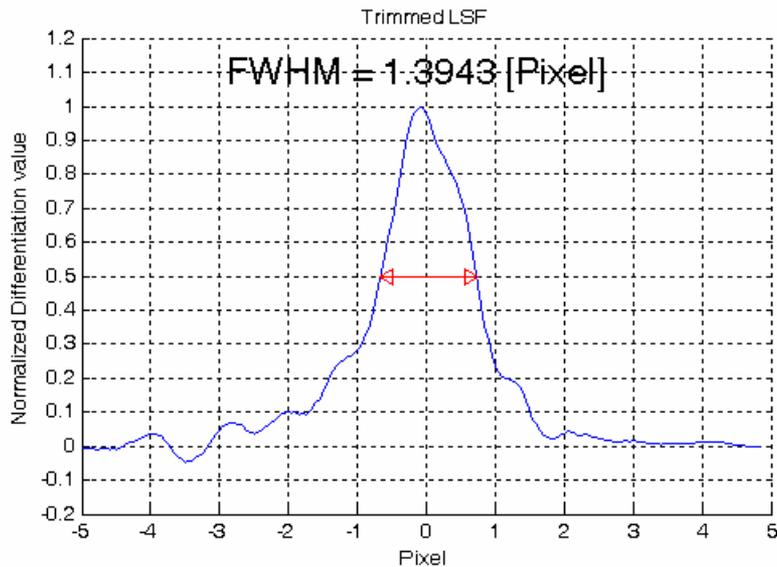
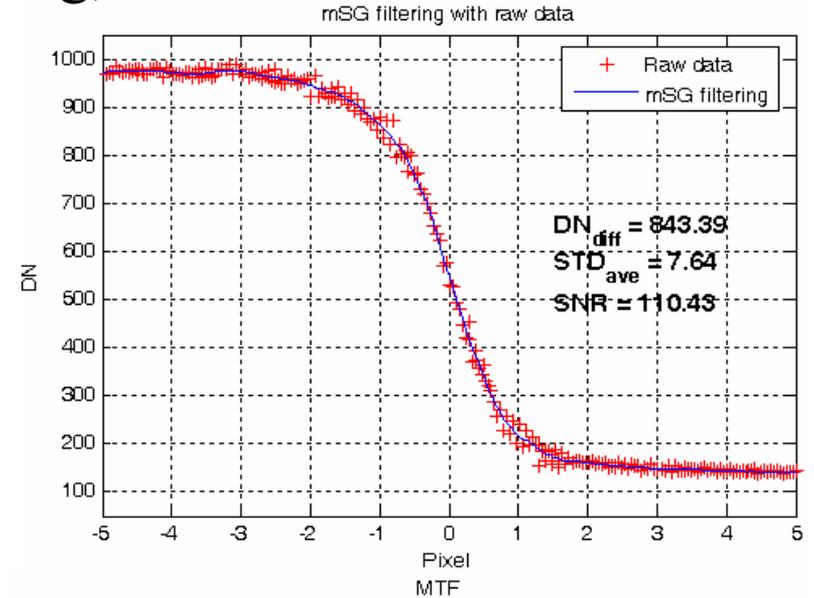
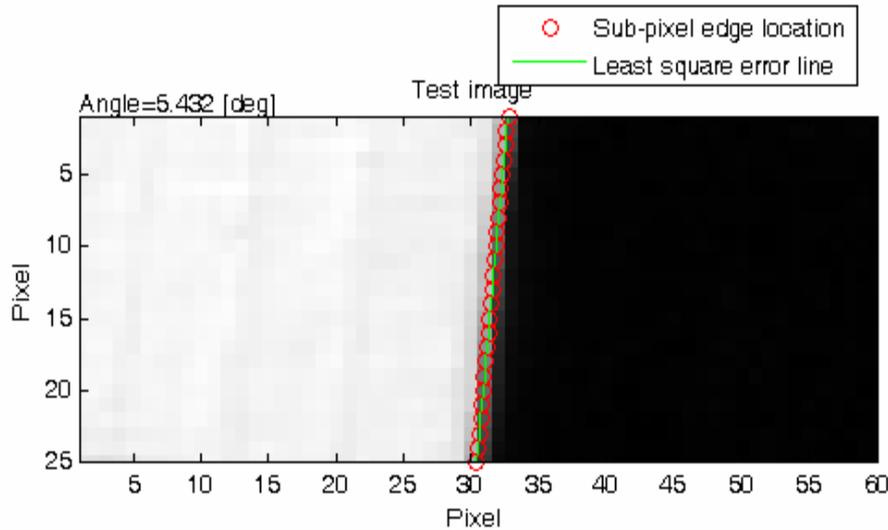
NASA Stennis tarp.

Results

- Brookings image information

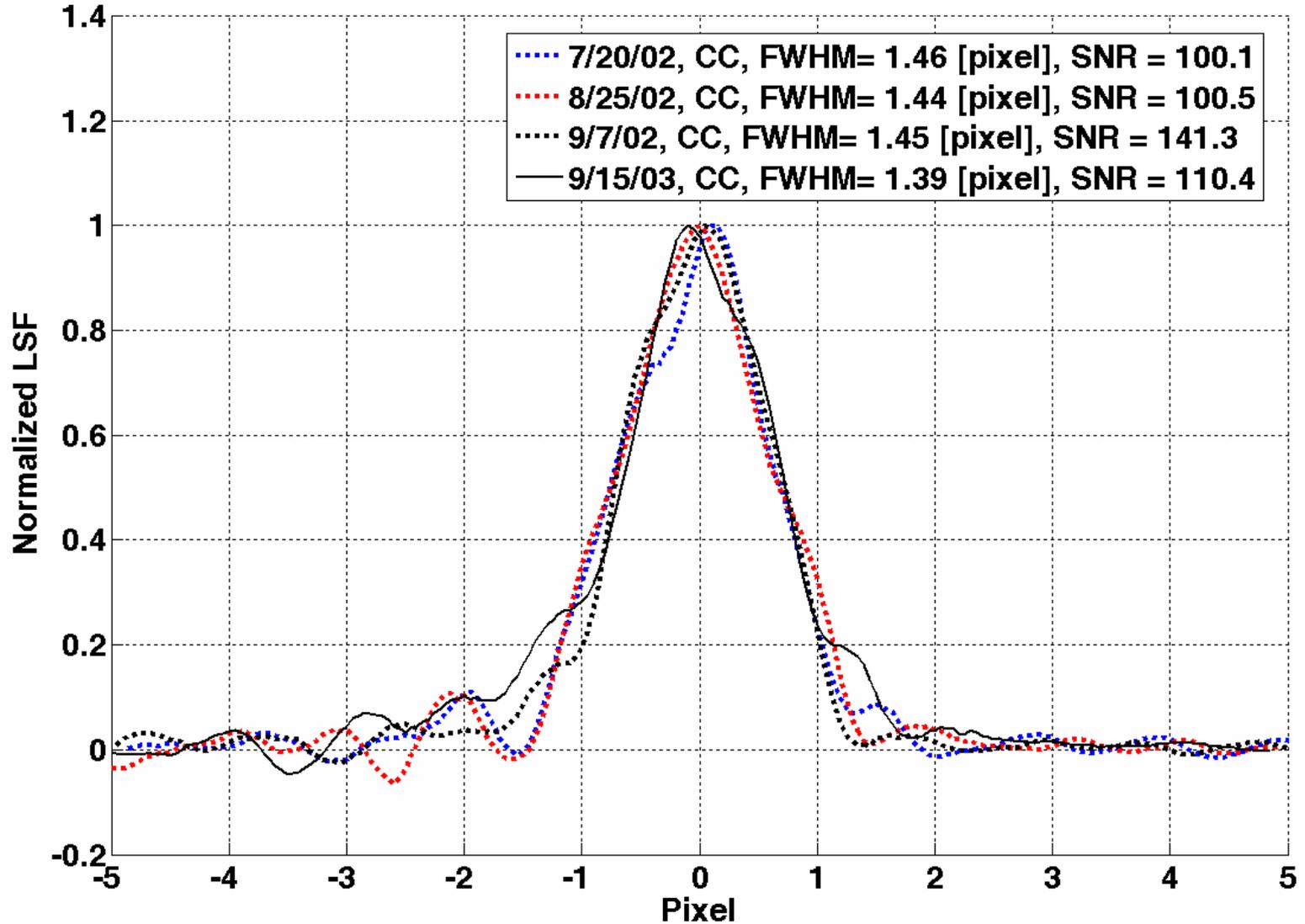
Acquisition Date	Blue Tarp Width [m]	Stennis Tarps ?	Resampling Kernel	Scene Type
8/23/2003	8.84	No	CC	Standard
			CC	Orthorectified
			MTF	Standard Full
9/15/2003	8.80	Yes	CC	Standard
			MTF	Standard
10/21/2003	8.84	No	CC	Standard
			MTF	Standard

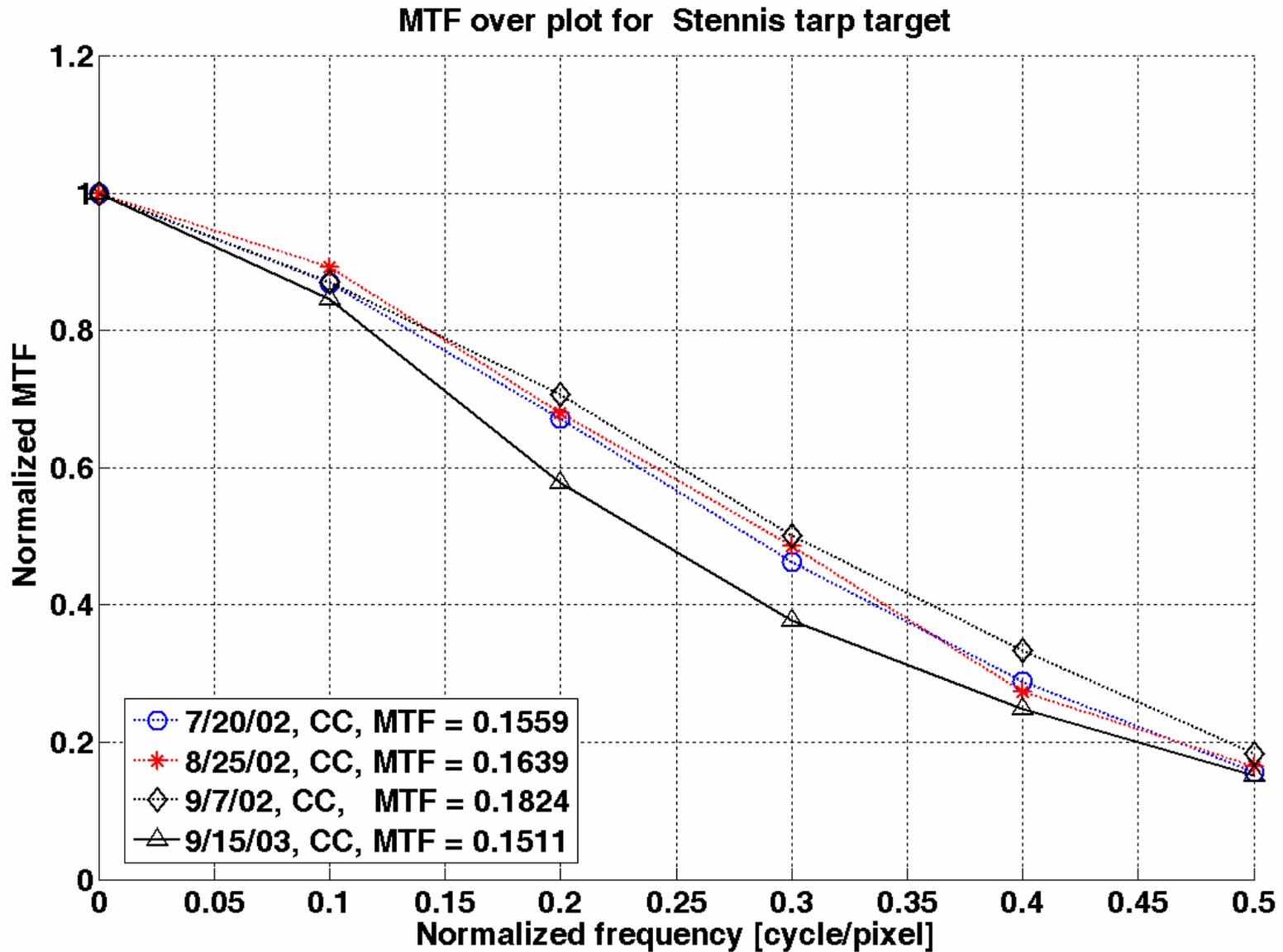
- Procedure plots for edge method
 - Cubic convolution resampling, CC



Panchromatic band Stennis tarp target on 9-15-2003 with CC

LSF over plot for Stennis tarp



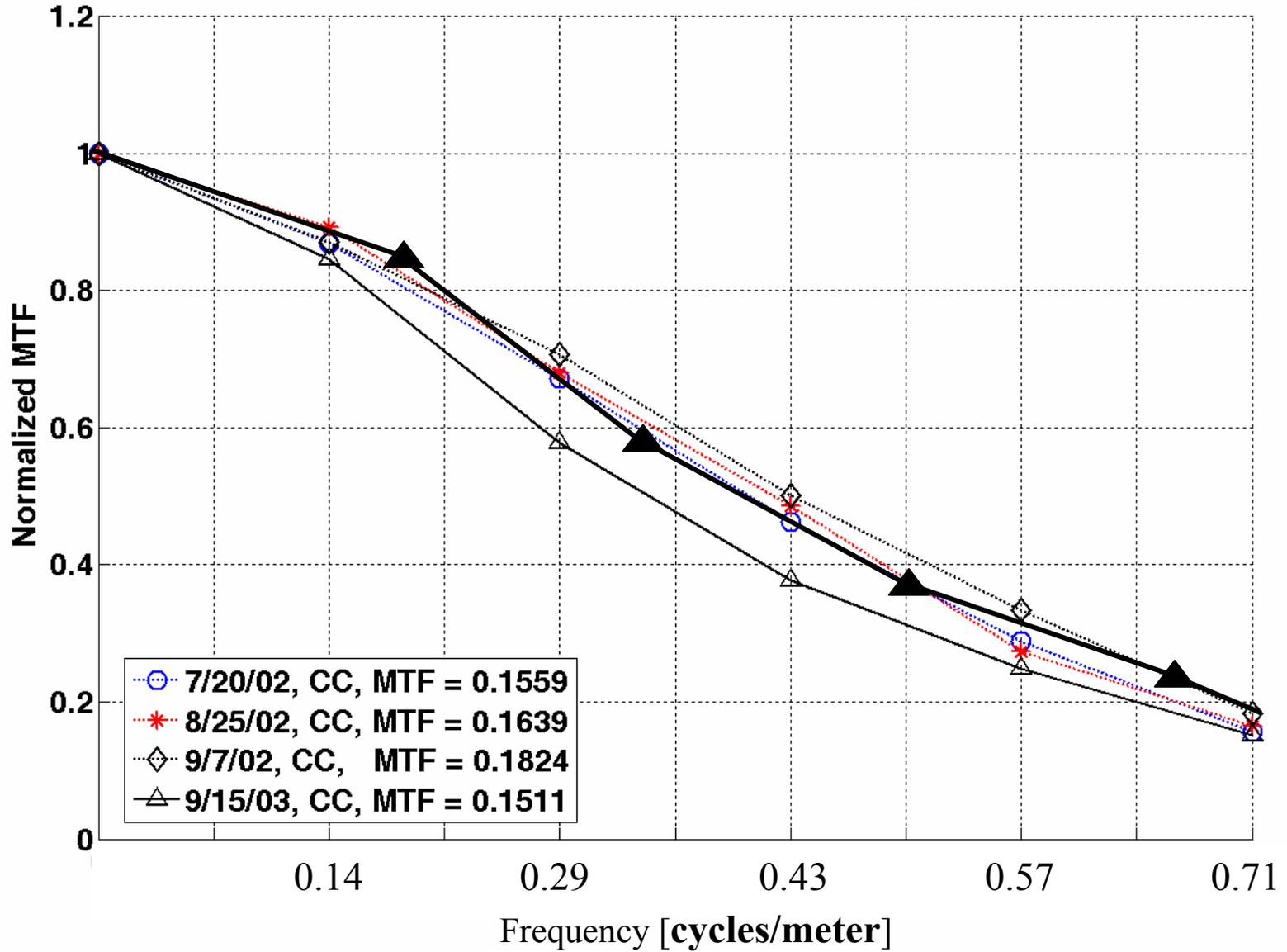


MTF over plots of panchromatic band with Stennis Target 19

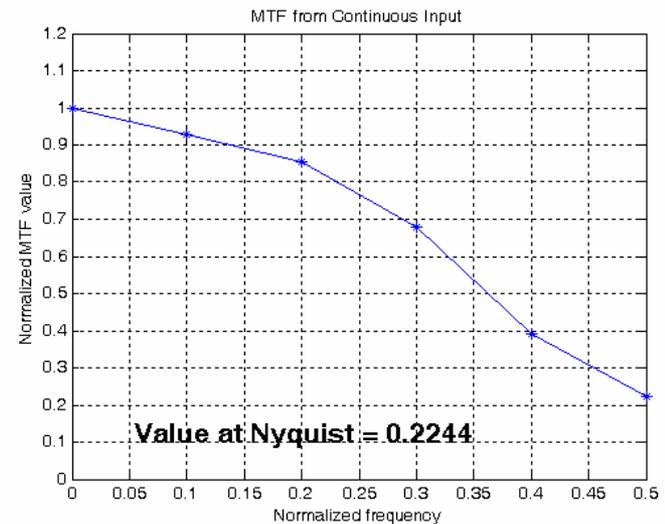
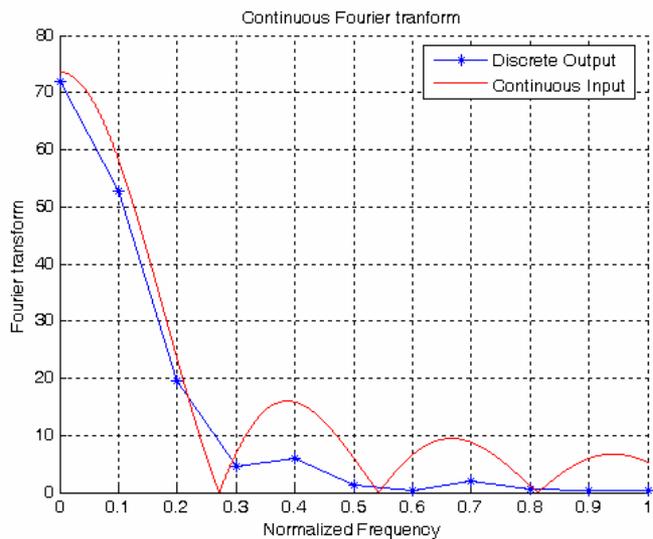
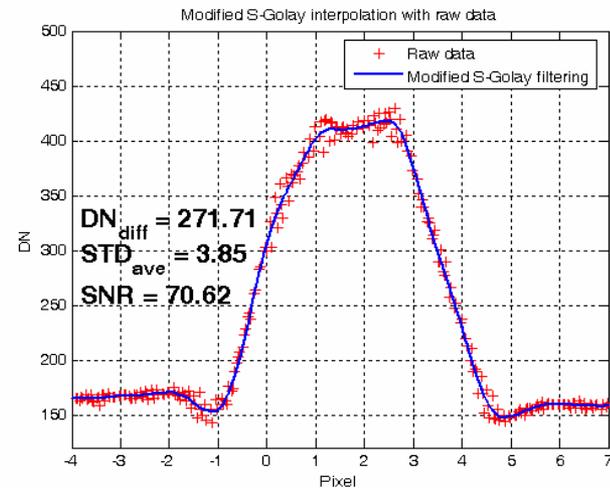
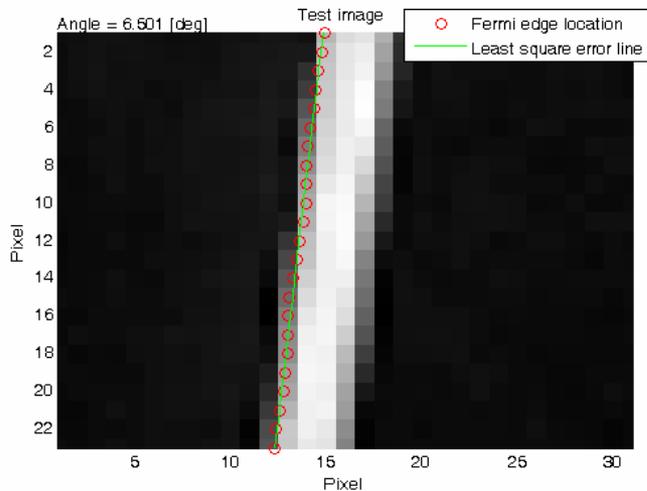
What really changed from 2002 to 2003?

- Panchromatic Ground Sample Distance (GSD)
 - 0.7m in 2002.
 - 0.6m in 2003.
 - Change was not known *a priori*
- Impacts MTF measurements
 - Normalized frequency scale doesn't change—Nyquist frequency stays the same.
 - Need to rescale in more 'absolute' terms to compare between the two dates.

MTF over plot for Stennis tarp target

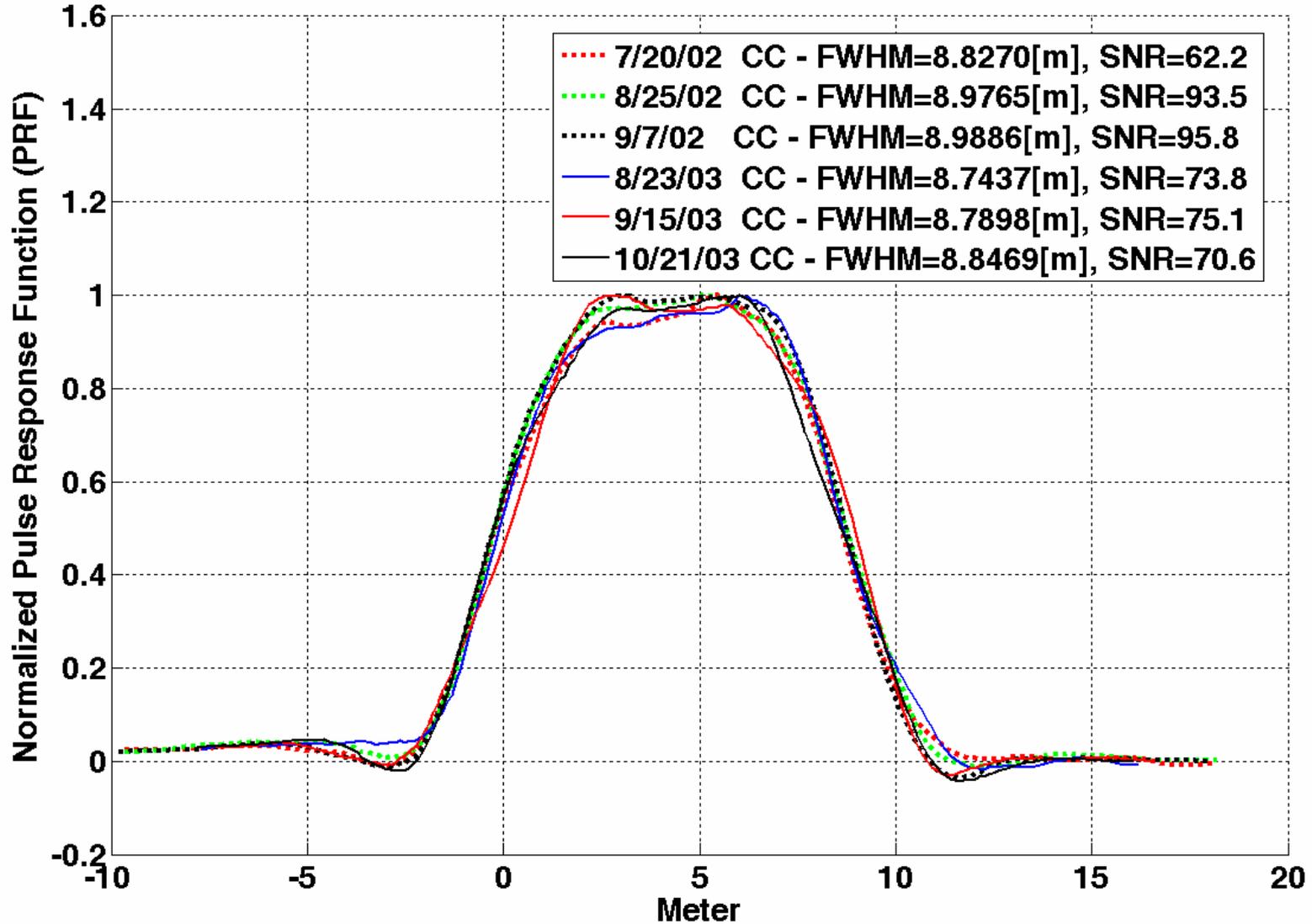


- Procedure plots for pulse method
 - With cubic convolution interpolation

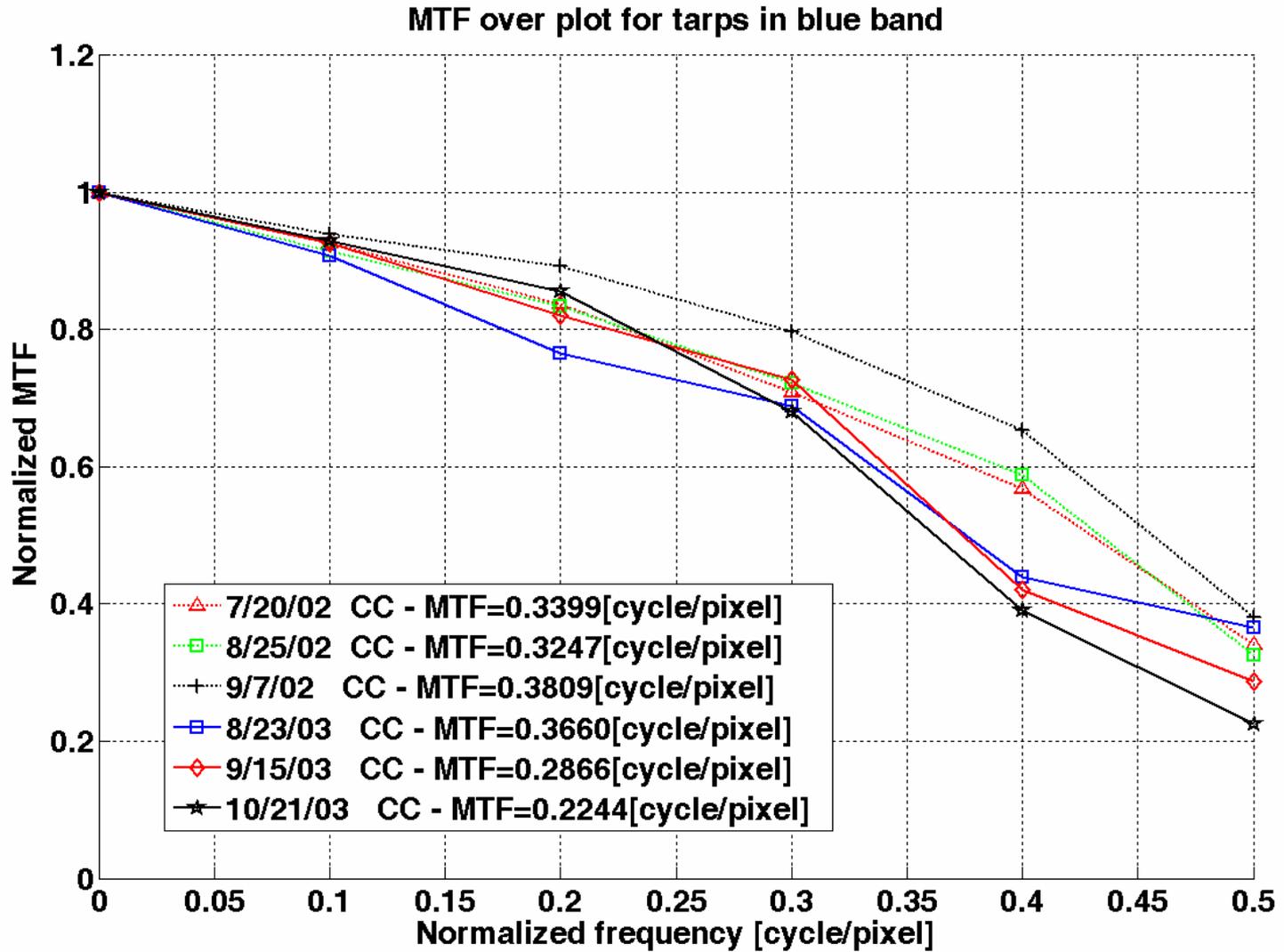


Blue band tarp target on Oct 21, 2003

Pulse Response Function (PRF) over plot for tarps in blue band



PRF over plots in blue band from 2002 to 2003



MTF over plot in blue band

- Panchromatic band

Date	Interpolation method	FWHM [pixel]	SNR	MTF
7/20/2002	CC	1.456	100.1	0.1599
8/25/2002	CC	1.4355	100.5	0.1639
9/7/2002	CC	1.4523	141.3	0.1824
9/15/2003	CC	1.3943	110.4	0.1511

- Blue band

Date	Interpolation method	FWHM [pixel]	FWHM [meter]	SNR	MTF
6/27/2002	CC	4.1680	11.6704	57.7	0.3227
7/20/2002	CC	3.1525	8.8270	62.2	0.3333
8/25/2002	CC	3.2059	8.9765	93.5	0.3238
9/7/2002	CC	3.2102	8.9886	95.8	0.3687
8/23/2003	CC	3.6432	8.7437	73.8	0.3660
9/15/2003	CC	3.6624	8.7898	75.1	0.2866
10/21/2003	CC	3.6862	8.8469	70.6	0.2244

3.17 3.66

0.34

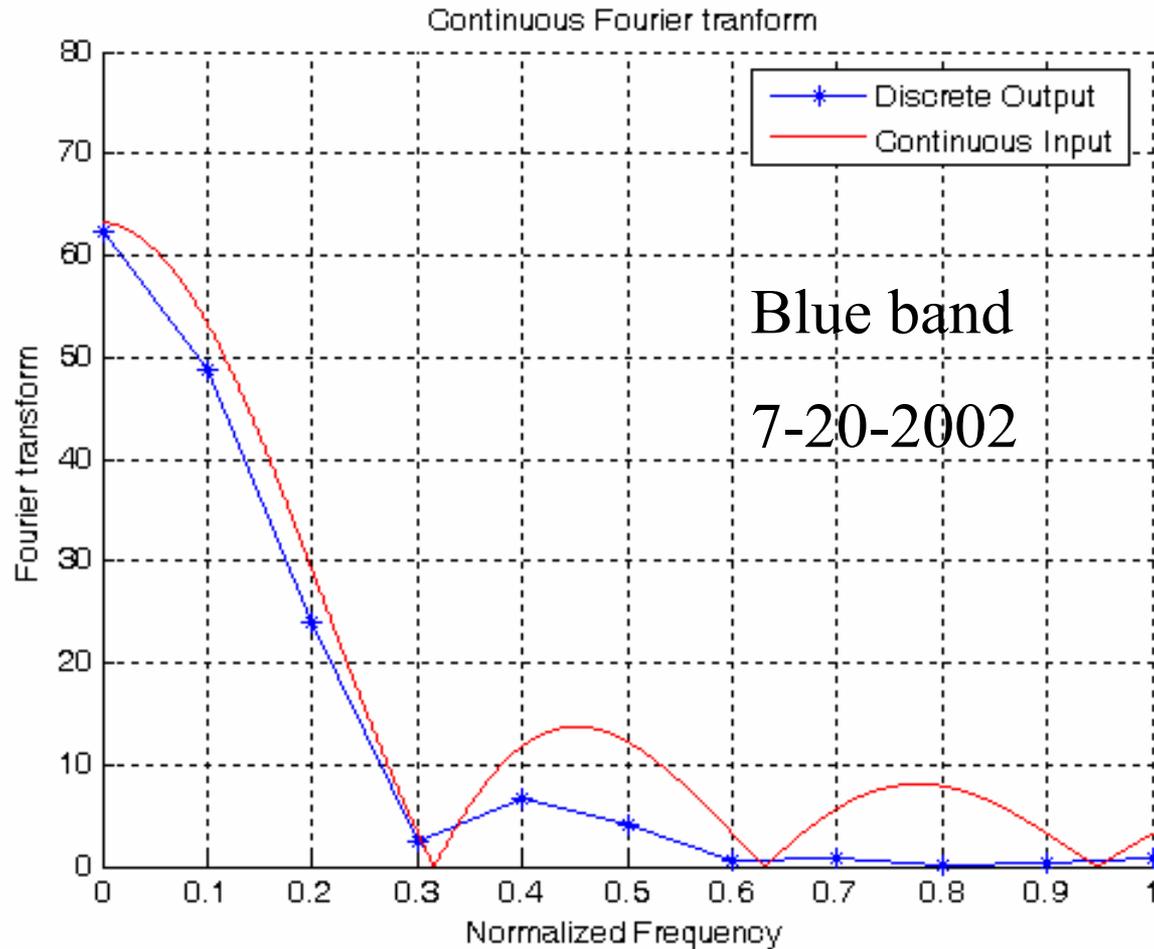
0.29

- T-test on 2002 and 2003 Nyquist frequency values in blue band
 - $H_0: \mu_1 = \mu_2$
 - $H_a: \mu_1 \neq \mu_2$
 - Where $\mu_1 = 2002$ data, $\mu_2 = 2003$ data.
 - T-test for comparing the two samples was done at 95% confidence level.
 - Computed T value was $25.56 > T_{\text{table}} [2.57]$.
 - Hence, the two sample data are significantly different.

What really changed from 2002 to 2003?

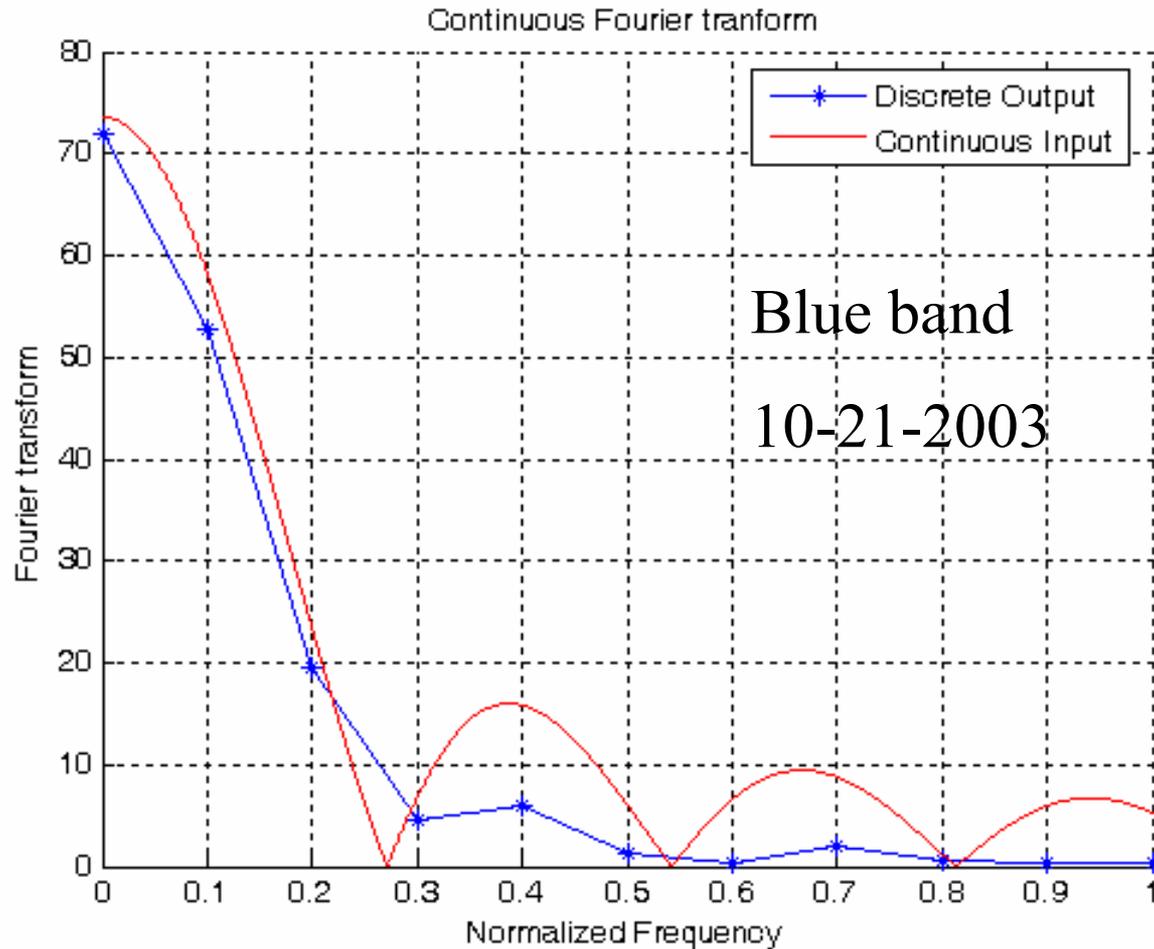
- Multispectral Ground Sample Distance (GSD)
 - 2.8m in 2002.
 - 2.4m in 2003.
 - Change was not known *a priori*.
- Impacts MTF measurements
 - Same scaling problem as before.
 - Pulse target was designed for 2.8m GSD to optimize signal-to-noise ratio.

- GSD change vs. input sinc function



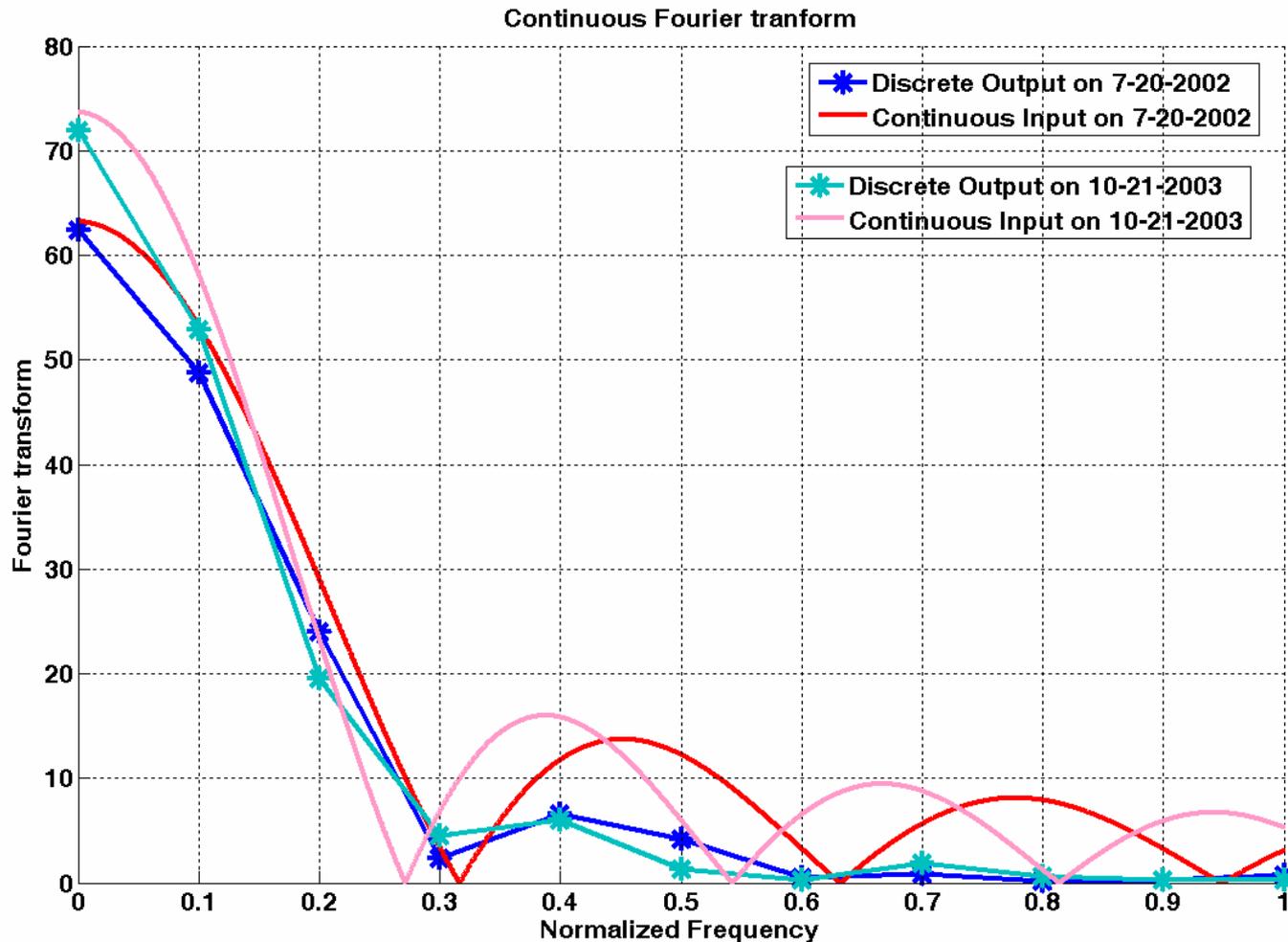
2.8 meter GSD in 2002

- GSD change vs. input sinc function

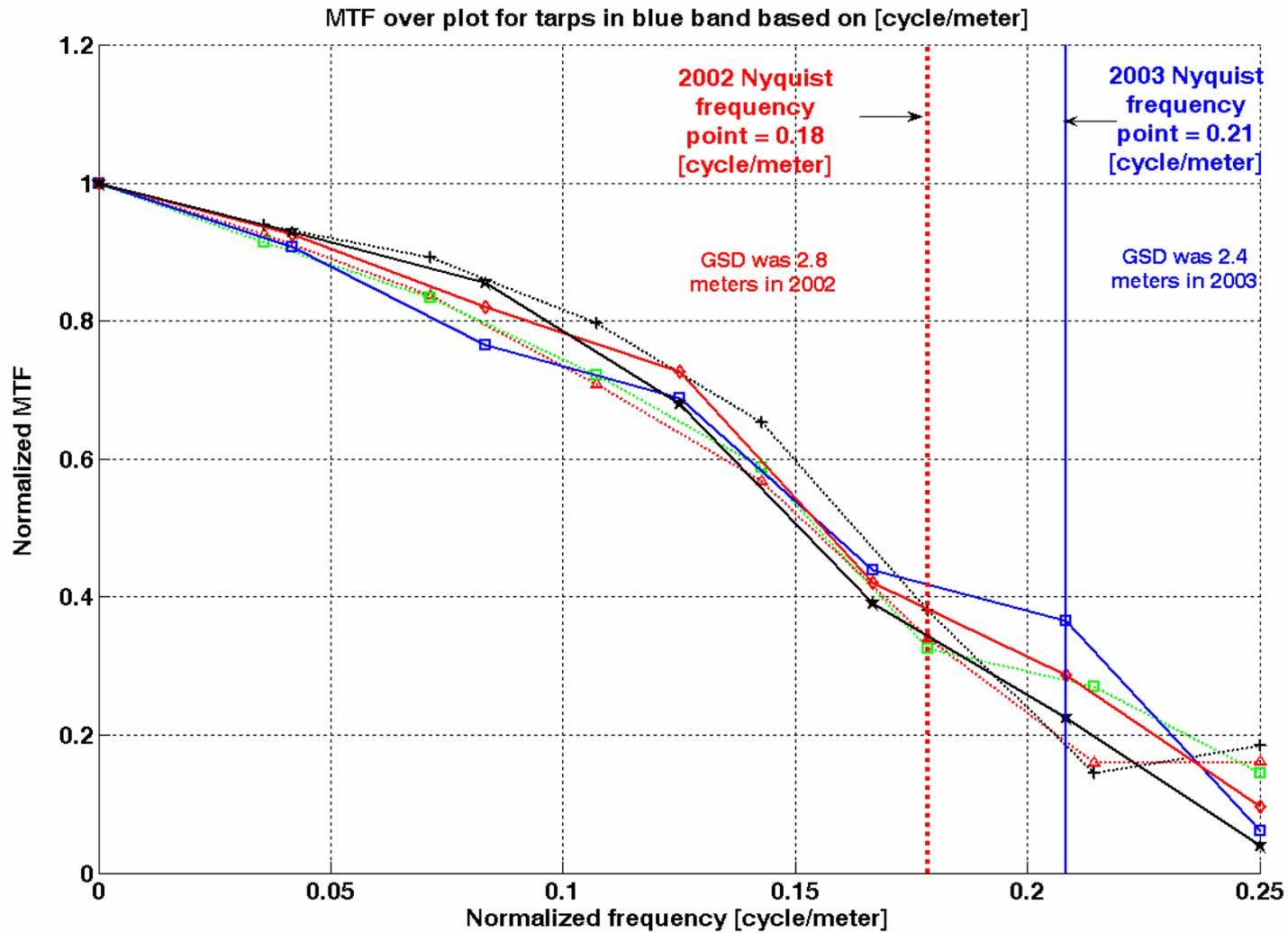


2.4 meter GSD in 2003

- GSD change vs. input sinc function

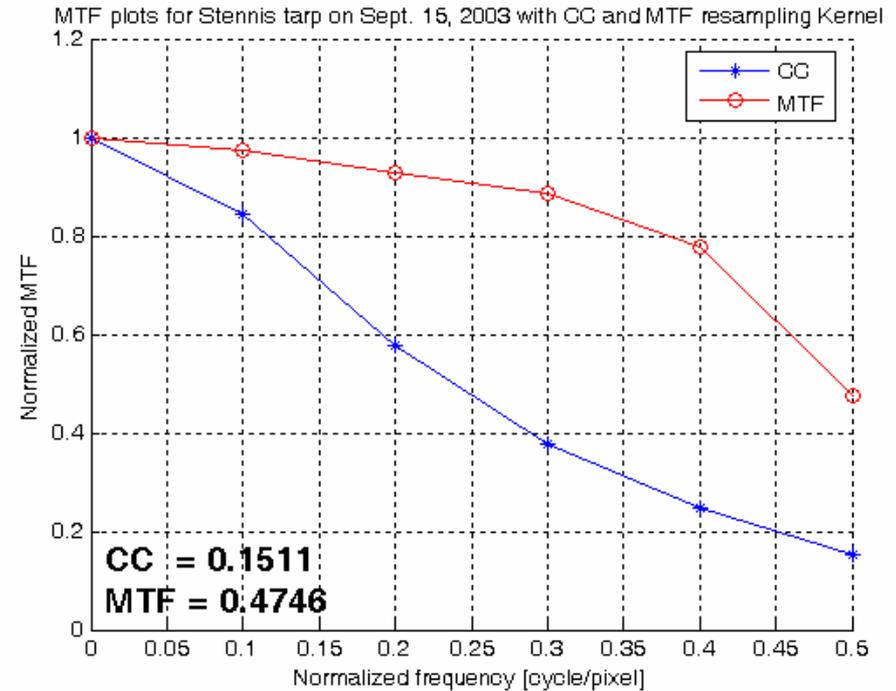
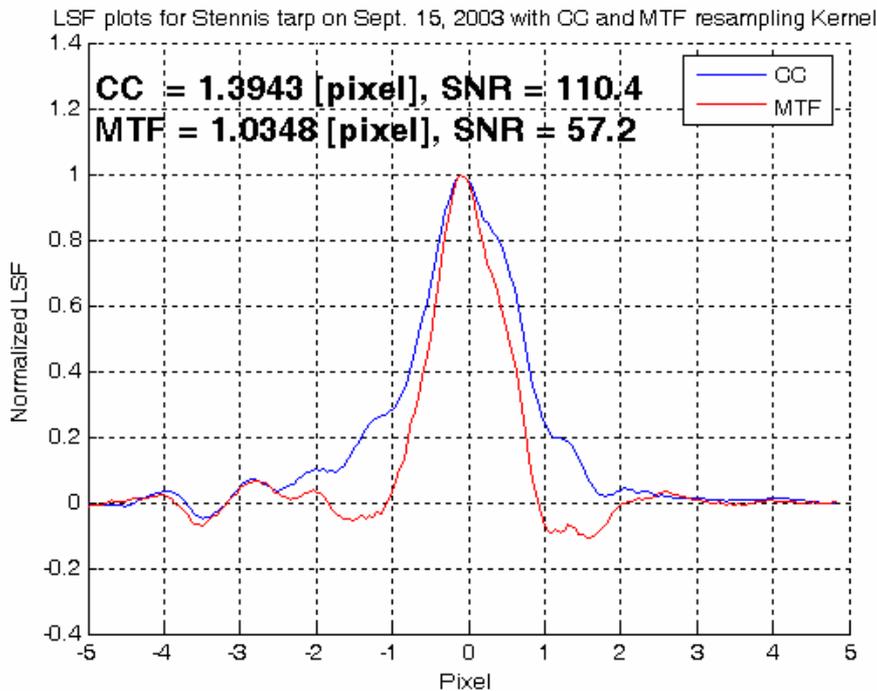


2.8 meter GSD in 2002 & 2.4 meter GSD in 2003



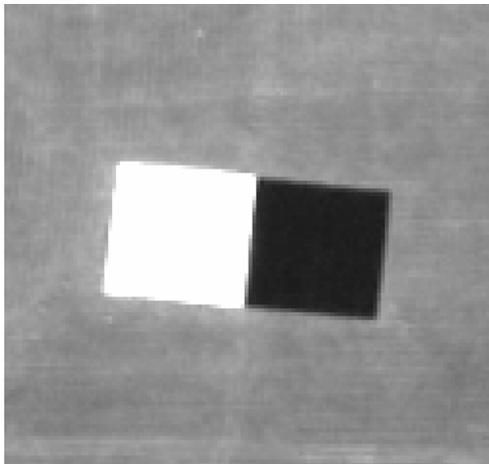
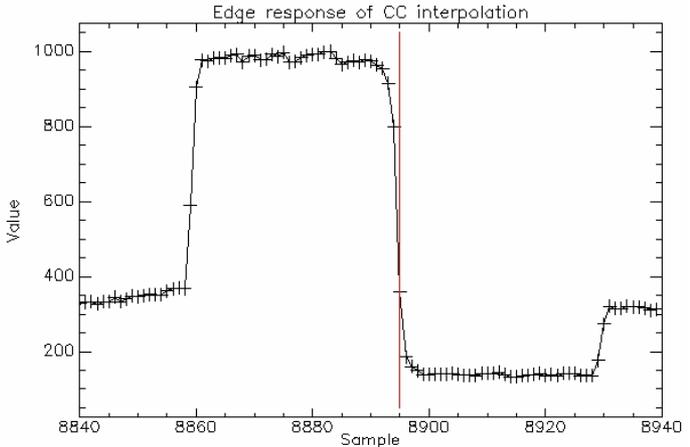
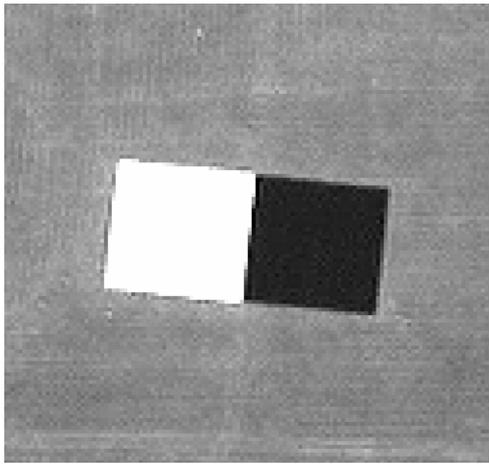
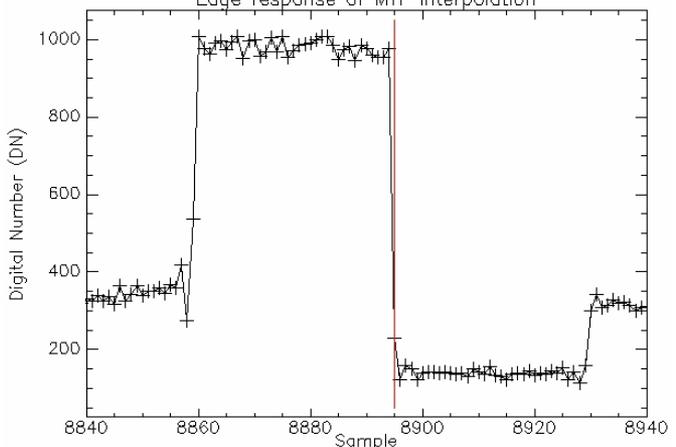
MTF over plot in blue band in [cycle / meter] unit

- Differences between CC and MTF resampling kernel



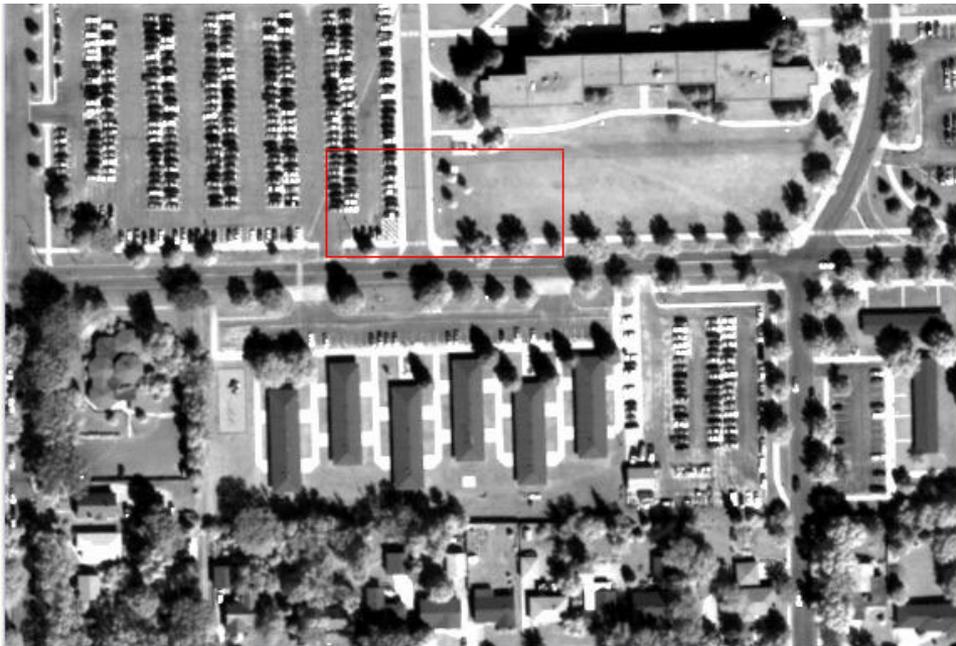
Panchromatic band analysis of Stennis tarp on
 Sept 15, 2003

- Visual Inspection of CC and MTF Resampled Products

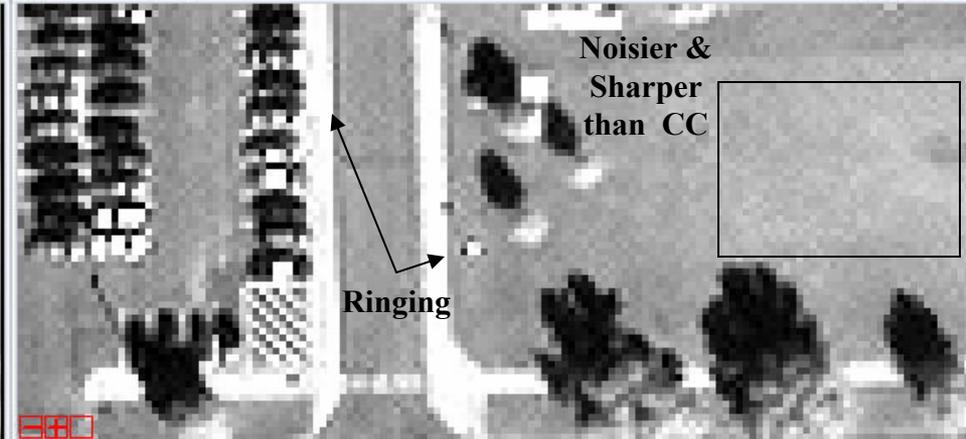
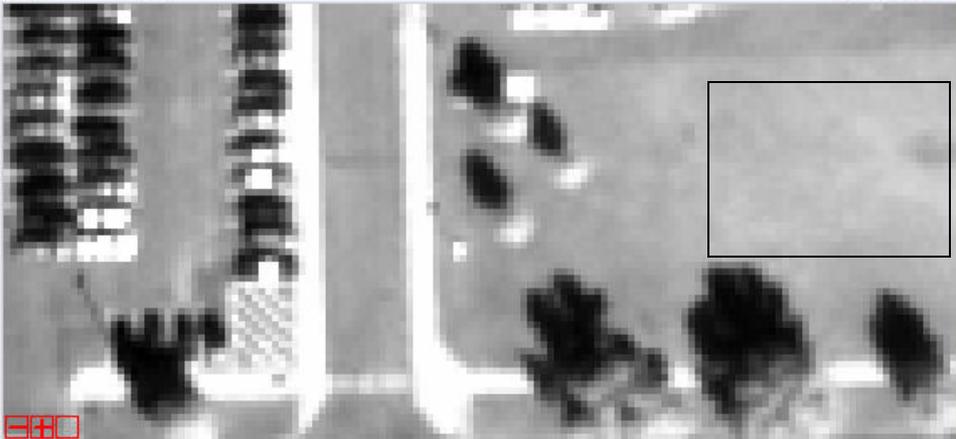
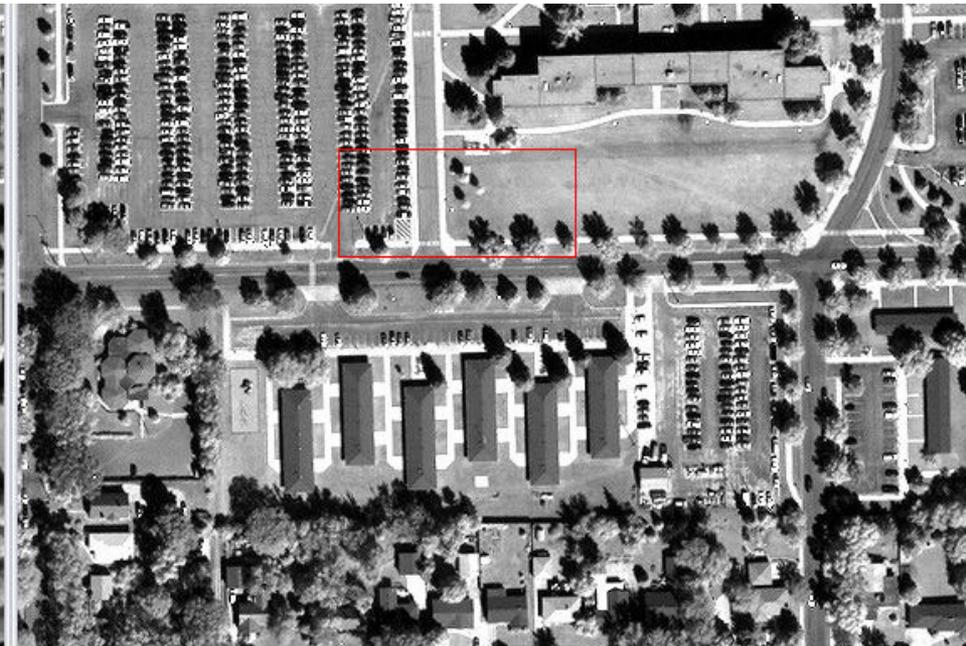
Resampling Method	image	Middle line profile
<p>CC — less noisy Smooth transition</p>	 <p data-bbox="556 825 954 865">Uniform grassy area</p>	
<p>MTF — Noisy Sharp transition</p>	 <p data-bbox="469 1349 1051 1389">Mowing pattern is observable</p>	

SDSU campus image on Sept. 15, 2003

CC resampling



MTF resampling



Conclusions

- Quickbird has consistently met SDP specifications with significant margins.

Band	SDP Spec	2002	2003
Pan	0.09	0.17	0.15
MS	0.20	0.34	0.29

- No degradation in Panchromatic PSF/MTF from 2002 to 2003 measured (only 1 measurement in 2003).
- Apparent degradation in Multispectral PSF/MTF suggested from 2002 to 2003 is actually due to decreased GSD. Target was not optimized for this change.
- Should SDP spatial data quality specification be altered to reflect GSD differences?
- Resampling kernel selection can significantly increase contrast, but consequently reduces SNR and can introduce artifacts.