

# On-orbit Modulation Transfer Function (MTF) Measurements for IKONOS and QuickBird

## Civil Commercial Imagery Evaluation Workshop

*3/15/2006*

*Dennis Helder, Jason Choi, and Cody Anderson*

*Image Processing Laboratory*

*Electrical Engineering and Computer Science Department*

*South Dakota State University*



# Outline

- Introduction
- Techniques
- Target/Site Description
- Results
  - Ikonos
  - Quickbird
- Conclusions

## Other IP Lab Contributors:

Tim Ruggles

Jim Dewald

Shriharsha Madhavan

Russ VanDerWerff

Amit Angal

Cam Helder

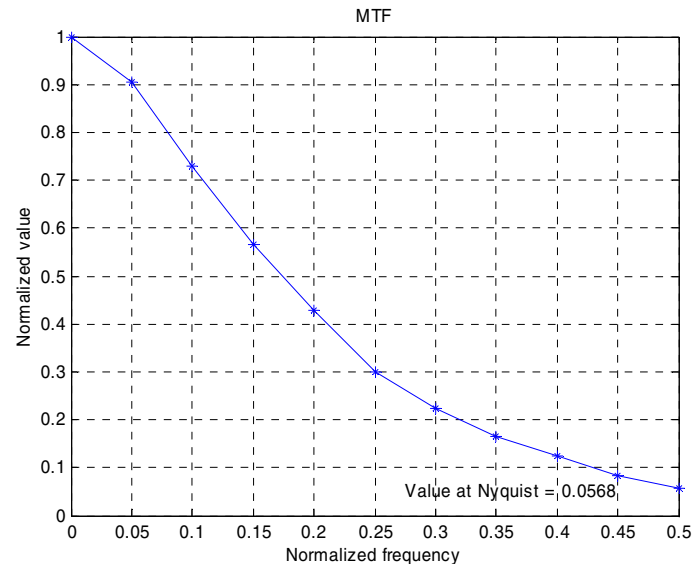
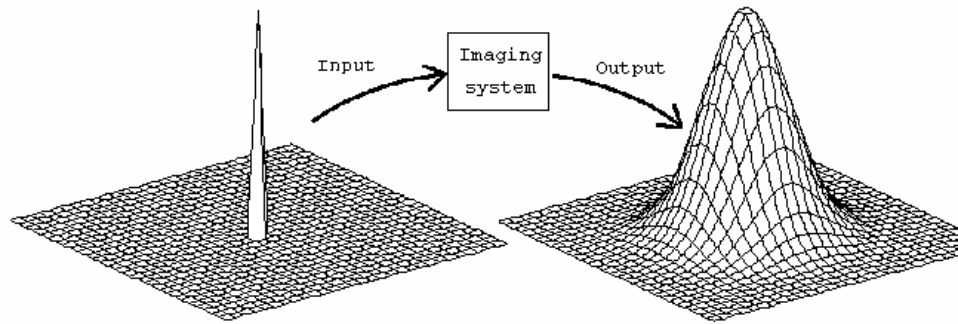
Larry Leigh

Dave Aaron

This work was supported by NASA grant NNS04AB66C

# 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.



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

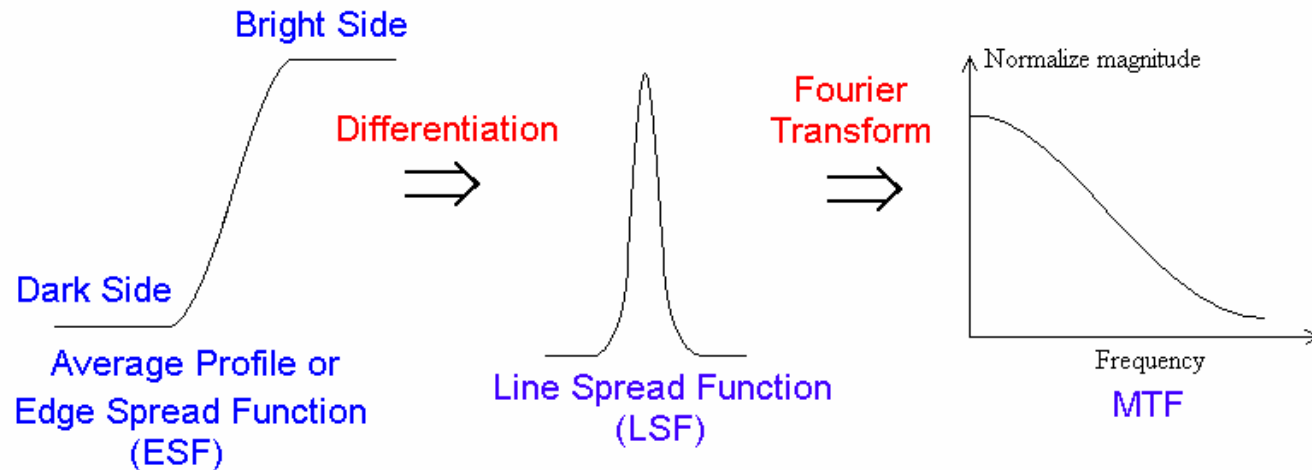
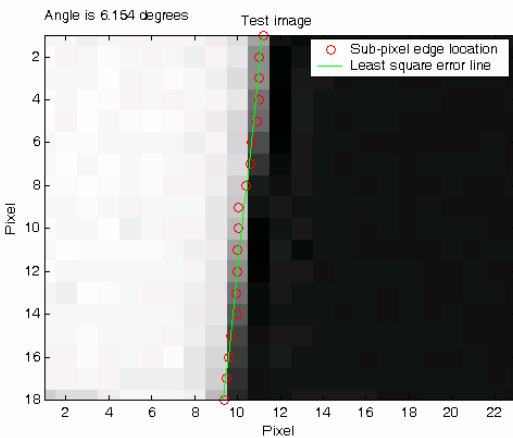
$$MTF(\omega_x, \omega_y) = \frac{|H(\omega_x, \omega_y)|}{|H(0,0)|}$$

- 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).

# Techniques

- Edge Method

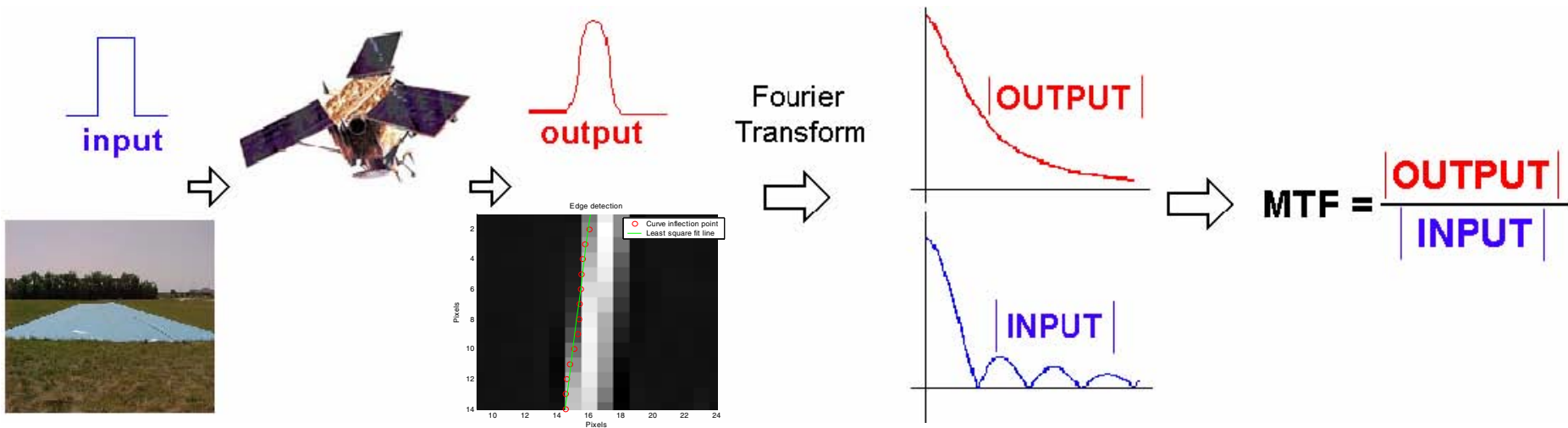
- Sub-pixel edge locations were found by Fermi function fit.
- A least-square error line was calculated through the edge locations.
- Modified Savitzky-Golay filtering was applied on each line.
- The filtered profile was differentiated to obtain LSF
- MTF calculated by applying Fourier transform to LSF.



## Edge Method

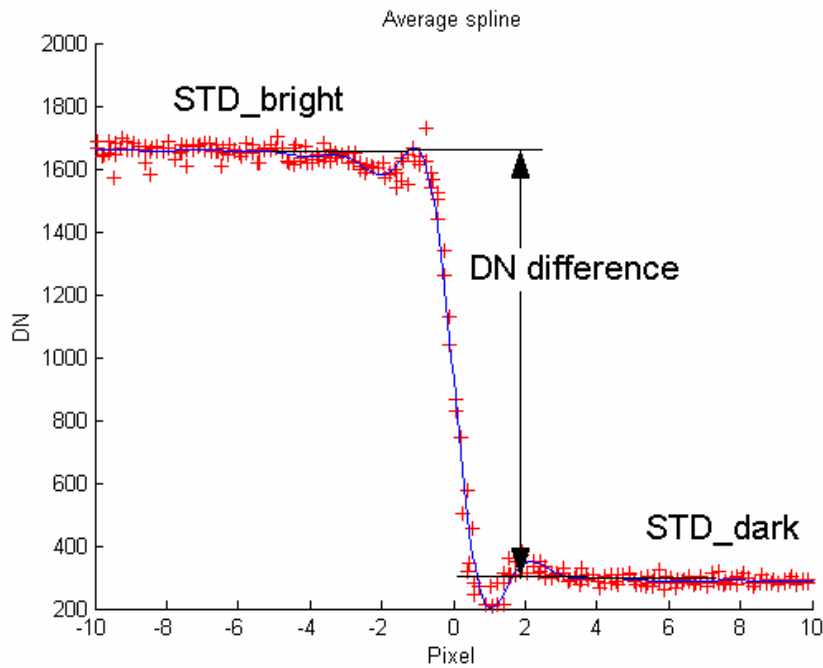
- Pulse method

- 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.

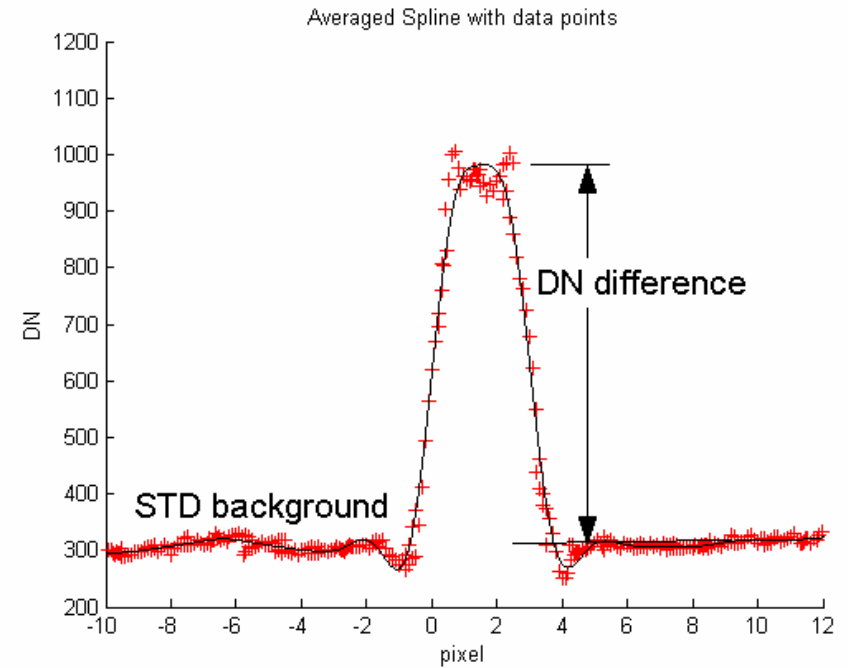


Pulse method

# SNR Definition

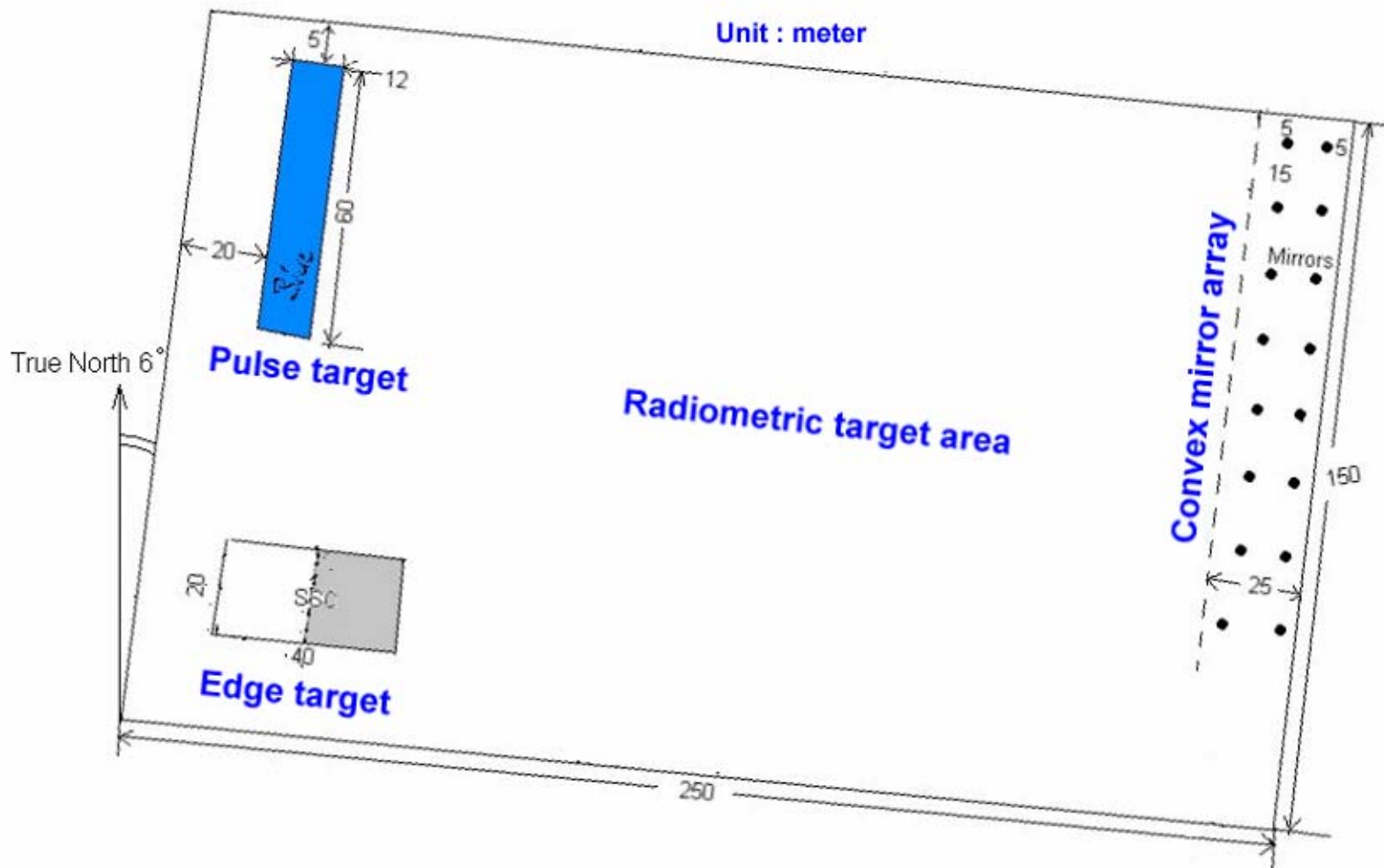


$$\text{SNR} = \frac{\text{DN difference}}{(\text{STD\_bright} + \text{STD\_dark}) / 2}$$



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

# Target Description



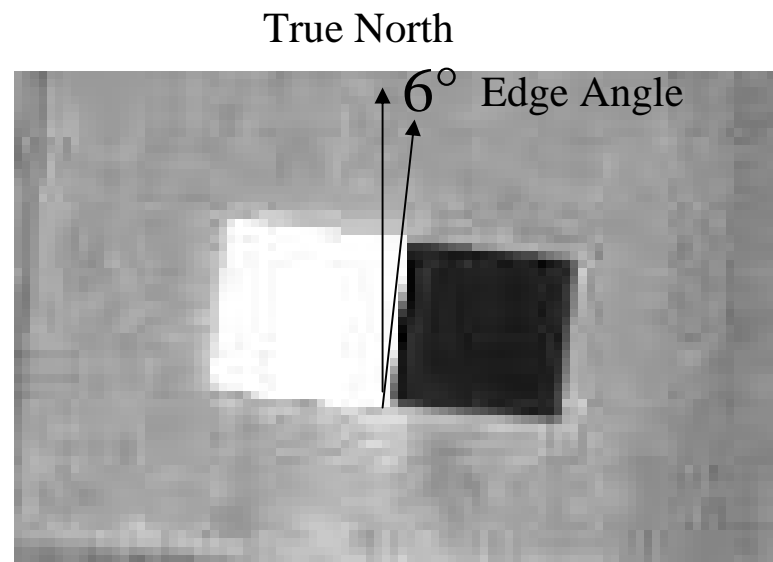
Field Plan



# Field campaign pictures on 6-22-2005



- NASA Stennis Tarp Target
  - Radiometrically and spectrally stable target with a large DN difference from 3.6% and 52.1% reflectance panels.
  - Edge oriented to obtained sub-sampled edge profile.
  - Blue tarps oriented at same angle.



NASA Stennis tarps

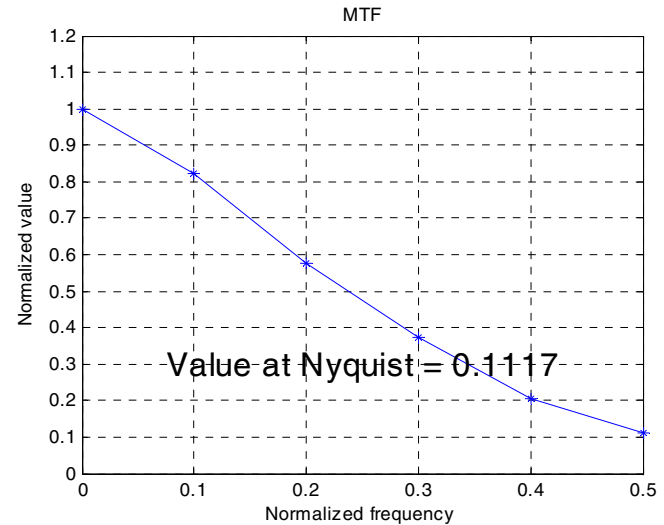
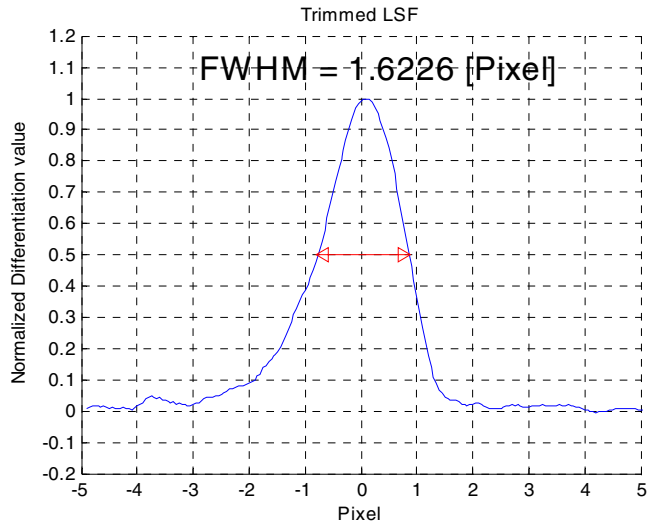
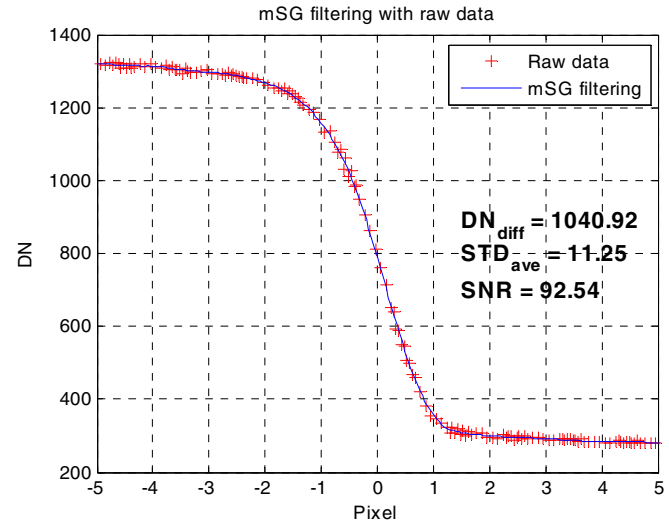
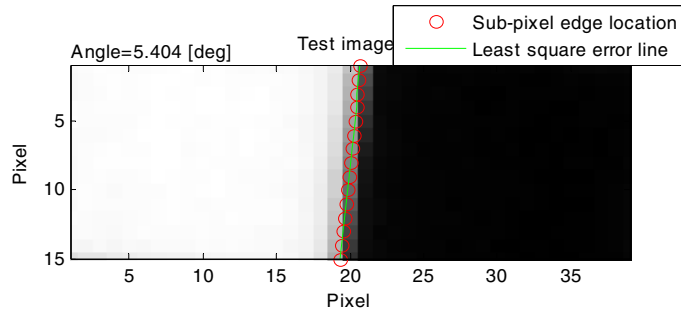
# IKONOS Acquisitions

- IKONOS Scene Information

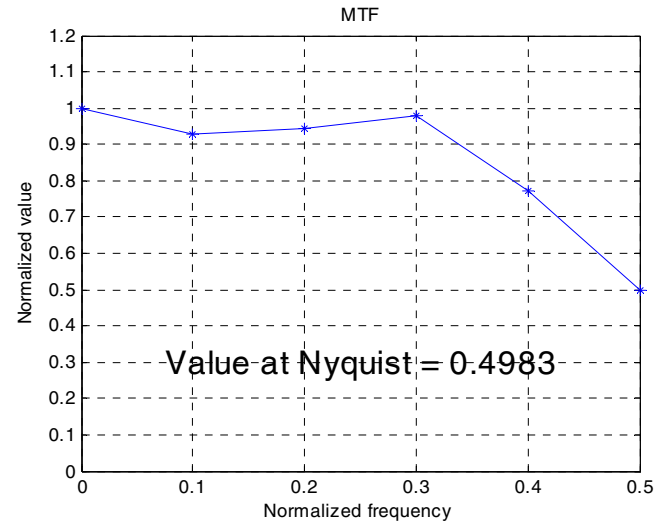
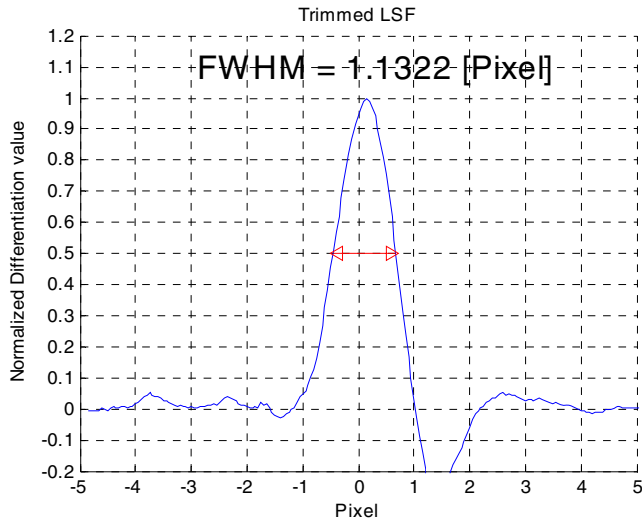
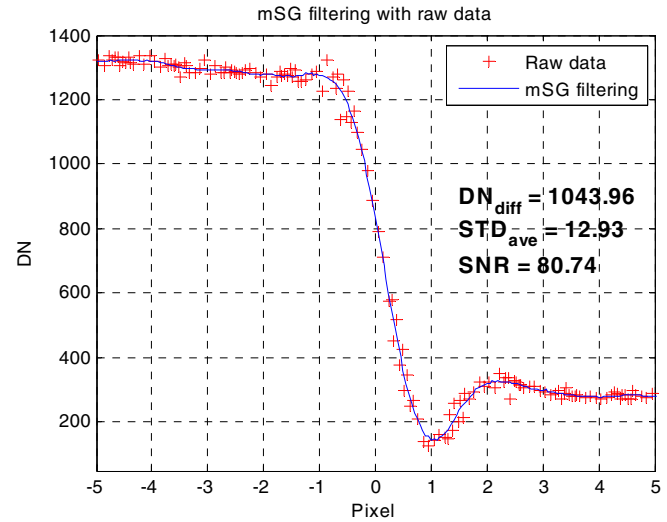
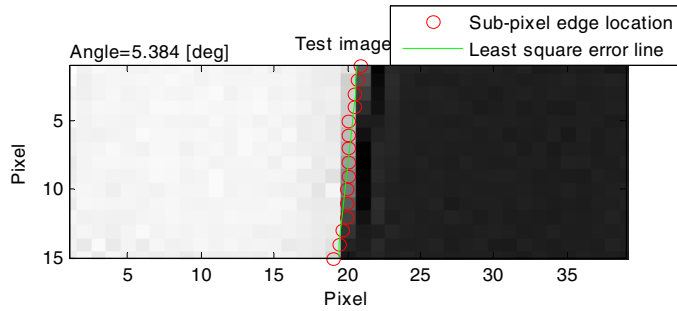
| Date     | Sensor | Targets                                | Resampling or MTF processing | Product Type                     |
|----------|--------|--|------------------------------|----------------------------------|
| 8/1/2005 | IKONOS | Stennis tarps<br>Blue tarps<br>Mirrors | CC / MTFC On                 | Standard Geometrically Corrected |
|          |        |  | CC / MTFC Off                | Standard Geometrically Corrected |



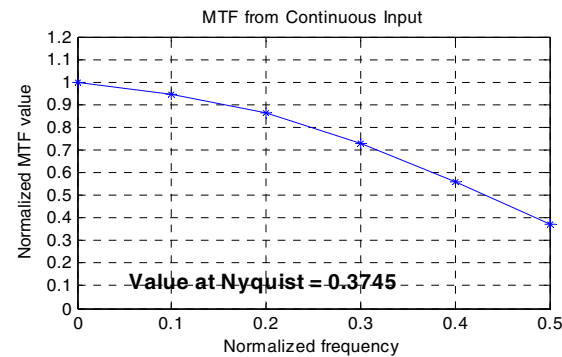
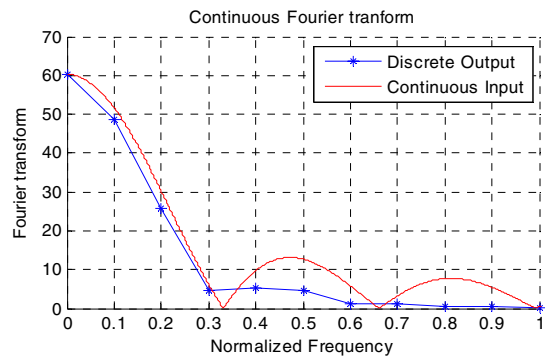
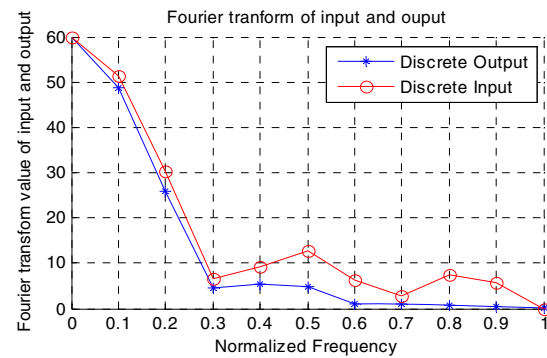
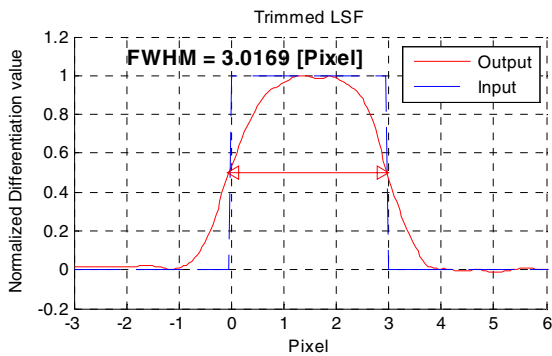
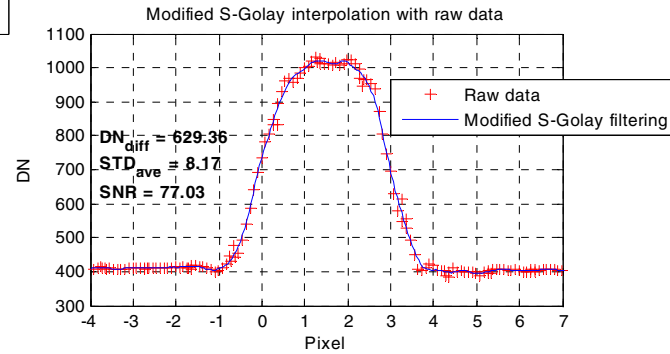
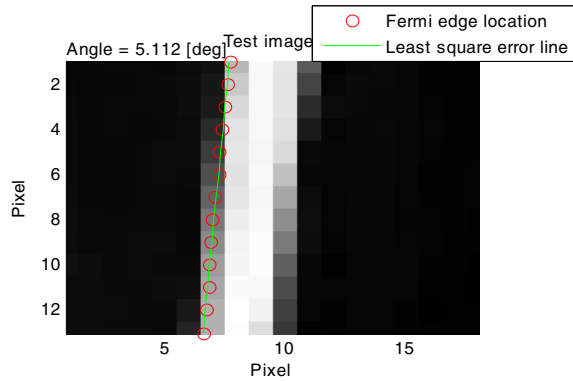
| Date     | Sensor | Band | Product    | Target  | Elevation | Azimuth |
|----------|--------|------|------------|---------|-----------|---------|
| 8/1/2005 | IKONOS | Pan. | CC/MTF off | Stennis | 66.0      | 118.7   |



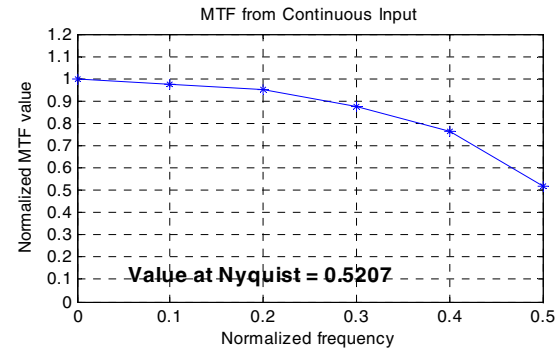
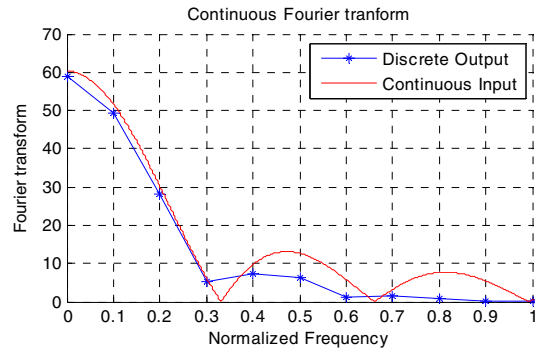
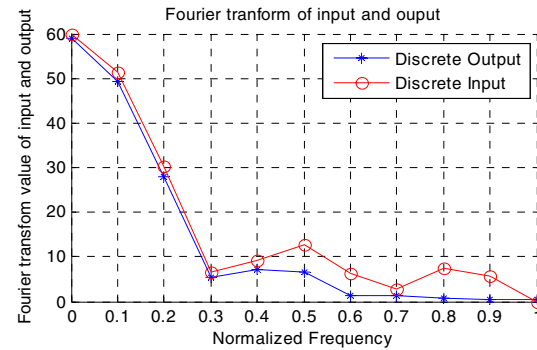
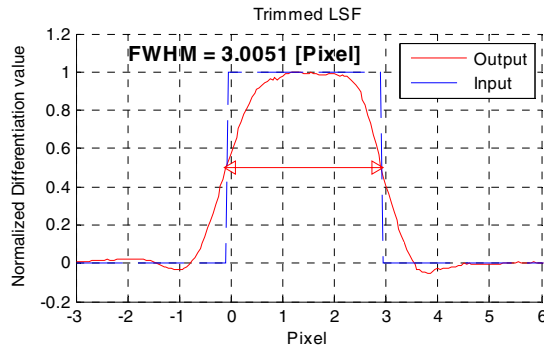
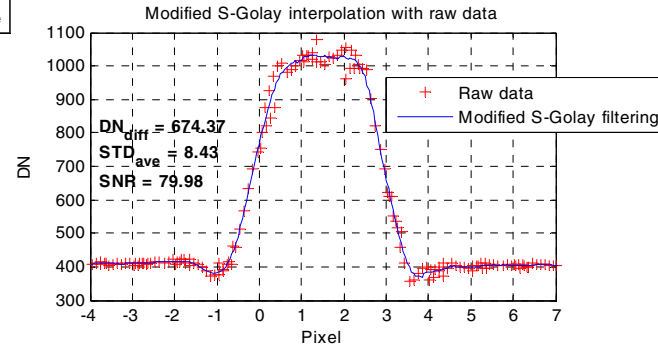
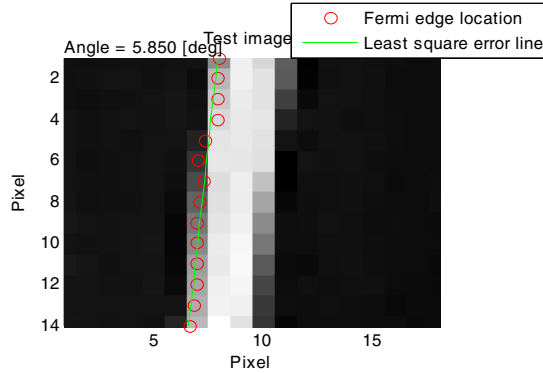
| Date     | Sensor | Band | Product   | Target  | Elevation | Azimuth |
|----------|--------|------|-----------|---------|-----------|---------|
| 8/1/2005 | IKONOS | Pan. | CC/MTF on | Stennis | 66.0      | 118.7   |



| Date     | Sensor | Band | Product    | Target    | Elevation | Azimuth |
|----------|--------|------|------------|-----------|-----------|---------|
| 8/1/2005 | IKONOS | Blue | CC/MTF off | Blue tarp | 66.0      | 118.7   |



| Date     | Sensor | Band | Product   | Target    | Elevation | Azimuth |
|----------|--------|------|-----------|-----------|-----------|---------|
| 8/1/2005 | IKONOS | Blue | CC/MTF on | Blue tarp | 66.0      | 118.7   |

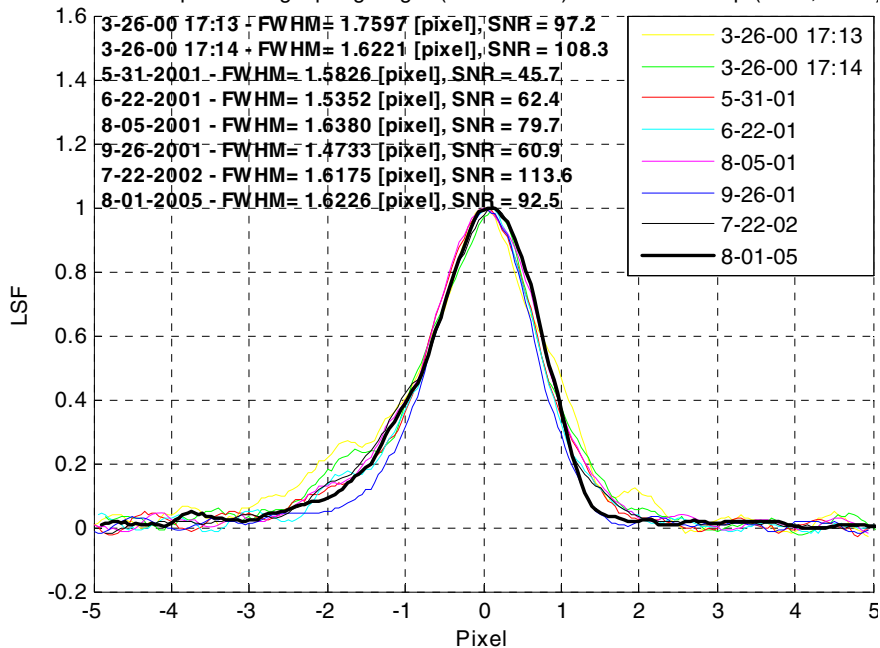


# Multi-year IKONOS Comparison

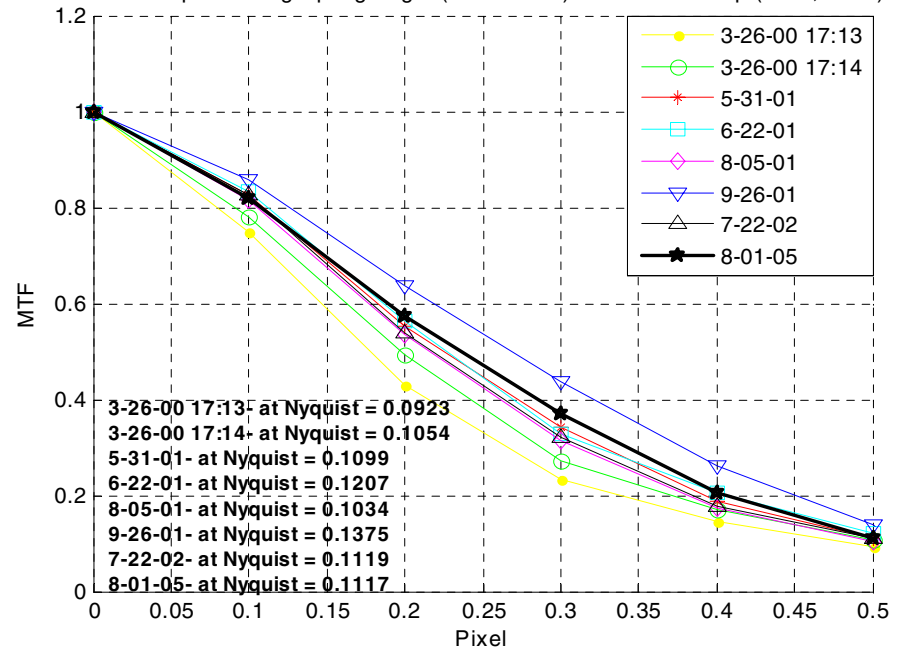
- Consistent FWHM: 1.61 +/- 0.08
- Values at Nyquist frequency were very stable.
  - Mean = 0.11, STD = 0.01
- No trends in PSF/MTF over 5 years.

| Date   | Sensor | Band | Product        | Target                   |
|--|--------|------|----------------|--------------------------|
| 8/1/05, 7/22/02, 9/26/01, 8/5/01,<br>6/22/01, 5/31/01, 3/26/00 | IKONOS | Pan. | CC/MTFC<br>off | Stennis / Big<br>Springs |

LSF over plot for Big Spring target (2000~2001) and Setnnis tarp (2002, 2005)



MTF over plot for Big Spring target (2000~2001) and Setnnis tarp (2002, 2005)

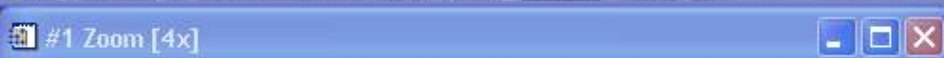
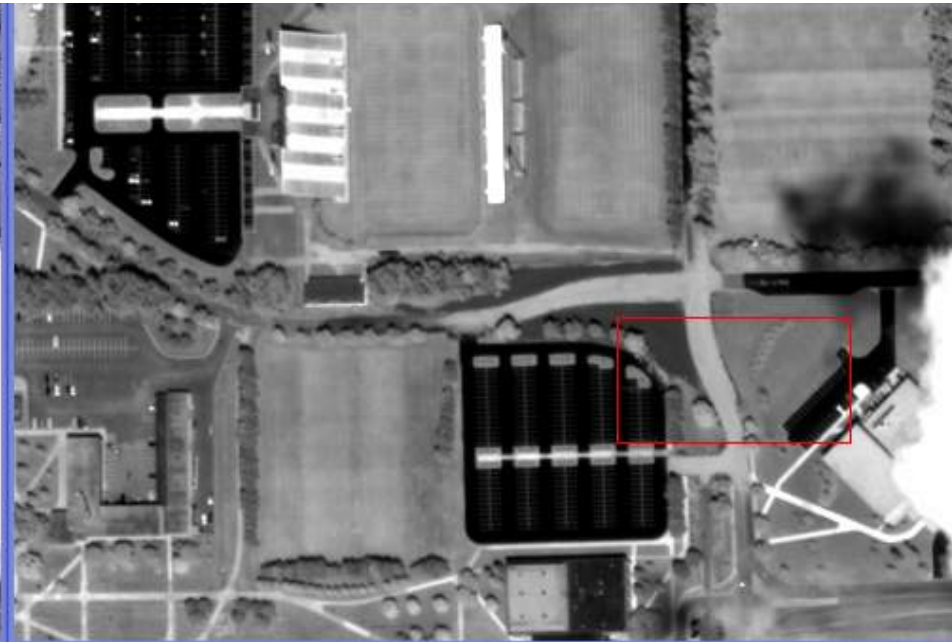
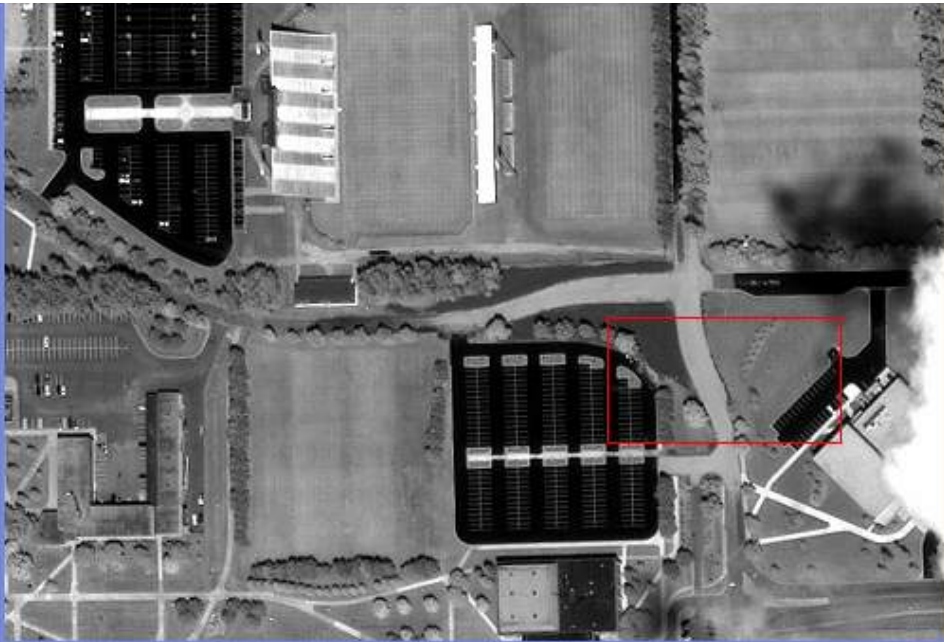




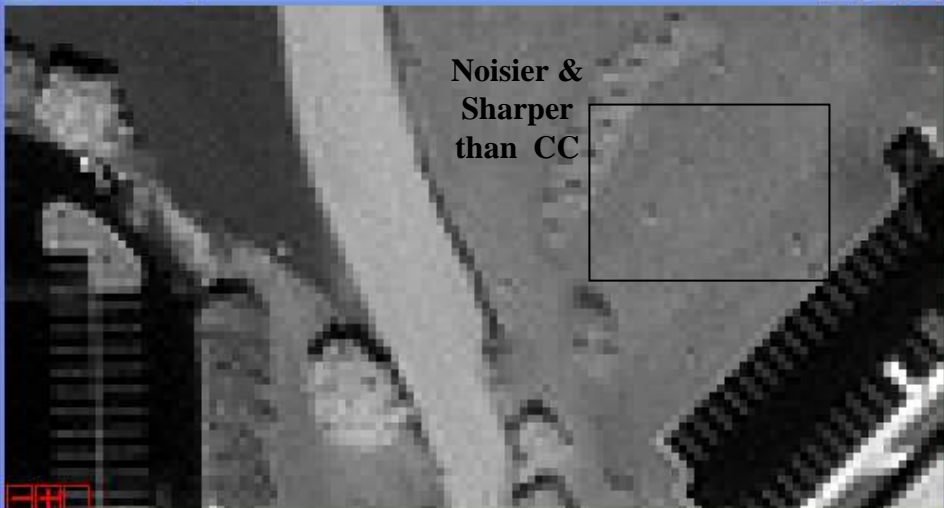
# IKONOS SDSU campus on 8/1/2005

CC With MTEFC

CC Without MTEFC



Noisier &  
Sharper  
than CC



# IKONOS Summary

- Very consistent, high-quality sensor
  - Pan FWHM = 1.61 +/- 0.08
  - Pan MTF @ Nyquist = 0.11 +/- 0.01
  - Multispectral MTF @ Nyquist = 0.52 (2005 data)
- ‘MTFC on’ processing provides increased MTF response with typical trade-off of increased contrast with some additional noise in Pan, less in Blue band.
  - Pan FWHM = 1.08 +/- 0.10
  - Pan MTF @ Nyquist = 0.48 +/- 0.08
- No indication of sensor degradation in five years.

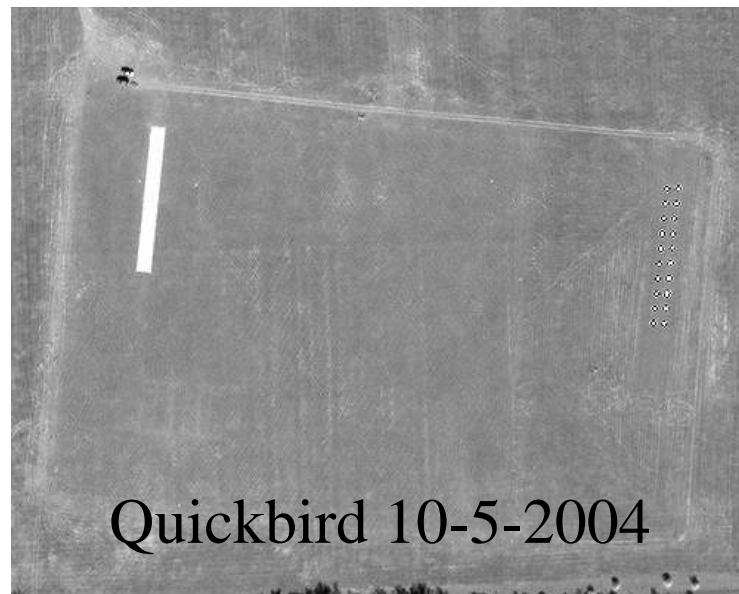
# Quickbird Acquisitions

- Quickbird scene information

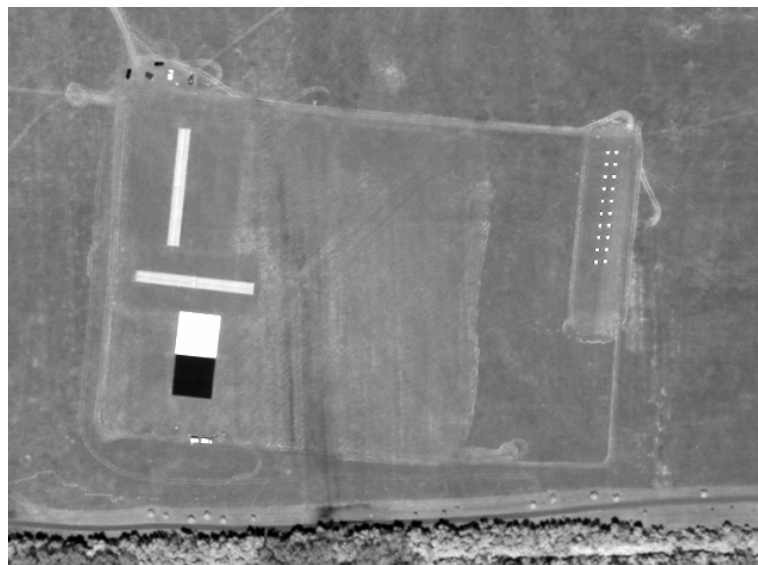
| Date       | Sensor    | Targets  | Resampling or MTF processing          | Product Type                                      |
|------------|-----------|--|---------------------------------------|---|
| 8/30/2004  | Quickbird | Blue tarps<br>Mirrors                              | <b>Resampling<br/>Kernel<br/>= CC</b> | <b>Standard2A<br/>(Radiometrically corrected)</b> |
|            |           |  | <b>MTF</b>                            | <b>Standard2A</b>                                 |
| 10/5/2004  | Quickbird | Blue tarps<br>Mirrors                              | <b>CC</b>                             | <b>Standard2A</b>                                 |
|            |           |  | <b>MTF</b>                            | <b>Standard2A</b>                                 |
| 6/22/2005  | QuickBird | Vertical Stennis<br>tarps<br>Blue tarps<br>Mirrors | <b>CC</b>                             | <b>Standard2A</b>                                 |
|            |           |  | <b>MTF</b>                            | <b>Standard2A</b>                                 |
| 10/18/2005 | QuickBird | Stennis tarps<br>Blue tarps<br>Mirrors             | <b>MTF</b>                            | <b>Standard2A</b>                                 |
|            |           |  | <b>CC</b>                             | <b>Standard2A</b>                                 |



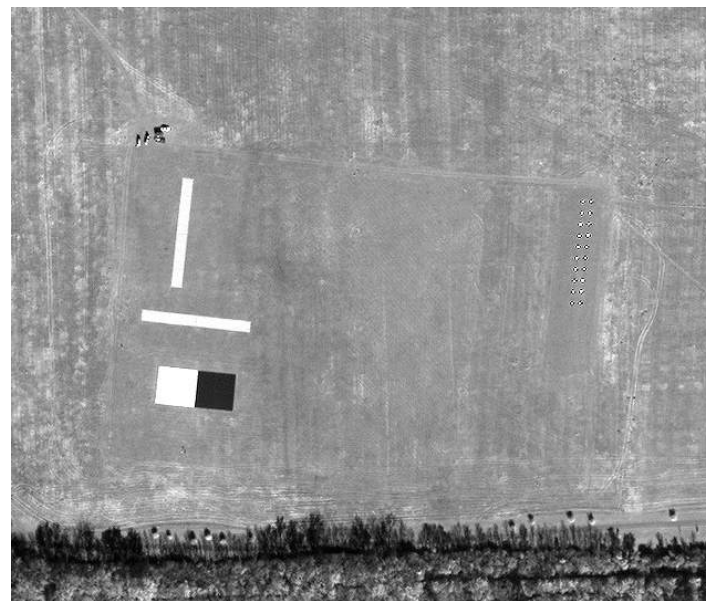
Quickbird 8-30-2004



Quickbird 10-5-2004

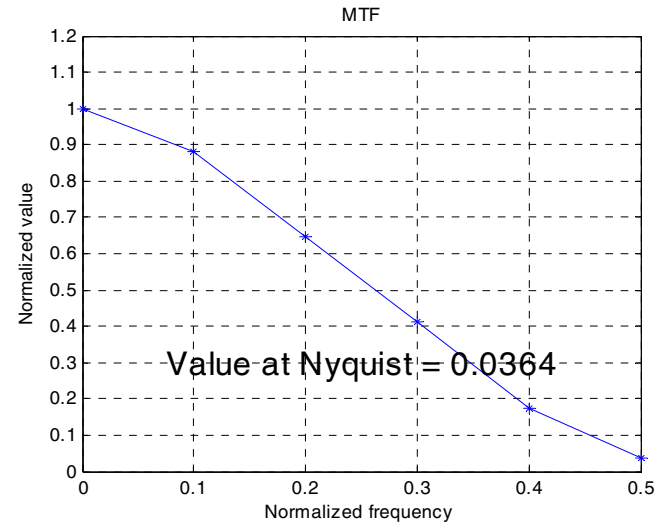
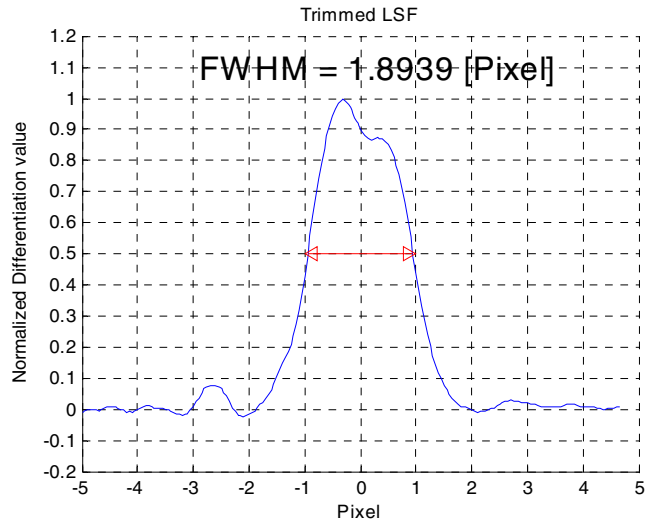
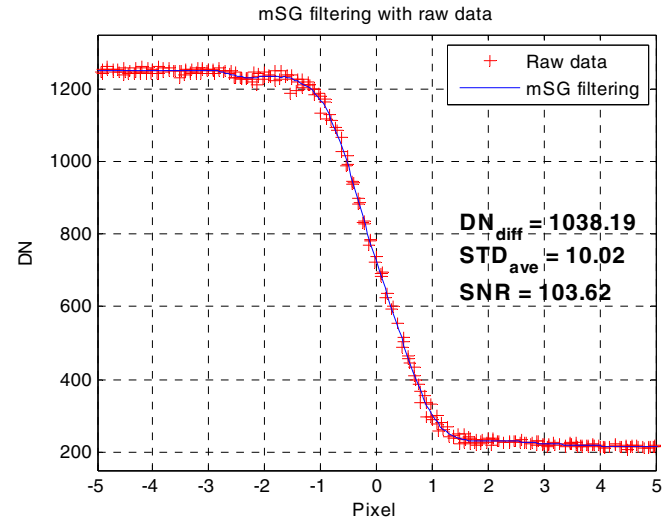
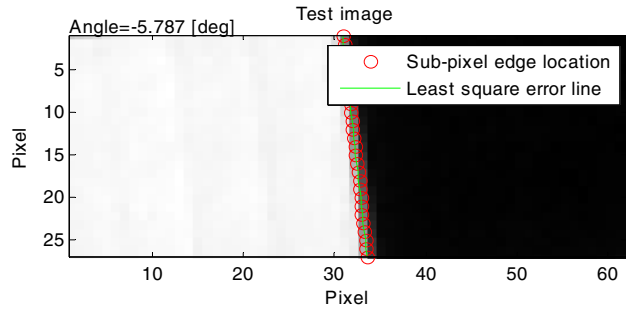


QB 6-22-2005

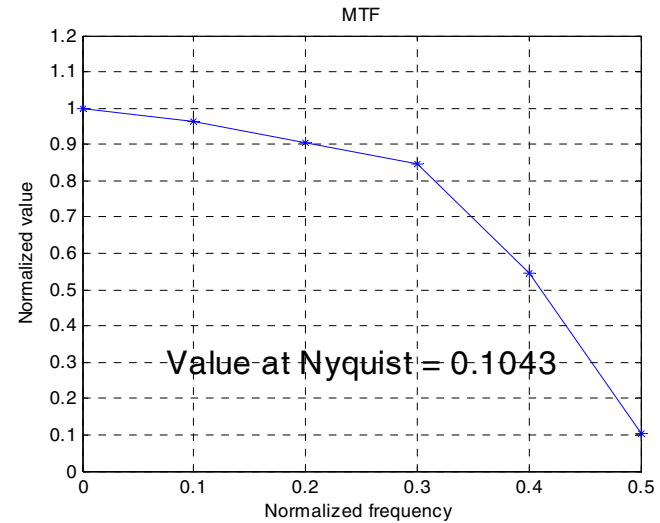
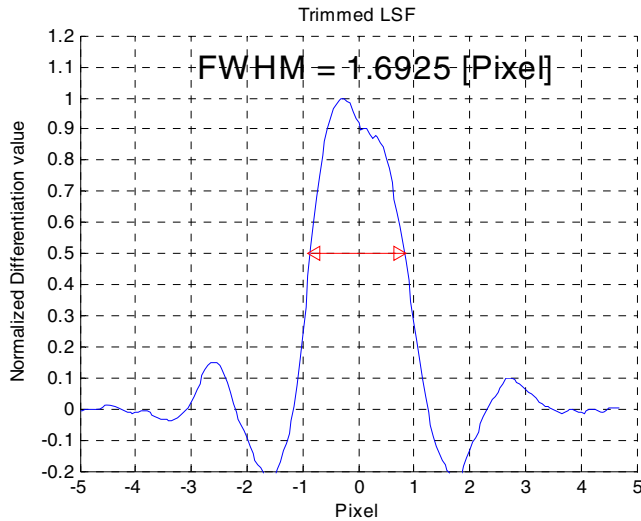
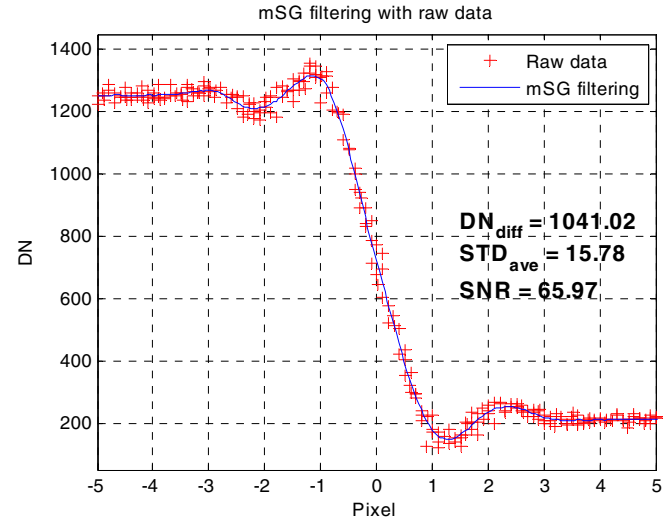
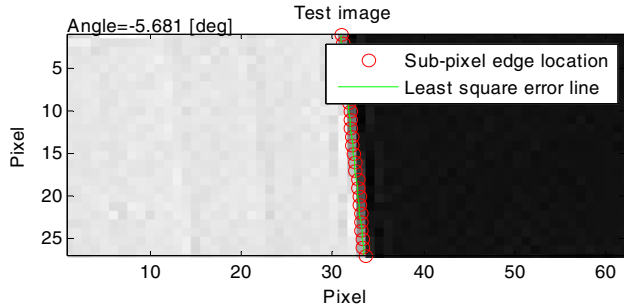


QB 10-18-2005

| Date      | Sensor    | Band | Resampling | Target               | Elevation | Azimuth |
|-----------|-----------|------|------------|----------------------|-----------|---------|
| 6/22/2005 | Quickbird | Pan. | CC         | Stennis <b>along</b> | 88.2      | 75.9    |

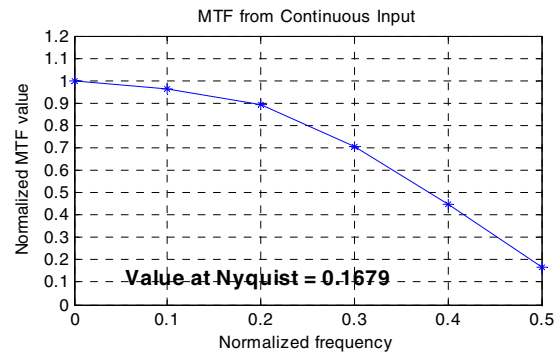
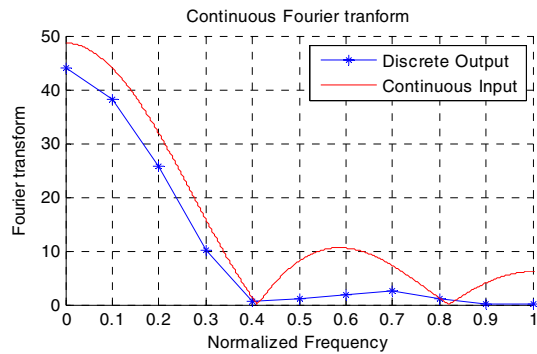
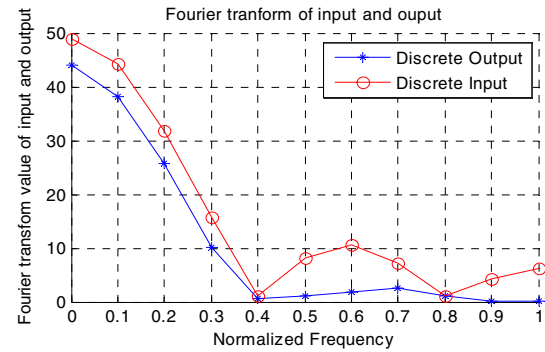
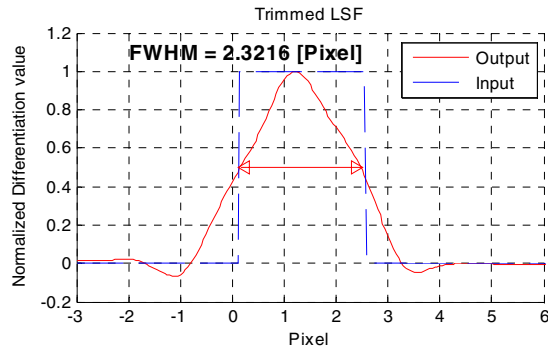
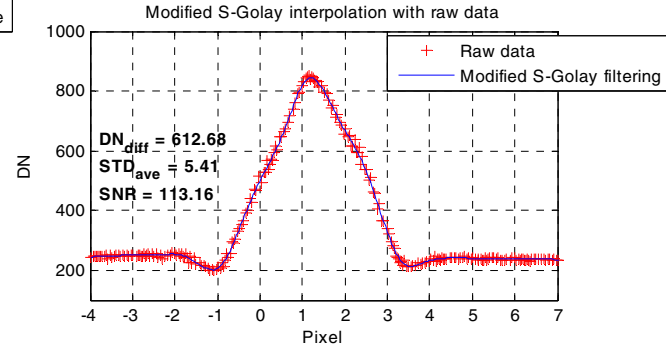
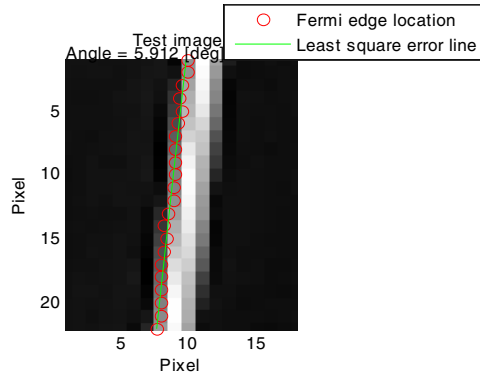


| Date      | Sensor    | Band | Resampling | Target        | Elevation | Azimuth |
|-----------|-----------|------|------------|---------------|-----------|---------|
| 6/22/2005 | Quickbird | Pan. | MTF        | Stennis along | 88.2      | 75.9    |

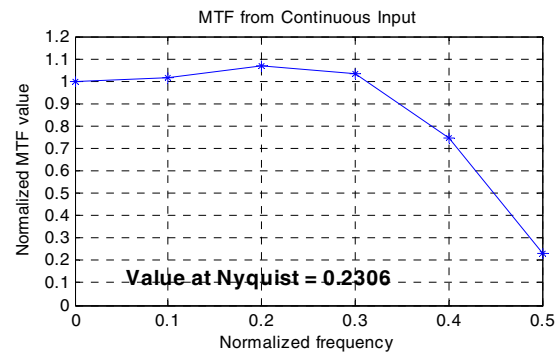
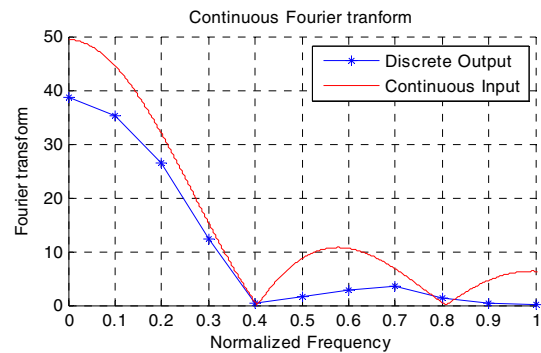
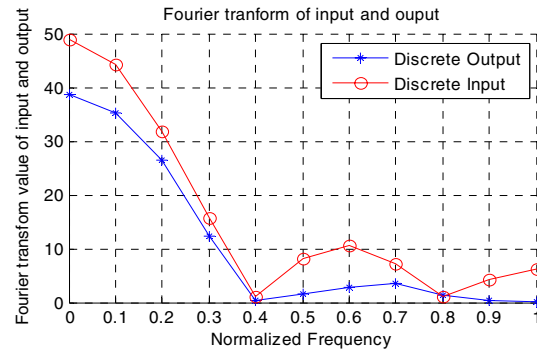
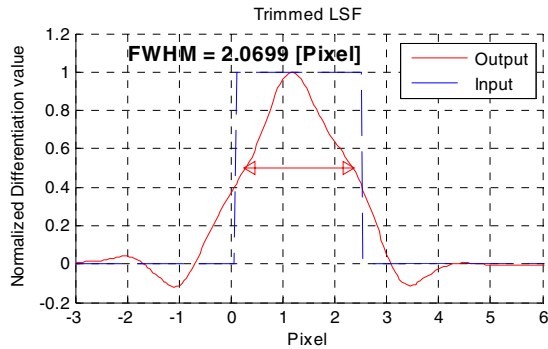
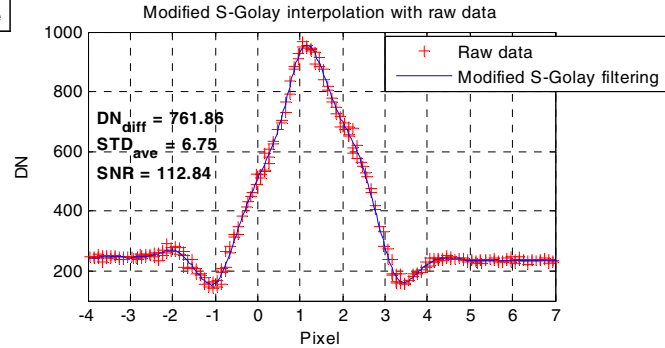
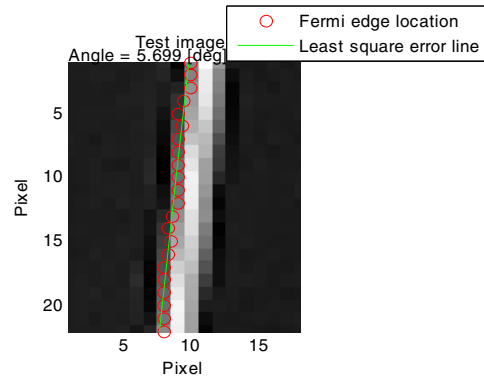


Along-track Stennis tarp target MTF result of QuickBird on 6/22/2005 (MTF)

| Date      | Sensor    | Band | Resampling | Target          | Elevation | Azimuth |
|-----------|-----------|------|------------|-----------------|-----------|---------|
| 6/22/2005 | Quickbird | Blue | CC         | Blue tarp cross | 88.2      | 75.9    |



| Date      | Sensor    | Band | Resampling | Target          | Elevation | Azimuth |
|-----------|-----------|------|------------|-----------------|-----------|---------|
| 6/22/2005 | Quickbird | Blue | MTF        | Blue tarp cross | 88.2      | 75.9    |

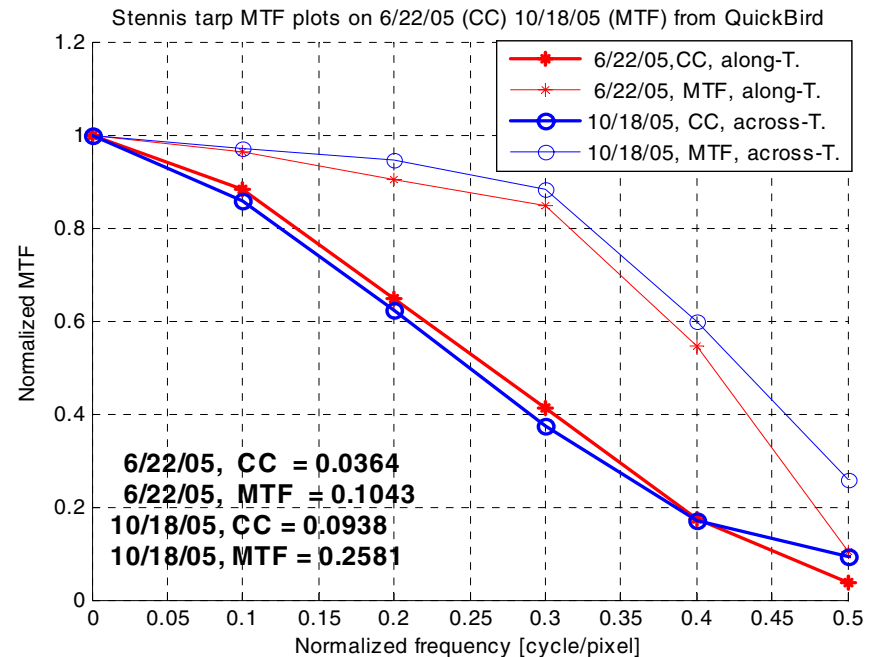
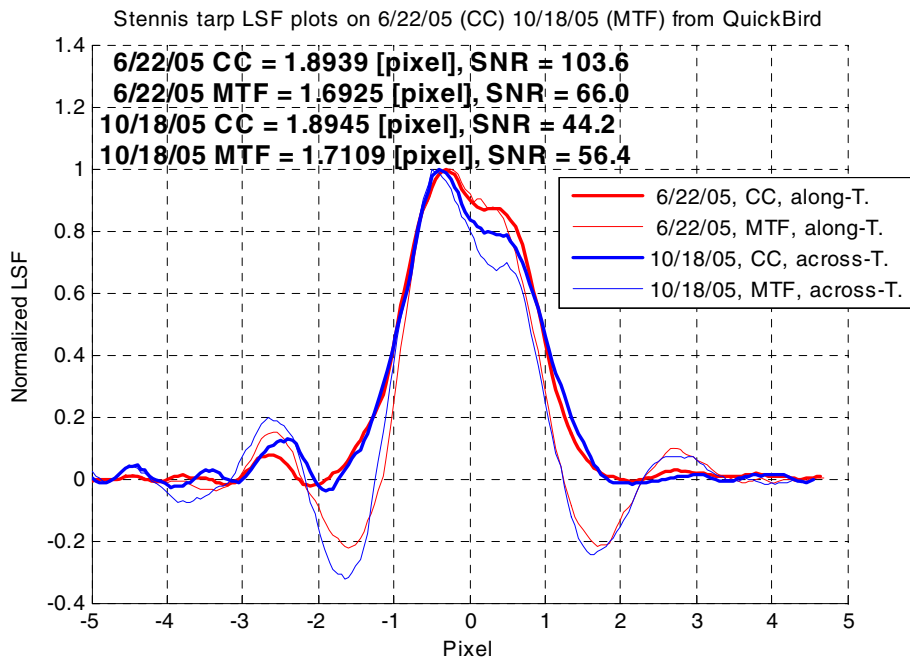




# QuickBird panchromatic band Along / Cross Track Direction Comparison

| Date                 | Sensor    | Band | Resampling | Target  |
|----------------------|-----------|------|------------|---------|
| 6/22/05,<br>10/18/05 | Quickbird | Pan. | MTF / CC   | Stennis |

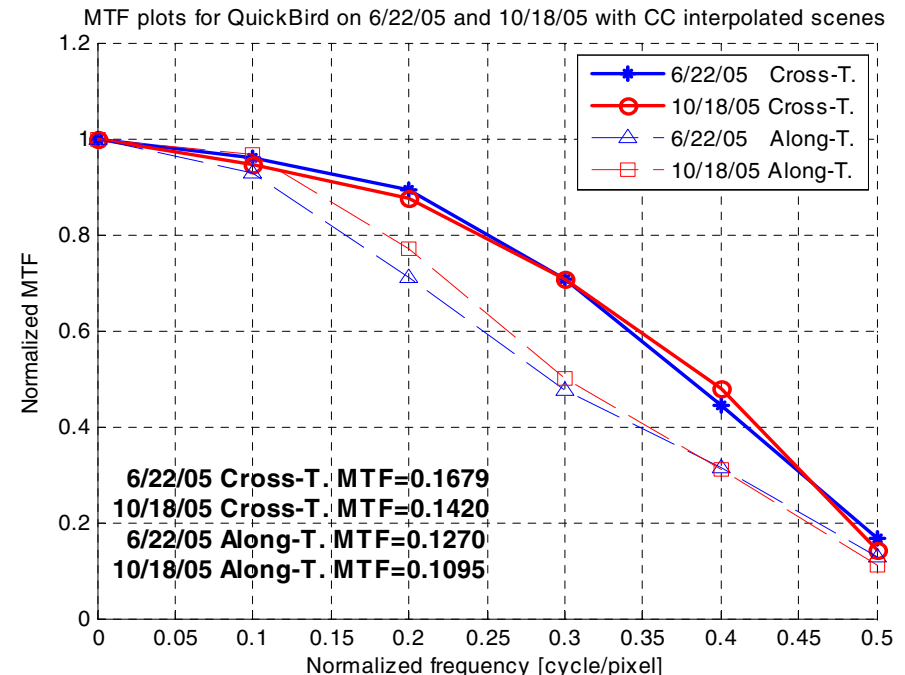
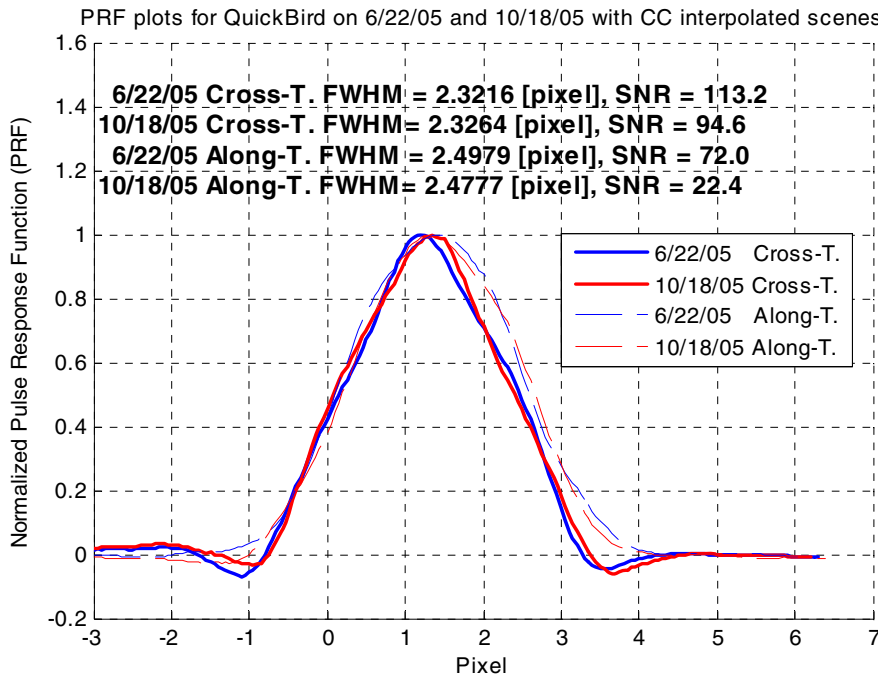
- First estimate of along-track PSF/MTF.
- Along-track PSF/MTF not significantly different than cross-track.



# QuickBird Blue Band Along / Cross Track Direction Comparison

| Date                 | Sensor    | Band | Resampling | Target                            |
|----------------------|-----------|------|------------|-----------------------------------|
| 6/22/05,<br>10/18/05 | Quickbird | Blue | CC only    | Blue tarps<br>Cross / along-track |

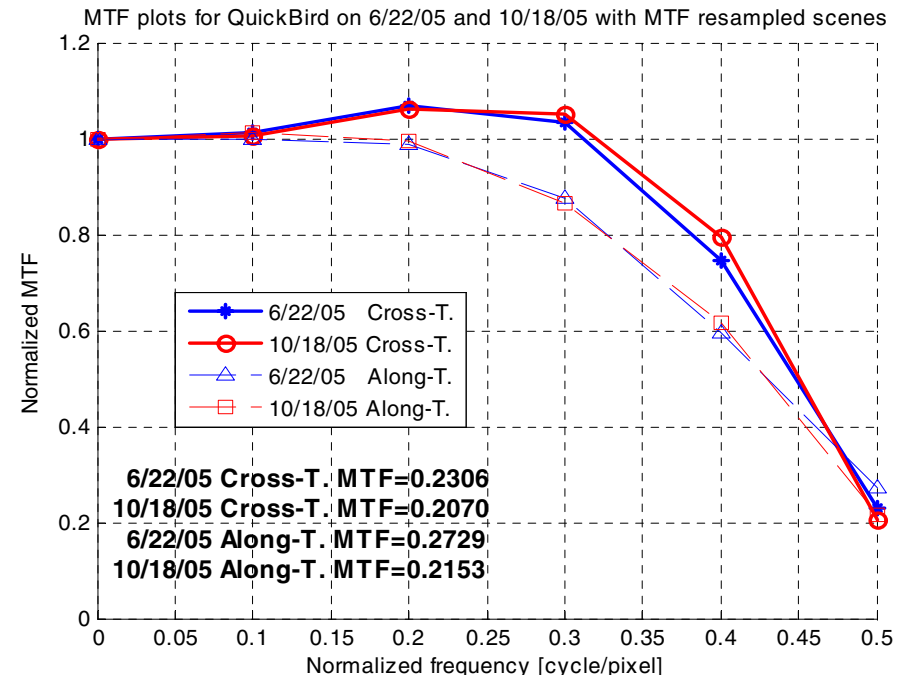
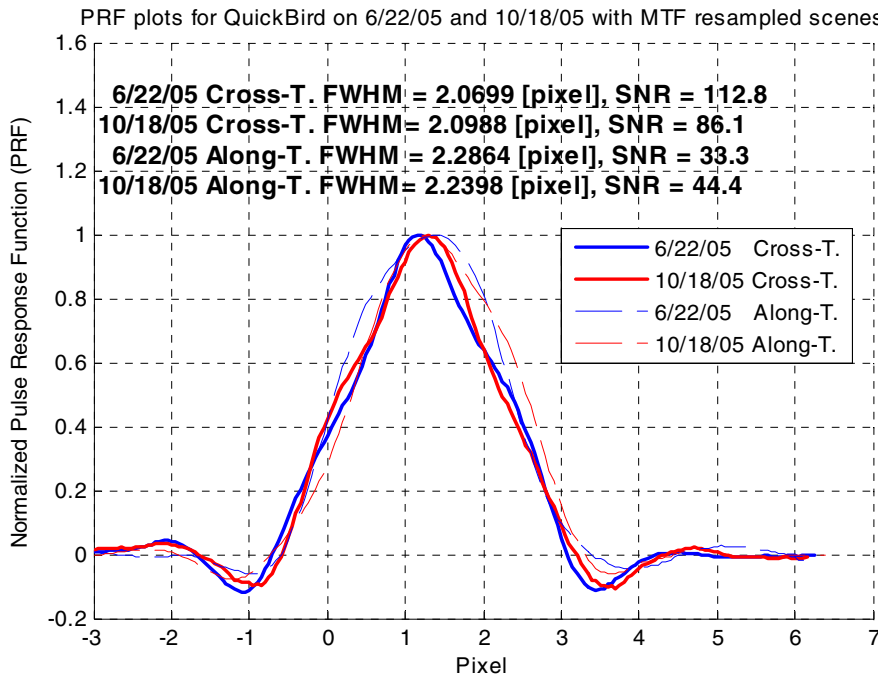
- Cross-track profile exhibits narrower PRF FWHM and under shoots.
- System MTF shape differs in the orthogonal directions.



# QuickBird Blue Band Along / Cross Track Direction Comparison

| Date                 | Sensor    | Band | Resampling | Target                            |
|----------------------|-----------|------|------------|-----------------------------------|
| 6/22/05,<br>10/18/05 | Quickbird | Blue | MTF only   | Blue tarps<br>Cross / along-track |

- FWHM values were reduced by MTF resampling process.
- MTF values were increased—most significantly in cross track direction.



# Quickbird Results Summary 2004-2005

| Band | Resamp. | Scan<br>Direction | FWHM<br>(gsd) |       | MTF at Nyquist<br>(cycles/gsd) |       | Obs. |
|------|---------|-------------------|---------------|-------|--------------------------------|-------|------|
|      |         |                   | mean          | sigma | mean                           | sigma |      |
| Pan. | CC      | Cross             | 1.89          |       | 0.09                           |       | 1    |
|      |         | Along             | 1.89          |       | 0.04                           |       | 1    |
|      | MTF     | Cross             | 1.71          |       | 0.26                           |       | 1    |
|      |         | Along             | 1.69          |       | 0.10                           |       | 1    |
| Blue | CC      | Cross             | 2.32          | 0.01  | 0.18                           | 0.07  | 4    |
|      |         | Along             | 2.49          | 0.01  | 0.12                           | 0.01  | 2    |
|      | MTF     | Cross             | 2.11          | 0.05  | 0.30                           | 0.17  | 4    |
|      |         | Along             | 2.27          | 0.02  | 0.25                           | 0.03  | 2    |

## Notes:

1. Blue Band FWHM's are for Pulse Response Functions.
2. Only one Pan band observation! Essentially same PSF/MTF in both scan directions.
3. MTF resampling provides noticeable contrast improvement; SNR is lowered, but still acceptable.
4. Overall SNR is good to excellent.
5. PRF is very repeatable in Blue band; MTF is noticeably less so

# Quickbird SDSU campus on 6/22/2005

MTF resampling

CC resampling

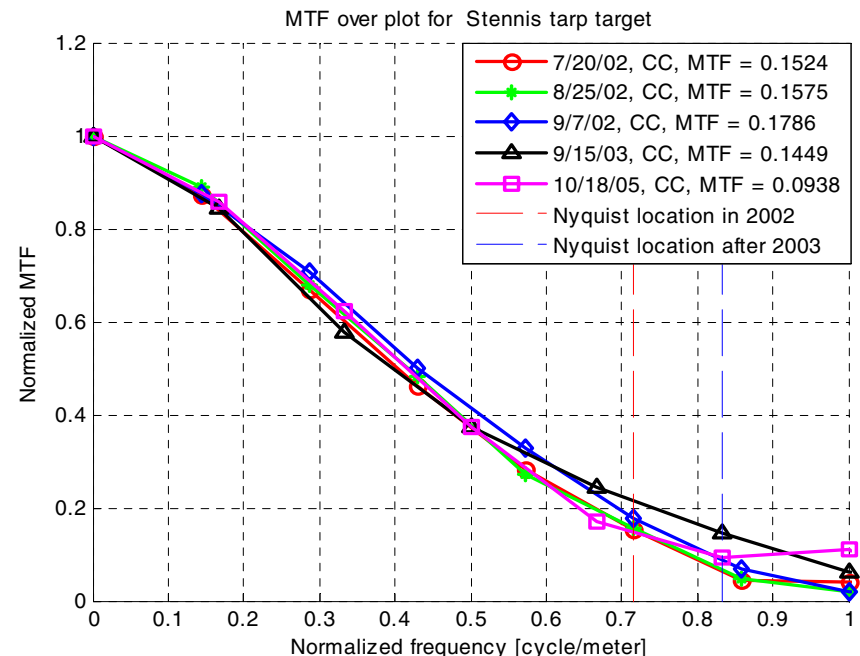
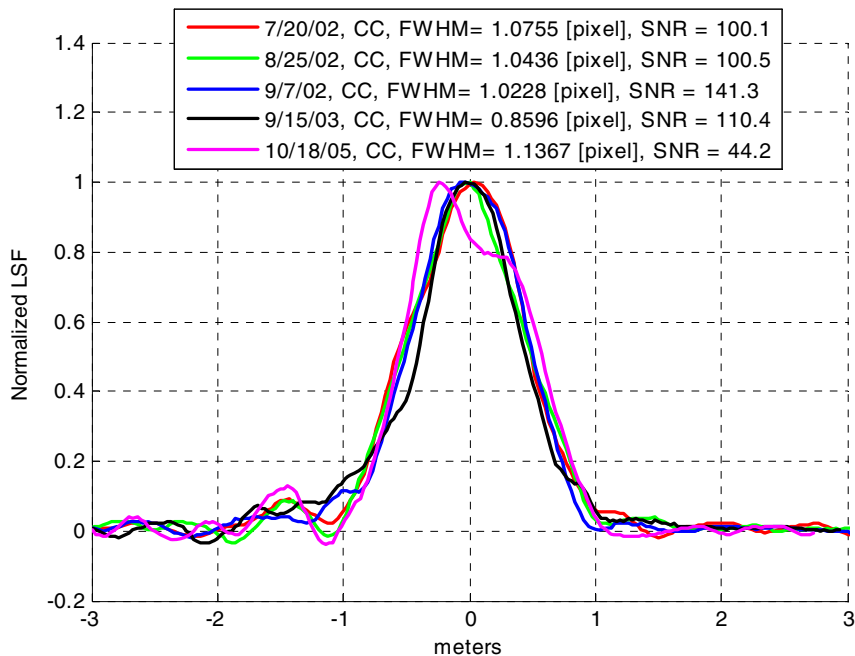


Noisier &  
Sharper  
than CC

# 2002/2003/2005 QuickBird Comparisons

| Date   | Sensor    | Band | Resampling | Target       |
|--|-----------|------|------------|--------------|
| 7/20/02, 8/25/02, 9/7/02,<br>9/15/03, 10/18/05 | Quickbird | Pan. | CC         | Stennis tarp |

- GSD changed from 0.7 to 0.6 meters after 2003.
- Spatial resolution performance appears consistent from 2002 to 2005.



# Overall Quickbird Conclusions

- Initial along-scan PSF/MTF estimates indicate slightly more blur than cross-scan, as expected.
- Good to excellent SNR.
- MTF compensation provides noticeable contrast boost with normal loss of SNR in Panchromatic band, but minimal loss of SNR in Blue band.
- No degradation of Panchromatic band PSF/MTF indicated from 2002 through 2005.