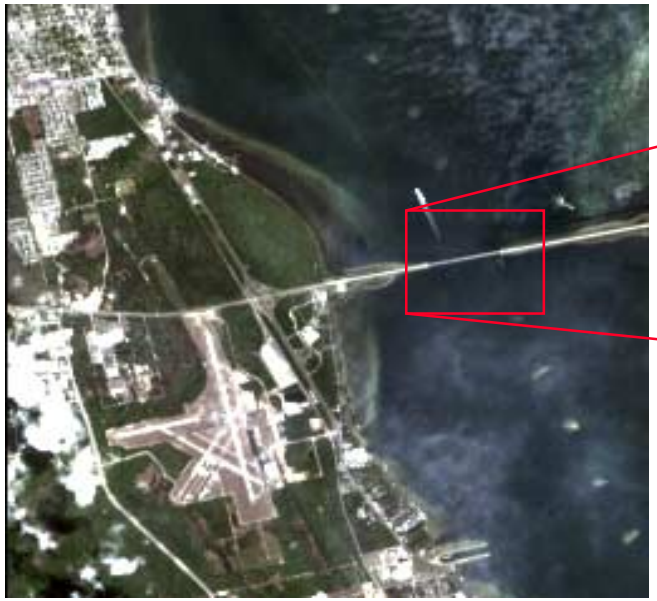
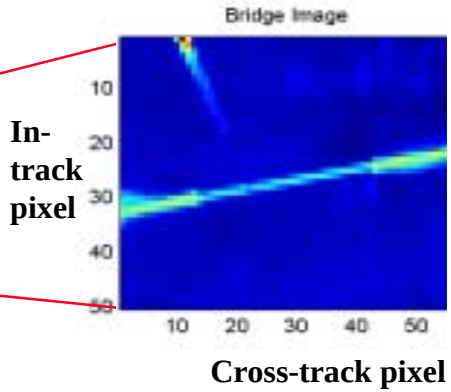
Measurement of Hyperion MTF from On-Orbit Scenes

Neil Nelson, Pamela Barry, TRW, Redondo Beach





Cape Canaveral

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IGARSS 2001

Presented by: Dr. Pamela Barry

Introduction

Hyperion Instrument and the Hyperion Data Cube

Geometric Characterization and Image Quality

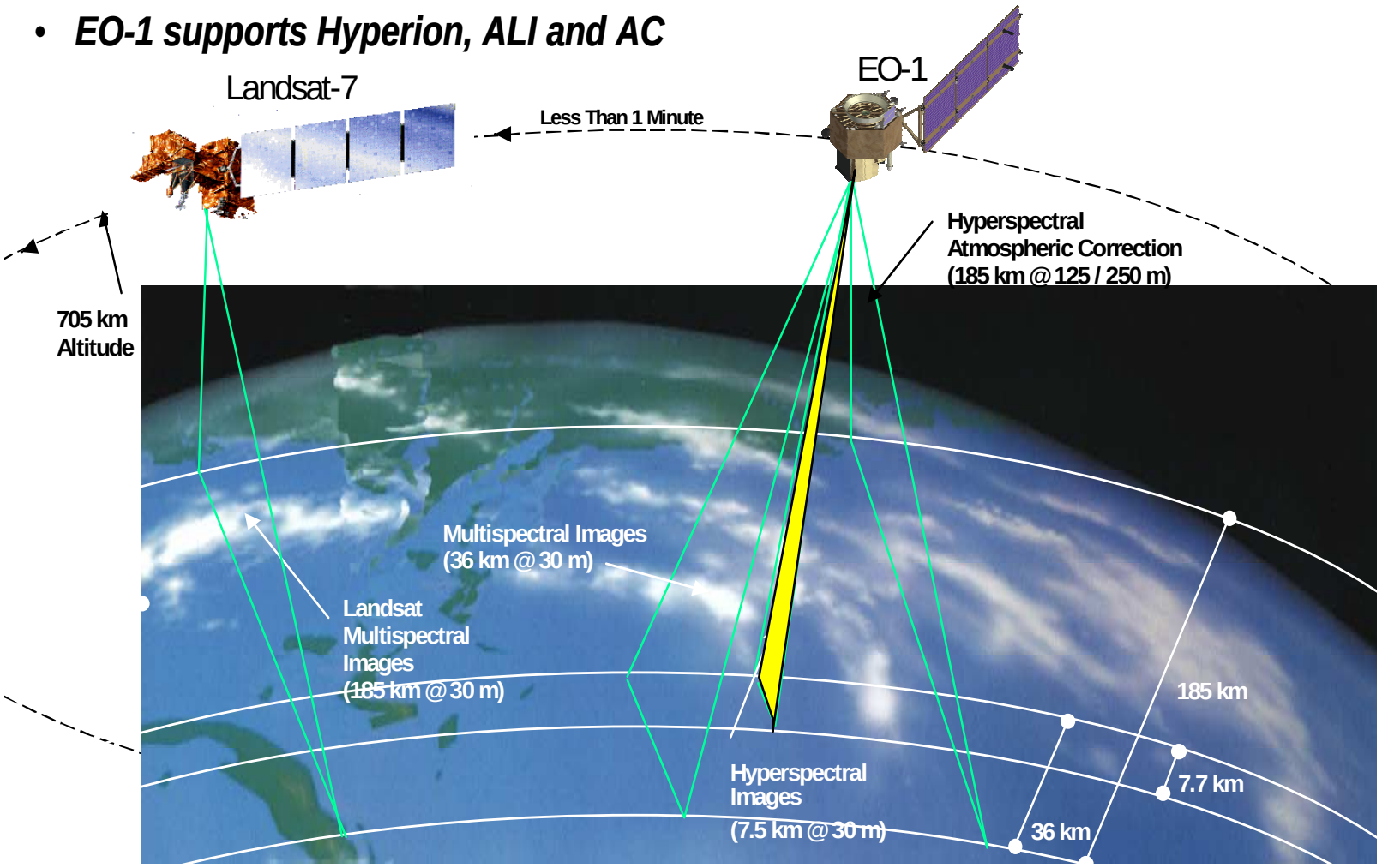
MTF Characterization

On-Orbit Approach to MTF Measurements

Example measurements and comparison with Pre-Flight

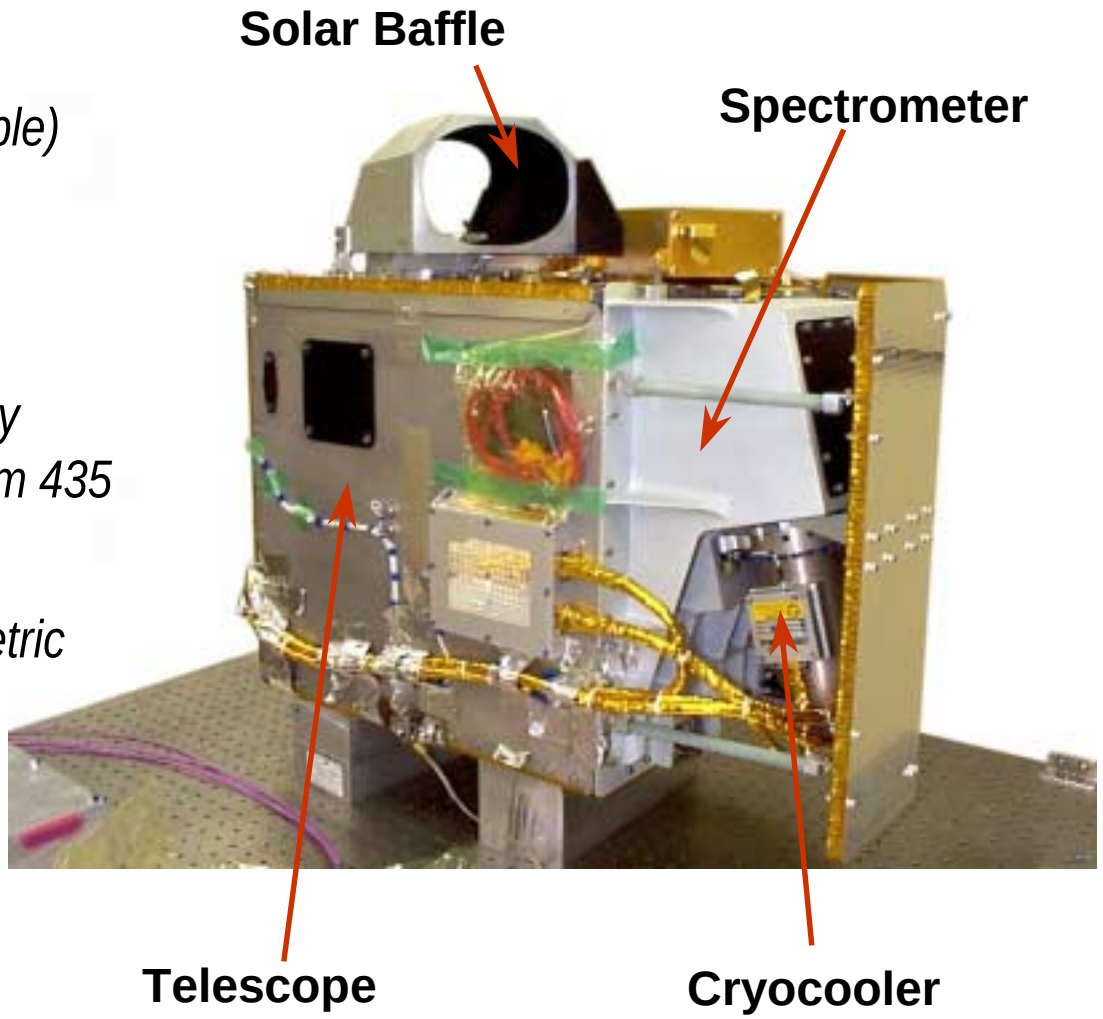
Hyperion Instrument – EO-1 Launch and Orbit

- *EO-1 Spacecraft launched November 21, 2000 from Vandenberg Air Force Base*
- *EO-1 orbit is one minute behind Landsat-7*
- *EO-1 supports Hyperion, ALI and AC*



Hyperion Image Overview

- *7.7 km swath width*
- *160 km swath length (time variable)*
- *30 meter spatial resolution*
- *10 nm spectral resolution*
- *200 radiometrically and spectrally calibrated continuous bands from 435 nm to 2400 nm*
- *Better than 6% absolute radiometric accuracy*

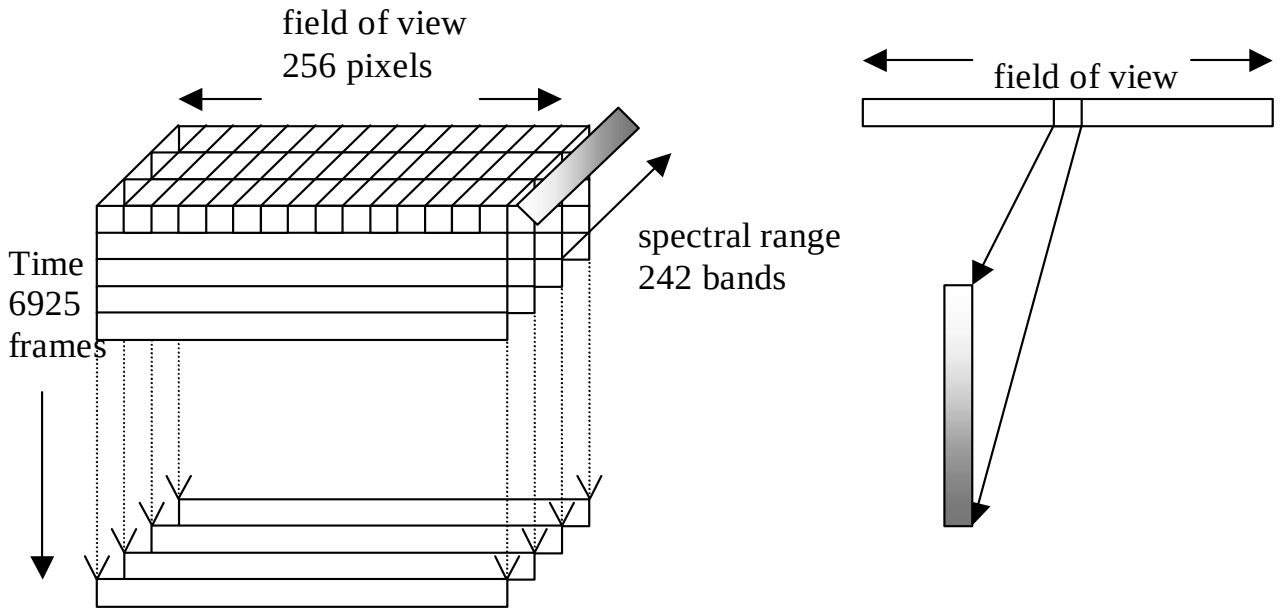


Hyperion Data Cube

Pushbroom configuration, entire swath width collected each frame sampled every 4.5 ms, or 223.4 frames/second.

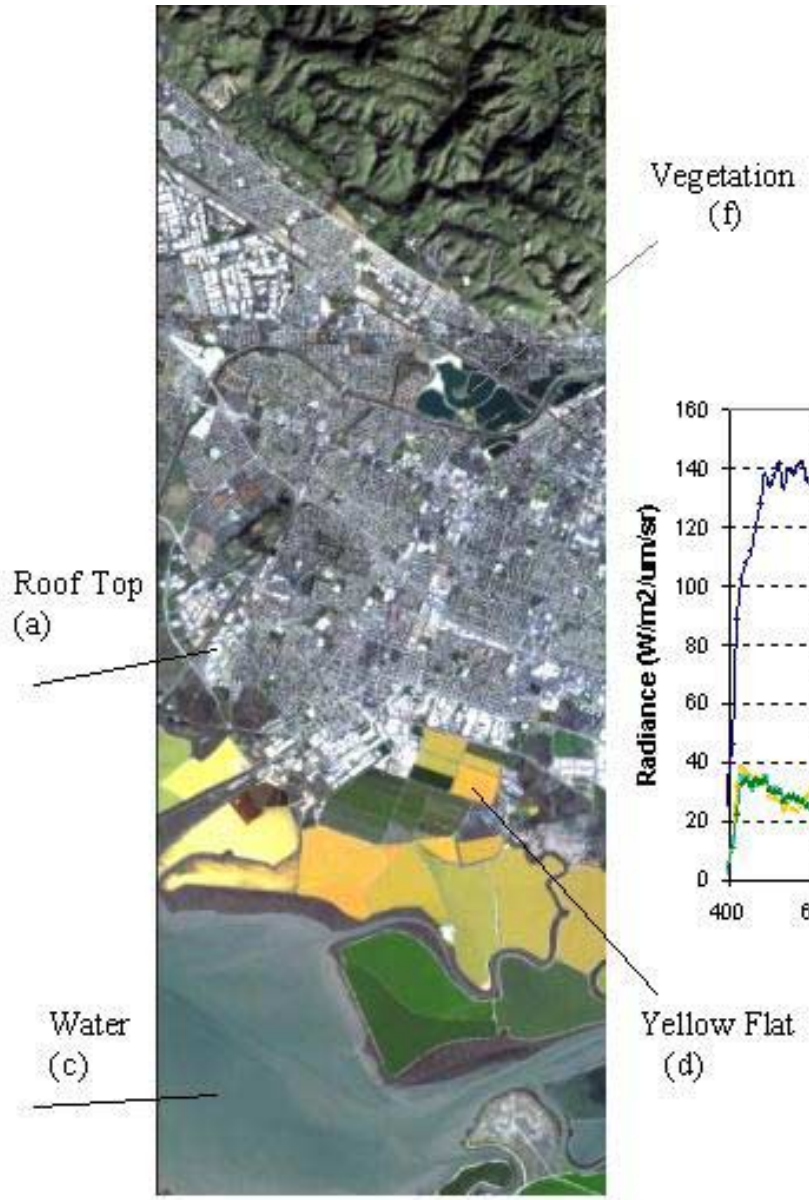
Common fore-optics, dichroic filter reflects 400 nm to 1000 nm to the VNIR and transmits 900 nm to 2500 nm to the SWIR.

Gratings disperse light onto two focal planes

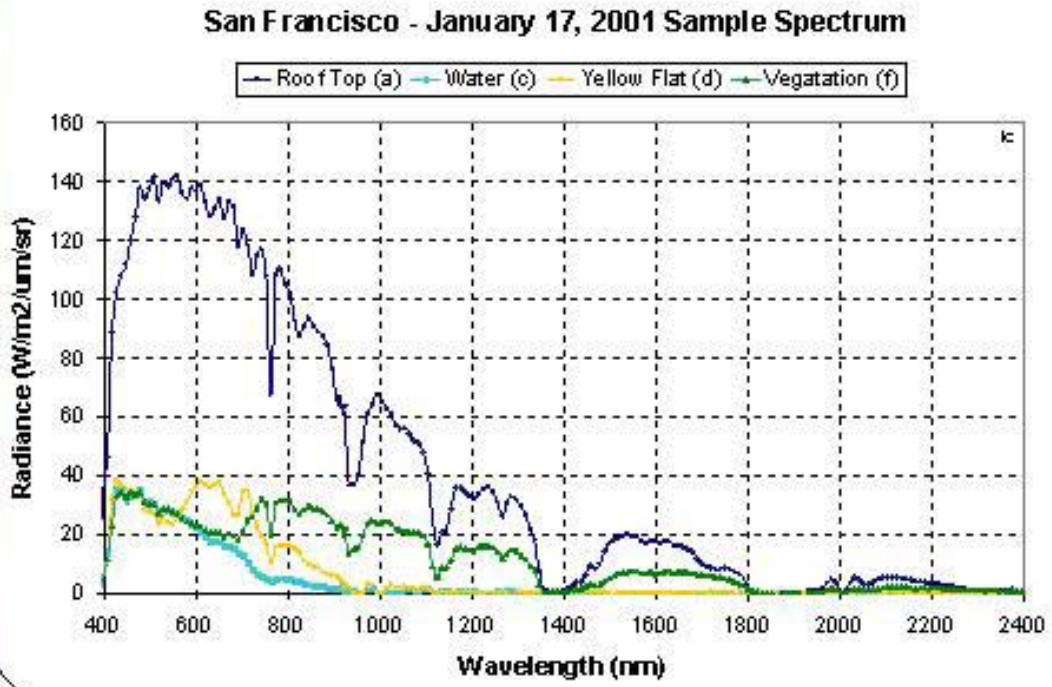


- ***Produces a three dimensional data cube 256x6925x242 in 30 seconds!***

Hyperion Example



Each Hyperion Spectrum represents the signal obtained from a 30 m x 30 m square region on the ground



Geometric Characterization and Image Quality

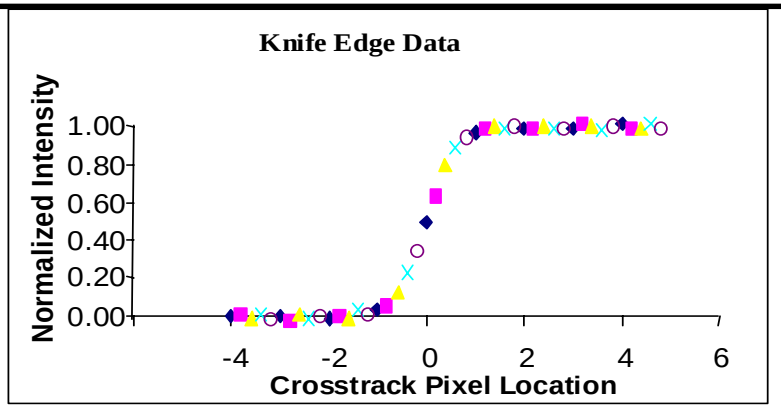
Applicable to optical systems in general:

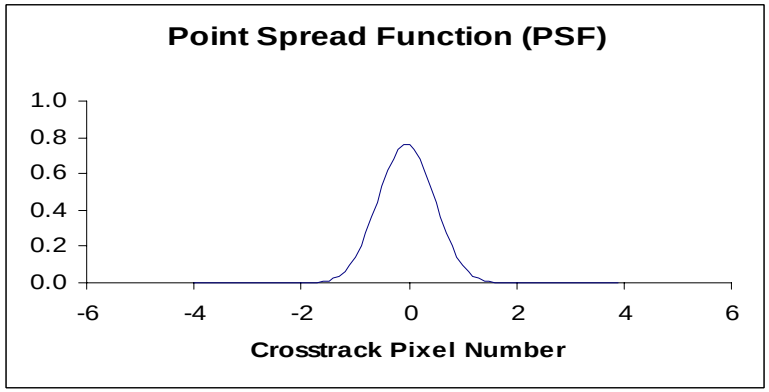
- *A square wave object imaged with edges slightly rounded.*
- *Curvature described by optical system spread function.*

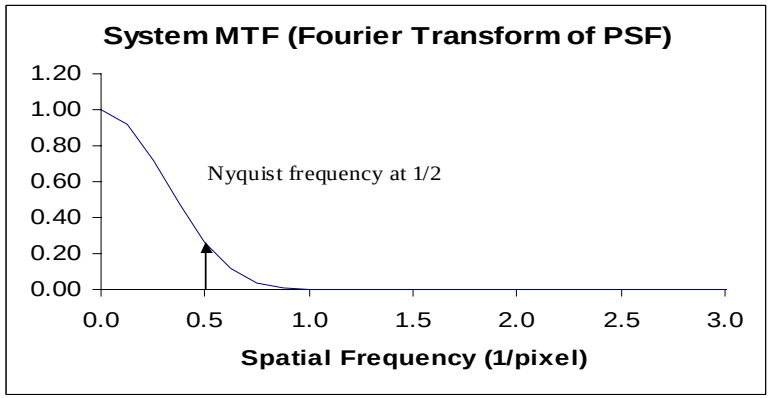
Contrast of bright-dark bars decreases as the size & spacing of bars decreases (spatial frequency increases).

Limiting resolution describes the minimum contrast resolvable for a defined (spatial) frequency.

Modulation Transfer Function (MTF) is a measure of the contrast resolvable as a function of spatial frequency.







Modulation Transfer Function (MTF)

On-Orbit Measurement objective

Perform in-track and cross-track MTF measurement using step and impulse response technique

Compare to pre-flight measurement and requirement

Measurements made at Nyquist frequency = 1/(2*GSD) for range of spectral wavelengths

Requirements

	VNIR MTF			SWIR MTF			
Wavelength (μm)	0.45	0.63	0.90	1.05	1.25	1.65	2.20
Minimum MTF	0.20	0.20	0.15	0.14	0.14	0.15	0.15

*In-Track MTF Pre-Flight Results (= Cross-Track MTF *2/pi)*

Wavelength (μm)	FOV> 200	Center FOV	FOV < 20
0.500	0.29	0.27	0.22
0.630	0.27	0.28	0.22
0.900	0.24	0.26	0.22
1.050	0.28	0.3	0.28
1.250	0.28	0.3	0.27
1.650	0.27	0.27	0.25
2.200	0.28	0.27	0.23

Modulation Transfer Function (MTF)

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Comparison at Nyquist frequency = 1/(2*GSD) for range of spectral wavelengths and field-of-view locations

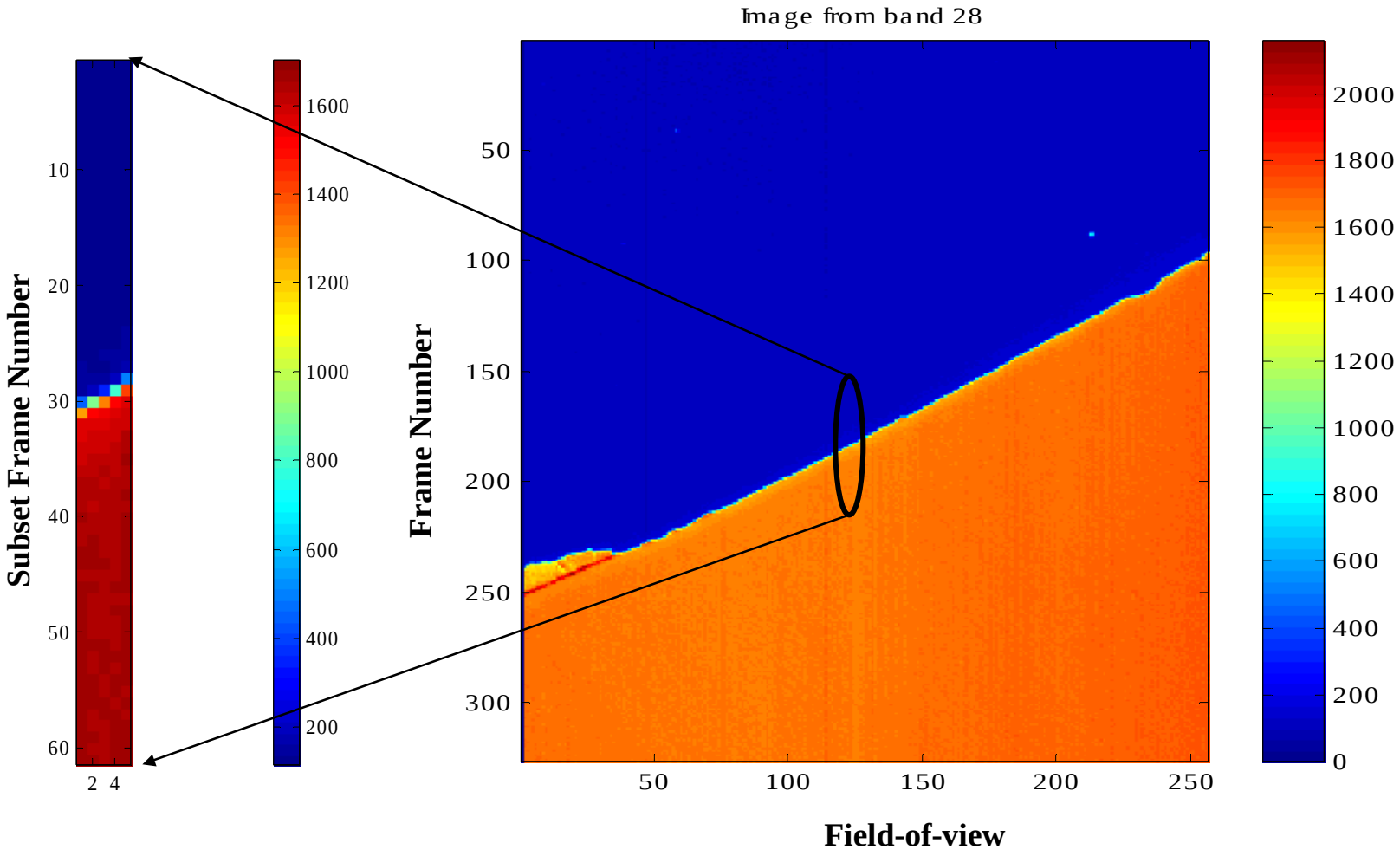
In-Track MTF Comparison

Wavelength	Requirement	Pre-flight	On-Orbit
630 nm	> 0.2	.22-.27	.23-.27
900 nm	> 0.15	.22-.24	.24-.28
1250 nm	> 0.14	.27-.30	.20-.25
1650 nm	> 0.15	.25-.27	.28

In-Track Edge: MTF Calculation Process

Scene is Ross Ice Shelf from Jan 16, 2001

Edge information is taken from pixel 134.

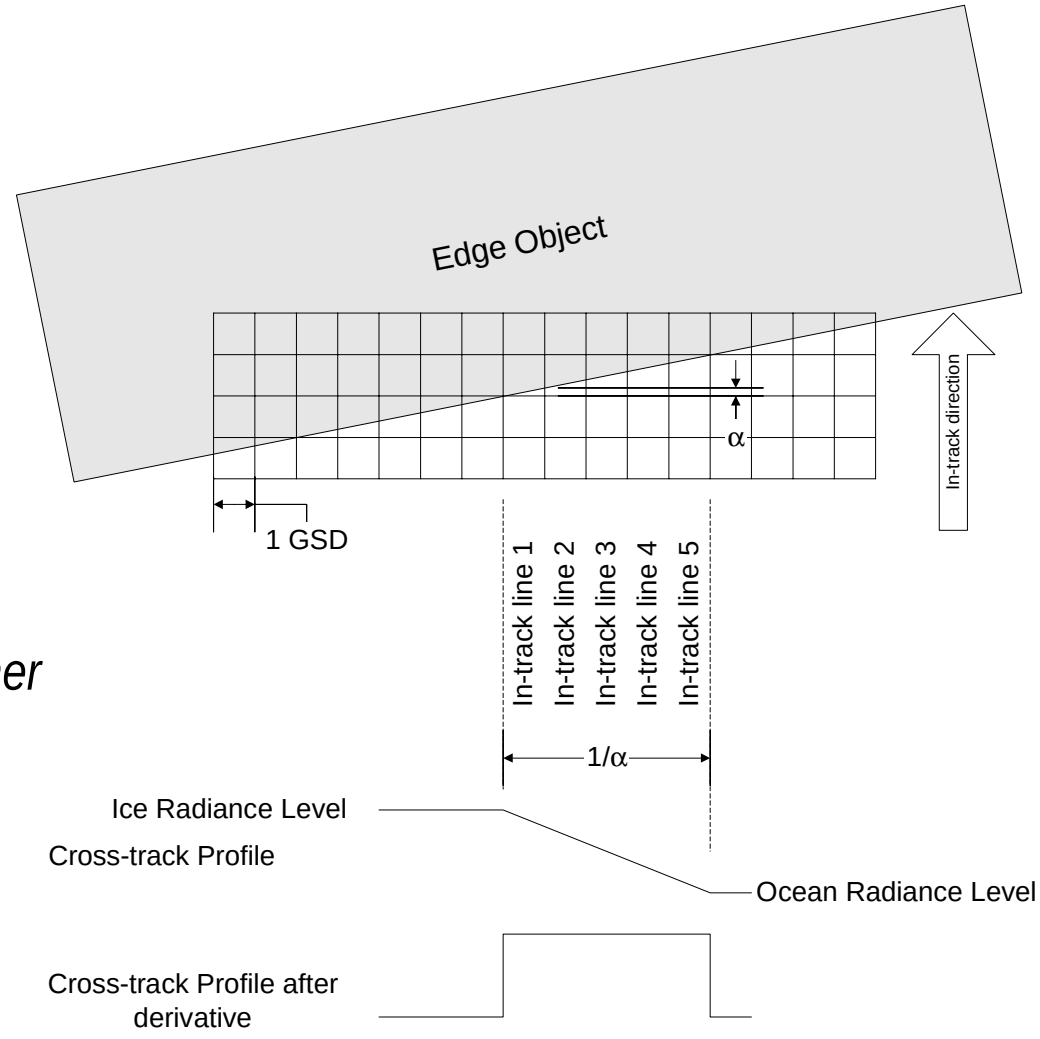


MTF Measurement Technique

Example for In-Track Interlace

Edge is detected in each in-track profile.

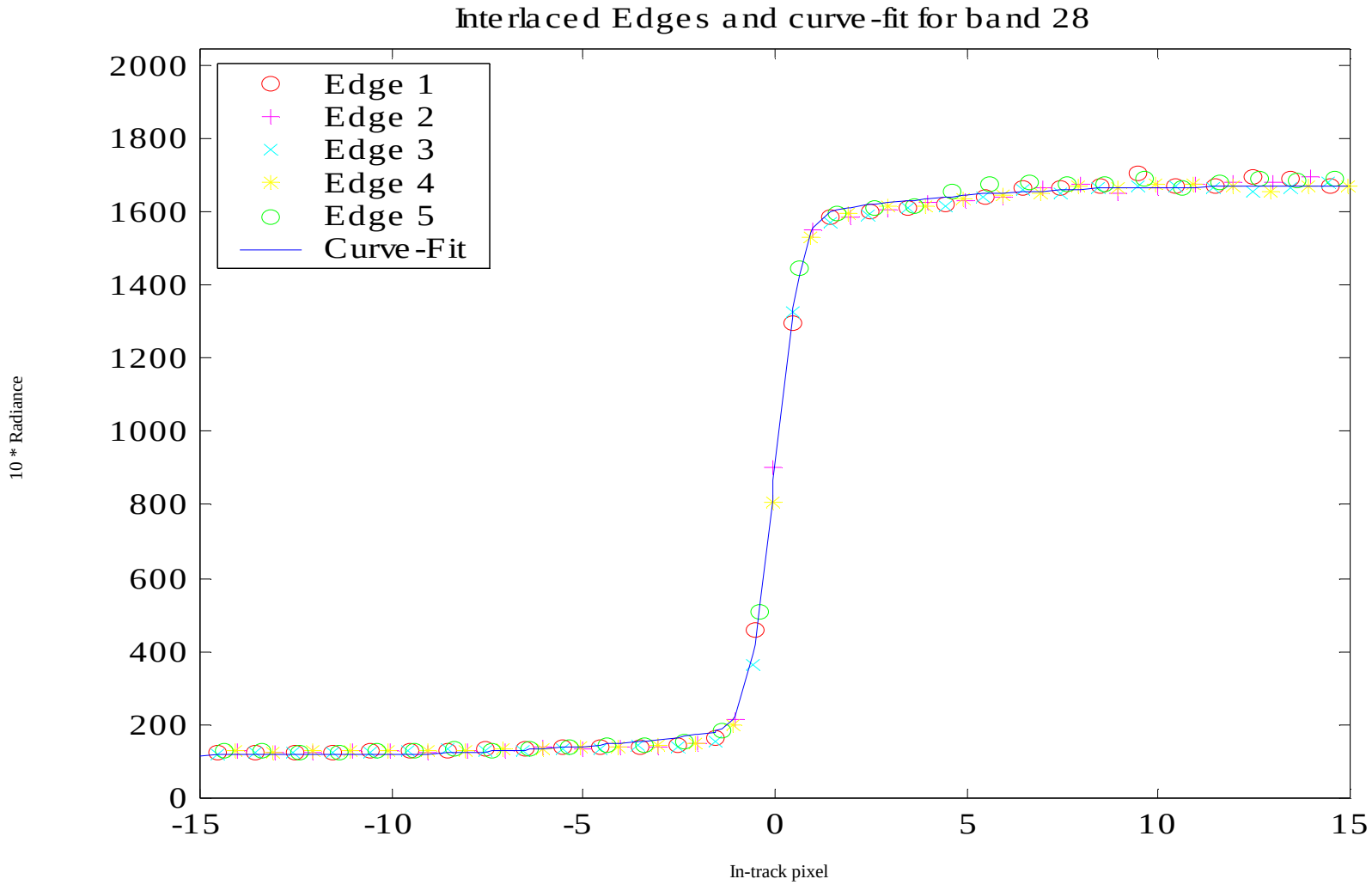
Profile from adjacent pixels are interlaced to sample the edge higher than GSD.



In-Track Edge: MTF Calculation Process – cont.

Edge is detected in adjacent in-track profiles and interlaced.

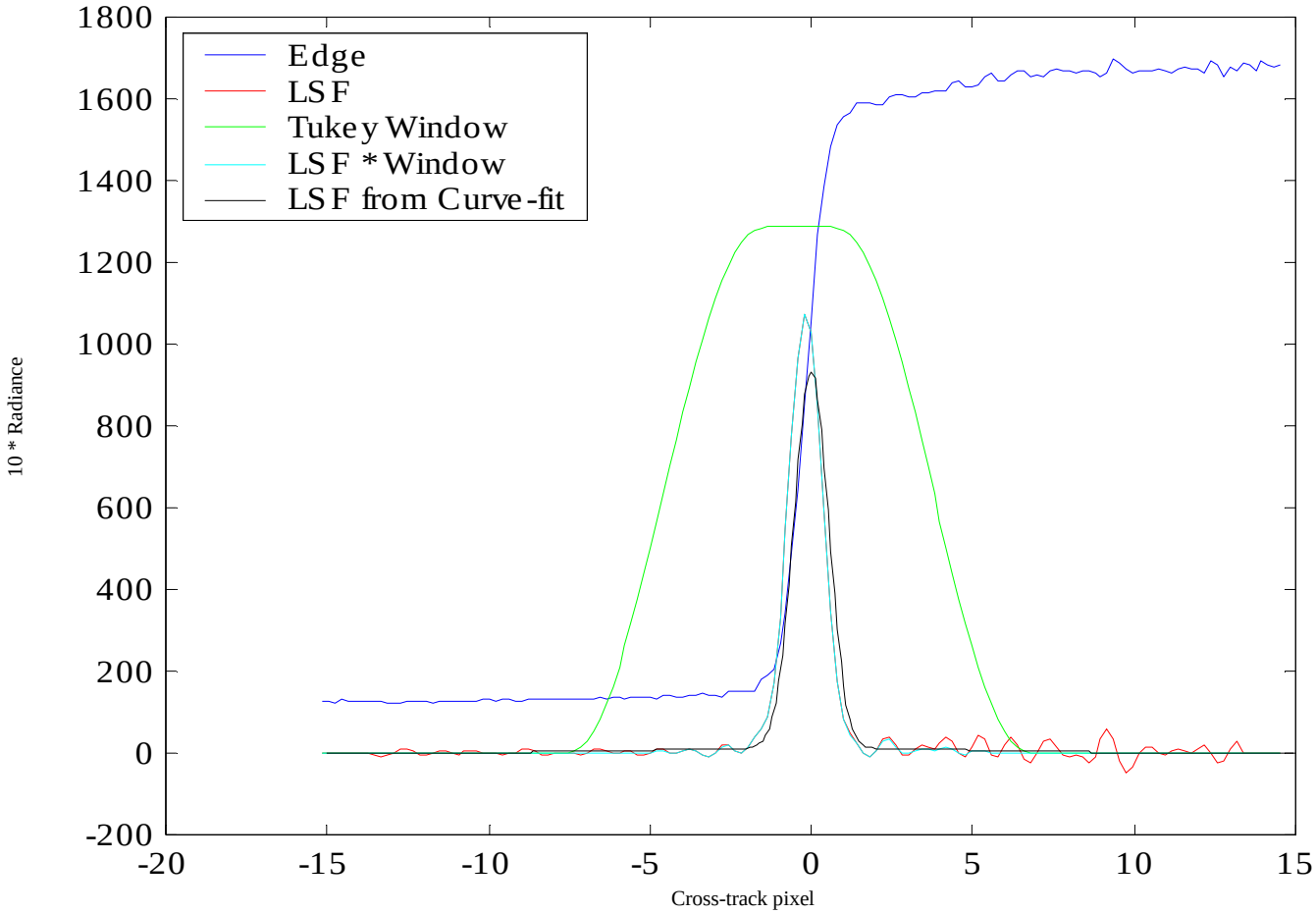
An error function is fit to the high resolution (interlaced) edge profile.



In-Track Edge: MTF Calculation Process – cont.

The LSF is analytically derived from the curve fit.

MTF result at Nyquist is between 0.25 to 0.28; pre-flight measurement was 0.28.



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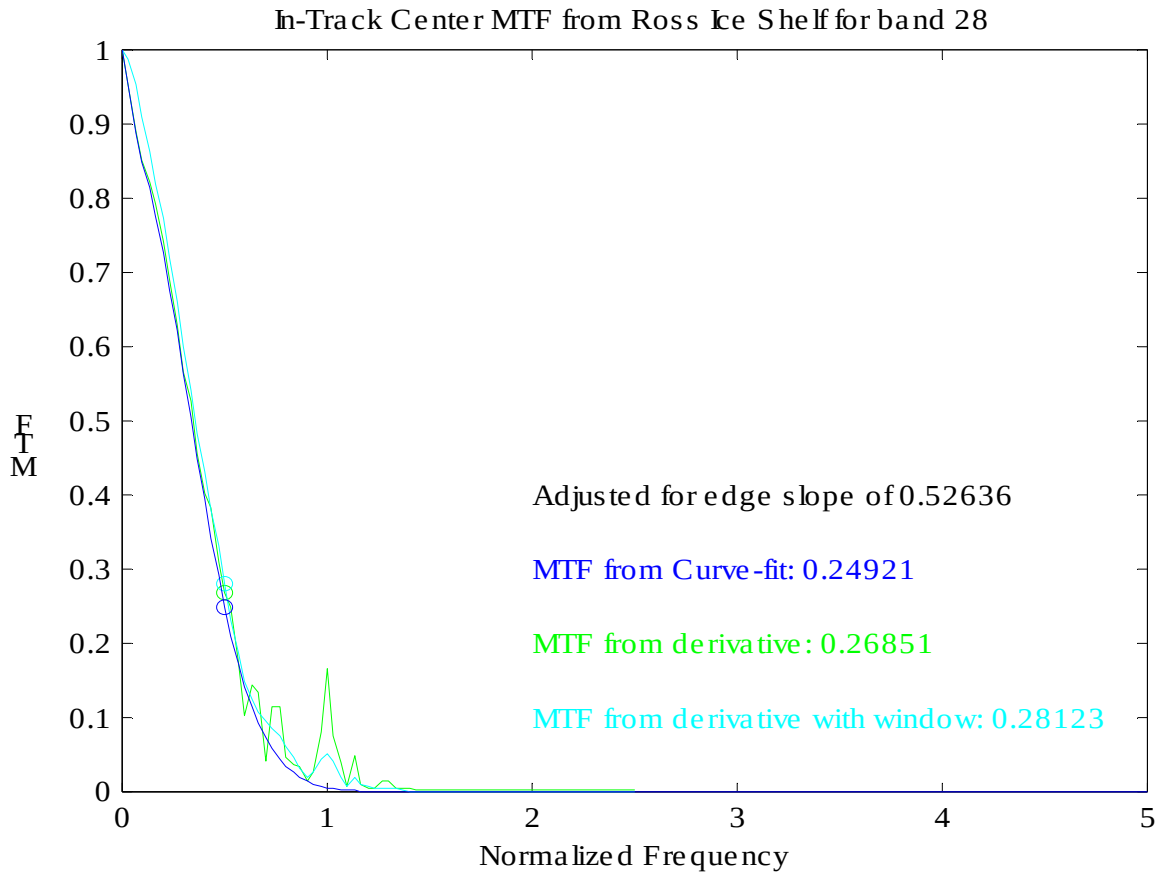


Figure 7.2.3-3 Calculated MTF

MTF Calculation Process Summary

MTF measurement on-orbit requires collection of scenes

step response: Ross Ice Shelf, Lunar Collect

impulse response: Bridge (Eglin, Cape Canaveral)

Data Processing steps (simplified):

1.) Define Edge Spread Function (ESF): Interlace adjacent lines from an object that is at a slight angle to the spacecraft motion

- allows over sampling (sub-pixel) sampling

2.) Calculate Line Spread Function (LSF):

edge technique: calculate an error function curve-fit to the ESF to derive the LSF, OR take the band-limited derivative of the ESF with a Tukey window.

slit technique: LSF is obtained from interlacing adjacent lines and de-convolving the profile with the slit width (in the frequency domain)

3.) MTF is the Fourier Transform of the LSF

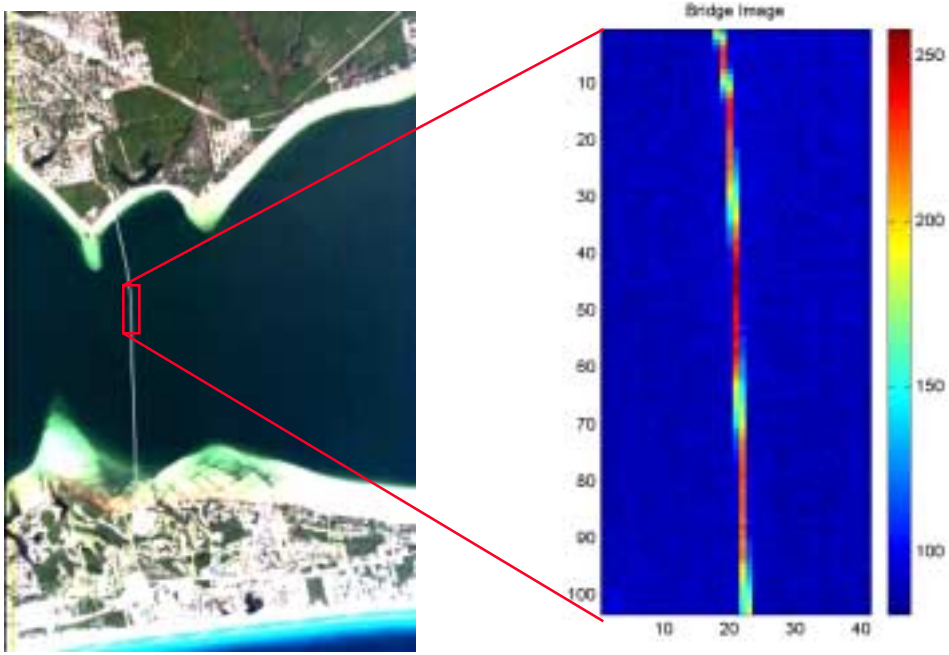
MTF Example: Cross-track Bridge

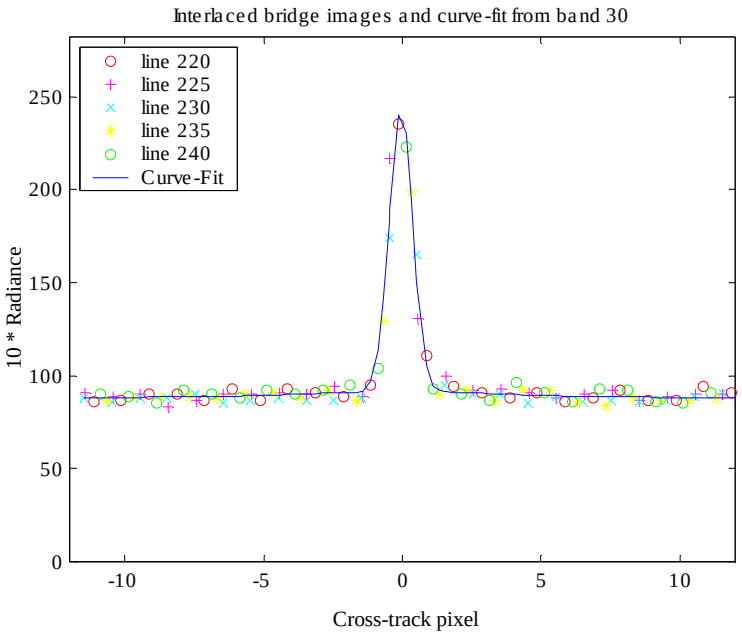
Scene is Port Eglin from Dec 24, 2000. Bridge is the Mid-bay bridge near Destin, Florida.

Bridge width acquired and utilized in the MTF processing. Bridge width is 13.02 meters.

Bridge angle to the S/C direction is small so every 5th line is used to develop the high resolution bridge image.

MTF result at Nyquist is between 0.39 to 0.42 while the pre-flight measurement was 0.42.

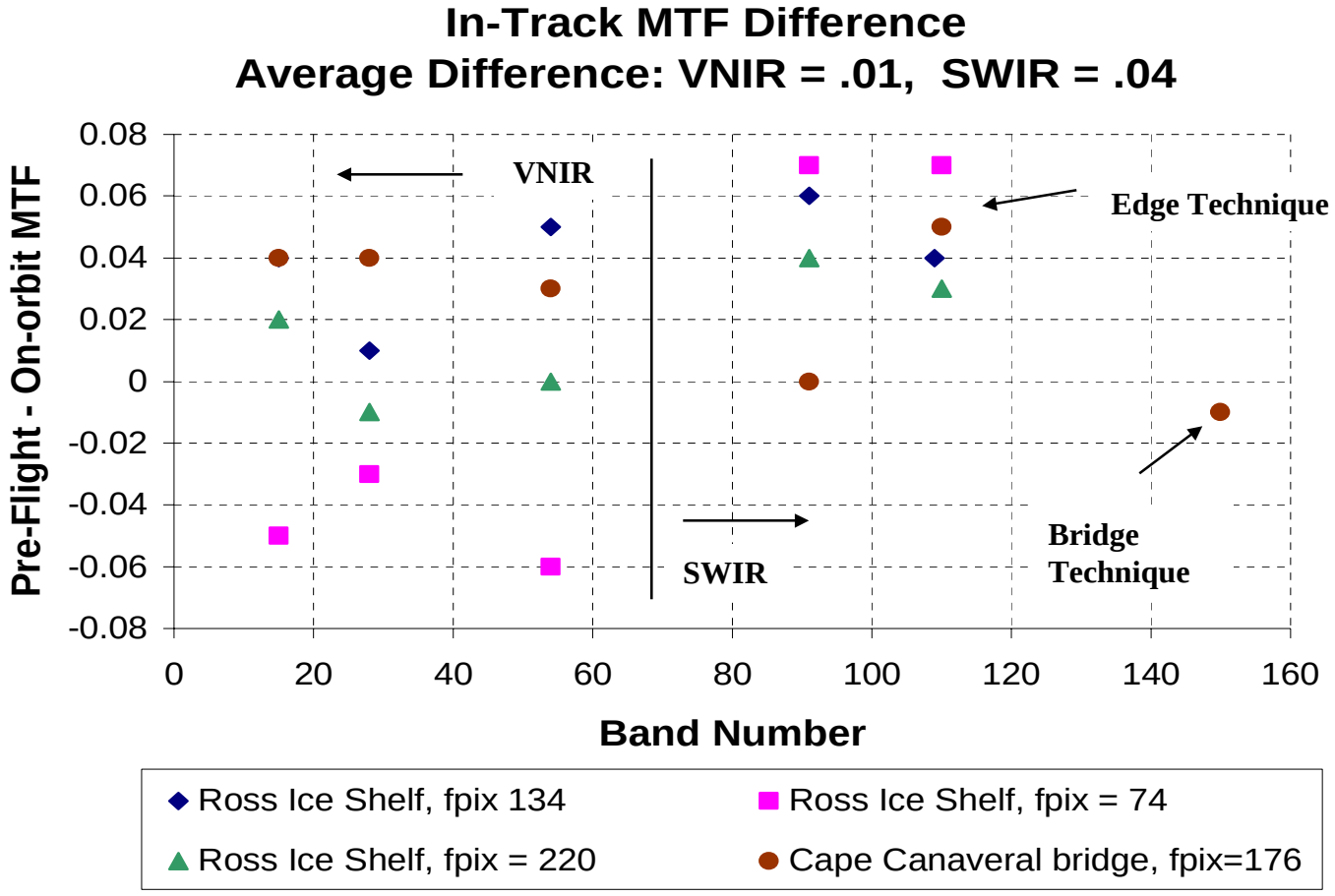




In-Track MTF Comparison

Edge and Bridge technique confirm MTF characterization for VNIR

Bridge Technique confirms MTF for SWIR, Edge technique using Ross indicates lower on-orbit value.



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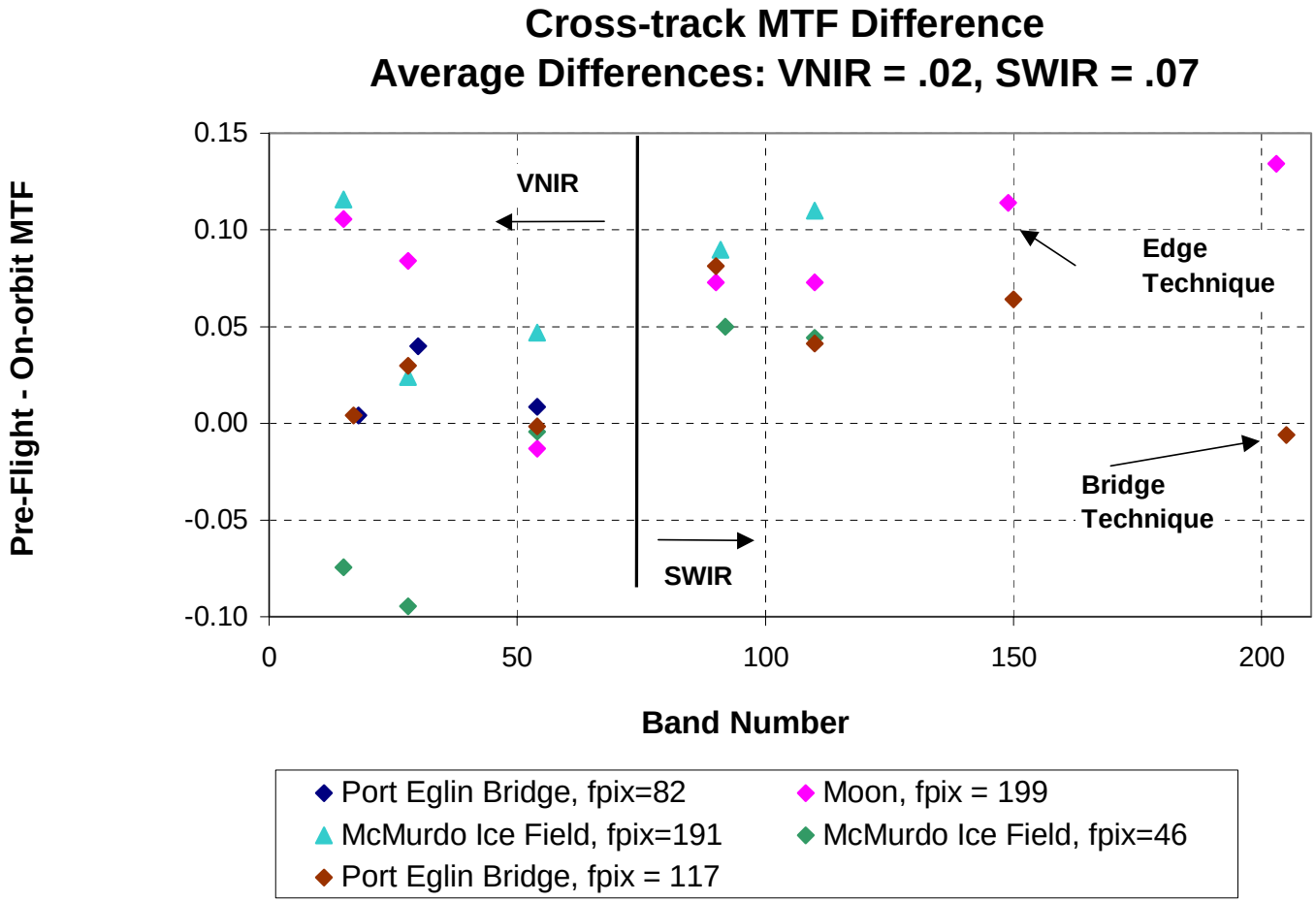


MTF Conclusions

MTF Requirements satisfied

VNIR In-track and Cross-track MTF on-orbit measurements confirm pre-flight measurements

SWIR MTF measurements dependent on technique

- **bridge technique confirms pre-flight measurement for cross-track and in-track MTF**
- **edge technique: suggestS lower on-orbit value, however also more suspect since were of ICE and MOON.**

Difficulties with ICE for SWIR: *Ice scenes do not provide enough reflectance beyond 1.25 μm, and Ice edges have less reflectance near the edge in the SWIR which impacts MTF measurement.*

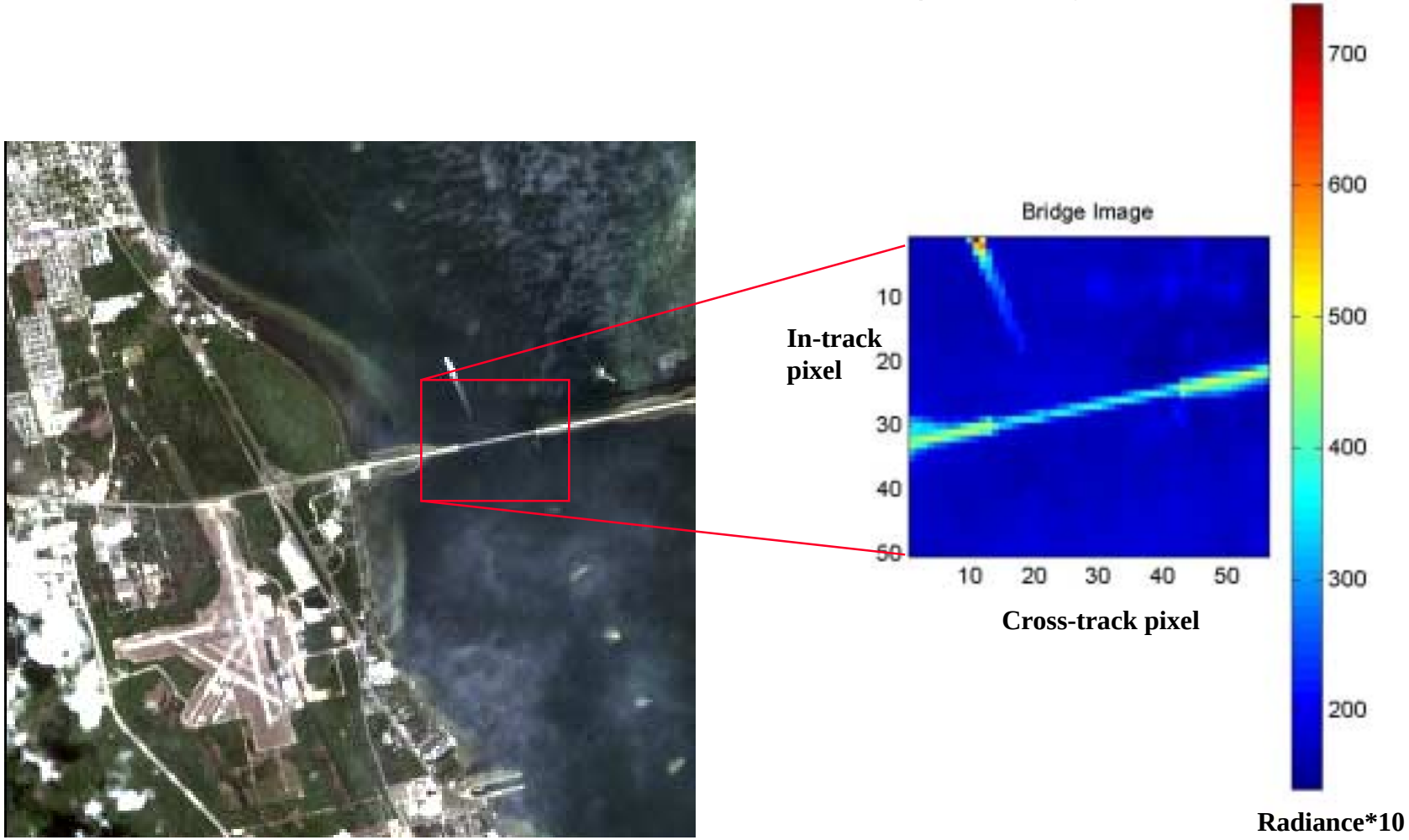
Difficulties with Moon for SWIR *Moon surface not uniform and spacecraft scans Moon.*

Backup Slides

MTF Example: In-track Bridge

Cape Canaveral Bridge was used as an impulse source.

Bridge is a movable double structure each 32' 8" wide and separated by 31' 4"



Pre-Flight MTF Characterization

Measured using knife-edge MTF technique:

- Knife-edge positioned at image relay focus with edge perpendicular to the slit of spectrometer
- Knife-edge illuminated with broadband light source
- Over-sampling by tilting steering mirror in fractional-pixel steps
- Fourier transform of the Point Spread Function (PSF) produces Cross-track MTF (CT-MTF)
- Along-track direction MTF taken as $\frac{2}{\pi}$ of the cross track value.