IKONOS Signal-to-Noise Ratio Estimation (MTFC On versus MTFC Off)

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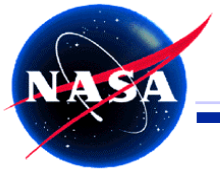


Introduction

- **Signal-to-Noise Ratio (SNR) is a critical parameter that drives image utility and assessment accuracies**
- **Users typically have no access to engineering data to estimate SNR**
  - Alternative in flight methods are needed
- **Various image processing algorithms affect the SNR (MTFC, compression, etc.)**
- **This presentation will focus on the differences in SNR estimates for MTFC On imagery and MTFC Off imagery**

Signal-to-Noise Ratio (SNR)

- SNR is measure of the mean signal to noise ratio
- SNR definitions

$$SNR = \frac{\mu}{\sigma}$$

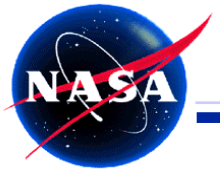
where

$$\mu = mean\ signal$$

$$\sigma = standard\ deviation\ of\ signal$$

Signal-to-Noise Ratio (SNR)

- Two types of SNR are typically measured
  - Temporal SNR
  - Spatial SNR



Signal-to-Noise Ratio (SNR)

- Temporal SNR
  - Mean signal is the mean of a time series of a pixel observing a temporal stable source
  - Noise is typically defined as the standard deviation of the time series
- Spatial SNR
  - Mean signal is the spatial average of a group of pixels observing a spatially varying scene
  - Noise is typically defined as the standard deviation of a region of pixels

Spatial SNR

- Spatial SNR is measurable from single frames of uniform scenes
- Spatial SNR of single frames of uniform scenes and temporal SNR derived from stable sources are the equivalent for perfectly uniform focal plane response

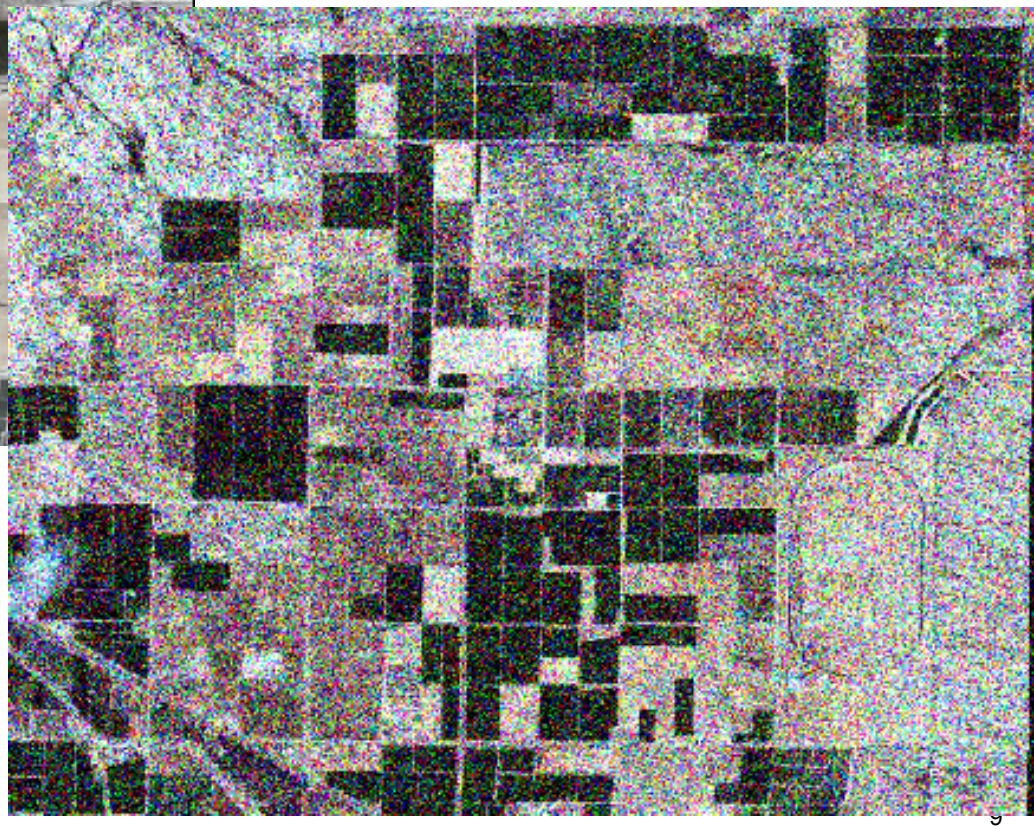
SNR Effects on Imagery

← Original Maricopa IKONOS Imagery
SNR ~ 100

Maricopa IKONOS Imagery with Noise Added →
SNR ~ 10

SNR Effects on Imagery

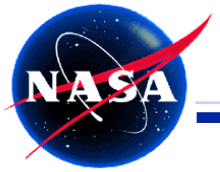
Original Maricopa IKONOS Imagery
SNR ~ 100



Maricopa IKONOS Imagery with Noise Added
SNR ~ 2

SNR General Comments

- Visual image interpretation does not require extremely high SNR data
- Multispectral image processing requires higher SNR than panchromatic imagery
  - High SNR is important (ALI is showing the benefits of SNR a few hundred or more)
- Hyperspectral Image processing requires extremely high SNR data
  - AVIRIS and HYMAP have demonstrated the benefits of SNR of several hundred or more



SNR Methodology

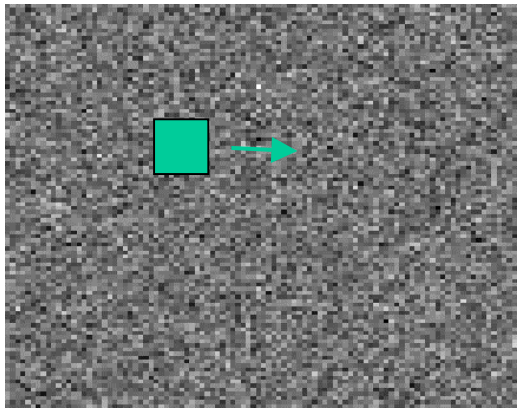
- Identify uniform scenes
  - Site uniformity increases over smaller areas
- Calculate a running “small window” estimate of the μ/σ for each band
  - Assume that, over small areas, the scene is dominated by sensor noise and not scene uniformity
  - Use varying size “windows;” convergence can be confirmed
  - Ratio of μ/σ gives an estimate of the SNR, where

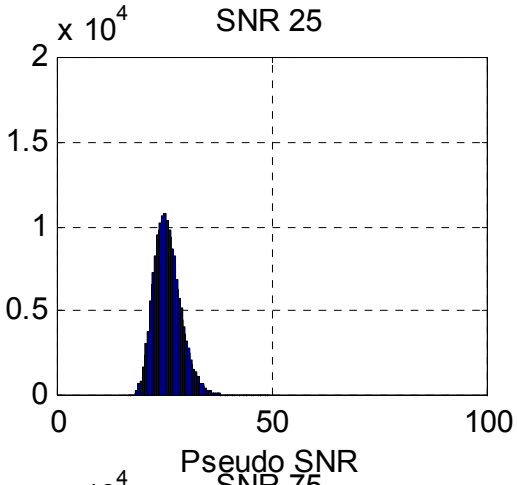
    μ is the mean radiance of the image or subimage

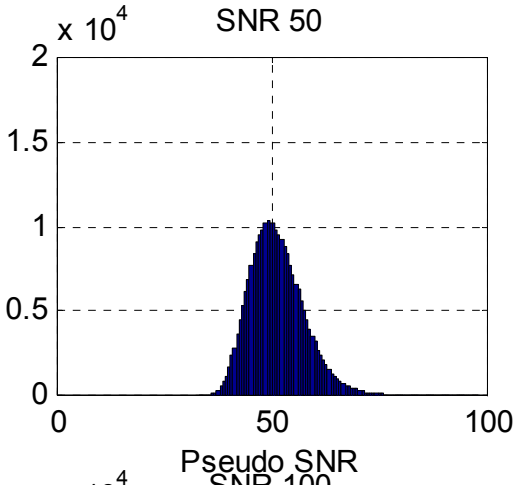
    σ is the standard deviation of the image or subimage
- Location of peak in the histogram of a “small window” μ/σ is a measure of the system SNR

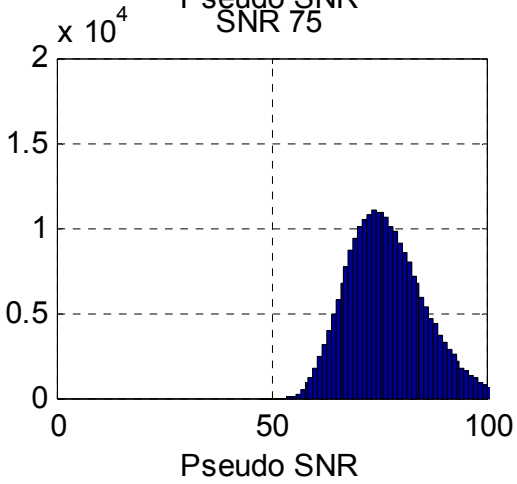
Simulated SNR Estimates

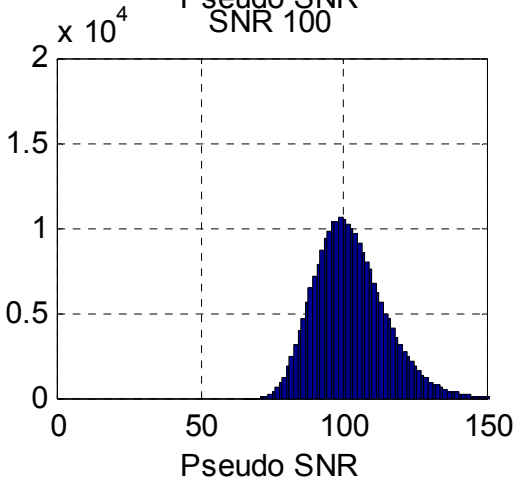
5x5 Window Pseudo SNR Histograms







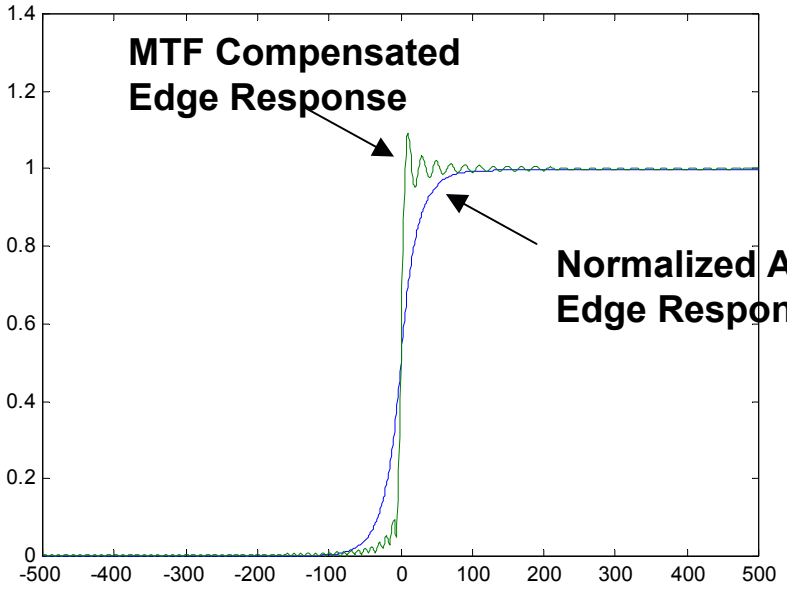




MTF Compensation (MTFC)

- MTFC is an edge sharpening technique used to partially restore image degradation caused by imperfections in the imaging process
- Results in sharpness of edge features within image
- Significantly affects radiometry of some pixels
- Lowers SNR of scene
- MTFC is an option for the SDP

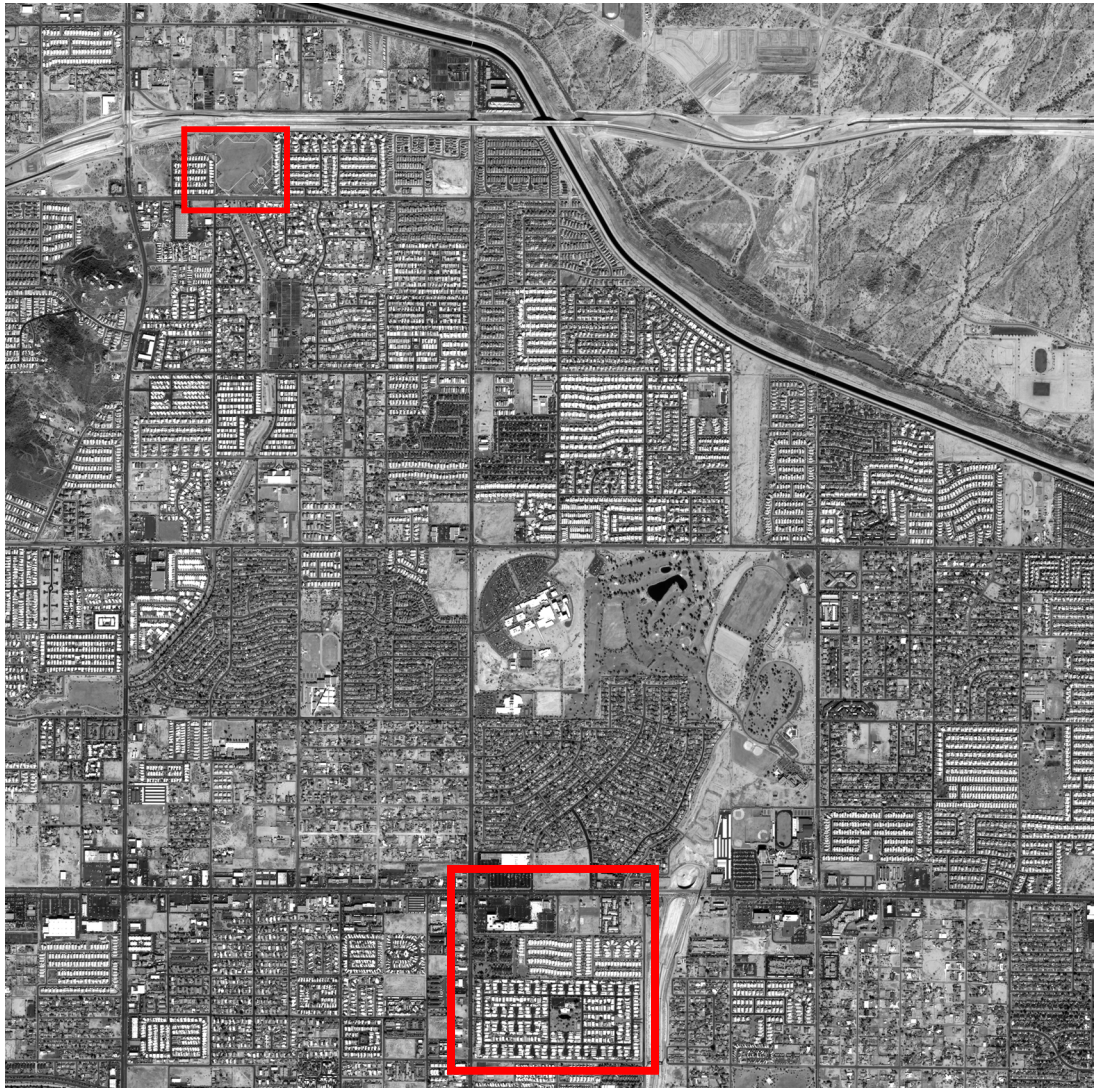
Simulated Edge Response



MTFC sharpens edges but can produce overshoot and ringing

Phoenix PO ID# 33667

- 1 Meter Panchromatic
- October 12, 1999
- MTFC ON
- Satellite Elevation Angle 60.7°



Phoenix MTFC ON/OFF Pan Comparison

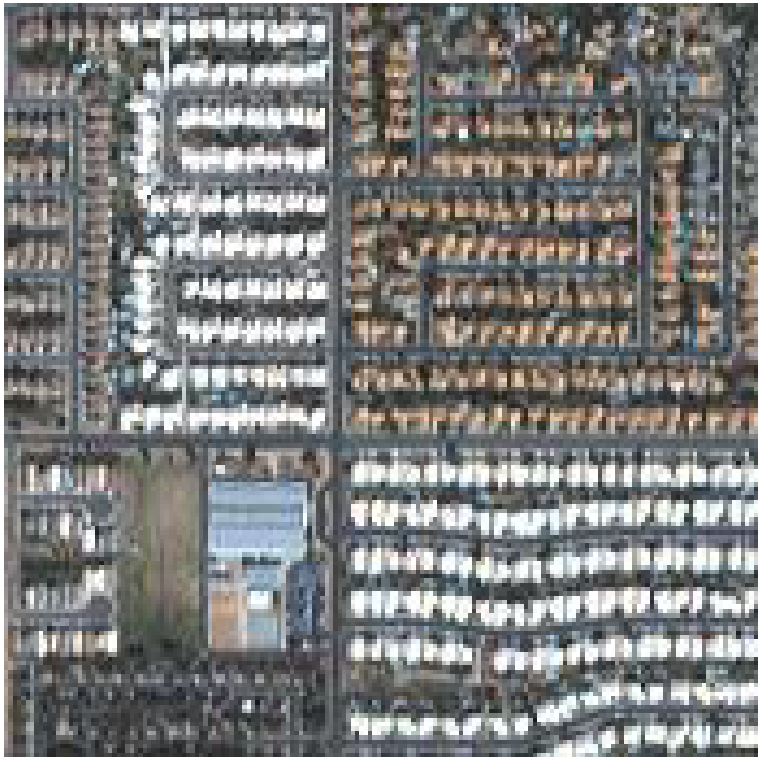
1m Panchromatic Imagery Acquired October 12, 1999

MTFC ON

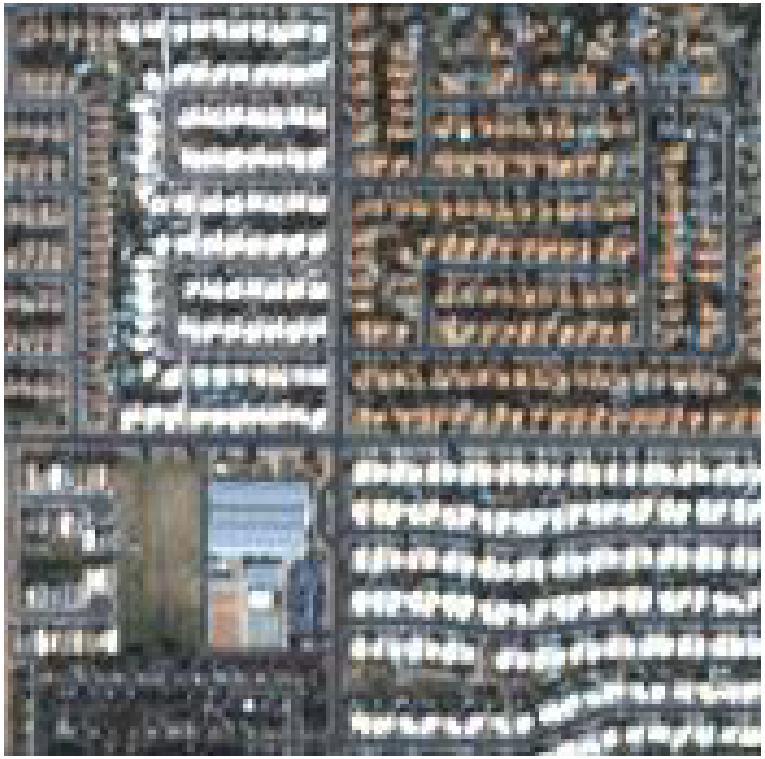
MTFC OFF

Phoenix MTFC ON/ OFF RGB Comparison

4m Multispectral Imagery Acquired October 12, 1999



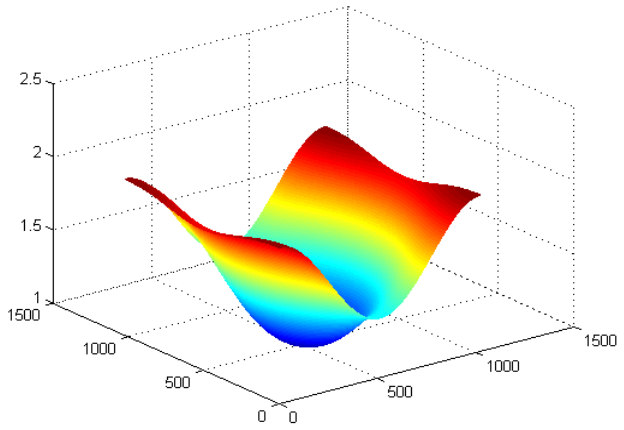
MTFC ON



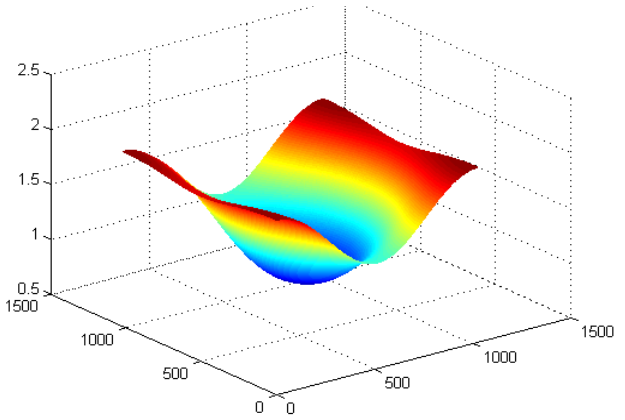
MTFC OFF

MTFC MS Kernels

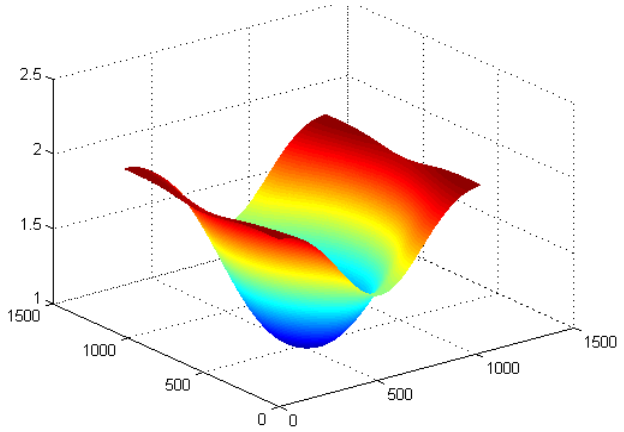
Blue Kernel



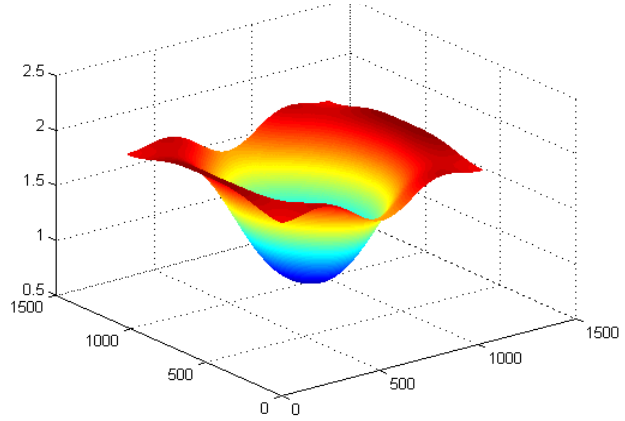
Green Kernel



Red Kernel

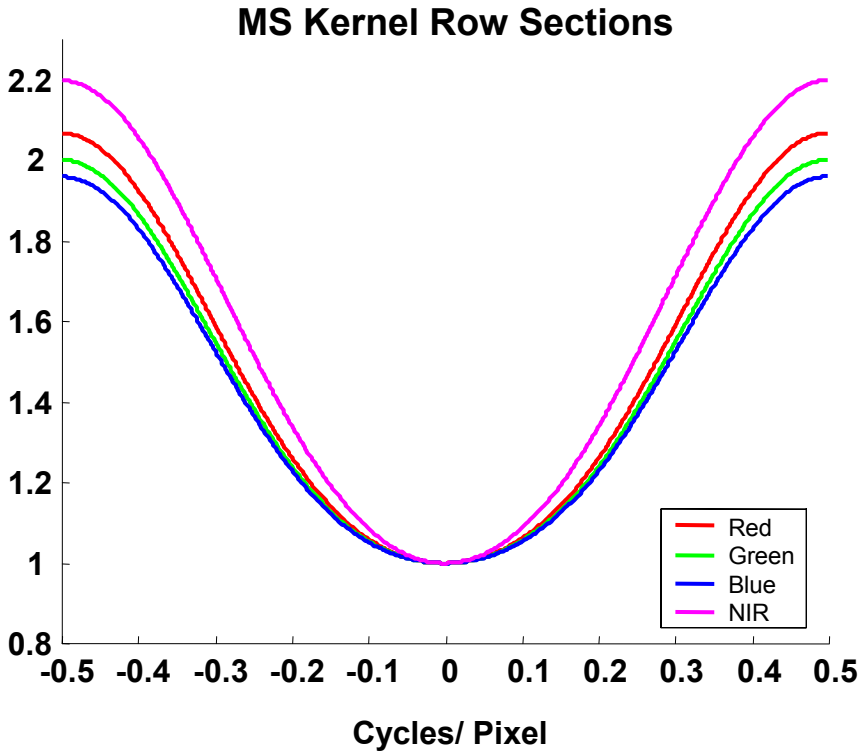


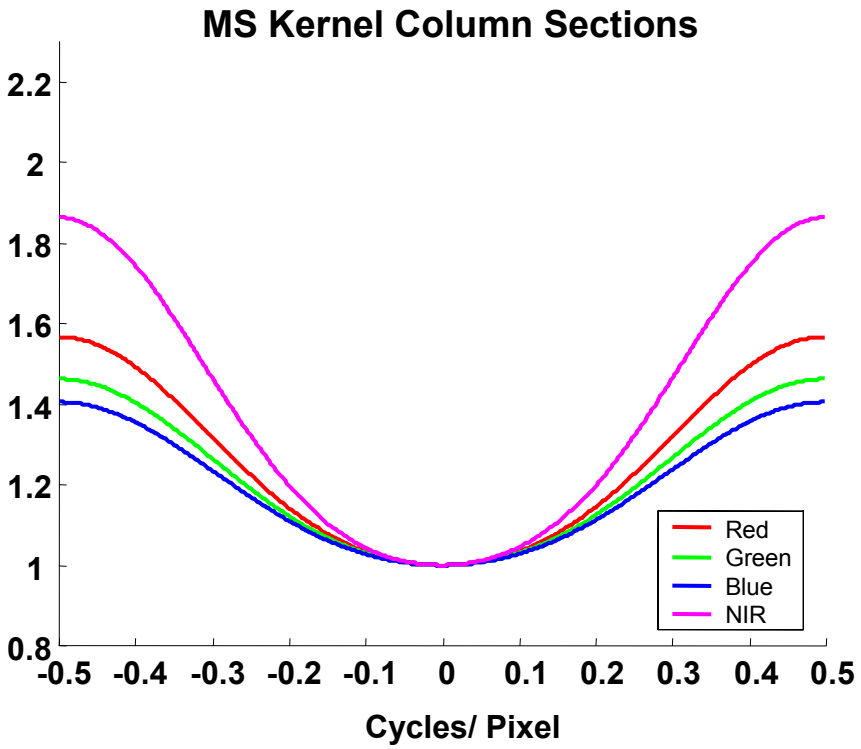
NIR Kernel



Row MTFC is stronger than column MTFC

MTFC MS Band Comparisons

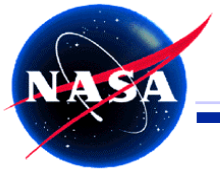




MTFC compensation increases with increasing wavelength

MTFC Analysis using Simulated Scenes

- Objective: Evaluate effects of MTFC on SNR
- Approach
  - Create a simulated random noise scene
  - Apply Space Imaging MTFC kernel
  - Perform Fourier transform to scenes with and without MTFC
  - Assess MTFC effects on spatial frequency content
- We expect MTFC to boost random noise component of simulated scene and, thus, lower the SNR



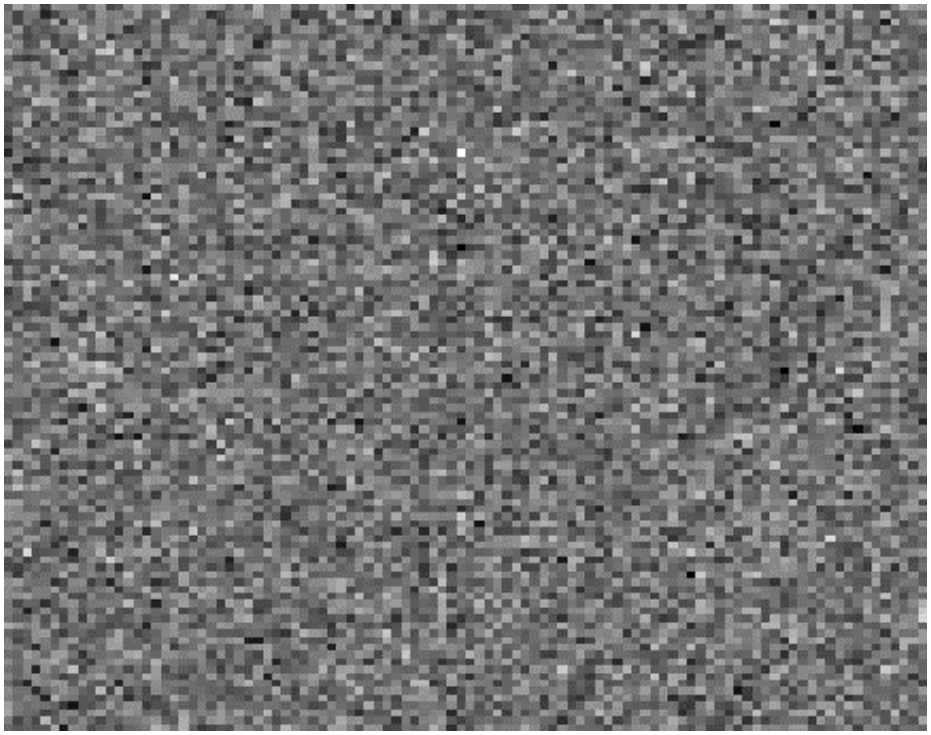
SNR of Photon Noise-Limited Systems

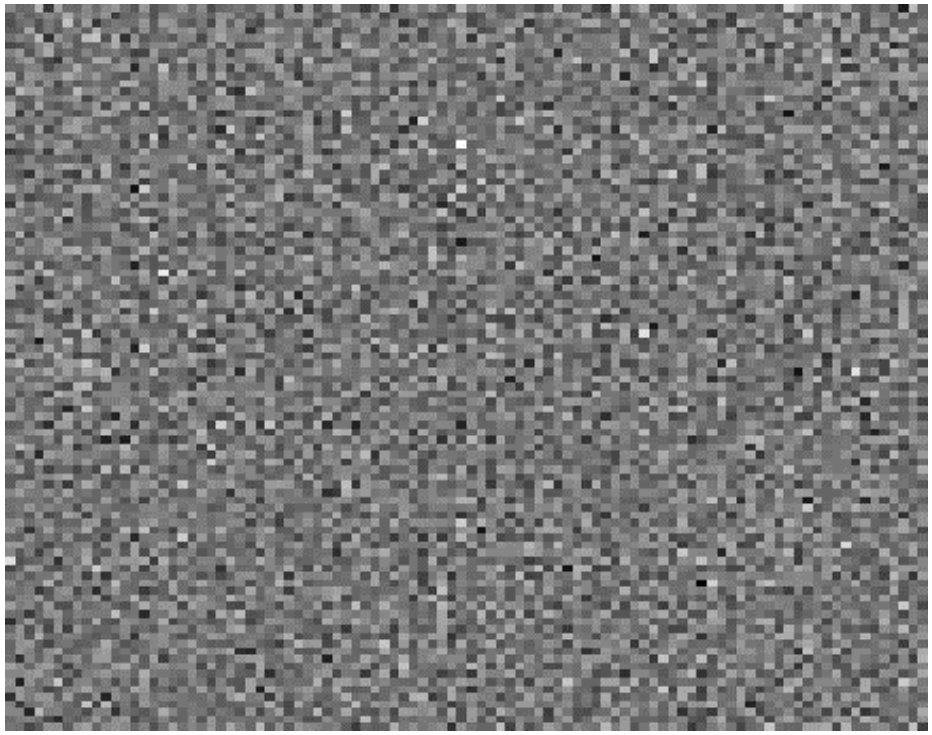
- Expect pushbroom architecture to be photon noise-limited for bright scenes
- Expect spatial white noise spectral density
- SNR proportional to Sqrt of radiance

$$\mathrm{SNR} \propto \sqrt{\mathrm{Radiance}}$$

SNR MTFC ON/MTFC OFF Imagery

NIR Kernel Applied to Simulated Imagery





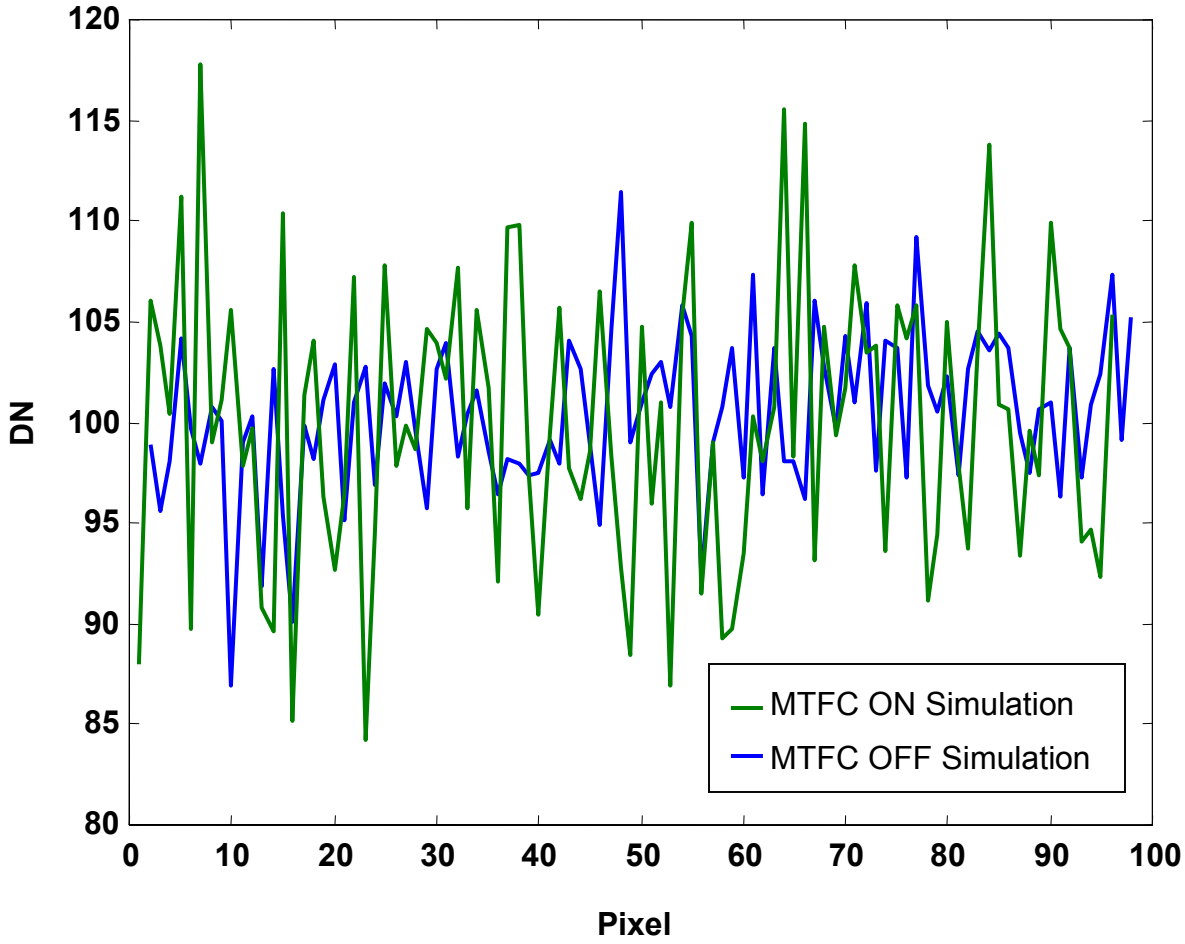
MTFC OFF SNR 25

MTFC ON SNR 13

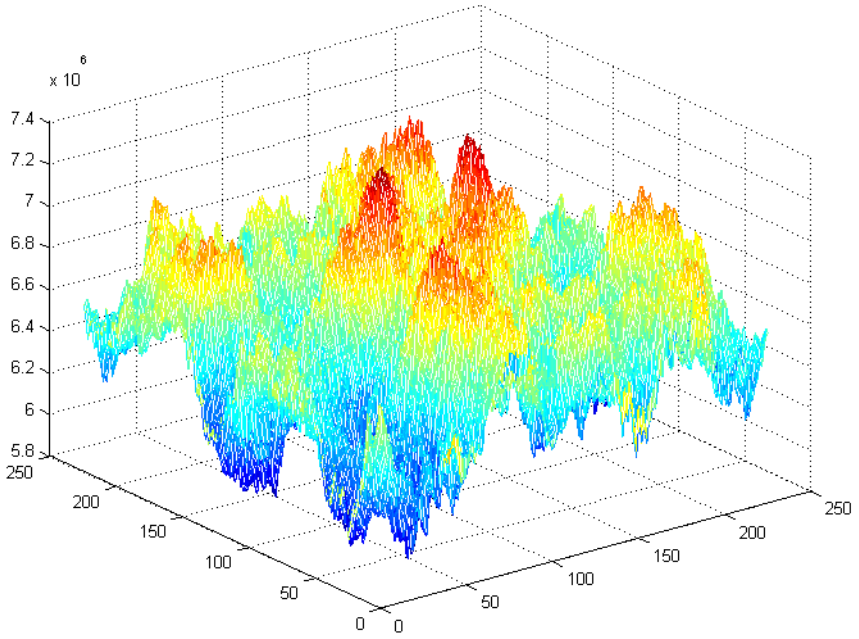
MTFC will lower SNR of a scene

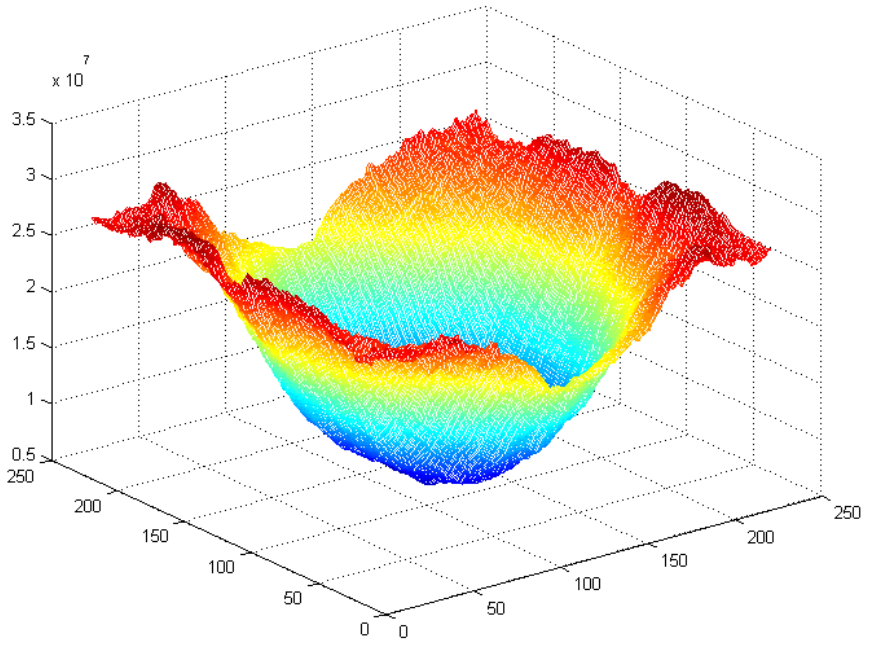
Intercomparison

Cross-section of simulated images



Spatial Noise Spectral Density





"White" Noise Spectra
MTFC Off

"Frequency Dependent" Noise Spectra
NIR MTFC Kernel Applied

MTFC boosts the noise at higher spatial frequencies

MTFC ON and MTFC OFF SNR Intercomparisons

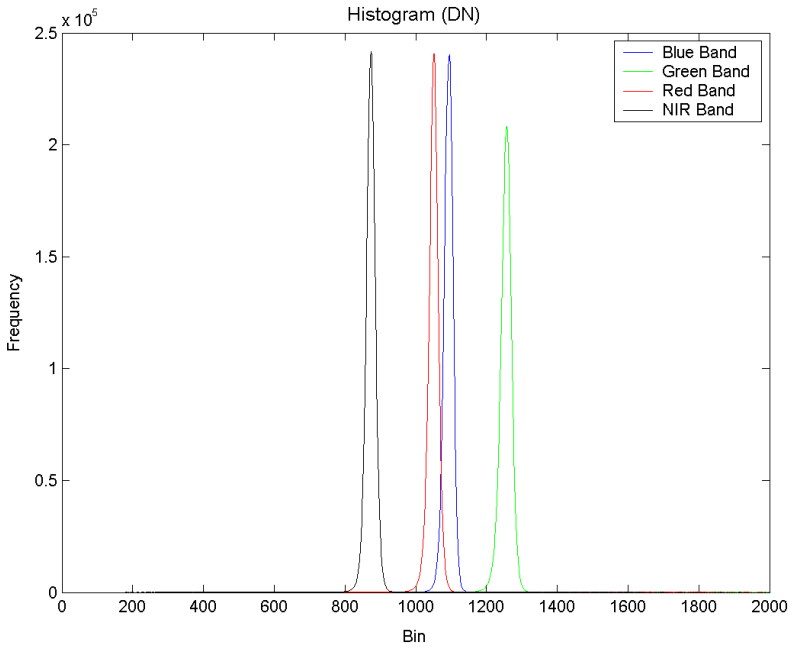
		SNR MTFC On	SNR MTFC Off	Ratio of SNRs (MTFC Off/MTFC On)
Simulated Image	Blue Band	15.3451	24.5302	1.60
	Green Band	15.0248	24.5302	1.63
	Red Band	14.5180	24.5302	1.69
	NIR Band	13.4859	24.5302	1.82

As expected, NIR Band shows the biggest effect.

MTFC and SNR Analysis of IKONOS Scenes

Antarctica Site 1 Uniformity

IKONOS Image 10/05/2000
Task 627, PO ID#52847, MTFC ON



Band	Mean Radiance Value $W/(m^2sr)$	Standard Deviation / Mean (Radiance Values)
1	17.3671	0.0147
2	19.3374	0.0167
3	12.5021	0.0190
4	11.7009	0.0214

% Nonuniformity = 0.0181

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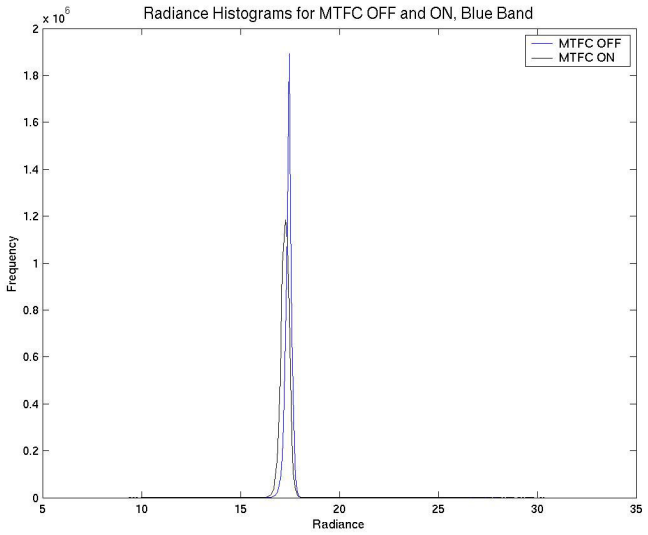
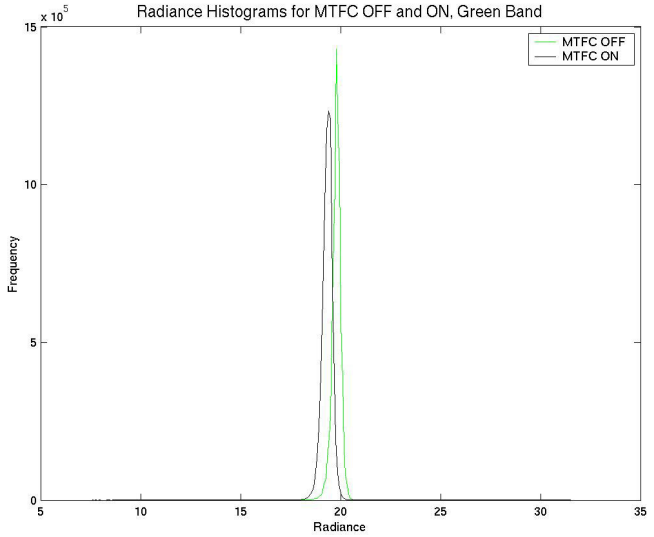
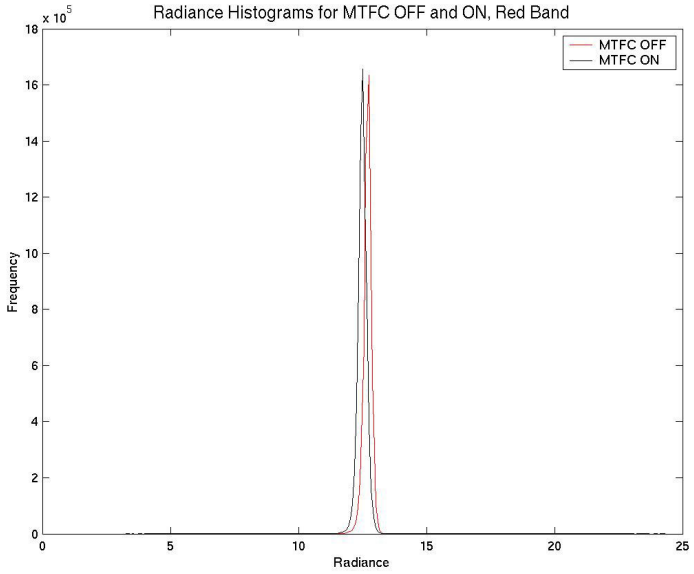
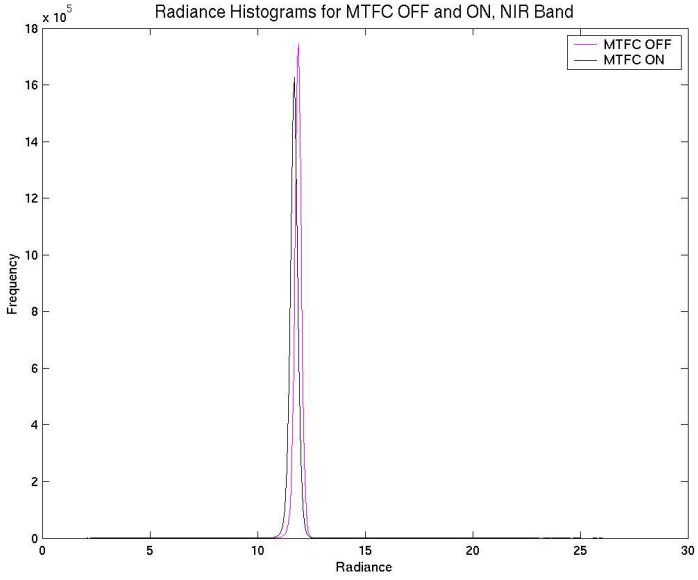
Antarctica Site 1: MTFC ON/OFF Histograms



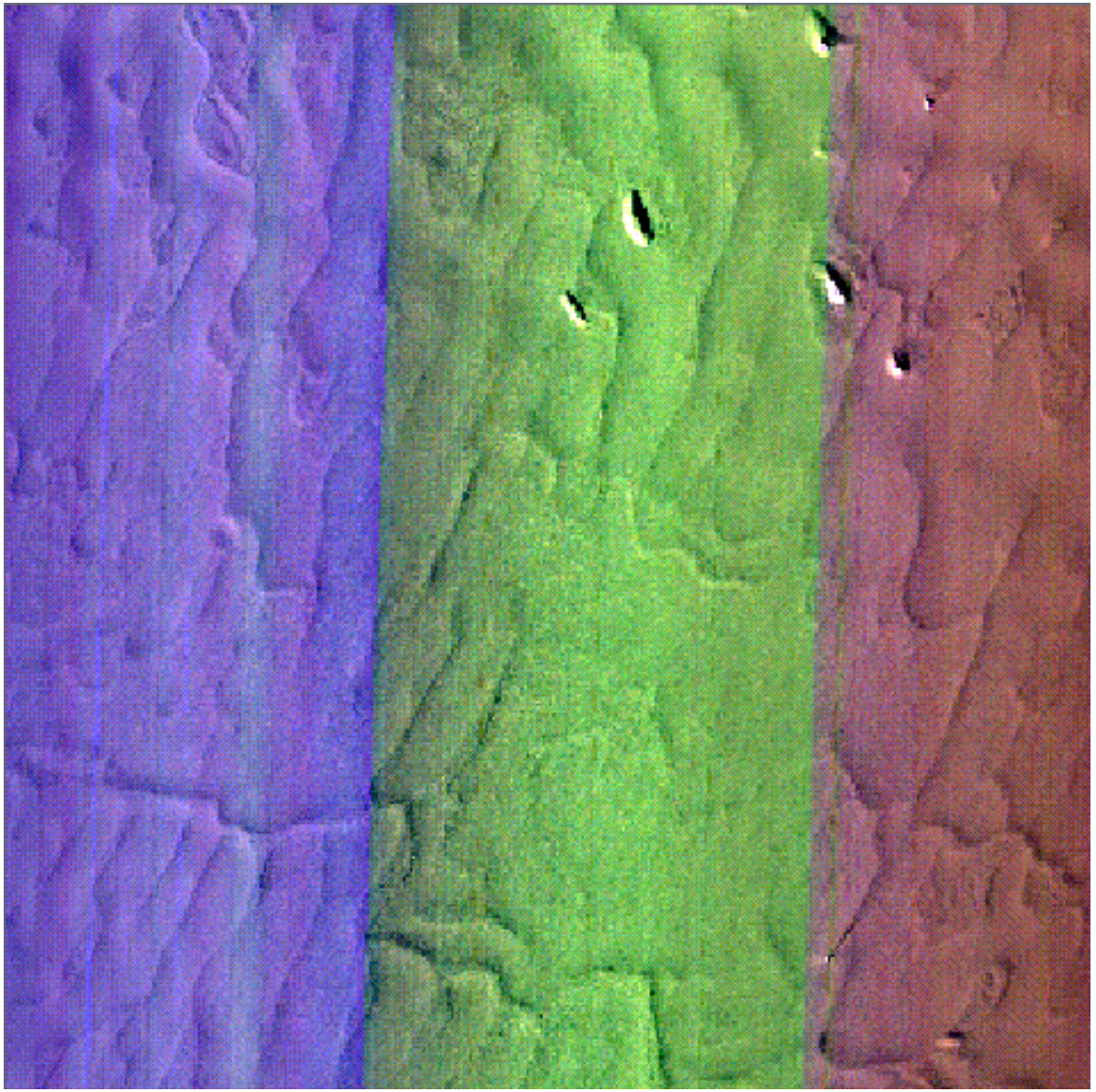






Antarctica Site 1 Difference Imagery

- Change detection image between MTFC On and Off Imagery



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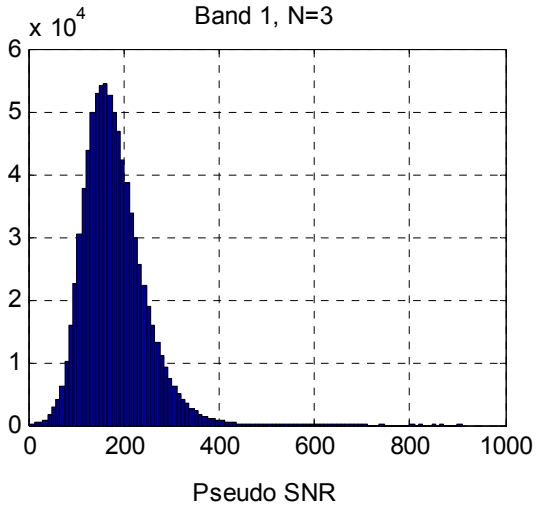
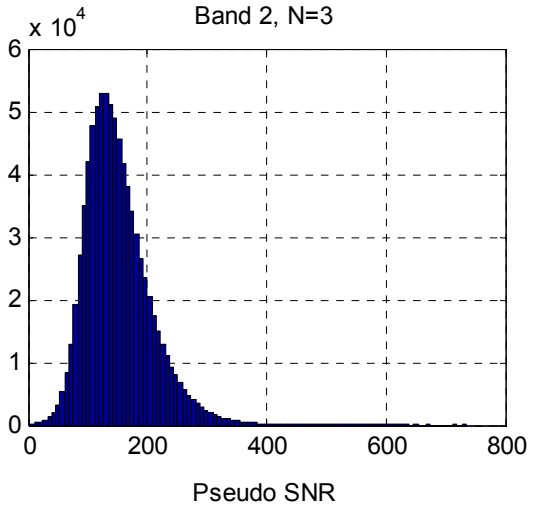
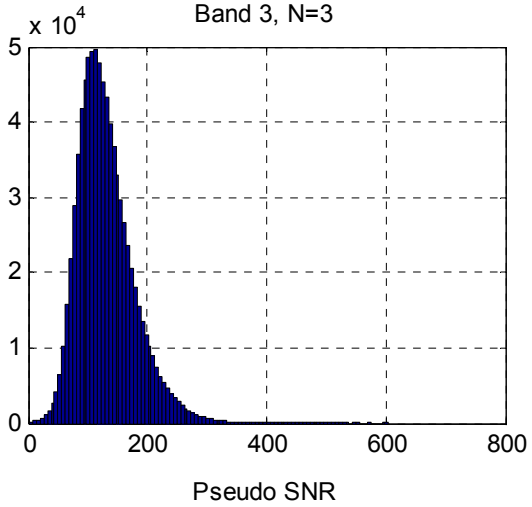
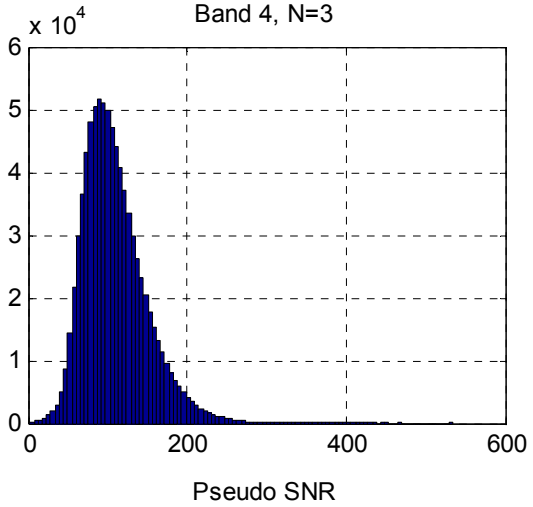
Antarctica Site 1 SNR Estimates

Task 627, PO ID#52847 MTFC ON
3 X 3 Window SNR Estimates



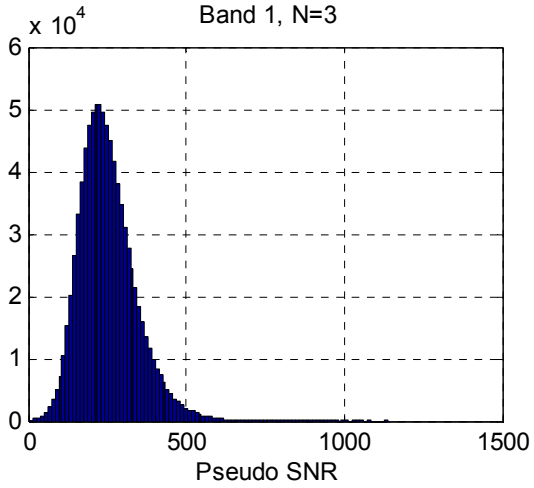


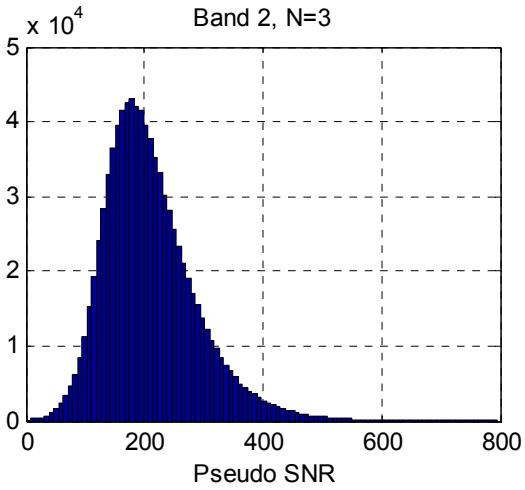


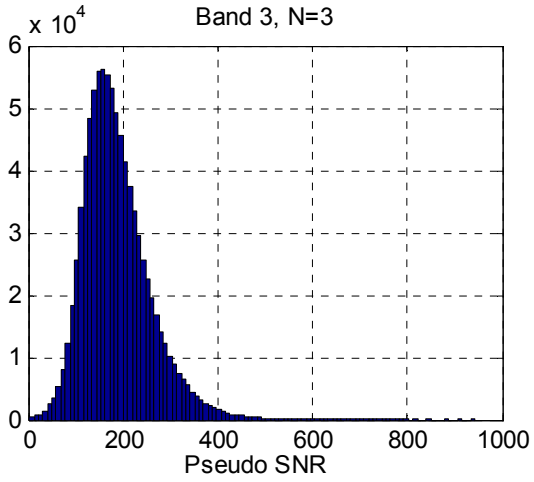


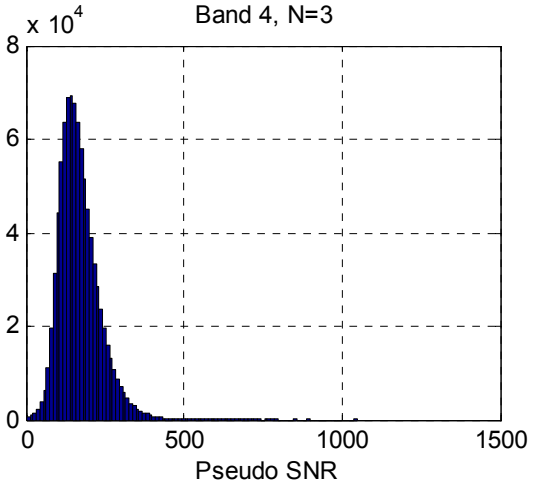
Antarctica Site 1 SNR Estimates

Task 1073, PO ID#70691 MTFC OFF
3 X 3 Window SNR Estimates









Antarctica Site 1 SNR Summary

Task 627, PO ID#52847 MTFC ON

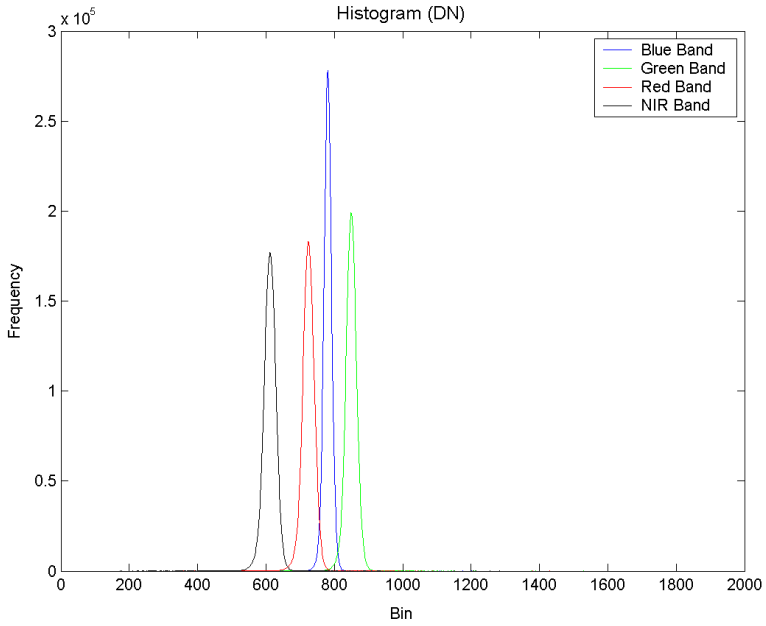
Image po_52847	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	17.2574	158.9590	152.3217	162.1035	0.1086	0.1133	0.1065
Band 2	19.3374	128.2430	125.5815	123.4439	0.1508	0.1540	0.1566
Band 3	12.5021	111.0286	110.2258	113.7190	0.1126	0.1134	0.1099
Band 4	11.7009	87.6125	89.7608	89.6405	0.1336	0.1304	0.1305

Task 1073, PO ID#70691 MTFC OFF

Image po_70691	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	17.4290	204.2186	210.1334	215.0895	0.0853	0.0829	0.0810
Band 2	19.7958	174.5591	167.8688	176.9799	0.1134	0.1179	0.1119
Band 3	12.7007	153.7300	153.9928	158.2200	0.0826	0.0825	0.0803
Band 4	11.8900	134.5521	134.7680	143.4790	0.0884	0.0882	0.0829

Antarctica Site 2 Uniformity

IKONOS Image 12/15/2000
Task 626, PO ID#59798, MTFC ON



Band	Mean Radiance Value $W/(m^2sr)$	Standard Deviation / Mean (Radiance Values)
1	12.4096	0.0154
2	13.0841	0.0196
3	8.6197	0.0248
4	8.1926	0.0300

%Nonuniformity = 0.0231

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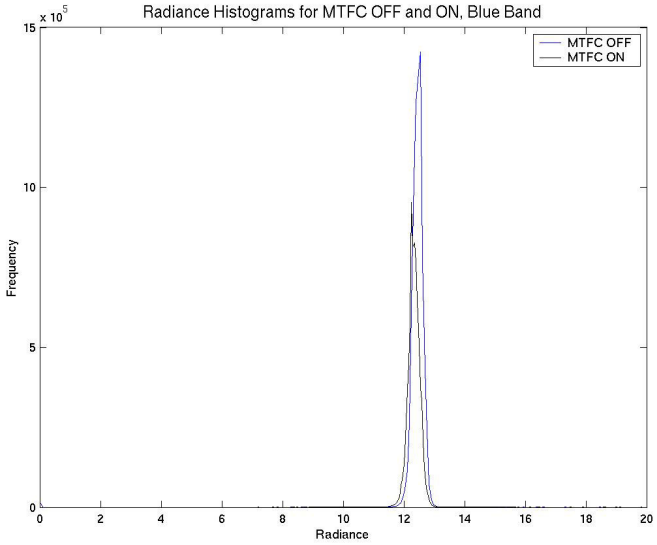
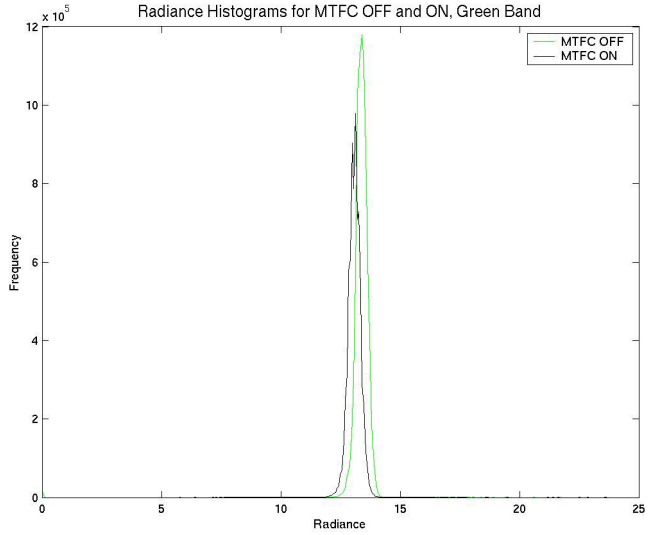
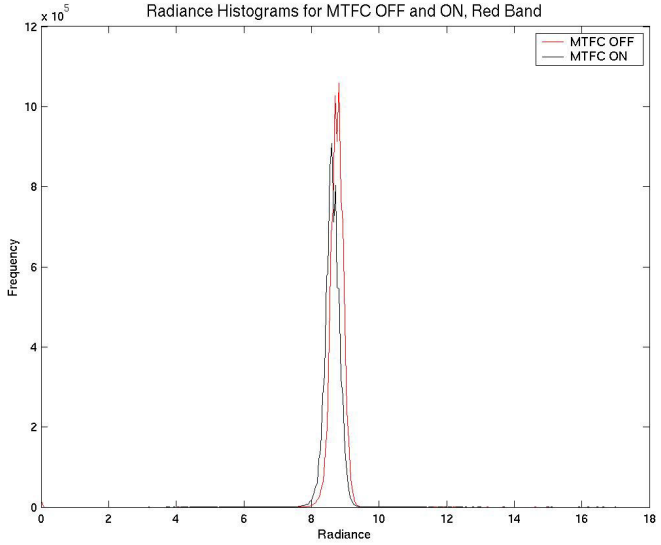
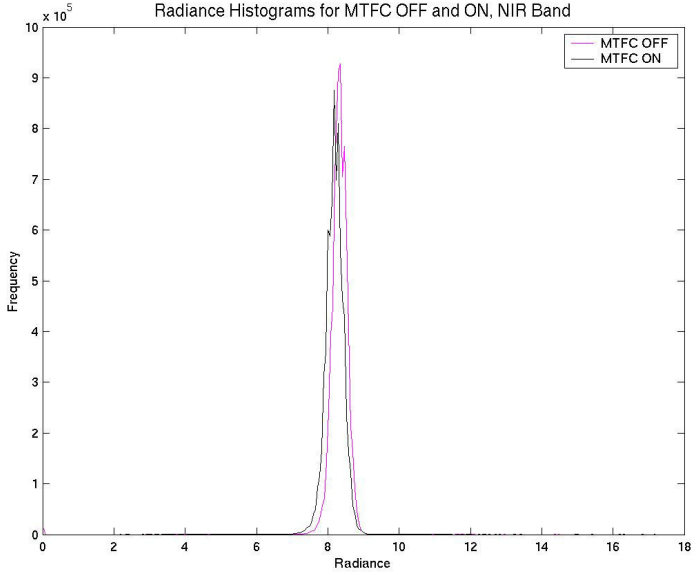
Antarctica Site 2: MTFC ON/OFF Histograms



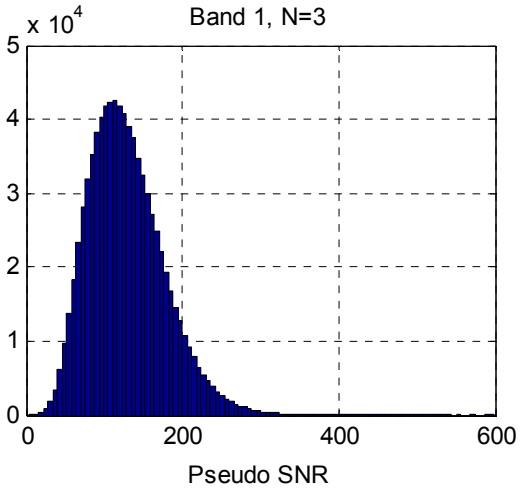


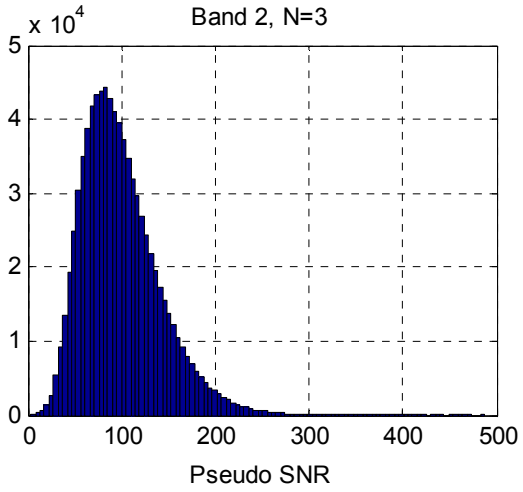


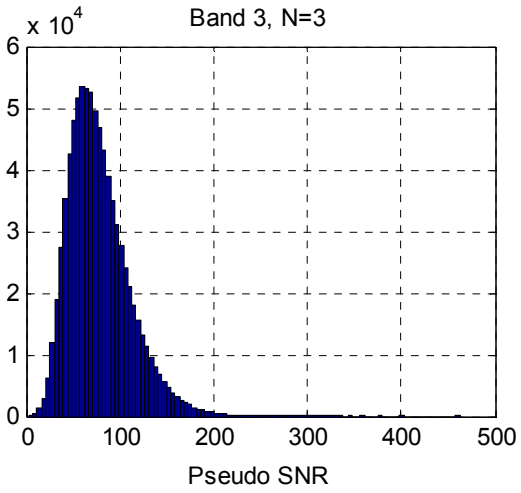


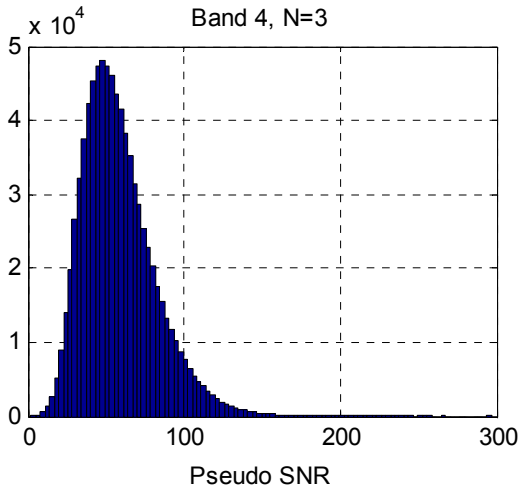
Antarctica Site 2 SNR Estimates

Task 626, PO ID#59798, MTFC ON
3 X 3 Window SNR Estimates



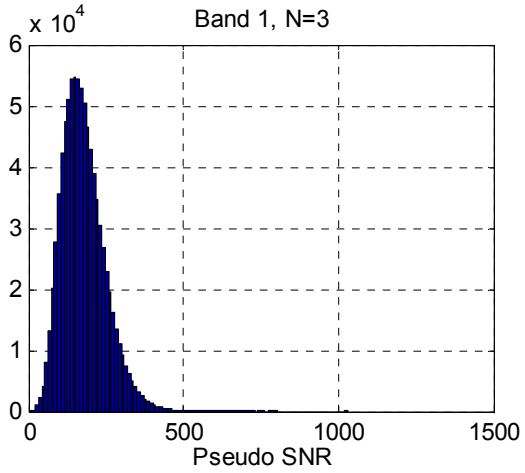


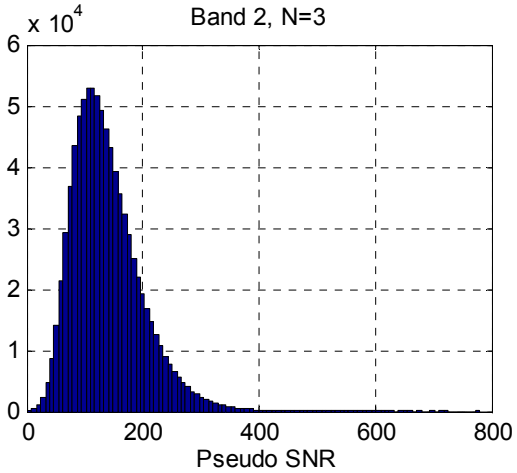


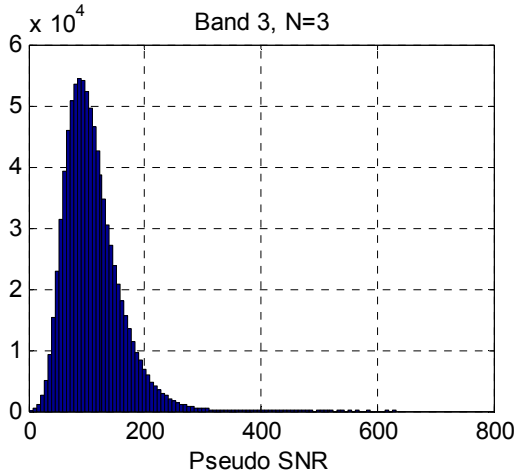


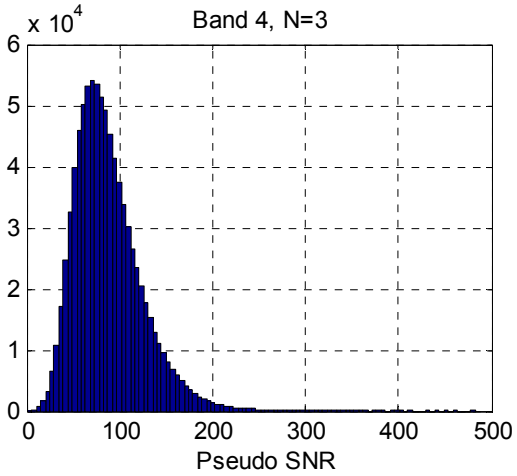
Antarctica Site 2 SNR Estimates

Task 1074, PO ID#70692, MTFC OFF
3 X 3 Window SNR Estimates









Antarctica Site 2 SNR Summary

Task 626, PO ID#59798 MTFC ON

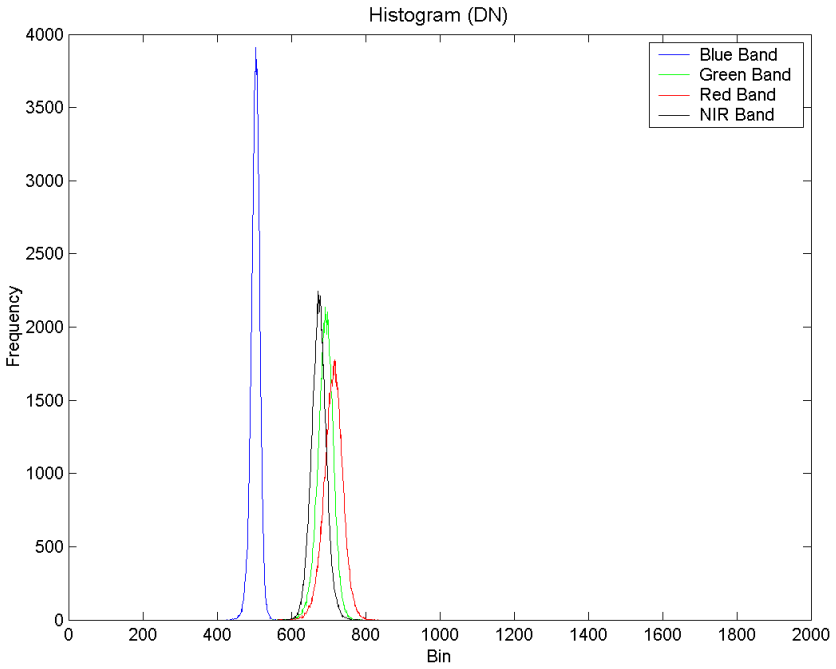
Image po_59798	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	12.3312	105.1424	106.6267	114.0335	0.1172	0.1156	0.1081
Band 2	13.0841	79.9226	78.1604	83.0814	0.1637	0.1674	0.1575
Band 3	8.6197	62.6517	64.9377	60.0106	0.1376	0.1327	0.1436
Band 4	8.1926	48.6615	47.7673	47.8084	0.1684	0.1715	0.1714

Task 1074, PO ID#70692 MTFC OFF

Image po_70692	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	12.4400	138.8677	148.6393	149.9750	0.0896	0.0837	0.0829
Band 2	13.3664	108.7855	109.1108	114.0075	0.1229	0.1225	0.1172
Band 3	8.7443	81.1174	87.6102	86.3378	0.1078	0.0998	0.1013
Band 4	8.3159	72.4791	69.4446	70.7555	0.1147	0.1197	0.1175

Ivanpah, CA Site Uniformity

IKONOS Subimage 7/21/2000
Task 789, PO ID#43117, MTFC ON

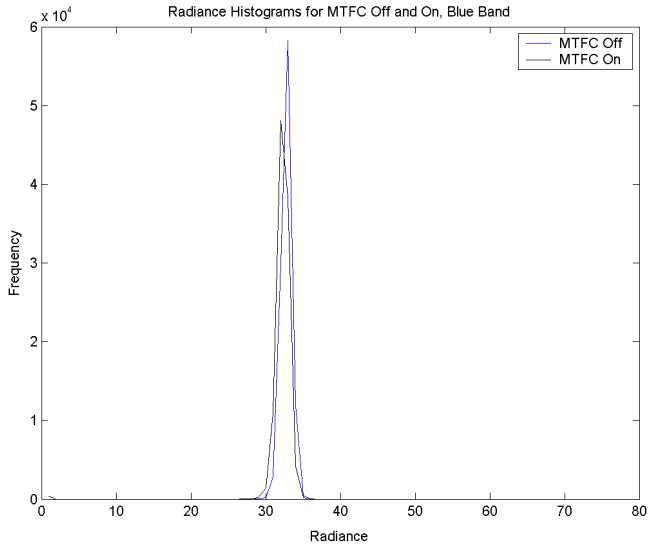


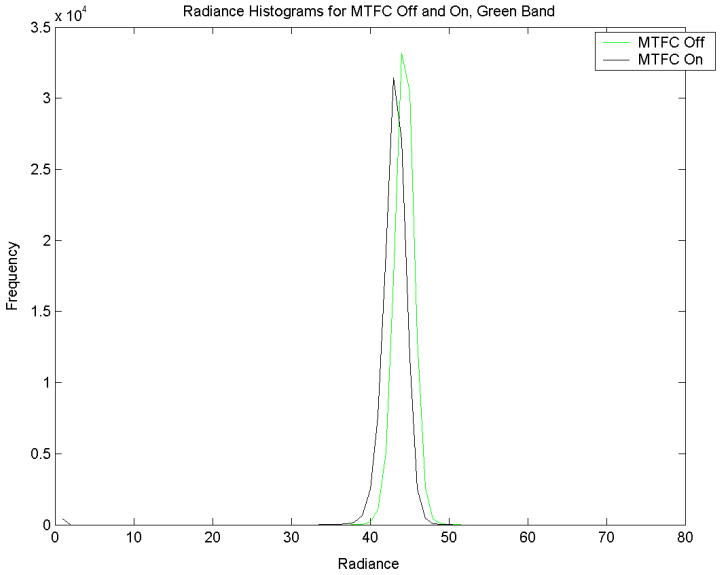
Band	Mean Radiance Value $W/(m^2sr)$	Standard Deviation / Mean (Radiance Values)
1	7.9765	0.0652
2	10.6203	0.0683
3	8.4575	0.0708
4	9.0073	0.0679

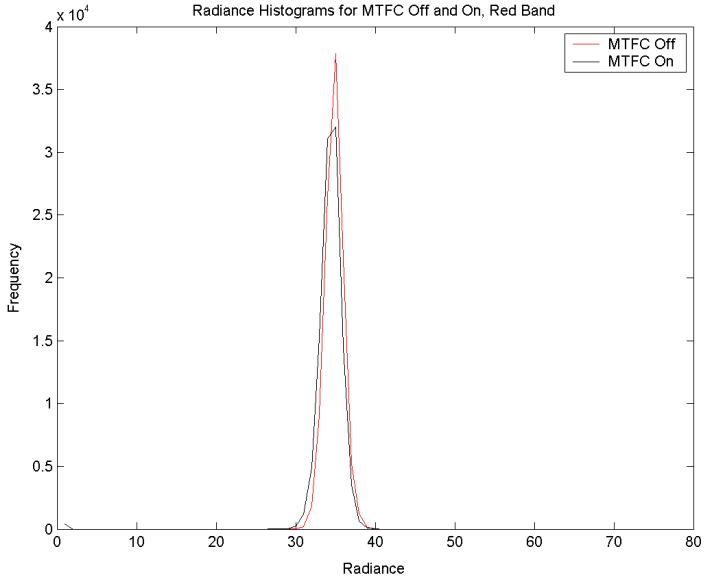
Nonuniformity = 6.8%

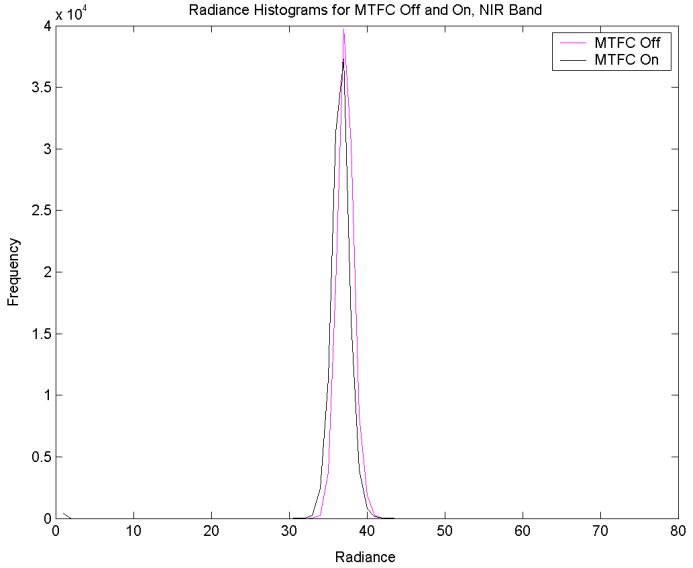
Includes material © Space Imaging LLC

Ivanpah: MTFC ON/OFF Histograms



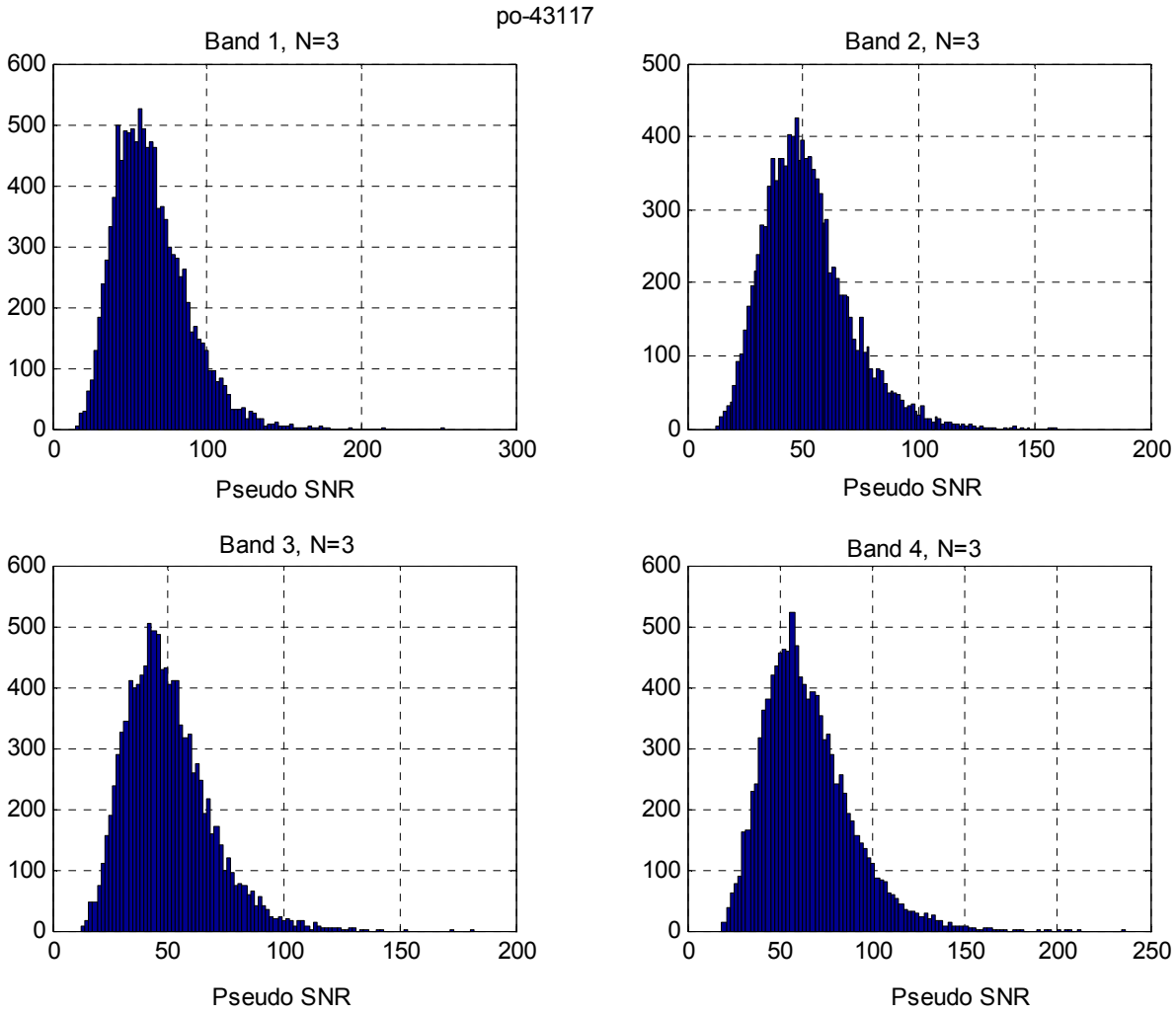






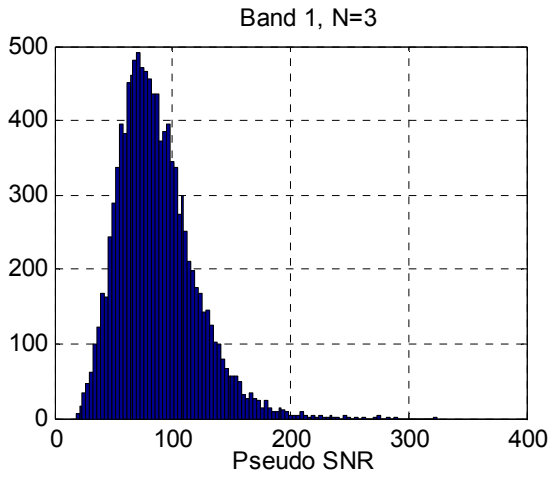
Ivanpah, CA Site SNR Estimates

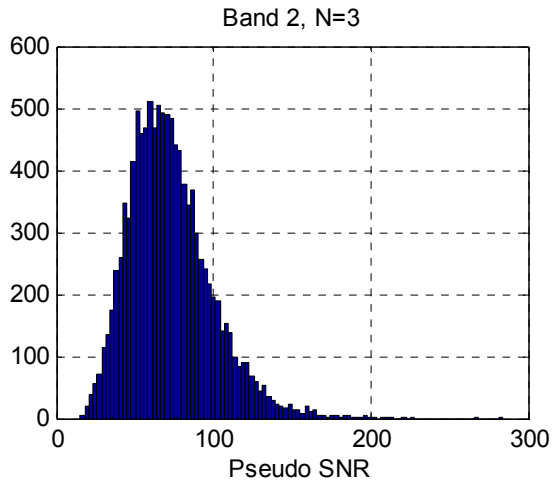
Task 789, PO ID#43117, MTFC ON
3 X 3 Window SNR Estimates

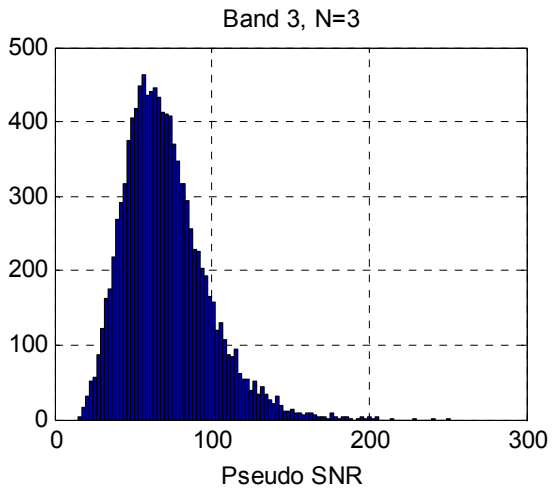


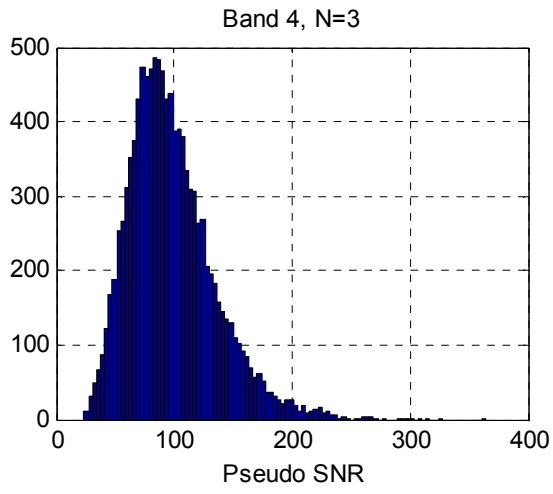
Ivanpah, CA Site SNR Estimates

Task 1075, PO ID#78337, MTFC OFF
3 X 3 Window SNR Estimates









Ivanpah, CA Site SNR Summary

Task 789, PO ID#43117, MTFC ON

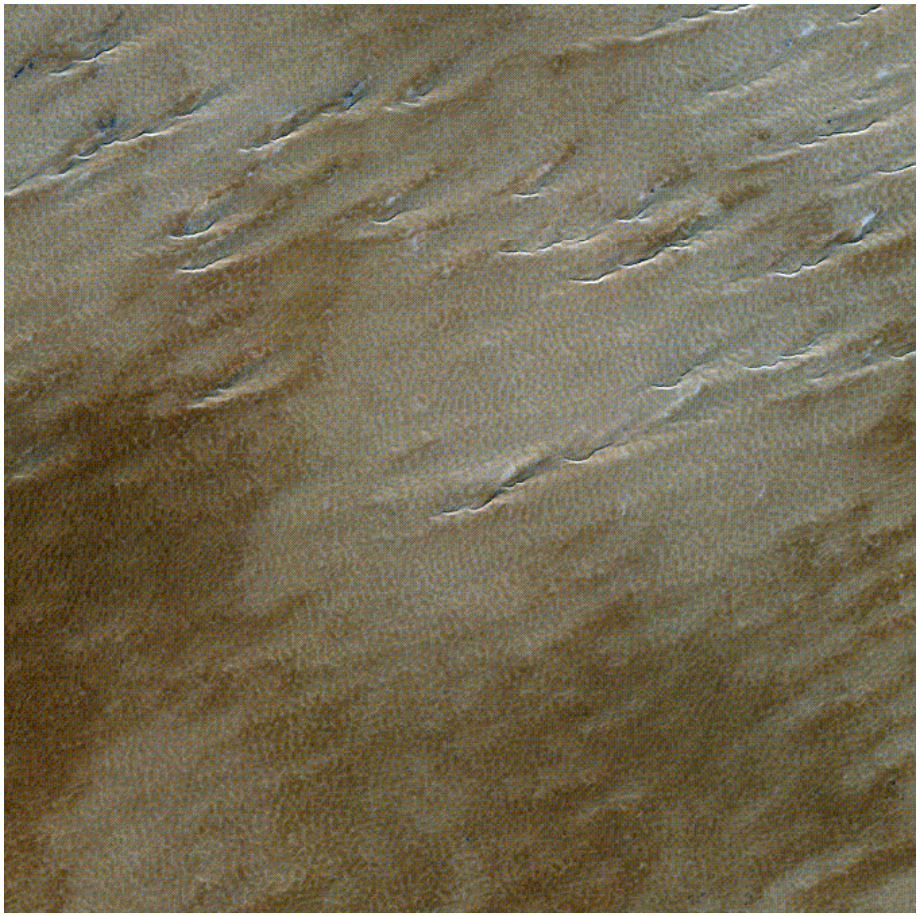
Image po_43117	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	7.9261	48.9298	55.9045	58.3568	0.1620	0.1418	0.1358
Band 2	10.6203	42.5958	44.1581	46.3774	0.2493	0.2405	0.2290
Band 3	8.4575	39.3525	43.1838	43.2600	0.2149	0.1958	0.1955
Band 4	9.0073	58.9569	53.2938	53.5841	0.1528	0.1690	0.1681

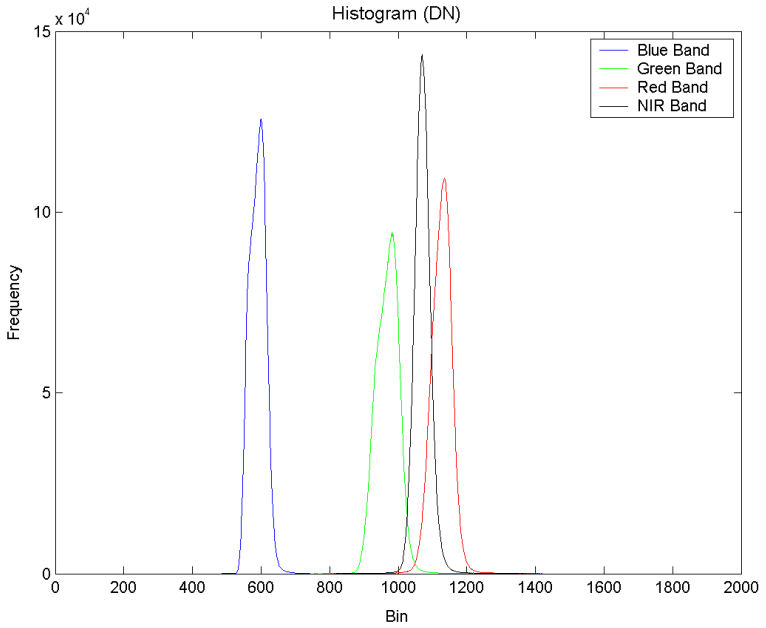
Task 1075, PO ID#78337, MTFC OFF

Image po_43117	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	8.0395	72.3758	64.0194	71.4836	0.1111	0.1256	0.1125
Band 2	10.9177	55.8062	68.8333	59.6598	0.1956	0.1586	0.1830
Band 3	8.5516	57.4001	62.1570	56.5216	0.1490	0.1376	0.1513
Band 4	9.1531	74.6895	78.0307	83.4690	0.1225	0.1173	0.1097

Mali Site Uniformity

IKONOS Image 11/03/2000
Task 895, PO ID#54711, MTFC ON



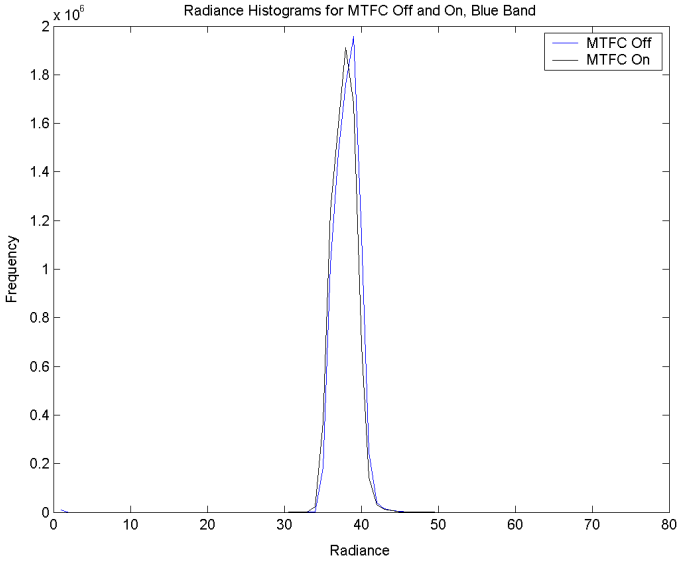


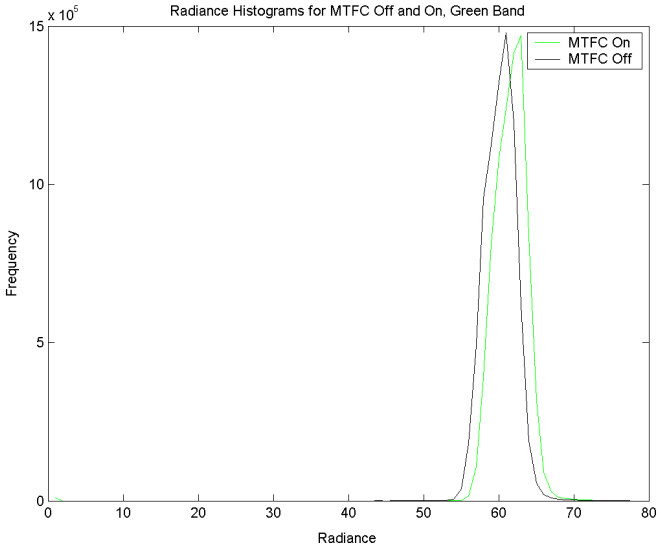
Band	Mean Radiance Value $W/(m^2sr)$	Standard Deviation / Mean (Radiance Values)
1	9.3836	0.0392
2	14.9279	0.0338
3	13.4130	0.0268
4	14.3605	0.0230

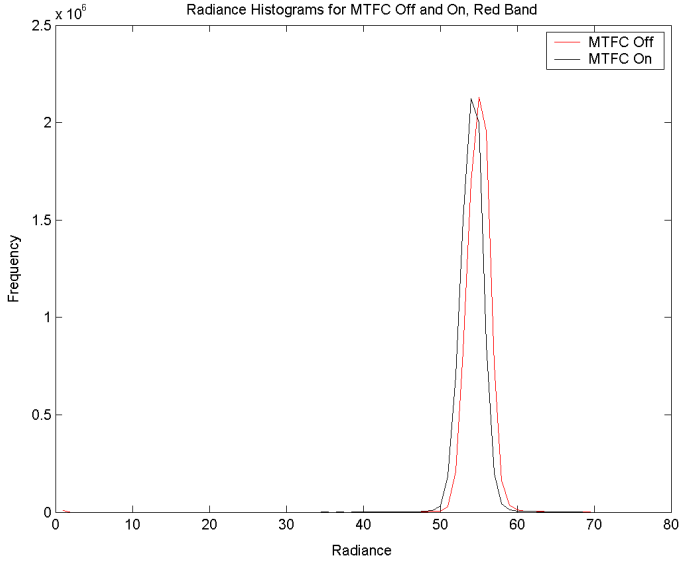
%Nonuniformity = 0.0313

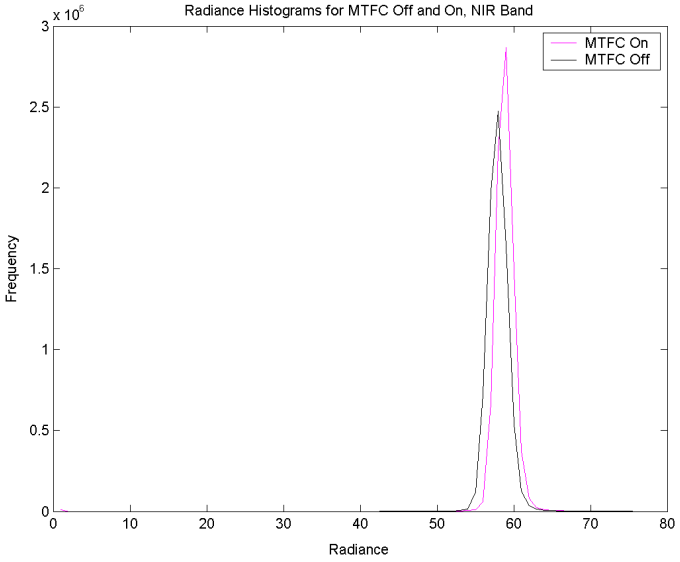
Includes material © Space Imaging LLC

Mali: MTFC ON/OFF Histograms



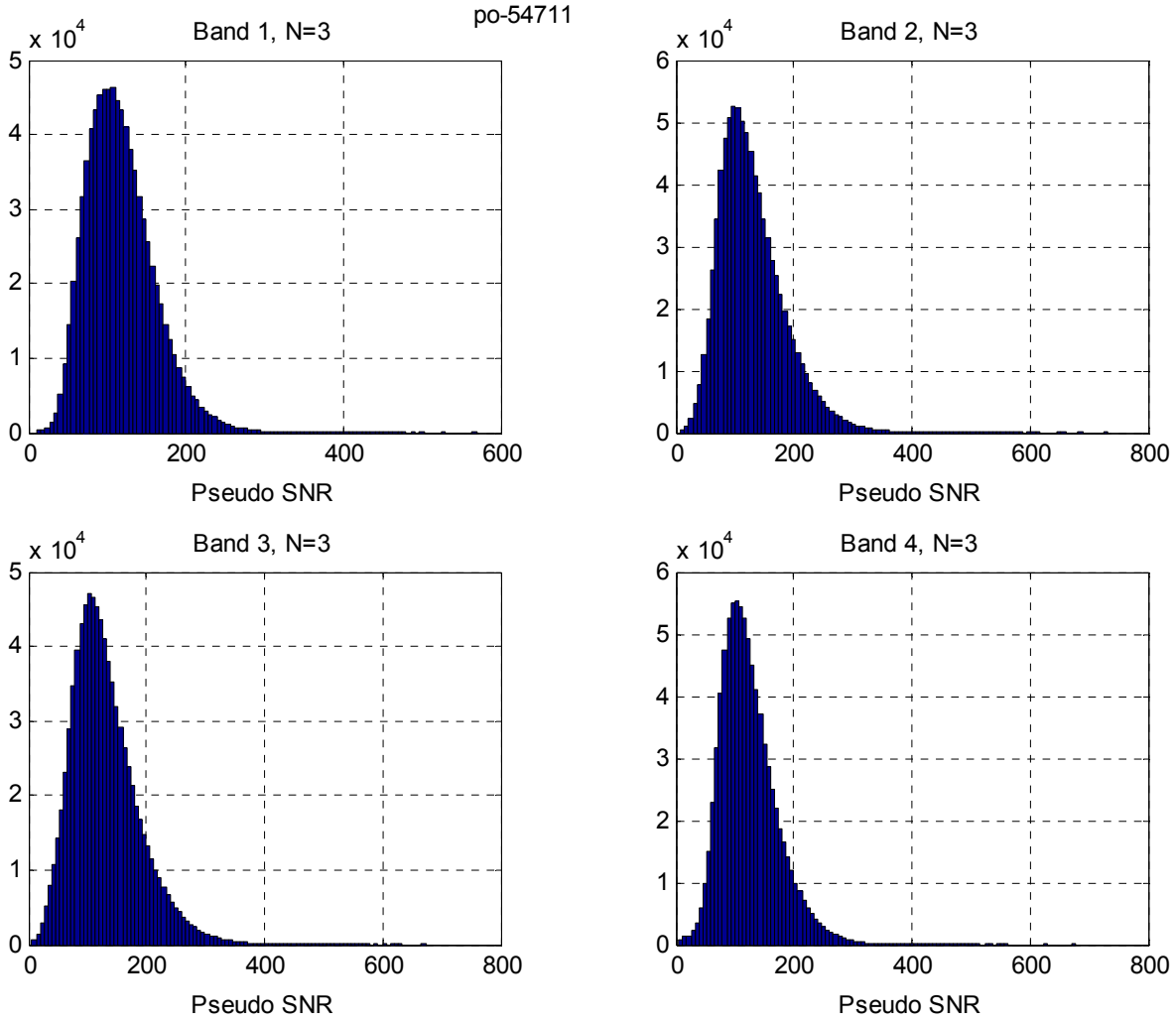






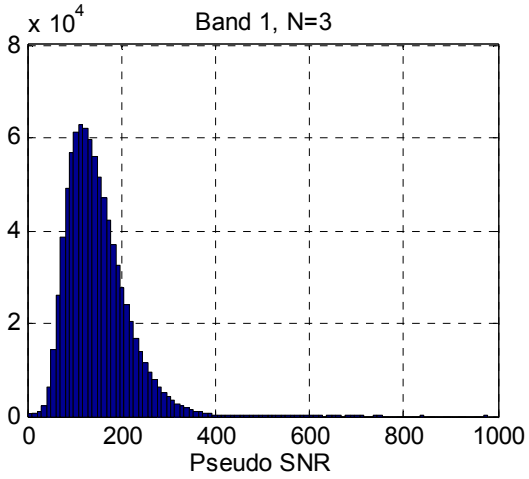
Mali Site SNR Estimates

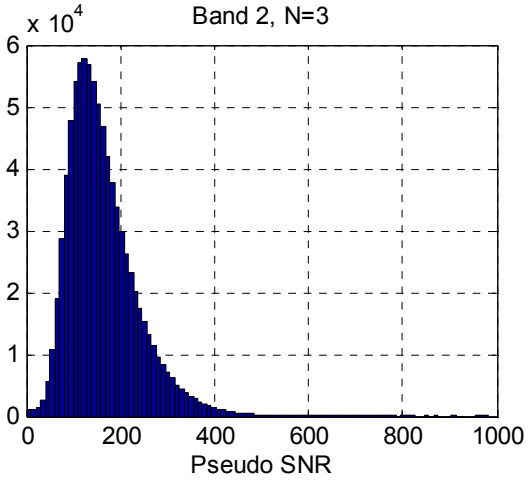
Task 895, PO ID#54711, MTFC ON
3 X 3 Window SNR Estimates

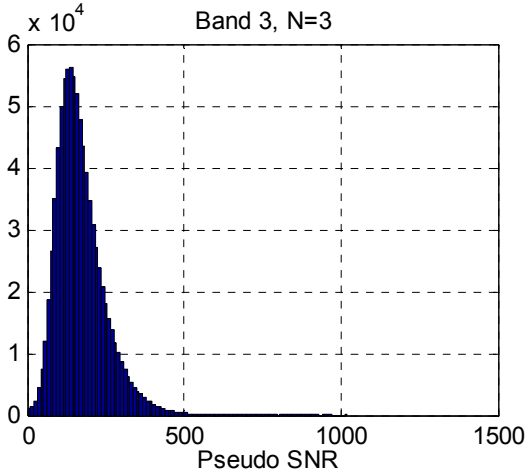


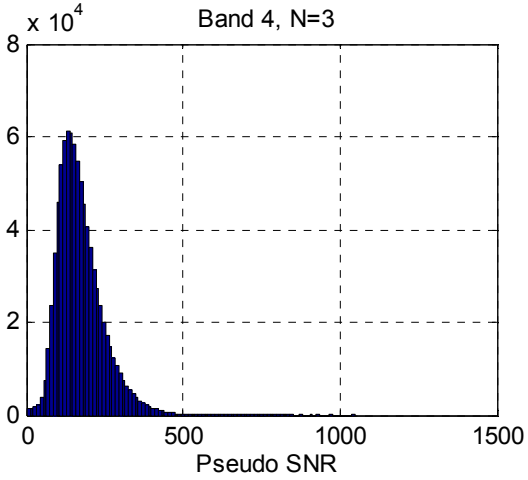
Mali Site SNR Estimates

Task 1076, PO ID#70709, MTFC OFF
3 X 3 Window SNR Estimates









Mali Site SNR Summary

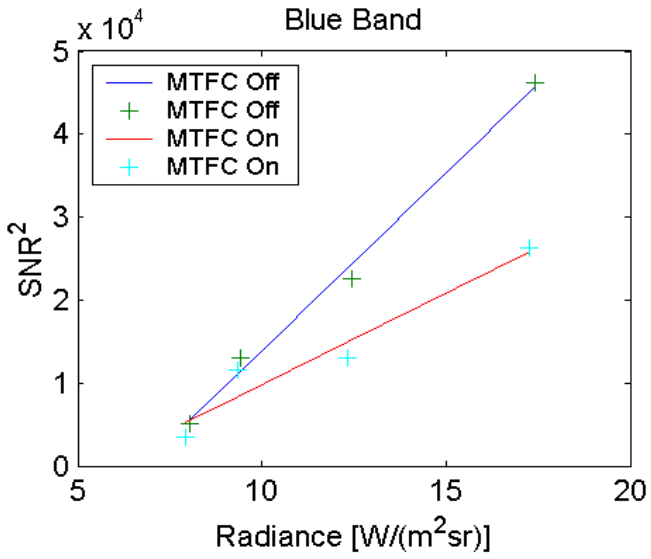
Task 895, PO ID#54711, MTFC ON

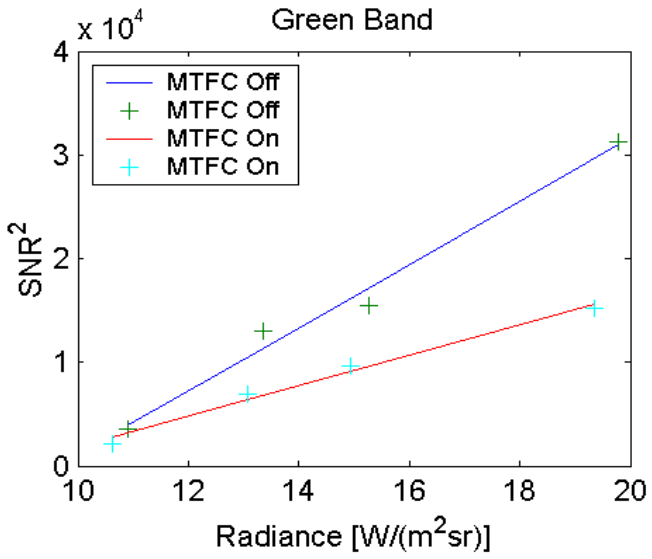
Image po_54711	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	9.3243	68.2870	82.5735	107.7011	0.1365	0.1129	0.0866
Band 2	14.9279	74.6577	88.2893	98.1259	0.2000	0.1691	0.1521
Band 3	13.4130	83.4950	97.7621	102.9711	0.1606	0.1372	0.1303
Band 4	14.3605	87.0275	92.9471	102.9551	0.1650	0.1545	0.1395

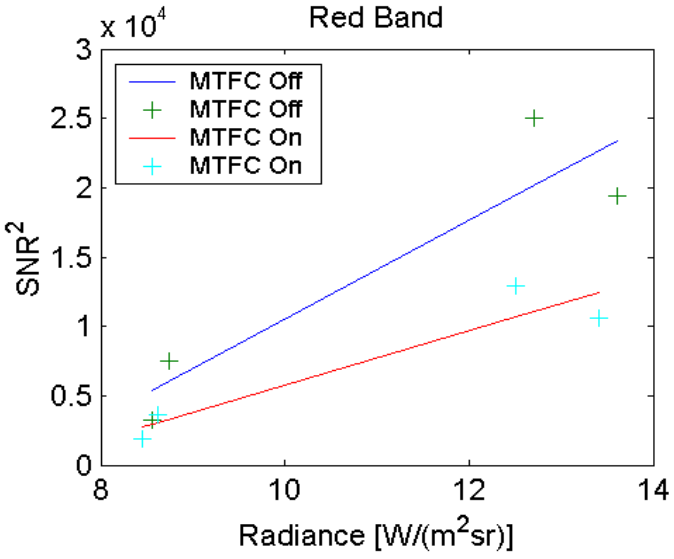
Task 1076, PO ID#70709, MTFC OFF

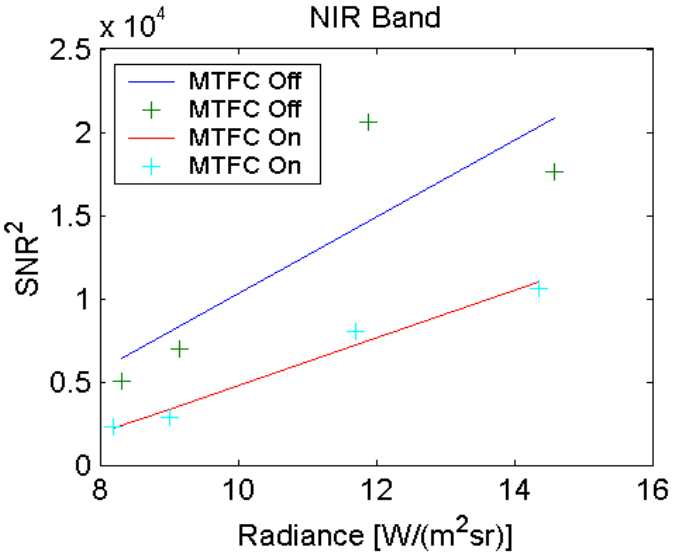
Image po_54711	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	9.4034	78.9816	94.1276	114.1455	0.1191	0.0999	0.0824
Band 2	15.2559	85.2664	106.4566	124.3069	0.1789	0.1433	0.1227
Band 3	13.6123	98.5840	116.0474	139.1695	0.1381	0.1173	0.0978
Band 4	14.5732	101.2879	121.4520	132.7356	0.1439	0.1200	0.1098

SNR^2 vs. Mean Radiance









SNR Difference Summary

		SNR MTFC On	SNR MTFC Off	Ratio (Off/On)
Antarctica	Band 1	162.1035	215.0895	1.3269
	Band 2	123.4439	176.9799	1.4337
	Band 3	113.7190	158.2200	1.3913
	Band 4	89.6405	143.4790	1.6006
Antarctica	Band 1	114.0335	149.9750	1.3152
	Band 2	83.0814	114.0075	1.3722
	Band 3	60.0106	86.3378	1.4387
	Band 4	47.8084	70.7555	1.4800
Ivanpah	Band 1	58.3568	71.4836	1.2249
	Band 2	46.3774	59.6598	1.2864
	Band 3	43.2600	56.5216	1.3066
	Band 4	53.5841	83.4690	1.5577
Mali	Band 1	107.7011	114.1455	1.0598
	Band 2	98.1259	124.3069	1.2668
	Band 3	102.9711	139.1695	1.3515
	Band 4	102.9551	132.7356	1.2893

The difference ratios follow the same trend as those for the simulated imagery, however, they don't agree quantitatively.

Summary

- SNR increases as expected with radiance for MTFC ON and MTFC OFF imager
- MTFC OFF imagery is showing higher SNR than MTFC ON
  - Blue Band between 5% and 25% higher
  - Green Band between 21% and 31% higher
  - Red Band between 23% and 31% higher
  - NIR Band between 22% and 38% higher
- Theoretical estimates are approximately 50% higher
- Compression effects are not easily identified and have not yet been quantified
  - Bright uniform scenes seem to minimize effects
- MTFC Off data could be preferable for performing quantitative work requiring high SNR
- MTFC On data is in general preferable when performing visual inspection
- Slight absolute radiometric shifts between pre 2/22/01 and post 2/22/01 calibration have been observed