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

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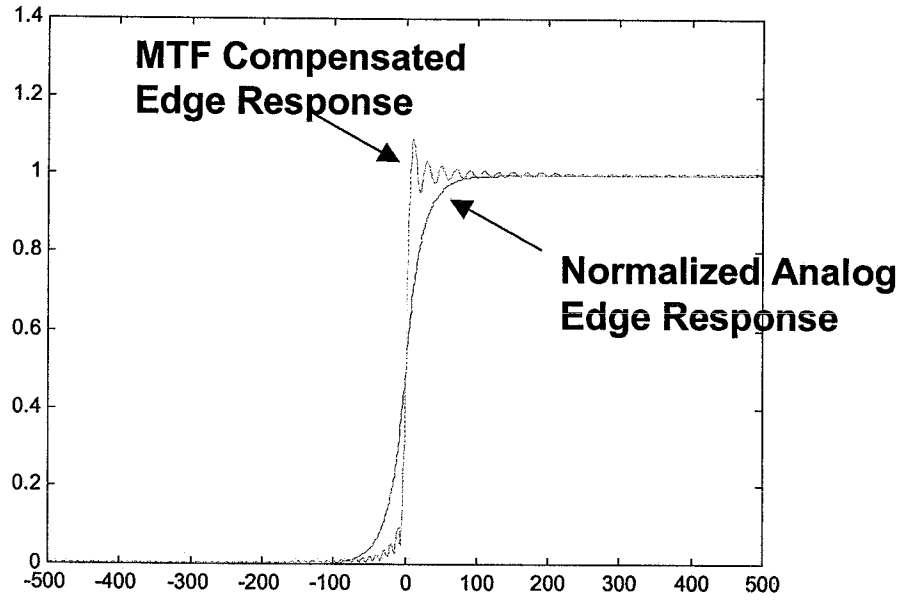
Introduction

- **Signal-to-Noise Ratio (SNR) is a critical parameter that drives the utility of imagery**
  - Various image processing algorithms affect the SNR (MTFC, compression, etc.)
- **Users have no access to engineering data to assess SNR**
  - For SNRs less than ~150, uniform areas can be used for on-orbit estimation of a system's SNR
- **This presentation will focus on the differences in SNR estimation between MTFC On imagery and MTFC Off imagery**

MTF Compensation (MTFC)

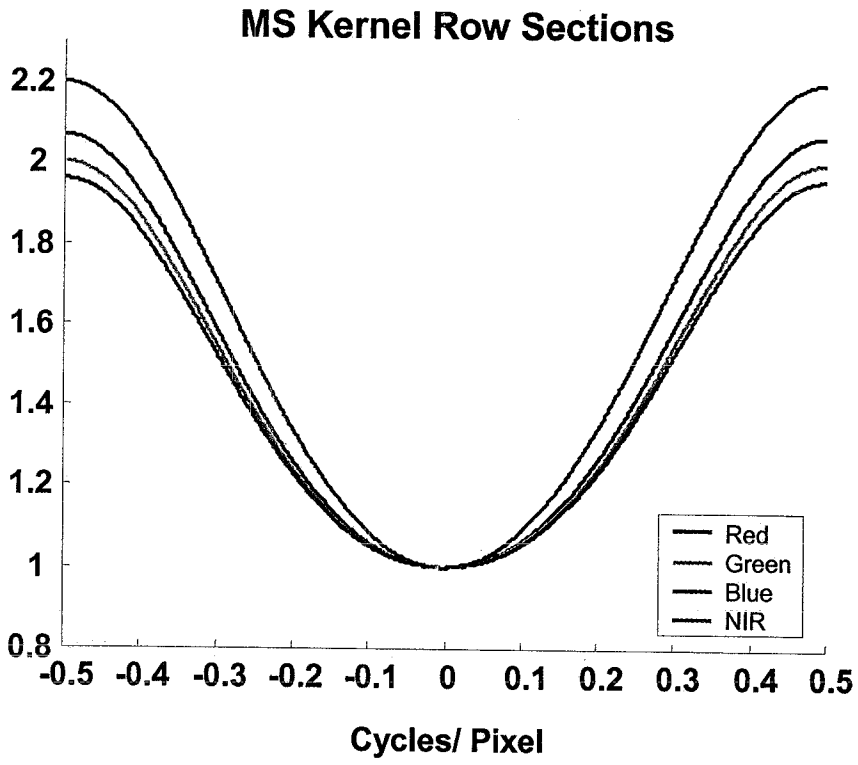
- MTFC is an edge sharpening technique used to partially restore image degradation caused by imperfections in the imaging process
- Results in sharpness of edge features within image
- Significantly affects radiometry of some pixels
- **Lowers SNR of scene**
- MTFC is applied to all IKONOS imagery unless otherwise requested

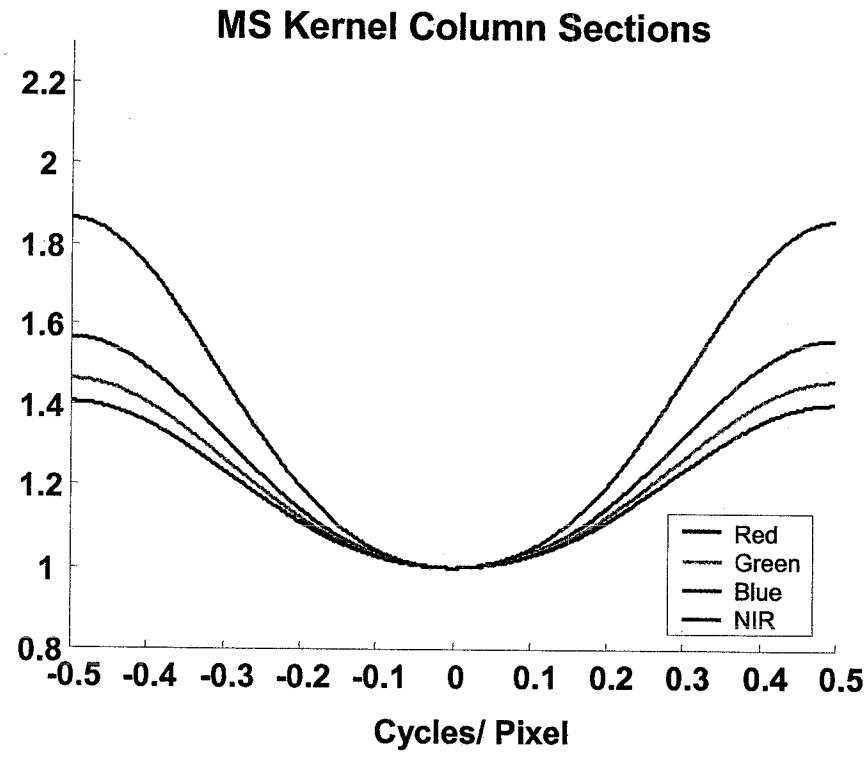
Simulated Edge Response



MTFC sharpens edges but can produce overshoot and ringing

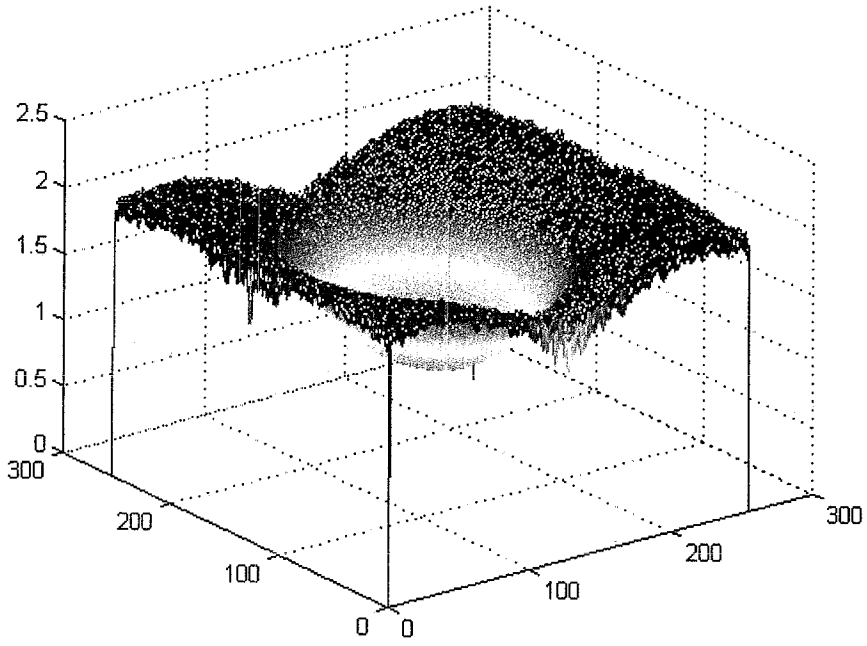
MTFC MS Band Comparisons

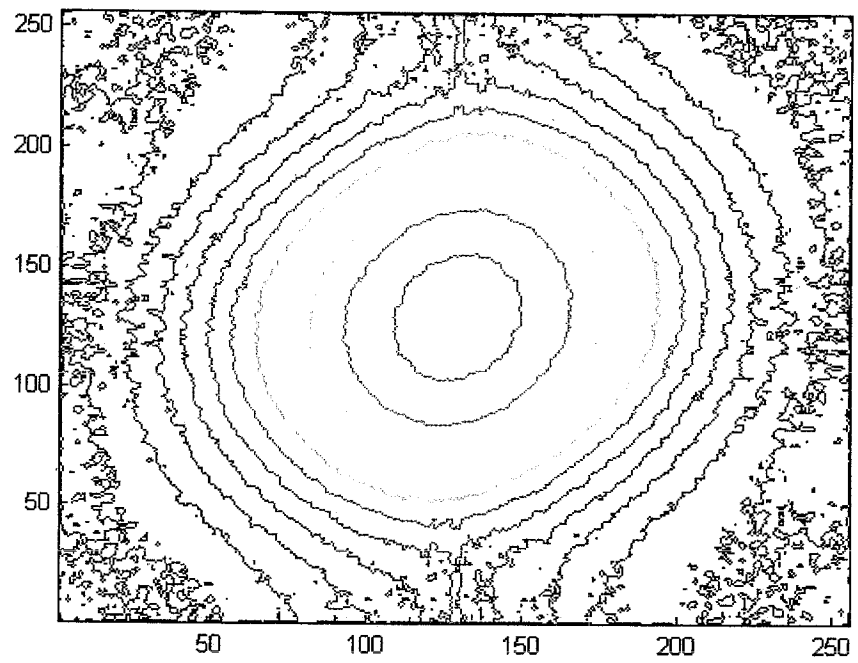




MTFC compensation increases with increasing wavelength

Estimated MS NIR MTFC





Estimated MTFC Function for the MS NIR Image

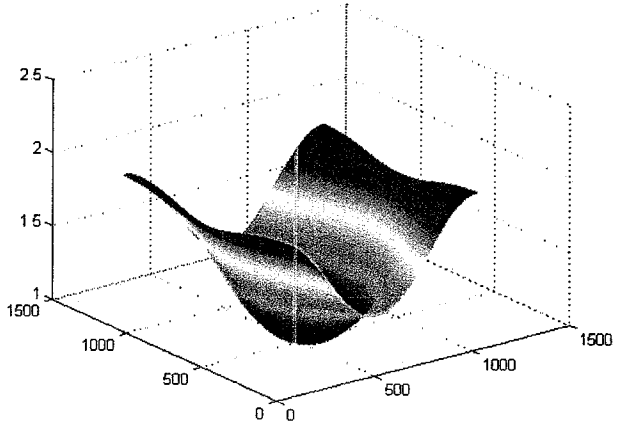
Stronger compensation in row direction

MS NIR MTFC Contour

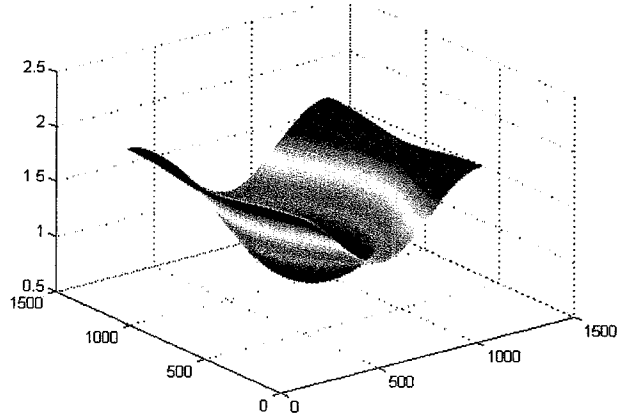
Rotation appears to be geometric correction effect

MTFC MS Kernels

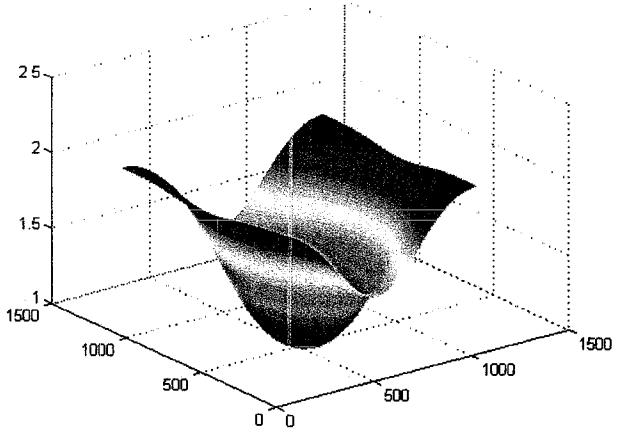
Blue Kernel



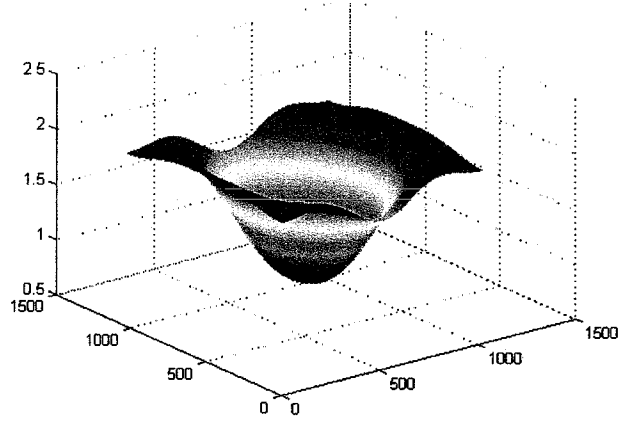
Green Kernel



Red Kernel



NIR Kernel



Row MTFC is stronger than column MTFC

Phoenix MTFC ON/MTFC OFF RGB Comparison

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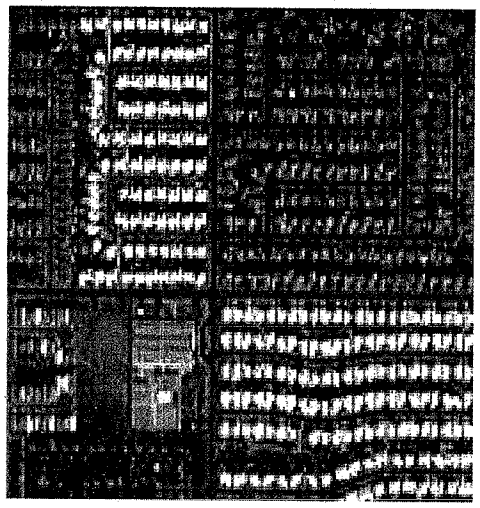
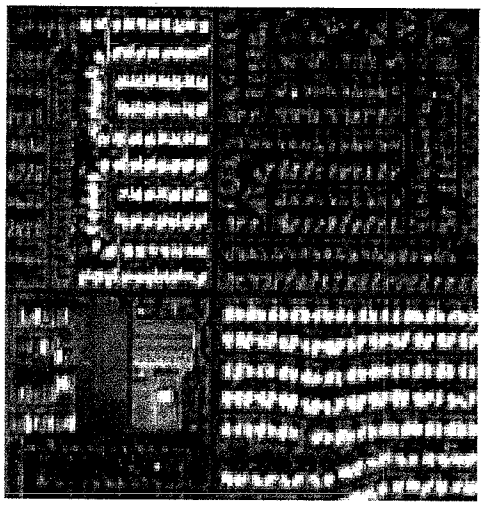
4-m Multispectral Imagery Acquired October 12, 1999

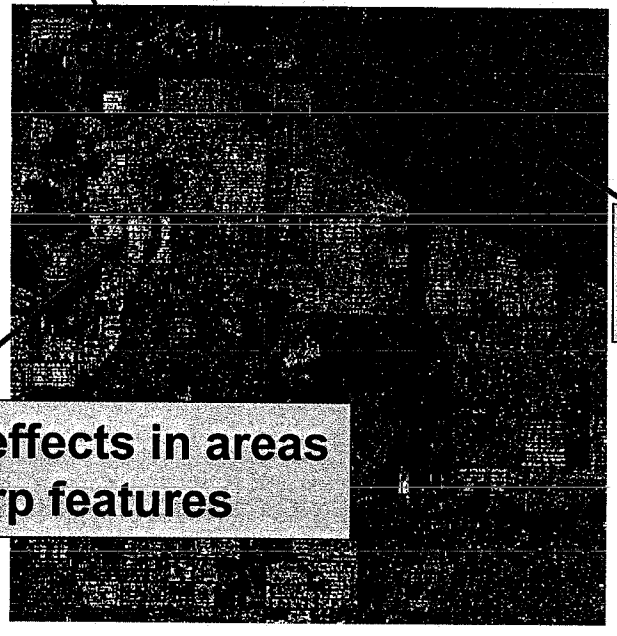
MTFC ON



MTFC OFF



Abs (MTFC ON - MTFC OFF)



Smallest effects in uniform areas

Largest effects in areas with sharp features

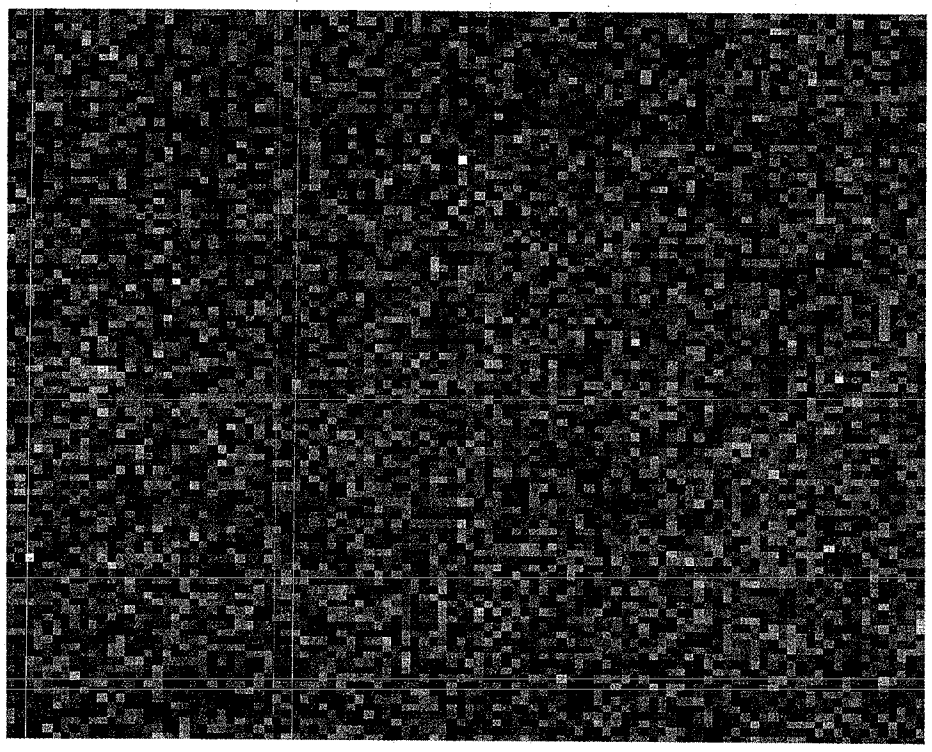
Includes material © Space Imaging, L.P.

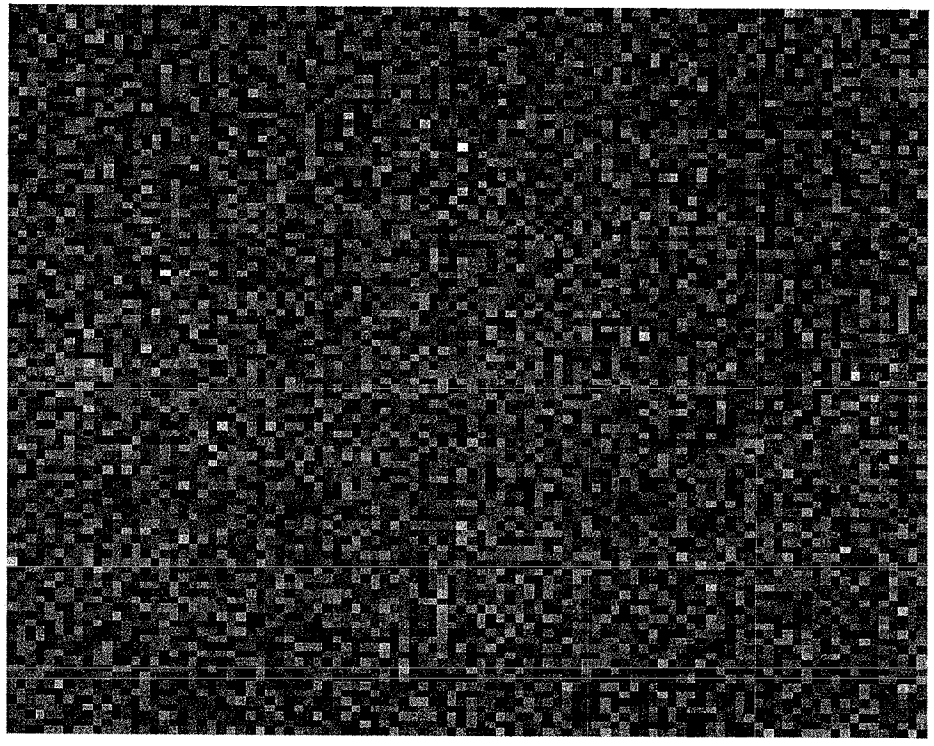
MTFC Analysis using Simulated Scene

- 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 MTFC ON/MTFC OFF Imagery

NIR Kernel Applied to Simulated Imagery





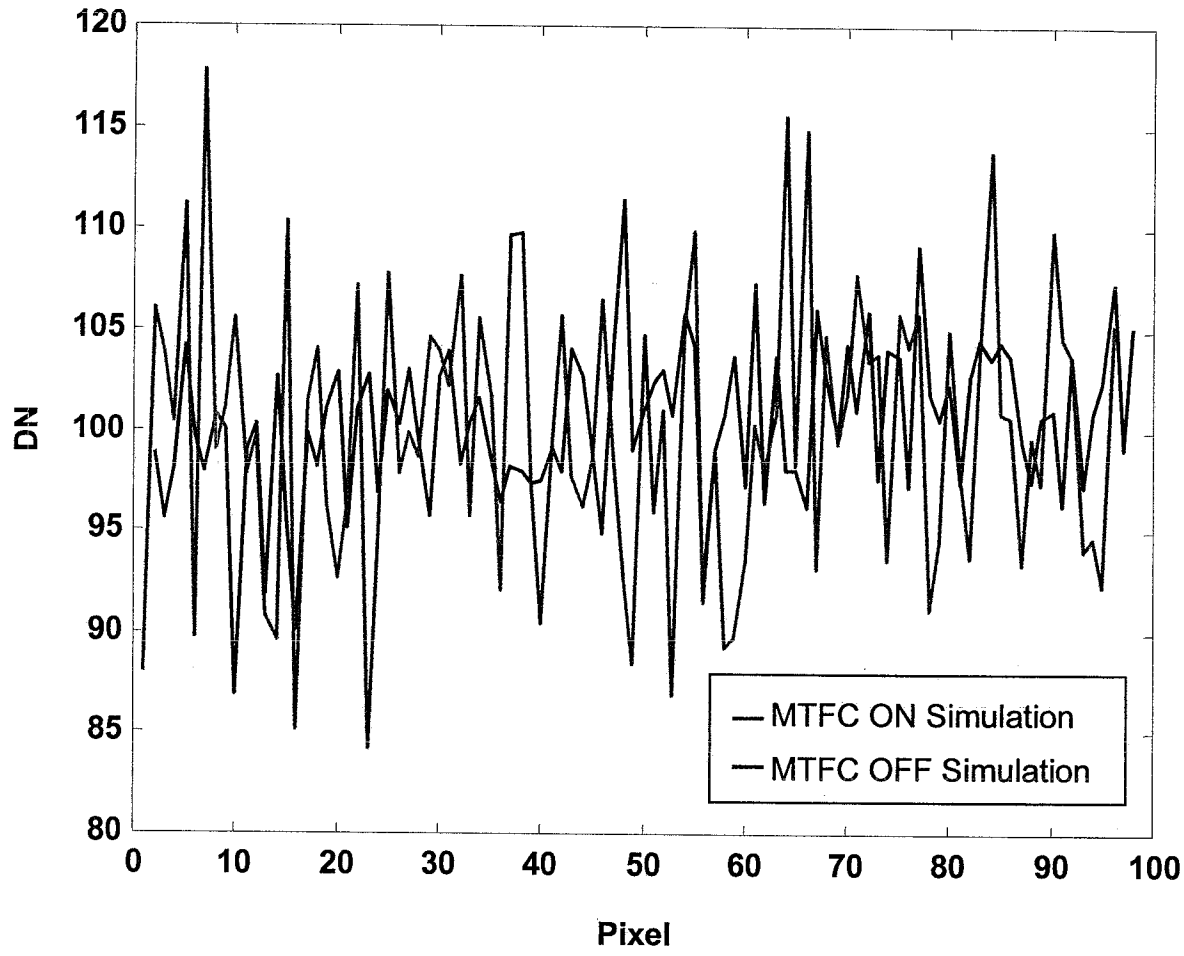
MTFC OFF SNR 25

MTFC ON SNR 13

MTFC will lower SNR of a scene

Intercomparison

Cross-section of simulated images



Intercomparisons

Insert FFTs of simulated images with and without MTFC

In-Flight SNR Estimation

Suppose we had a perfectly uniform scene. What limits our ability to measure the scene?

- **Sensor Artifacts**
  - FPA Nonuniformity
  - SNR

- **In principle, very uniform scenes can be used to estimate the SNR of an instrument**
  - This method has been used for Landsat and other sensors

SNR Methodology

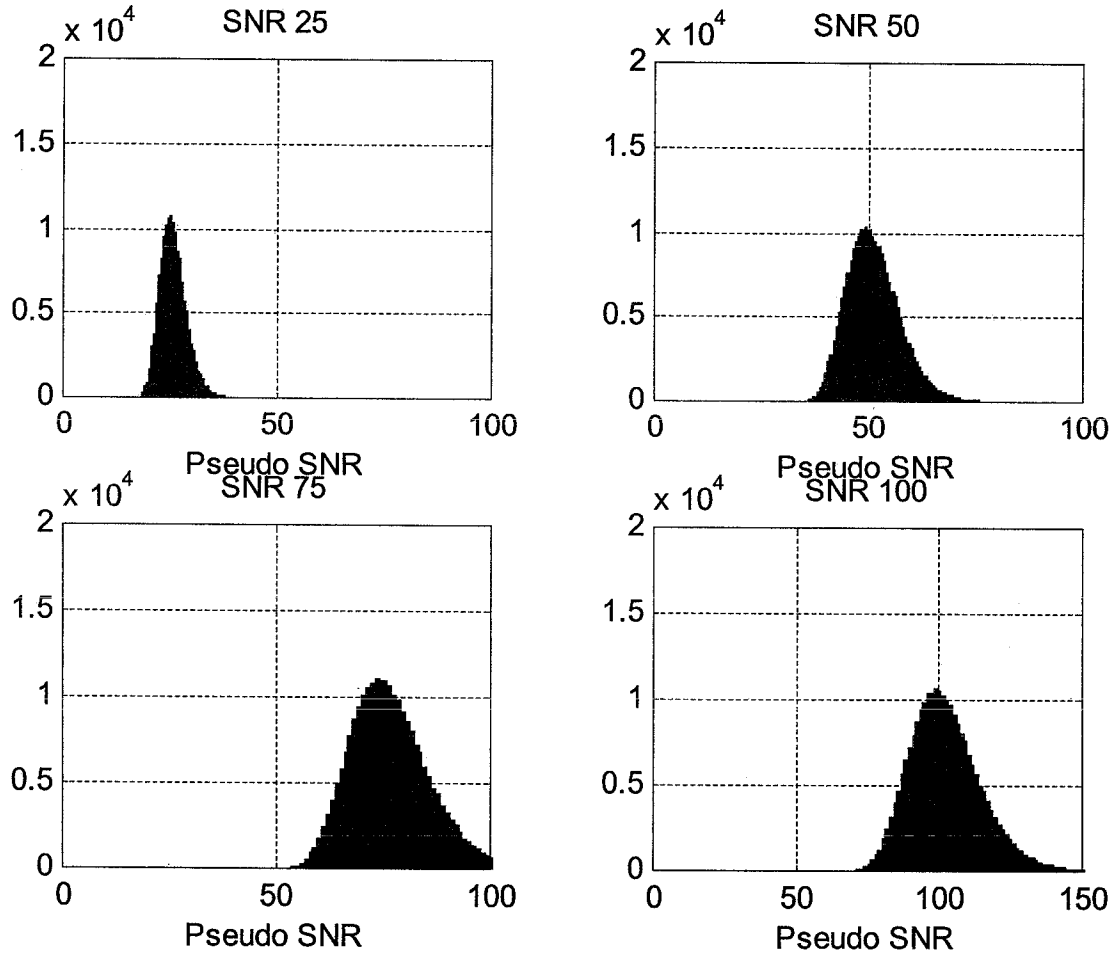
- **Identify uniform scenes**
  - Site uniformity increases over smaller areas
- **Calculate a running "small window" estimate of the μ/σ for each band**
  - Assume that, over small areas, the scene is dominated by sensor noise
  - Use varying size "windows;" smaller windows should give best results
  - 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
  - Expect Gaussian histograms for sensor noise
- Location of histogram peak is a measure of SNR

SNR Simulation

- **Start with large uniform scenes *(500x500 pixels)***
- **Apply varying degrees of random noise**
  - SNR = 25, 50, 75, 100
  - Assume Gaussian Noise Process
- **Compute μ/σ for varying size windows and produce histograms**
  - 30x30 Window
  - 10x10 Window
  - 5x5 Window
- **Location of histogram peak is a measure of the SNR**

Simulated SNR Estimates

5x5 Pseudo SNR Histograms



Previous SNR Results

- SNR estimates for 4 very uniform IKONOS scenes were previously presented
- Scenes included MTF Compensation (MTFC)
- Scenes without MTFC must be analyzed

IKONOS MTFC ON SNR Estimates, 3X3 Window

Band	Antarctica Site 1		Antarctica Site 2		Ivanpah		Mali	
	Mean Radiance Value W/(m2sr)	SNR	Mean Radiance Value W/(m2sr)	SNR	Mean Radiance Value W/(m2sr)	SNR	Mean Radiance Value W/(m2sr)	SNR
1	12.3312	114.0335	12.3312	114.0335	7.9765	56.6186	9.3243	107.7011
2	13.0841	83.0814	13.0841	83.0814	10.6203	47.1574	14.9279	98.1259
3	8.6197	60.0106	8.6197	60.0106	8.4575	42.0815	13.4130	102.9711
4	8.1926	47.8084	8.1926	47.8084	9.0073	56.8210	14.3605	102.9551

MTFC and SNR Analysis of IKONOS Scenes

Antarctica Site 1 Uniformity

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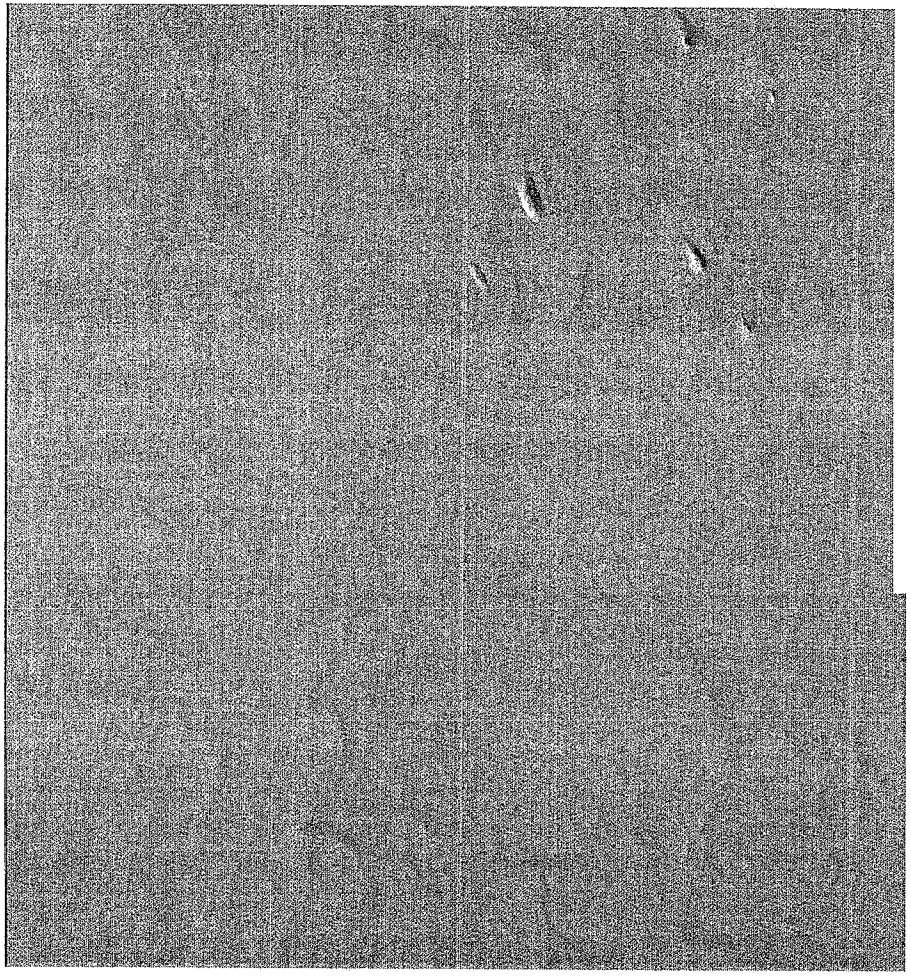
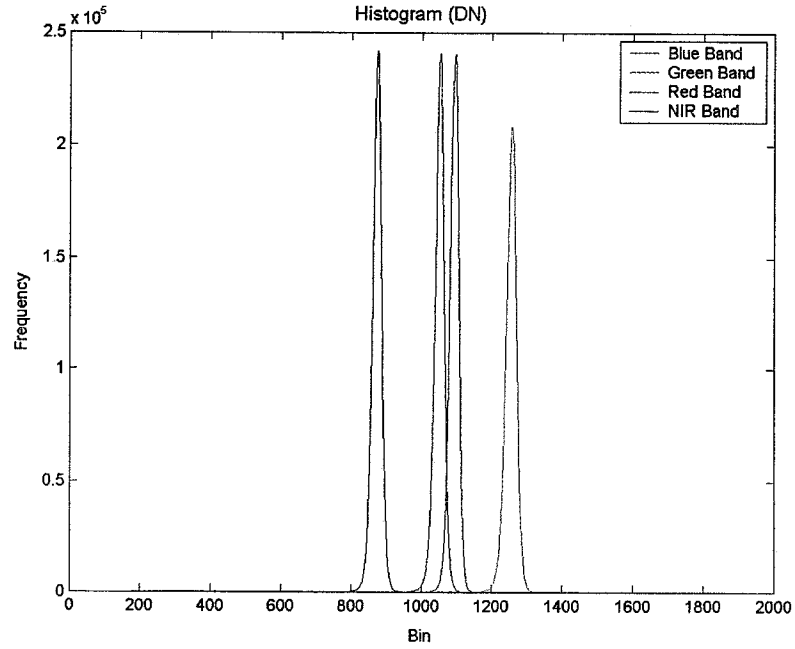
IKONOS Image 10/05/2000
Task 627, PO ID#52847, MTFC ON





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 Difference Imagery

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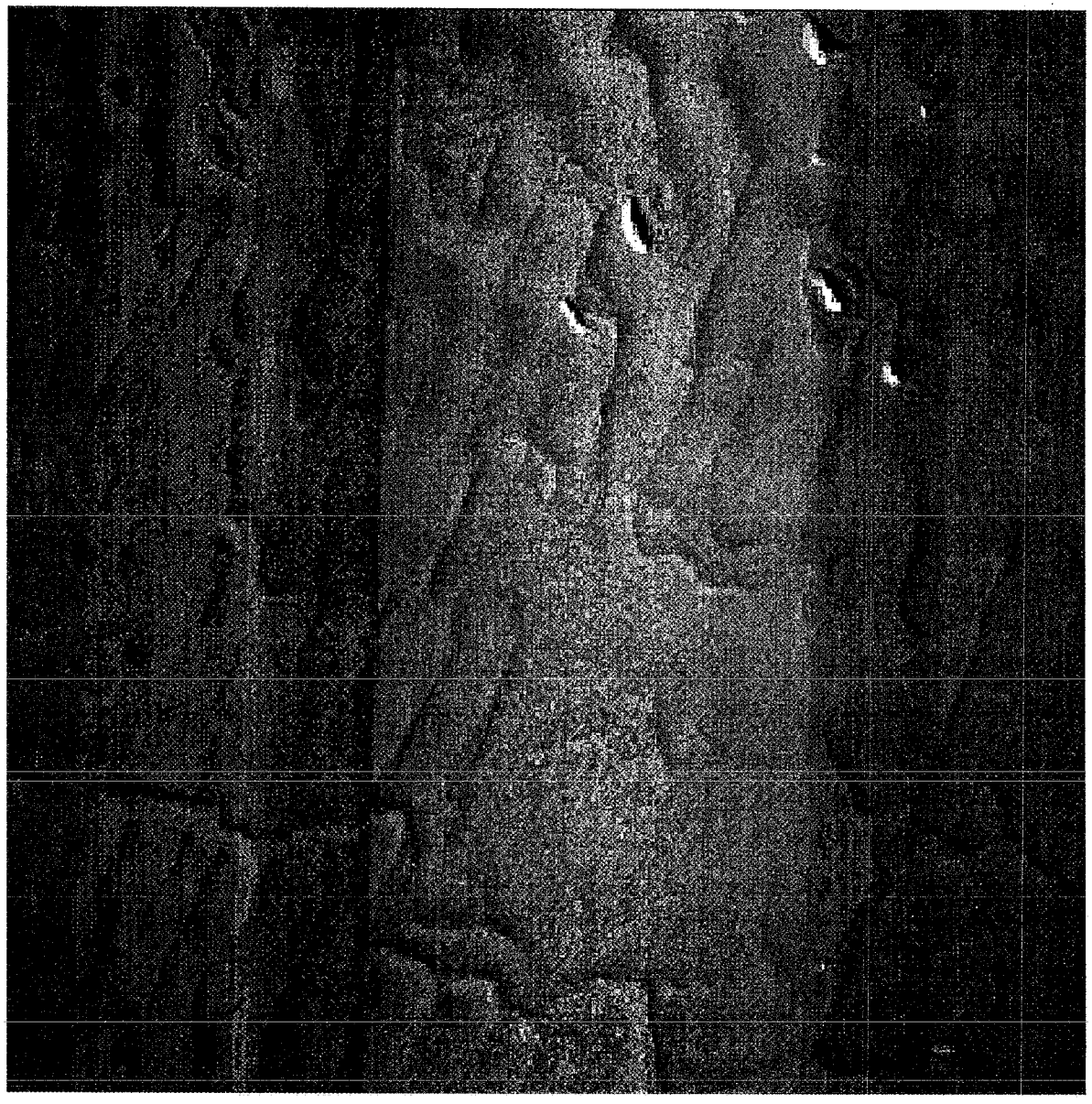
- Change detection image between MTFC On and Off Imagery



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Antarctica Site 1: MTFC ON/OFF Histograms

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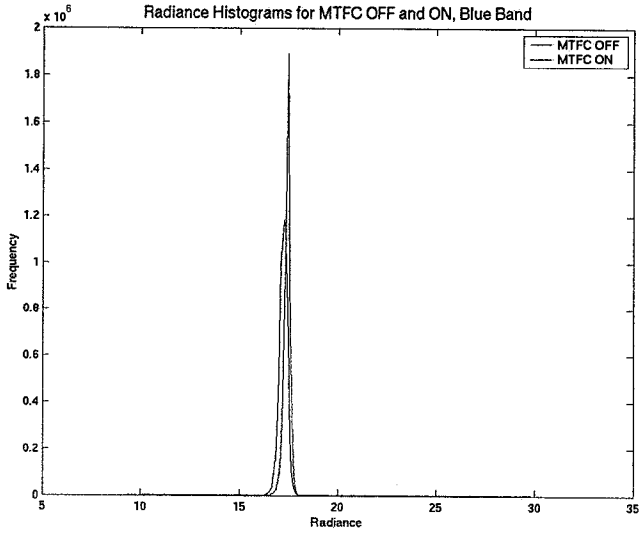

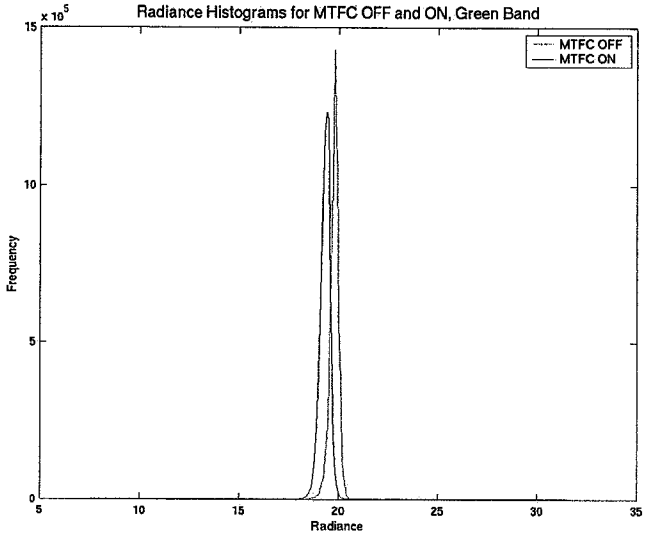

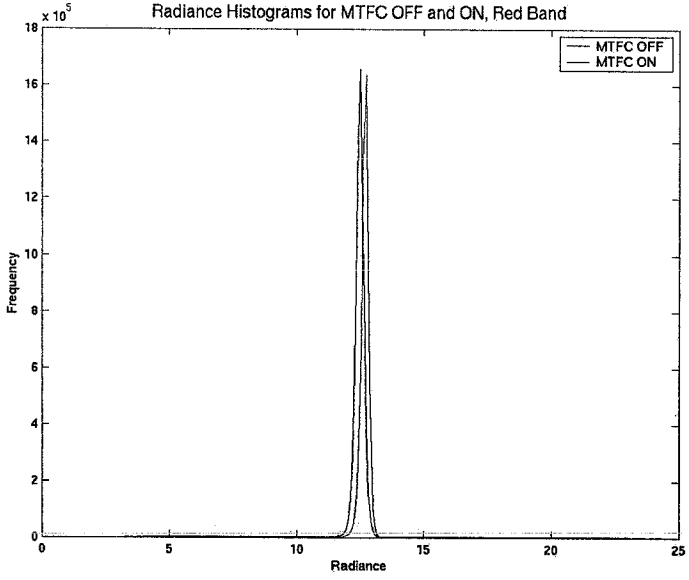

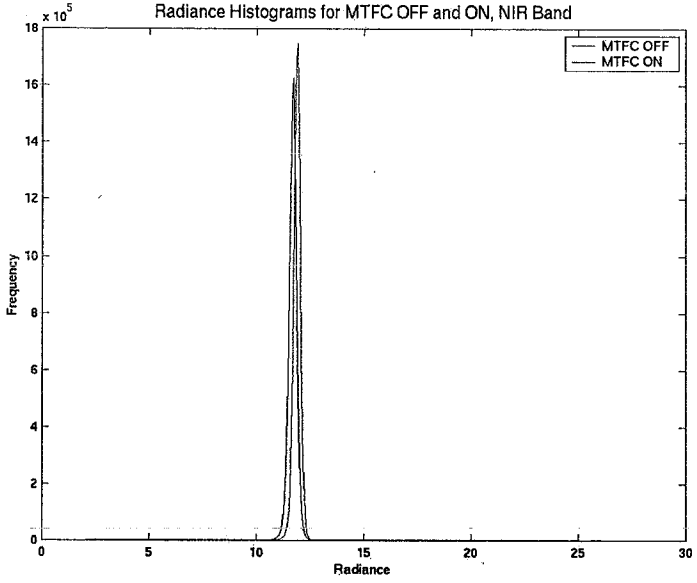

Antarctica MS NIR Band Histograms

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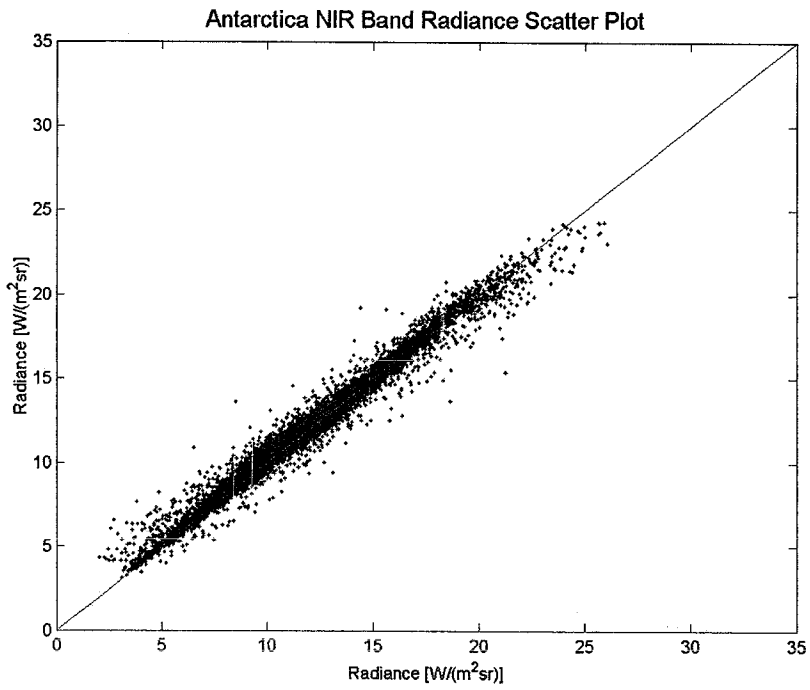

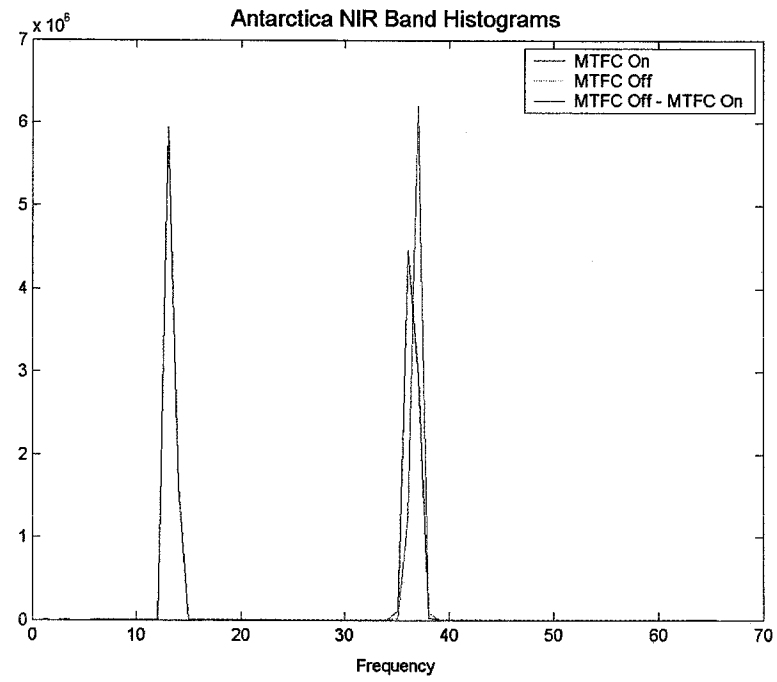

The histograms for MTFC ON and MTFC OFF do not show significant change

Antarctica Multispectral Statistics Summary

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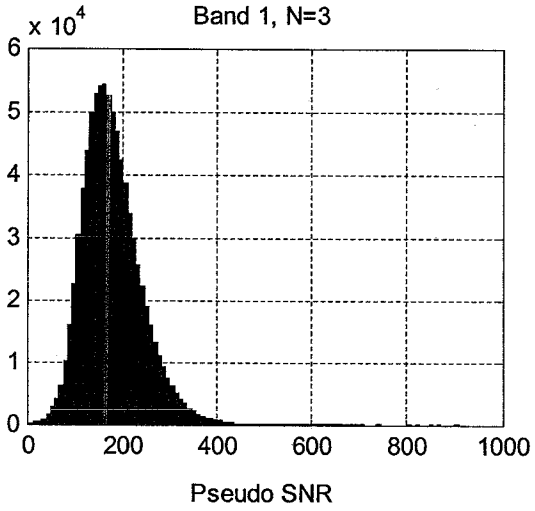
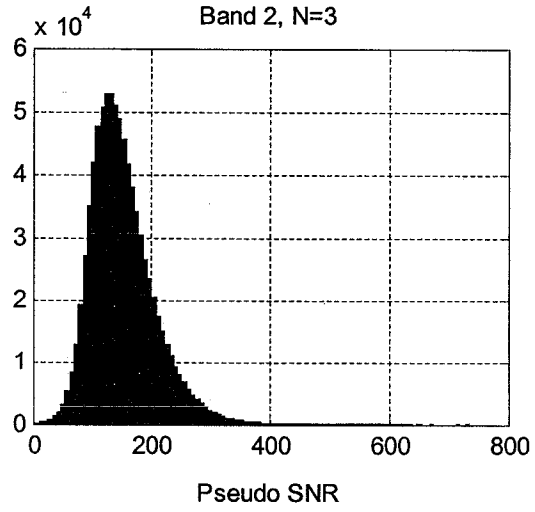
	Blue		Green		Red		NIR	
	MTFC On	MTFC Off	MTFC On	MTFC Off	MTFC On	MTFC Off	MTFC On	MTFC Off
Mean	17.257	17.429	19.337	19.796	12.502	12.701	11.701	11.891
Standard Deviation	0.253	0.216	0.323	0.297	0.237	0.223	0.251	0.229
Minimum	9.321	10.000	7.535	8.790	3.238	4.152	2.024	3.132
Maximum	30.395	28.118	31.541	28.157	24.357	21.570	26.059	24.282
Minimum Difference	-3.569		-5.408		-4.494		-5.155	
Maximum Difference	4.114		5.663		4.511		5.849	
RMS Difference %	0.77		0. 65		0.58		0.73	

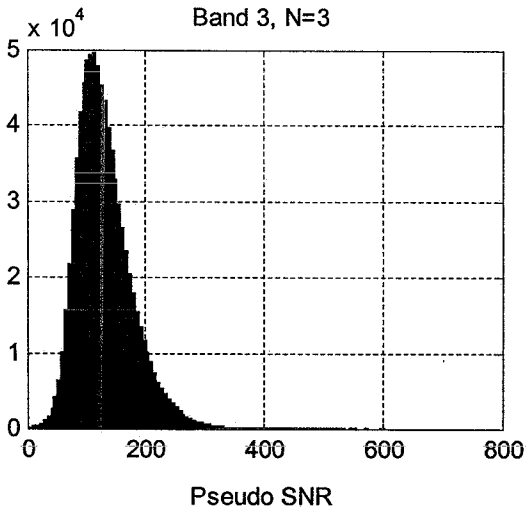
Vicarious calibrations are not significantly impacted by MTFC ON or MTFC OFF

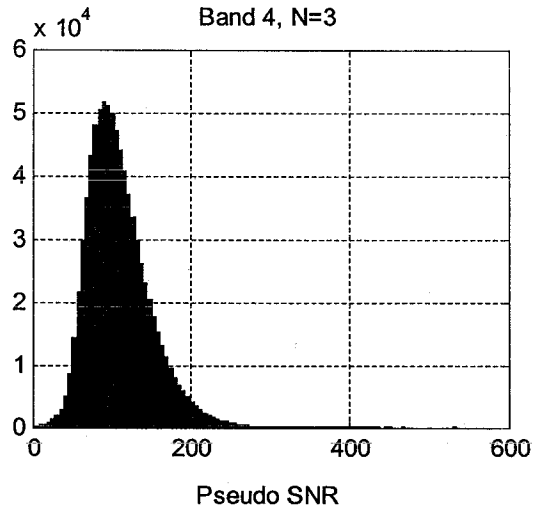
Antarctica Site 1 SNR Estimates

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



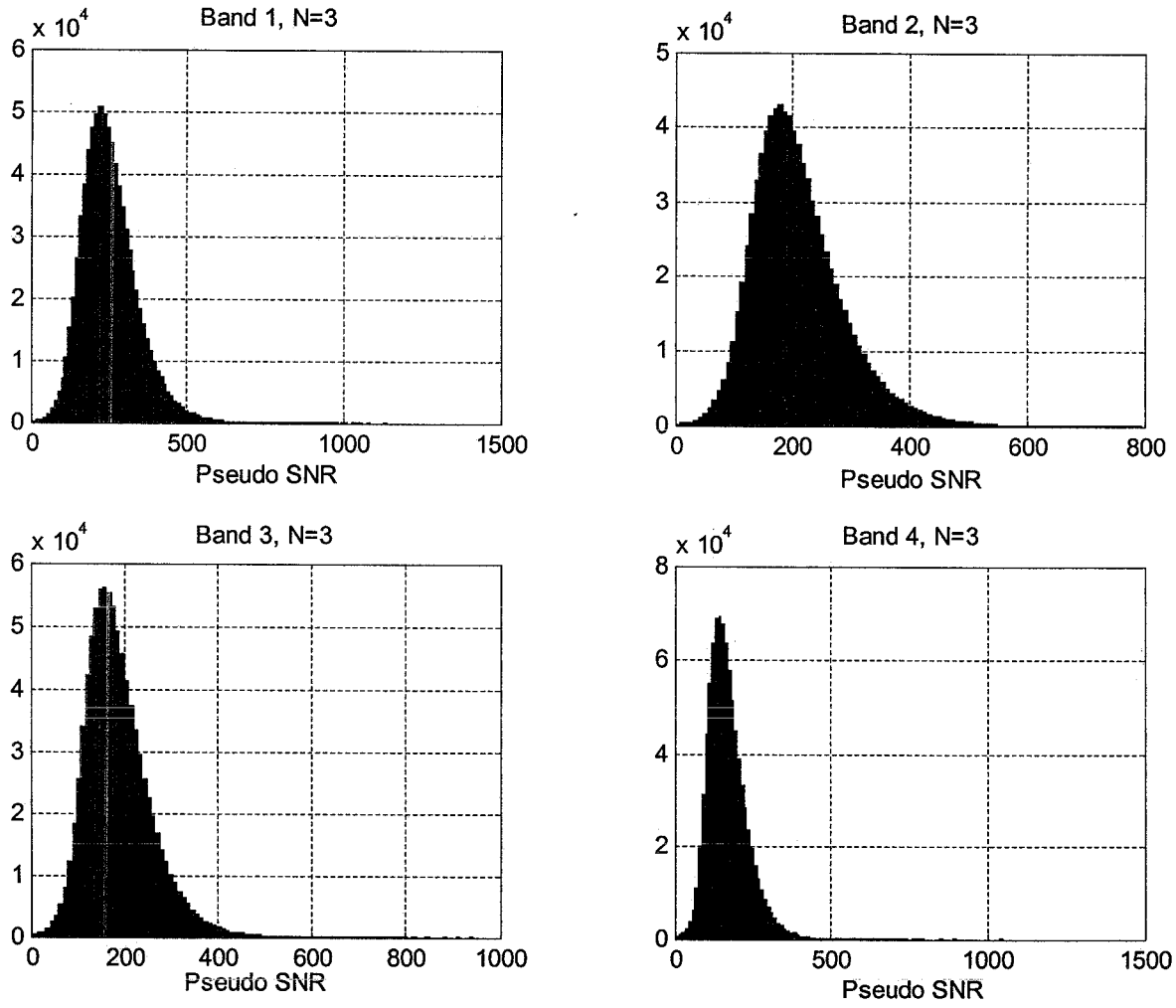






Antarctica Site 1 SNR Estimates

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

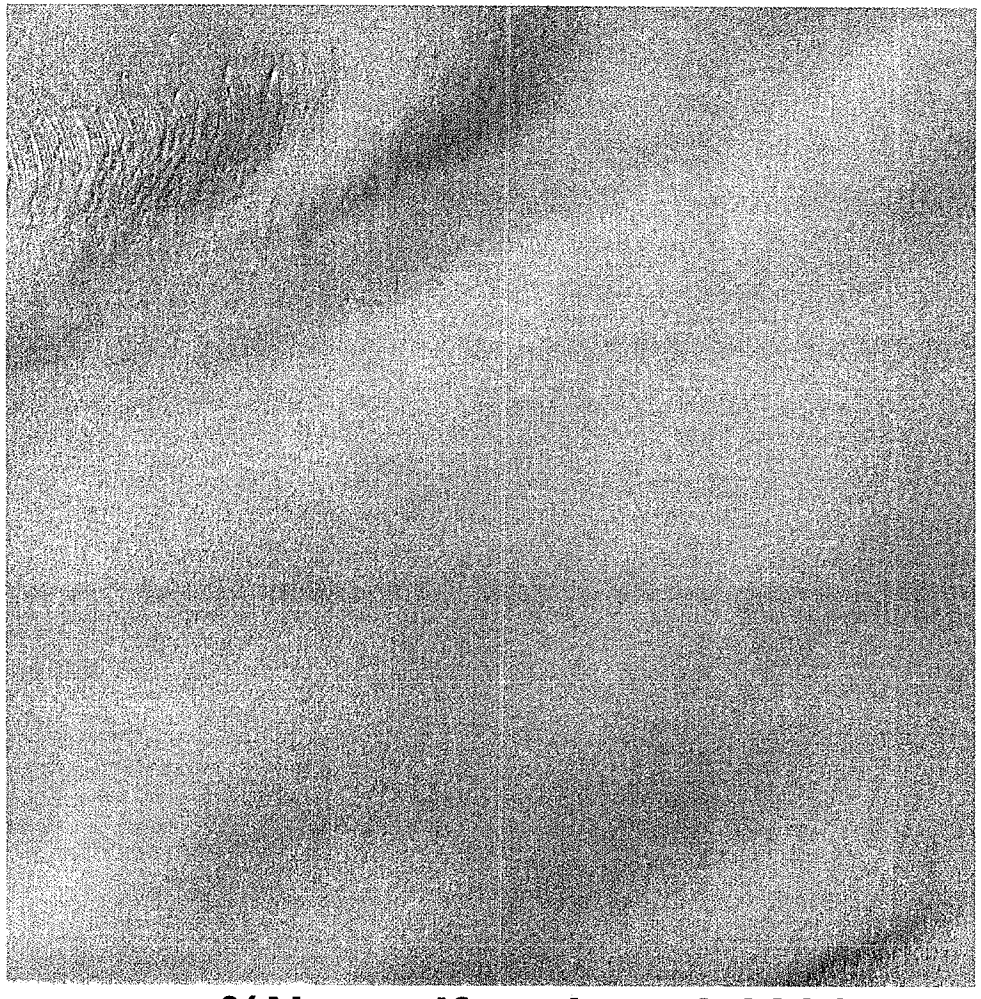
Image po_52847	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	17.2574	158.9590	152.3217	162.1035	0.1086	0.1133	0.1065
Band 2	19.3374	128.2430	125.5815	123.4439	0.1508	0.1540	0.1566
Band 3	12.5021	111.0286	110.2258	113.7190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

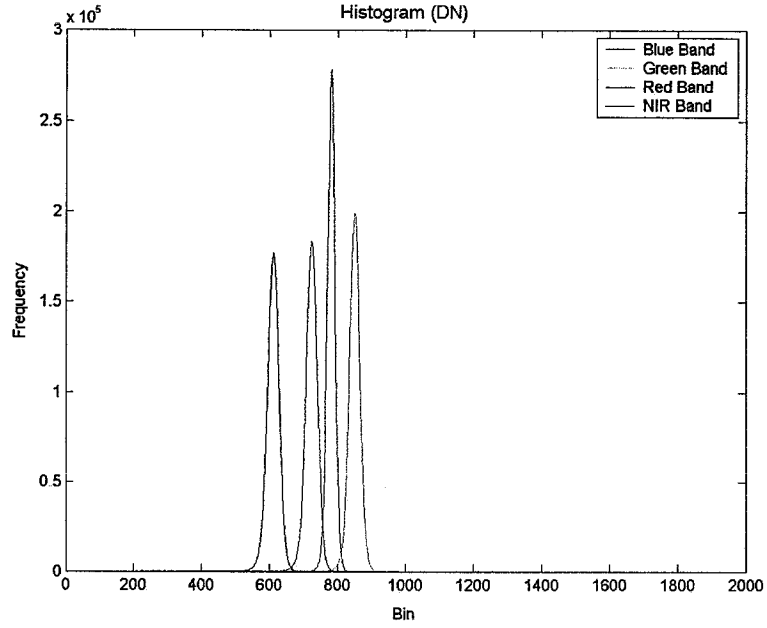
Image po_70691	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	17.4290	204.2186	210.1334	215.0895	0.0853	0.0829	0.0810
Band 2	19.7958	174.5591	167.8688	176.9799	0.1134	0.1179	0.1119
Band 3	12.7007	153.7300	153.9928	158.2200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



%Nonuniformity = 0.0231



Band	Mean Radiance Value W/(m^{2}sr)	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

Includes material © Space Imaging, L.P.

Antarctica Site 2: MTFC ON/OFF Histograms

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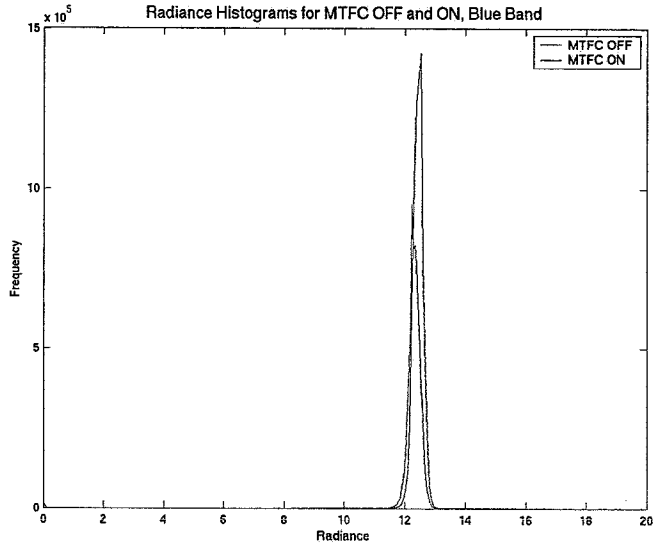
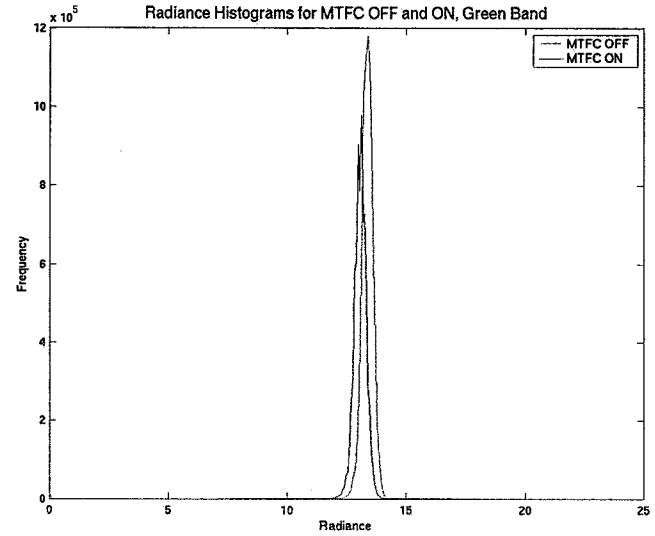
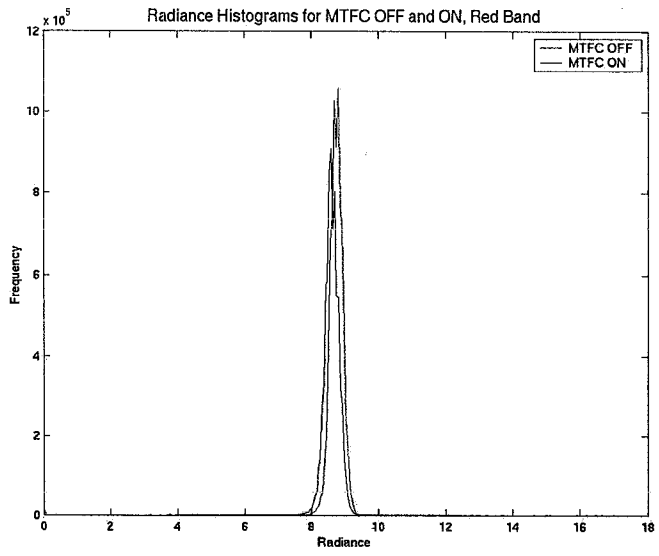
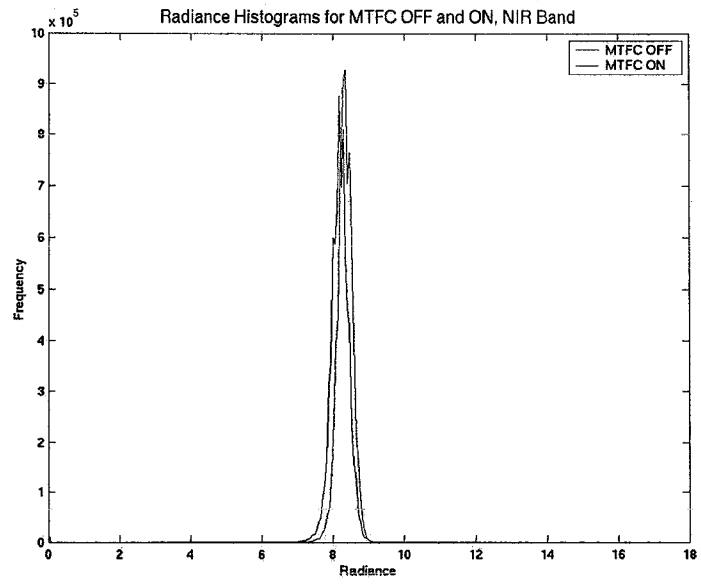




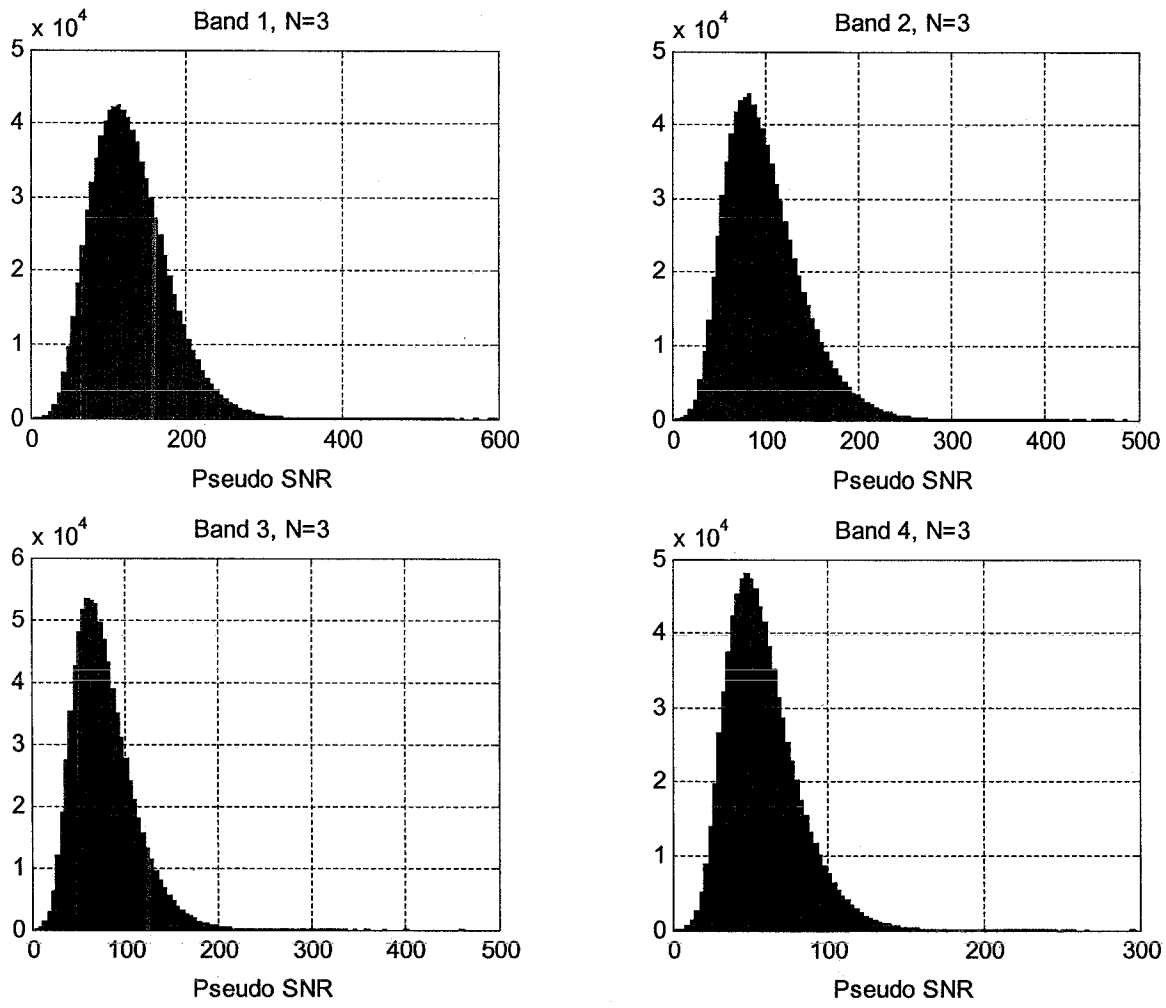




Antarctica Site 2 SNR Estimates

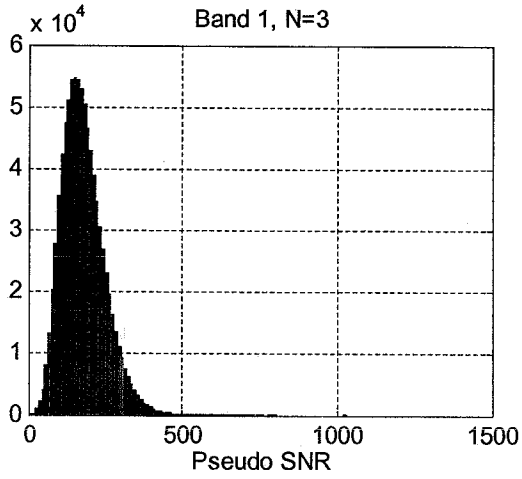
Stennis Space Center

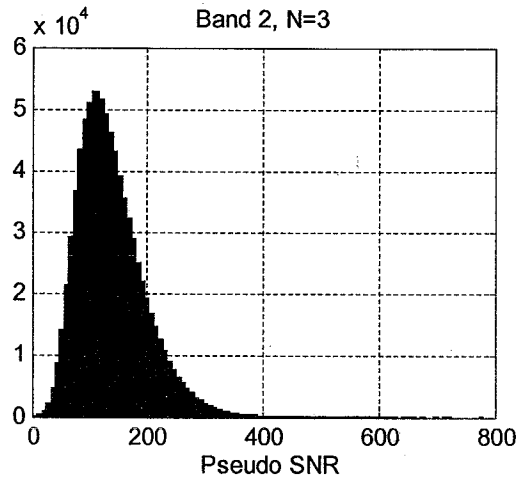
Task 626, PO ID#59798, MTFC ON
3 X 3 Window SNR Estimates

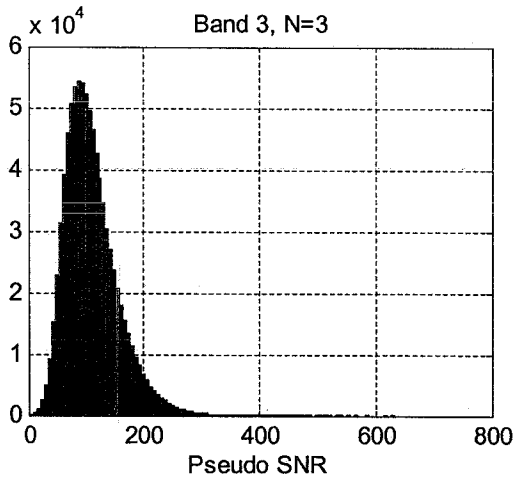


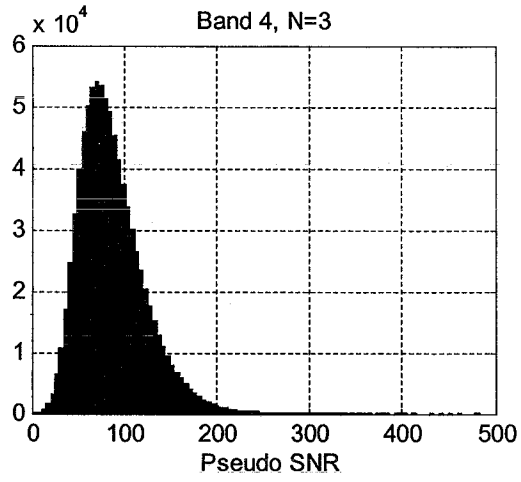
Antarctica Site 2 SNR Estimates

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









Antarctica Site 2 SNR Summary

Task 626, PO ID#59798

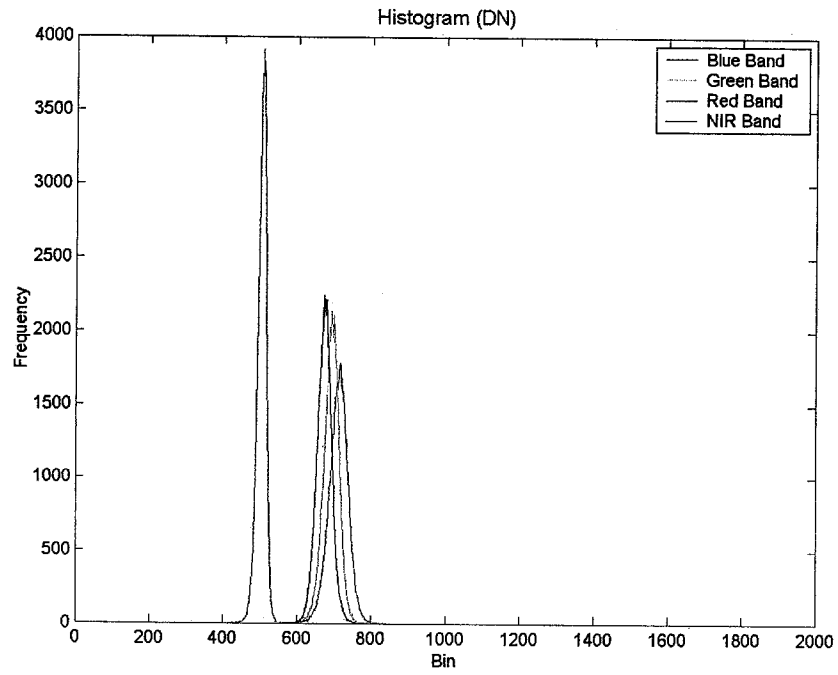
Image po_59798	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	12.3312	105.1424	106.6267	114.0335	0.1172	0.1156	0.1081
Band 2	13.0841	79.9226	78.1604	83.0814	0.1637	0.1674	0.1575
Band 3	8.6197	62.6517	64.9377	60.0106	0.1376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

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



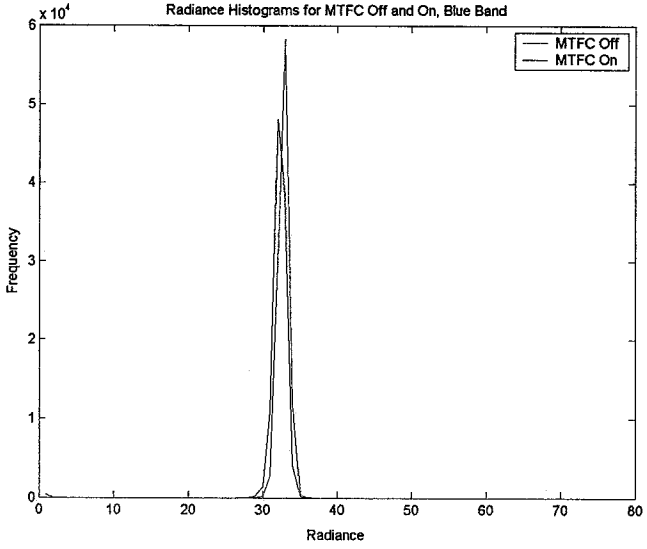
Band	Mean Radiance Value W/(m^{2}sr)	Standard Deviation / Mean (Radiance Values)
1	7.9765	0.0652
2	10.6203	0.0683
3	8.4575	0.0708
4	9.0073	0.0679

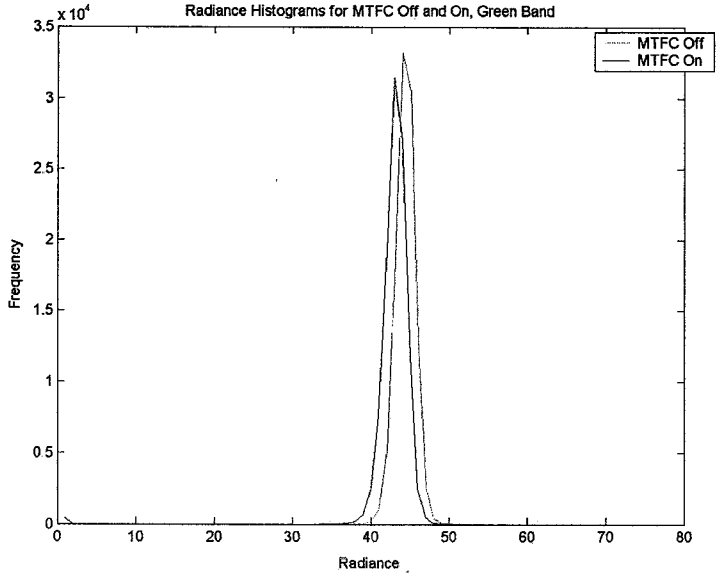
%Nonuniformity = 0.0681

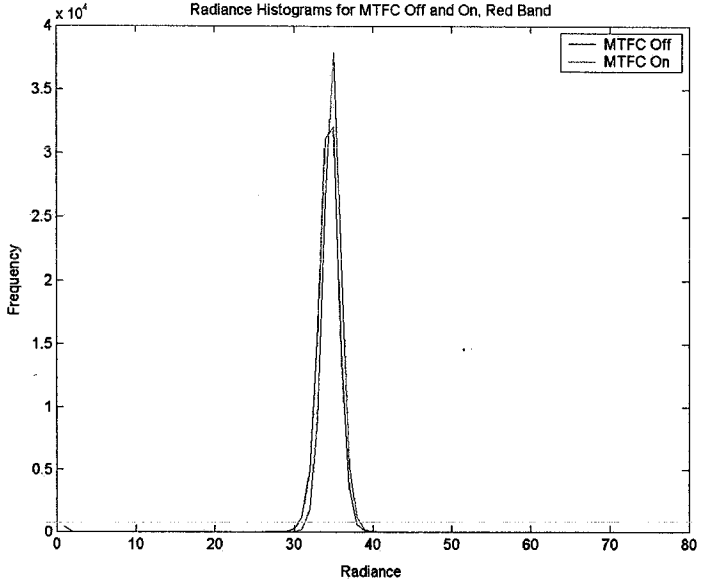
Includes material © Space Imaging, L.P.

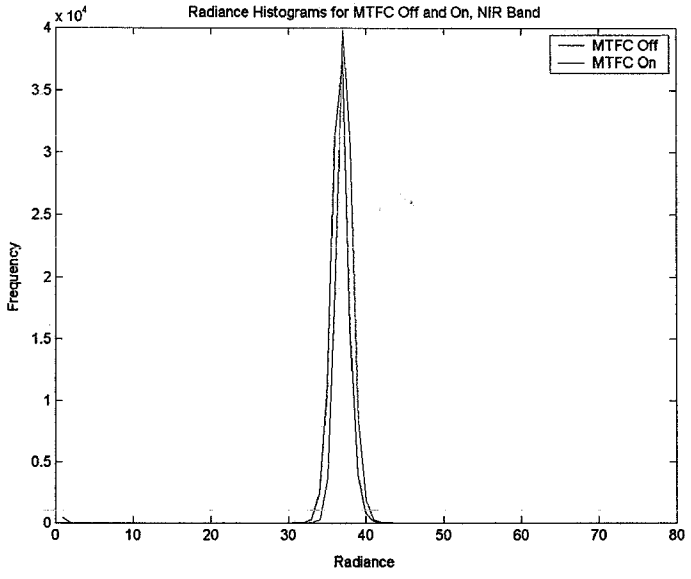
Ivanpah: MTFC ON/OFF Histograms

Stennis Space Center





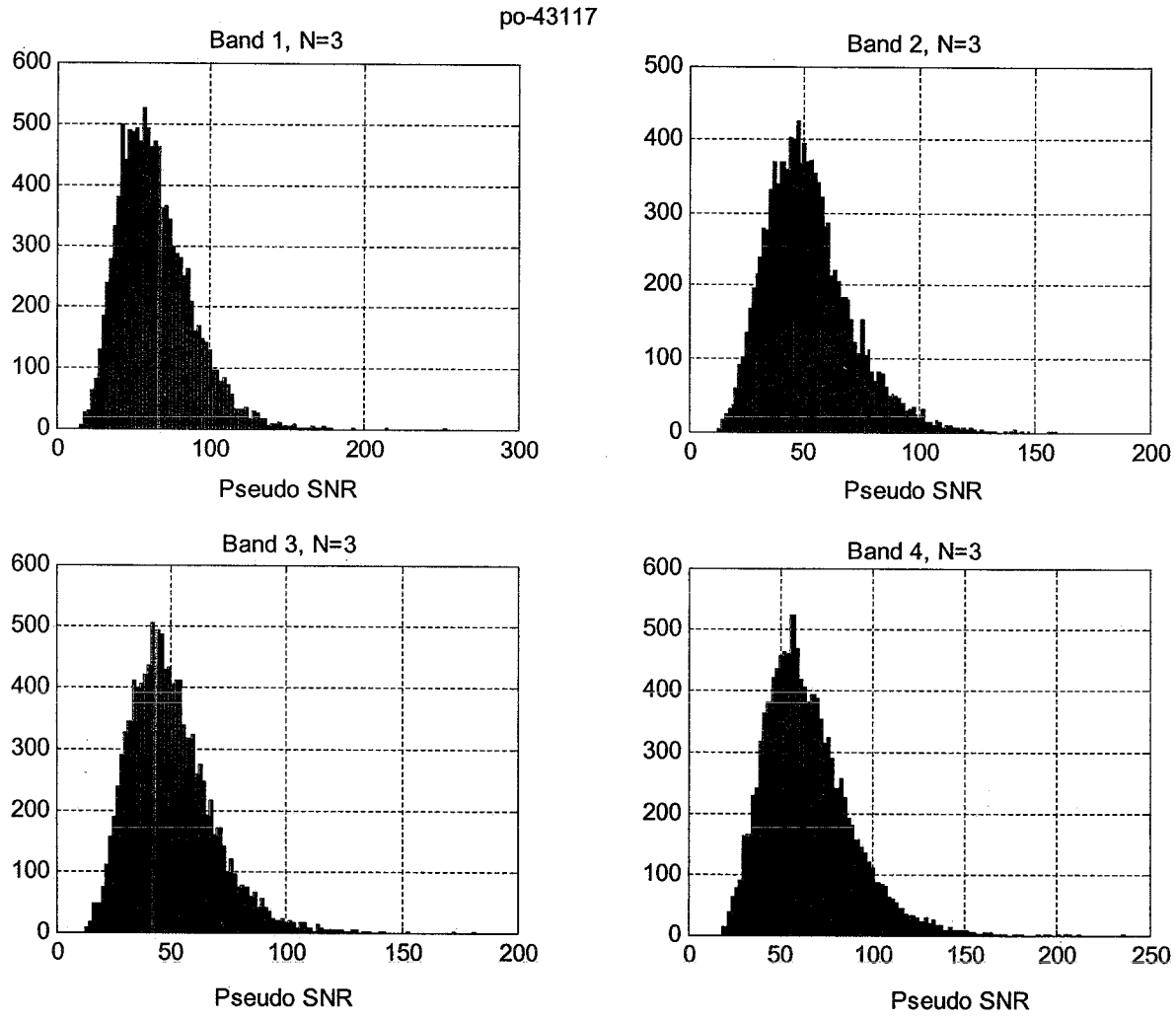




Ivanpah, CA Site SNR Estimates

Stennis Space Center

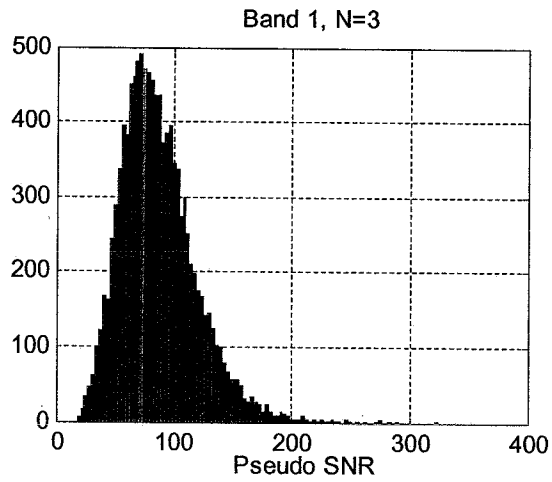
Task 789, PO ID#43117, MTFC ON
3 X 3 Window SNR Estimates

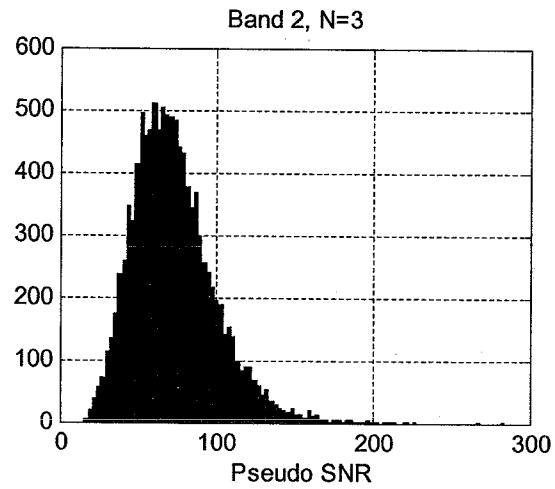


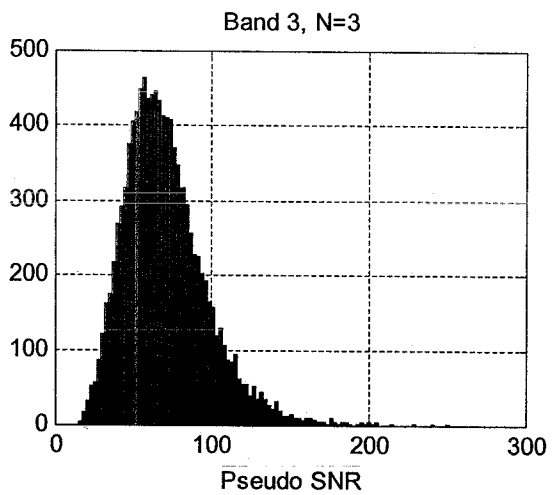
Ivanpah, CA Site SNR Estimates

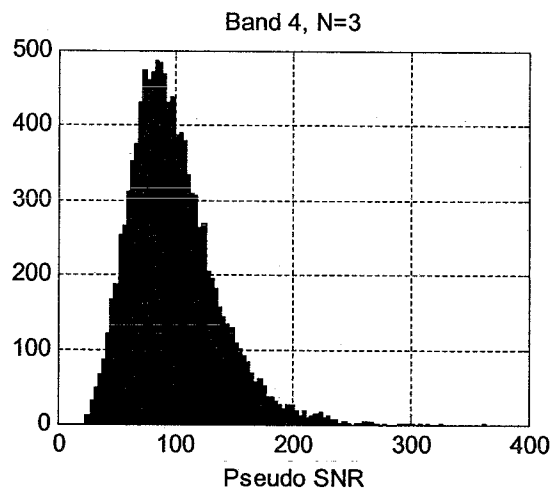
Stennis Space Center

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









Ivanpah, CA Site SNR Summary

Stennis Space Center

Task 789, PO ID#43117, MTFC ON

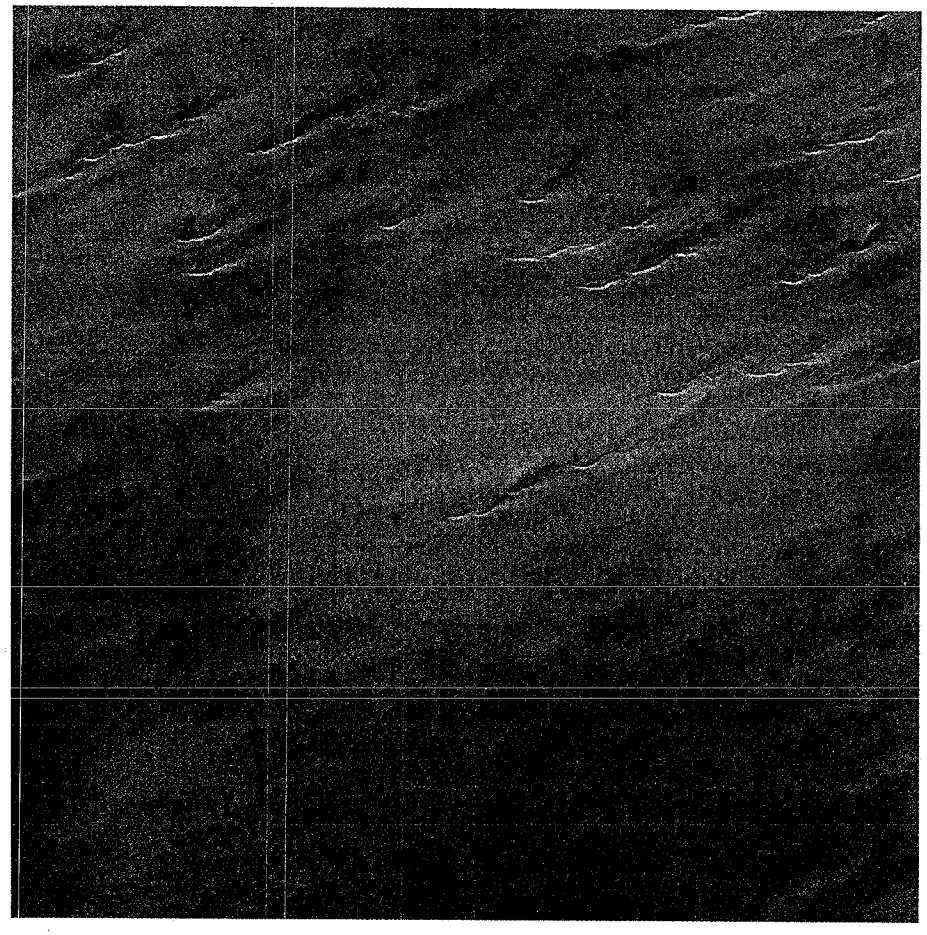
Image po_43117	Mean Radiance Value W/(m^{2}sr)	Signal-to-Noise Ratio			Noise Equivalent Radiance W/(m^{2}sr)		
		N=10	N=5	N=3	N=10	N=5	N=3
Band 1	7.9261	48.9298	55.9045	58.3568	0.1620	0.1418	0.1358
Band 2	10.6203	42.5958	44.1581	46.3774	0.2493	0.2405	0.2290
Band 3	8.4575	39.3525	43.1838	43.2600	0.2149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

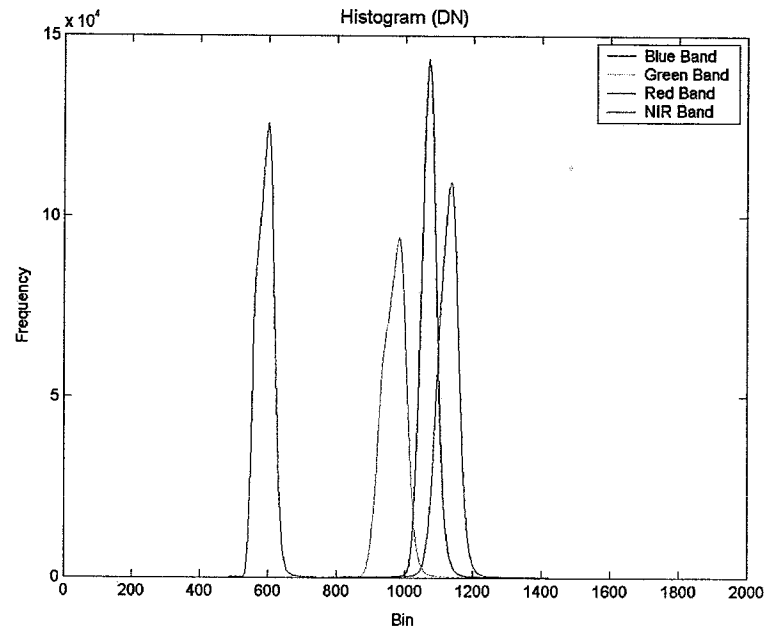
Task 1075, PO ID#78337, MTFC OFF

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





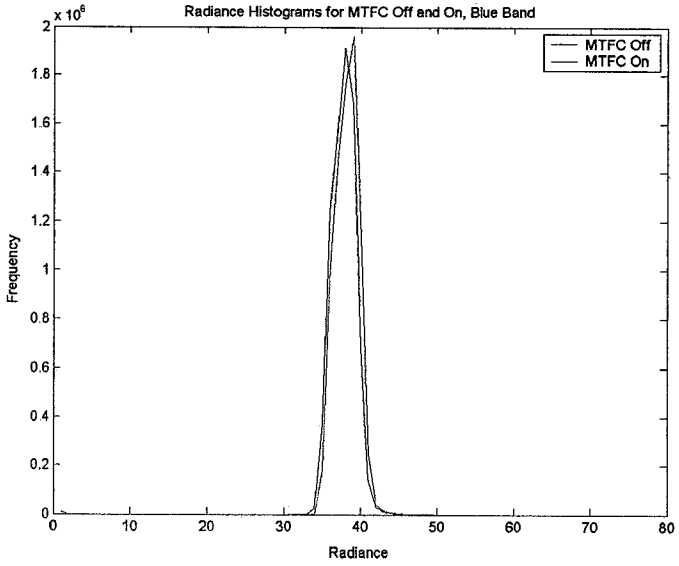
Band	Mean Radiance Value $W/(m^2sr)$	Standard Deviation / Mean (Radiance Values)
1	9.3836	0.0392
2	14.9279	0.0338
3	13.4130	0.0268
4	14.3605	0.0230

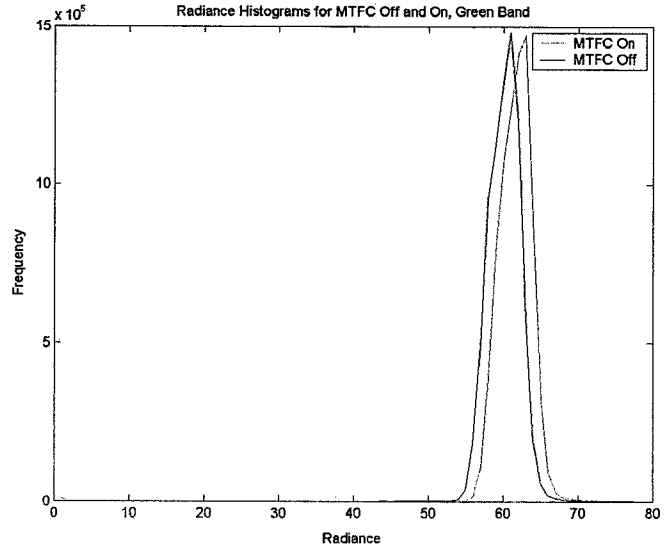
%Nonuniformity = 0.0313

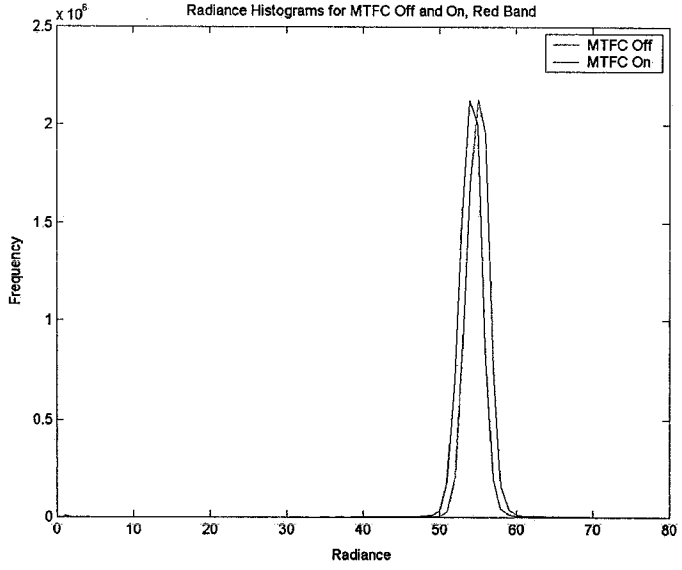
Includes material © Space Imaging, L.P.

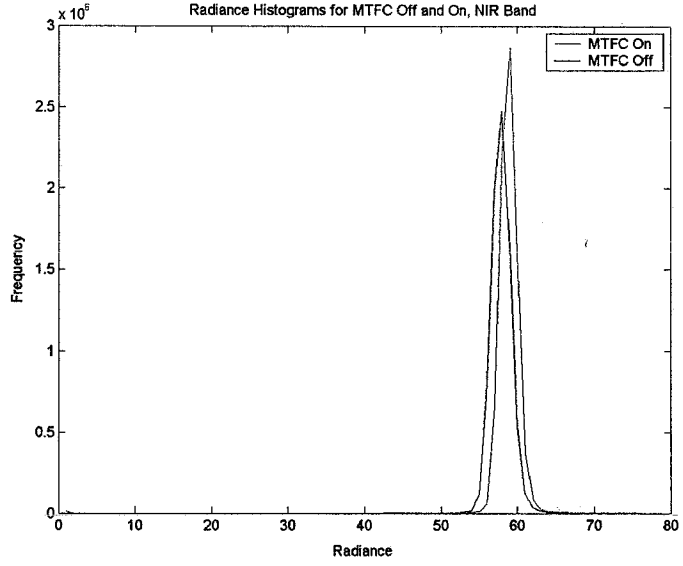
Mali: MTFC ON/OFF Histograms

Stennis Space Center





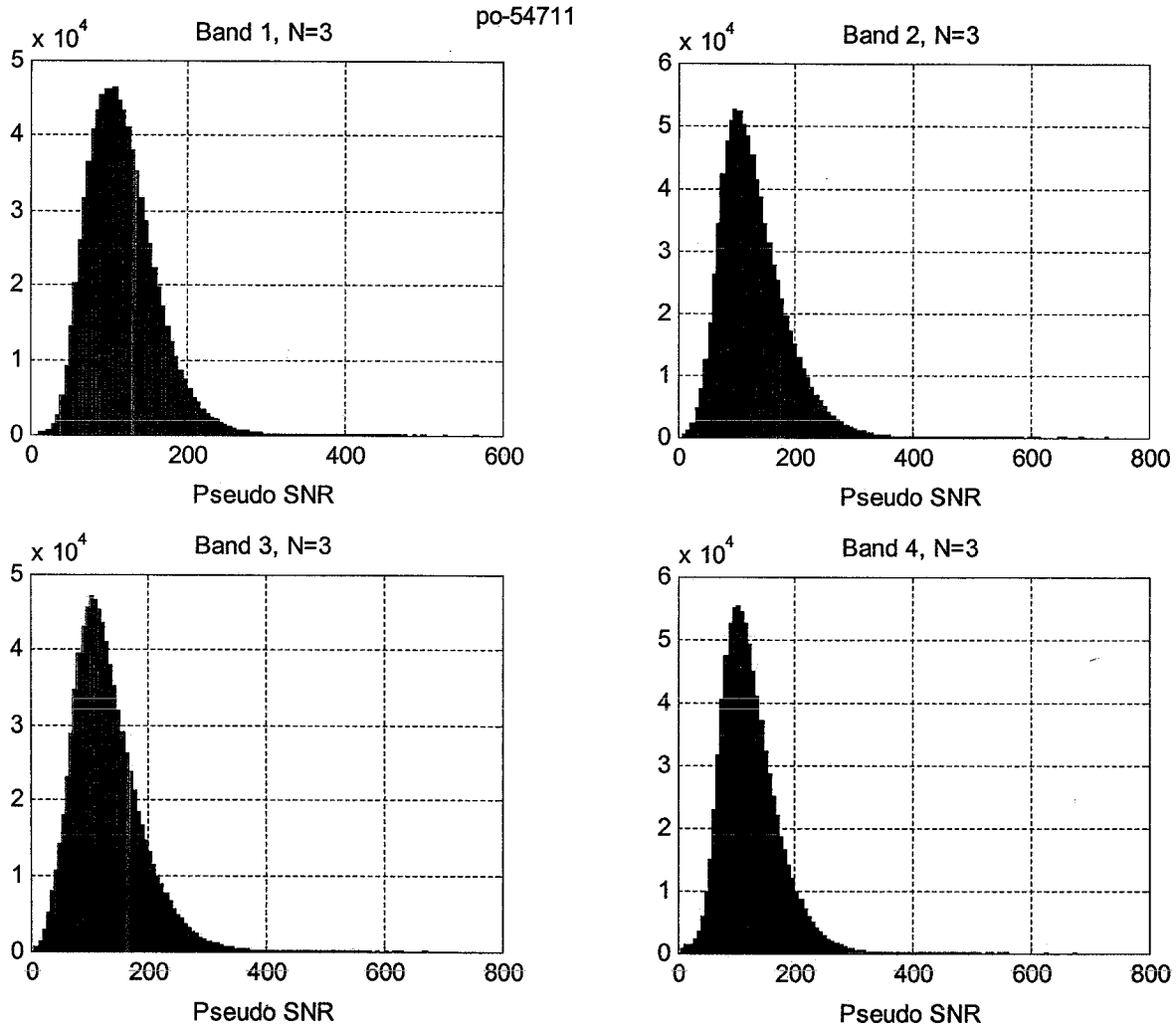




Mali Site SNR Estimates

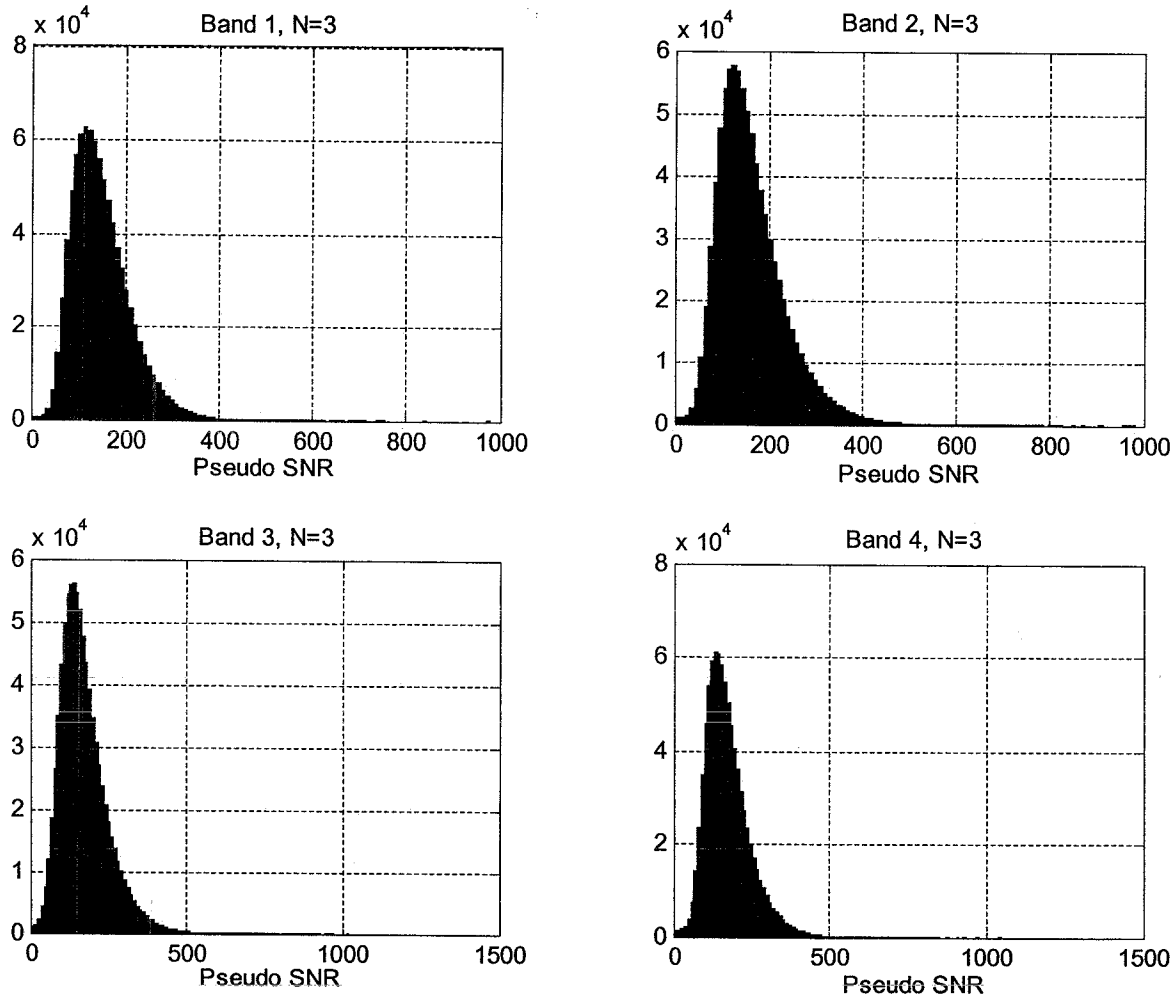
Stennis Space Center

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 of Photon Noise-Limited Systems

- Expect pushbroom architecture to be photon noise-limited for bright scenes

- SNR proportional to Sqrt of radiance

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

SNR^2 vs. Mean Radiance

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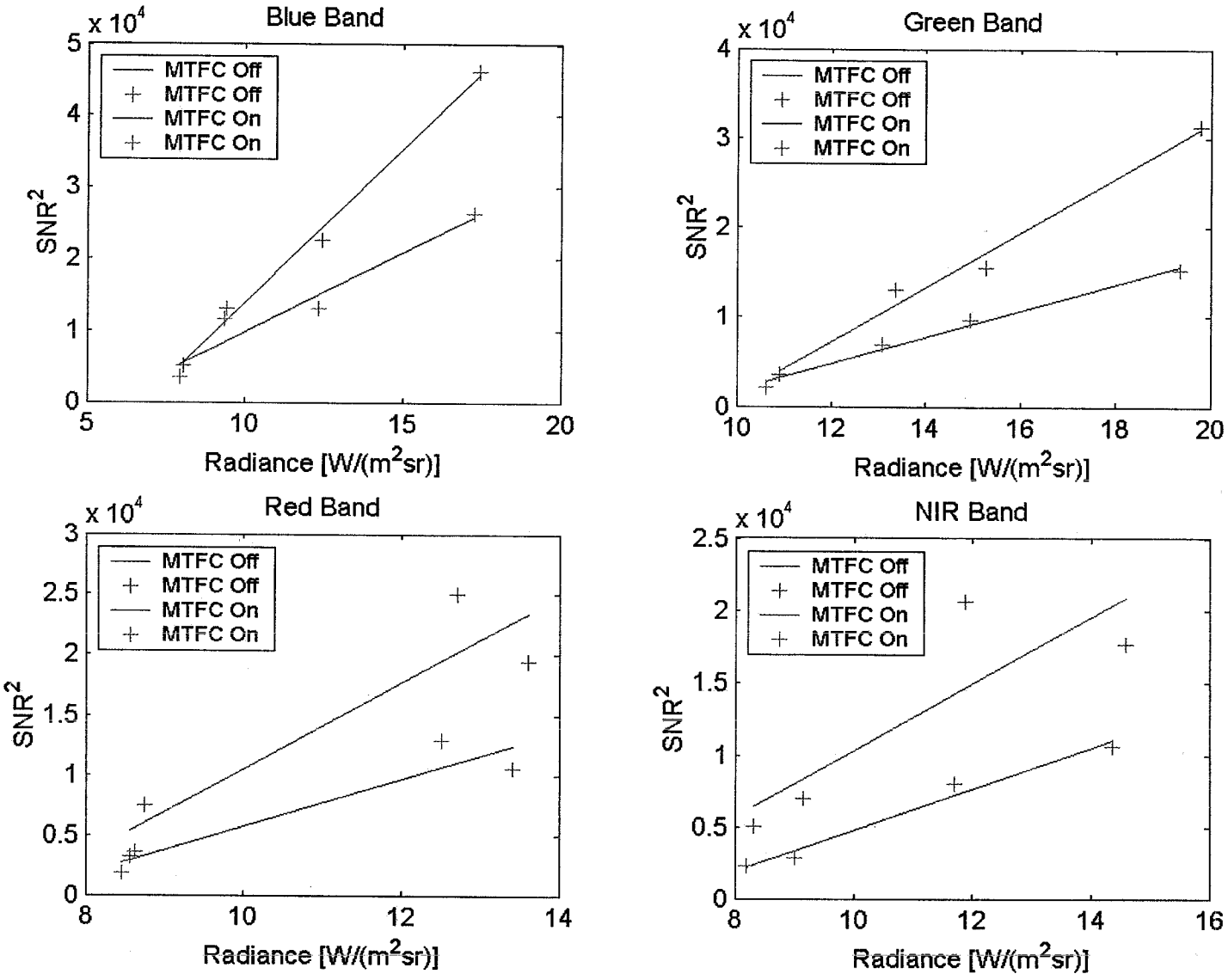

SNR Difference Summary

		SNR MTFC On	SNR MTFC Off	Ratio (Off/On)	% Difference (Off-On)/Off
Antarctica 1	Band 1	162.1035	215.0895	1.3269	24.63%
	Band 2	123.4439	176.9799	1.4337	30.25%
	Band 3	113.7190	158.2200	1.3913	28.13%
	Band 4	89.6405	143.4790	1.6006	37.52%
Antarctica 2	Band 1	114.0335	149.9750	1.3152	23.96%
	Band 2	83.0814	114.0075	1.3722	27.13%
	Band 3	60.0106	86.3378	1.4387	30.49%
	Band 4	47.8084	70.7555	1.4800	32.43%
Ivanpah	Band 1	58.3568	71.4836	1.2249	18.36%
	Band 2	46.3774	59.6598	1.2864	22.26%
	Band 3	43.2600	56.5216	1.3066	23.46%
	Band 4	53.5841	83.4690	1.5577	35.80%
Mali	Band 1	107.7011	114.1455	1.0598	5.65%
	Band 2	98.1259	124.3069	1.2668	21.06%
	Band 3	102.9711	139.1695	1.3515	26.01%
	Band 4	102.9551	132.7356	1.2893	22.44%

Summary

- MTFC OFF imagery has 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
- Compression effects are not easily identified and have not yet been quantified
- MTFC Off data should be used when performing quantitative work requiring high SNR
- MTFC On data should be used when performing visual inspection

REPORT DOCUMENTATION PAGE

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14. ABSTRACT