Uniform Site Evaluation and SNR Estimation

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March 19-21, 2001

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Introduction

- **Large uniform areas are typically used for standard vicarious calibrations**
  - Requires ground teams and coincident acquisitions
  - Difficult to coordinate and expensive
  - Alternative methods need to be explored
    - Radiance Method
    - Stable Uniform Site Method

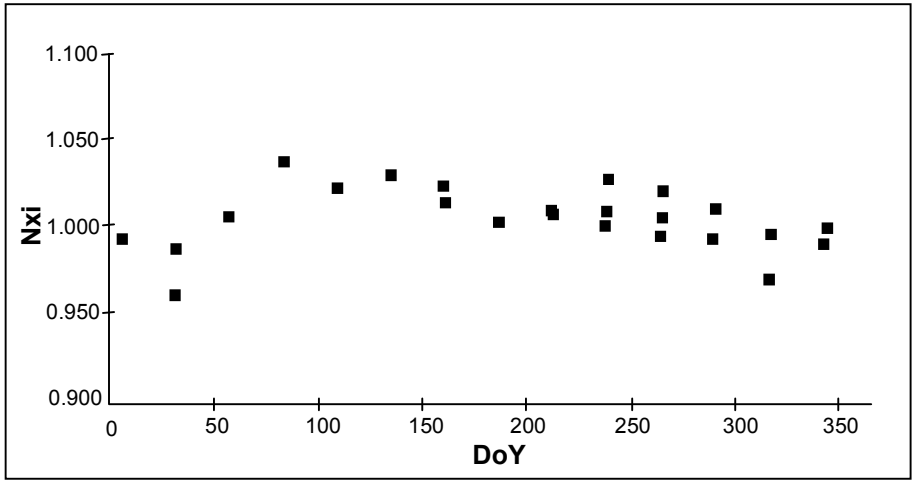
- **Uniform areas can also be used for on-orbit estimation of a system's SNR**

Desired Calibration Site Characteristics

- **Bright and Uniform**
  - High reflectance minimizes atmospheric uncertainties
  - Uniformity allows statistically meaningful results
- **Stable**
  - Long term studies are facilitated with stability
- **Low Precipitation and Cloud Cover**
  - Maintains stability and increases chance of acquisition
- **Large**
  - Large in extent to avoid adjacency effects and to characterize full sensor scene

Site Selection Methodology

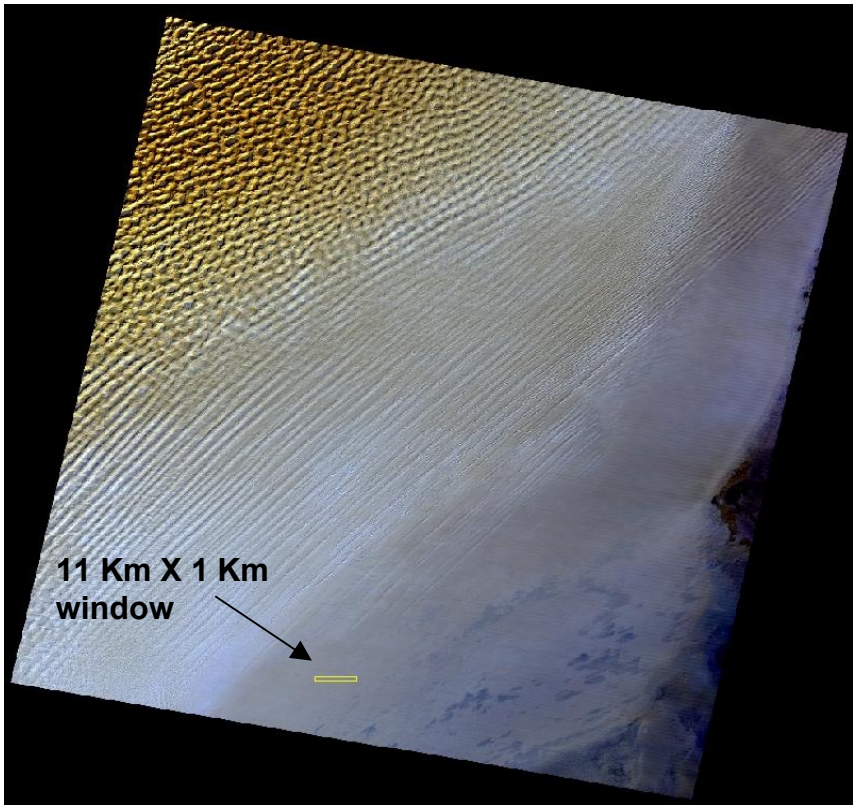
- **Review Literature**
  - Henry, P., Dinguirard, M., Bodilis, M. (1993), SPOT Multitemporal calibration over stable desert areas, SPIE Vol. 1938, pp. 67-76.
  - Gao, Bo-Cai (1993), An Operational Method for Estimating Signal to Noise Ratios from Data Acquired with Imaging Spectrometers, Remote Sensing of the Environment 42:23-33.
- **Utilize NASA Scientific Data Purchase EarthSat data products**
  - Landsat TM data for Africa
  - Begin with sites identified in past work
- **Develop algorithms to find most uniform areas**
  - Analyze footprints and swath widths comparable to new systems
- **Examine IKONOS data of ice fields in Antarctica and other vicarious calibration sites for SNR estimation**



Dinguirard & Bodilis Figure 5: Libya 73/297 Normalized DN versus Day of Year for SPOT Band2

Uniform Site Selection Algorithm

- **Identify scene size (window) of interest**
  - For IKONOS, we use an 11 Km X 1 Km window
- **Pick a site of interest**
  - Select Row/Path for 185 km x 185 km TM scene closest to site
- **Estimate uniformity figure of merit (% variance) of each window for each band of interest as a function of position within the TM scene**
  - Step window at 1-pixel intervals across entire TM scene
  - Identify most uniform region as one with lowest RMS variance



"Libya 1" site
Landsat 5, 01/13/87
Path 187 / Row 42

Uniformity Figure of Merit (FOM)

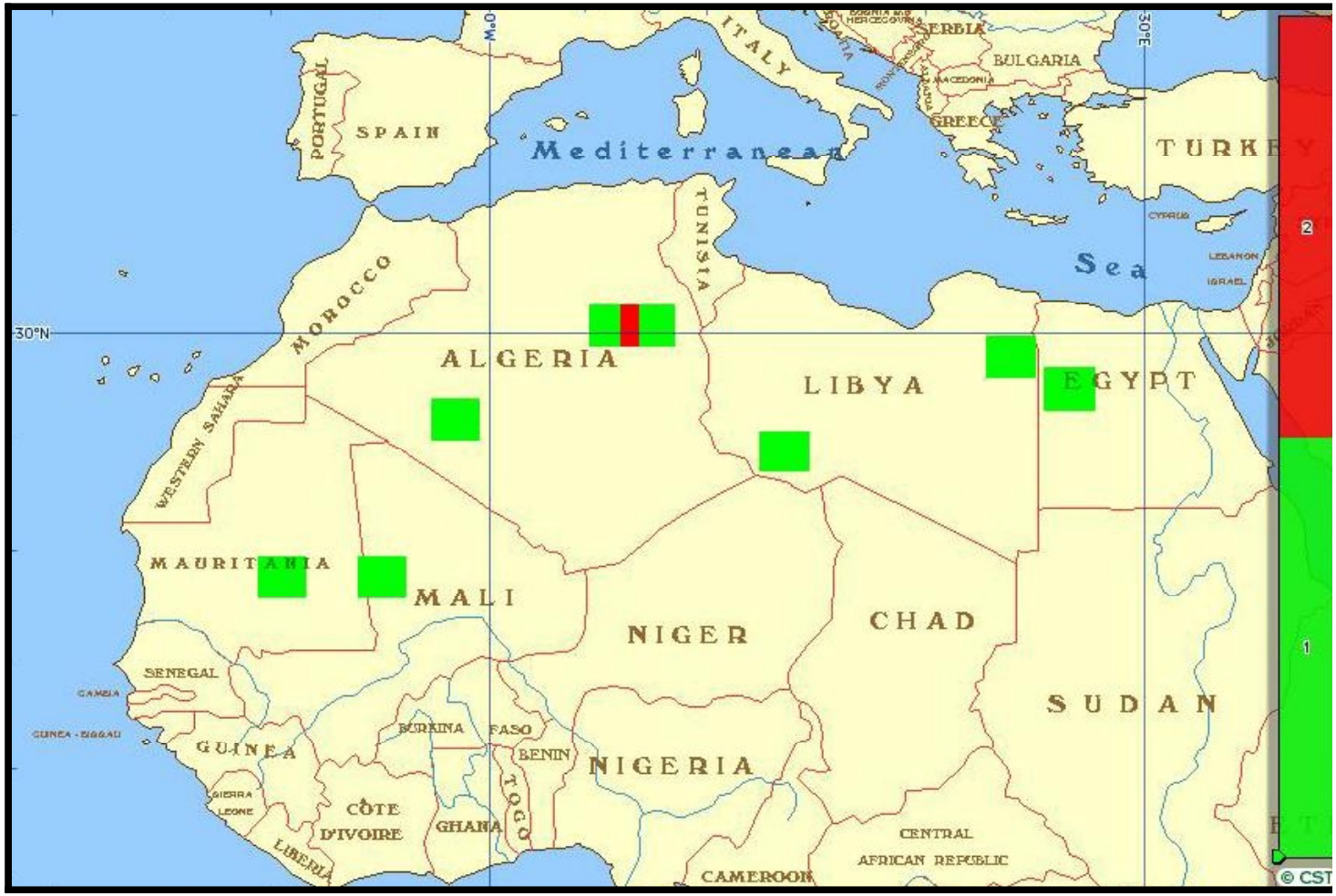
Figure of Merit is based on the mean of the root sum squares of several bands of interest.

$$FOM = SQRT[\quad (\sigma_i / \mu_i)^2] / SQRT(N)$$

Where
i = spectral band, i
σ = radiance standard deviation of the image or subimage for band i
μ = mean radiance of the image or subimage for band I
N = number of bands being analyzed

Images Used in Analysis

Selected 8 sites contained within a Landsat path/row



Red areas indicate overlap regions.

Uniformity of Landsat TM Scenes

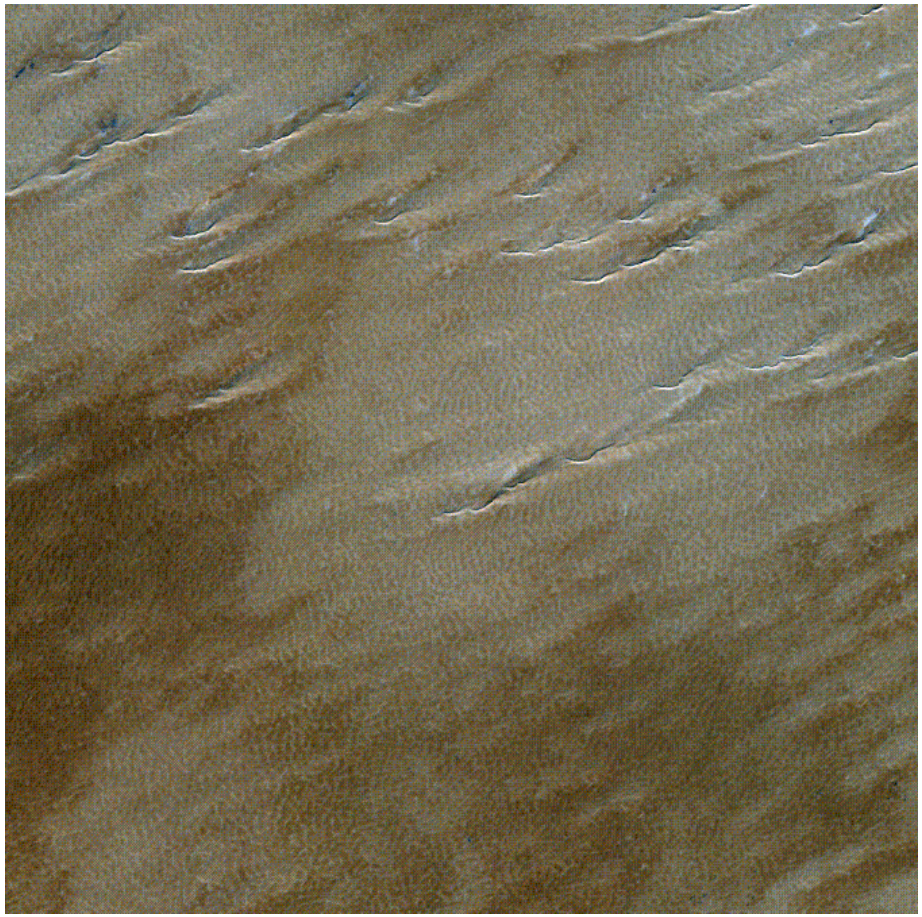
Scene Analyzed	Associated Site (from Cosnefroy et al. 1996)	Scene Center Latitude	Scene Center Longitude	Average FOM
p179r41_5t871020	“Egypt 1”	27:25:12.8017 N	26:36:56.4497 E	0.05906
p181r40_5t870119	“Libya 4”	28:51:34.9092 N	23:53:22.6894 E	0.07414
p187r43_5t870113	“Libya 1”	24:32:35.8606 N	13:31:16.5639 E	0.087085
p192r39_4t880127	“Algeria 3”	30:17:26.2917 N	7:15:37.7491 E	0.118828
p193r39_5t870107	“Algeria 4”	30:17:21.5617 N	5:41:36.5624 E	0.108773
p197r42_5t870204	“Algeria 2”	25:59:05.0692 N	1:32:51.6537 W	0.094952
p198r47_5t860107	“Mali 1”	18:46:50.0472 N	4:53:28.2929 W	0.056467
p201r47_4t880126	“Mauritania 1”	18:46:37.0622 N	9:28:16.8981 W	0.090302

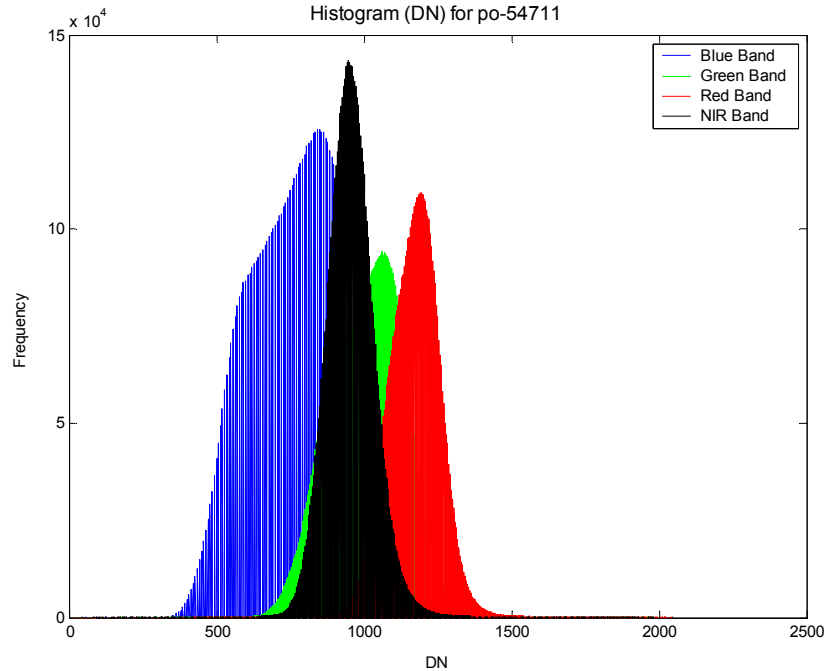
Most Uniform 11 Km X 1 Km Areas

Scene Analyzed	Associated Site (from Cosnefroy et al. 1996)	Center Latitude	Center Longitude	Lowest FOM
p179r41_5t871020	“Egypt 1”	27:15:26.51 N	27:16:47.09 E	0.016188
p181r40_5t870119	“Libya 4”	29:25:58.14 N	23:51:16.30 E	0.028736
p187r43_5t870113	“Libya 1”	23:54:10.25 N	13:17:06.36 E	0.008644
p192r39_4t880127	“Algeria 3”	29:34:55.27 N	6:32:58.51 E	0.016164
p193r39_5t870107	“Algeria 4”	30:49:32.29 N	5:56:56.83 E	0.015336
p197r42_5t870204	“Algeria 2”	25:11:15.81 N	0:52:22.84 W	0.015652
p198r47_5t860107	“Mali 1”	19:23:29.41 N	4:01:37.66 W	0.015617
p201r47_4t880126	“Mauritania 1”	19:31:23.59 N	9:31:00.34 W	0.016136

“Mali 1” Site Uniformity

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





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

FOM = 0.0313

Signal-to-Noise Ratio Estimates

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 SPOT 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

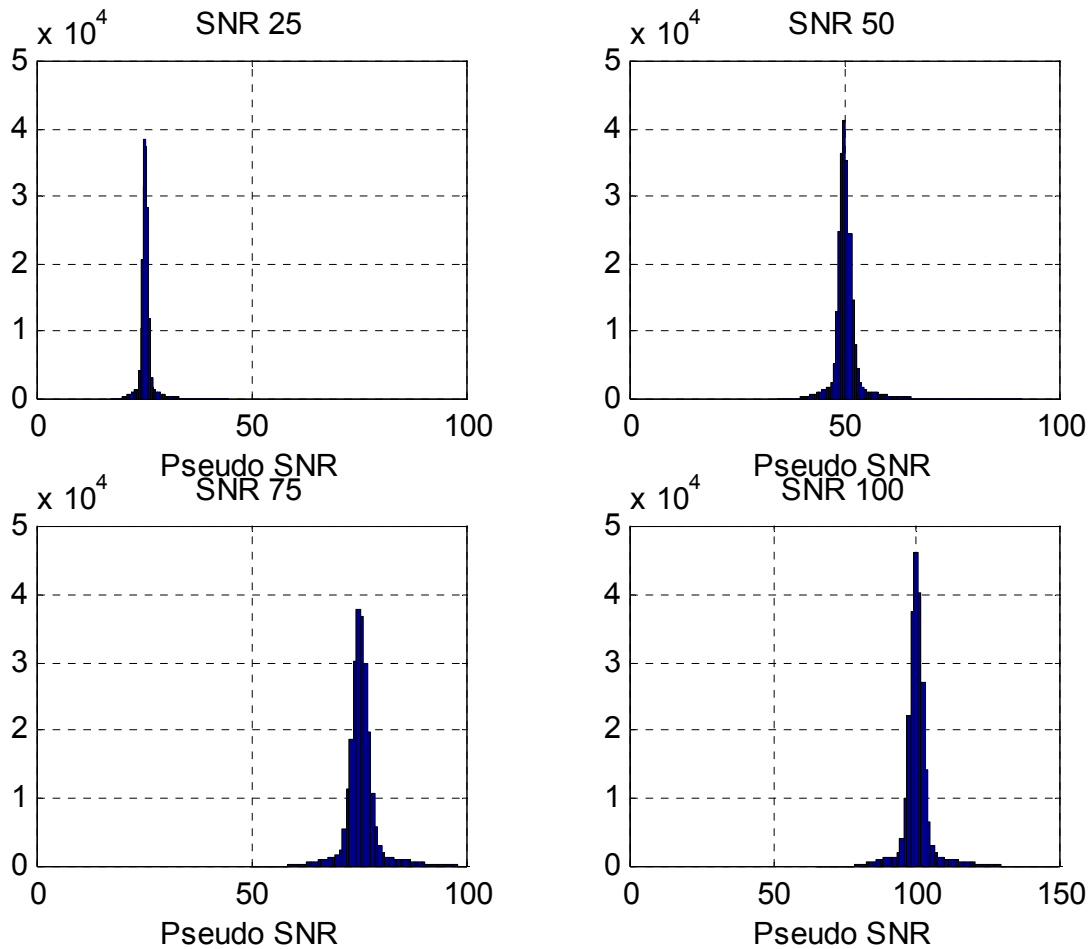
    σ is the standard deviation of the image or subimage
  - Expect Gaussian histograms for sensor noise

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**

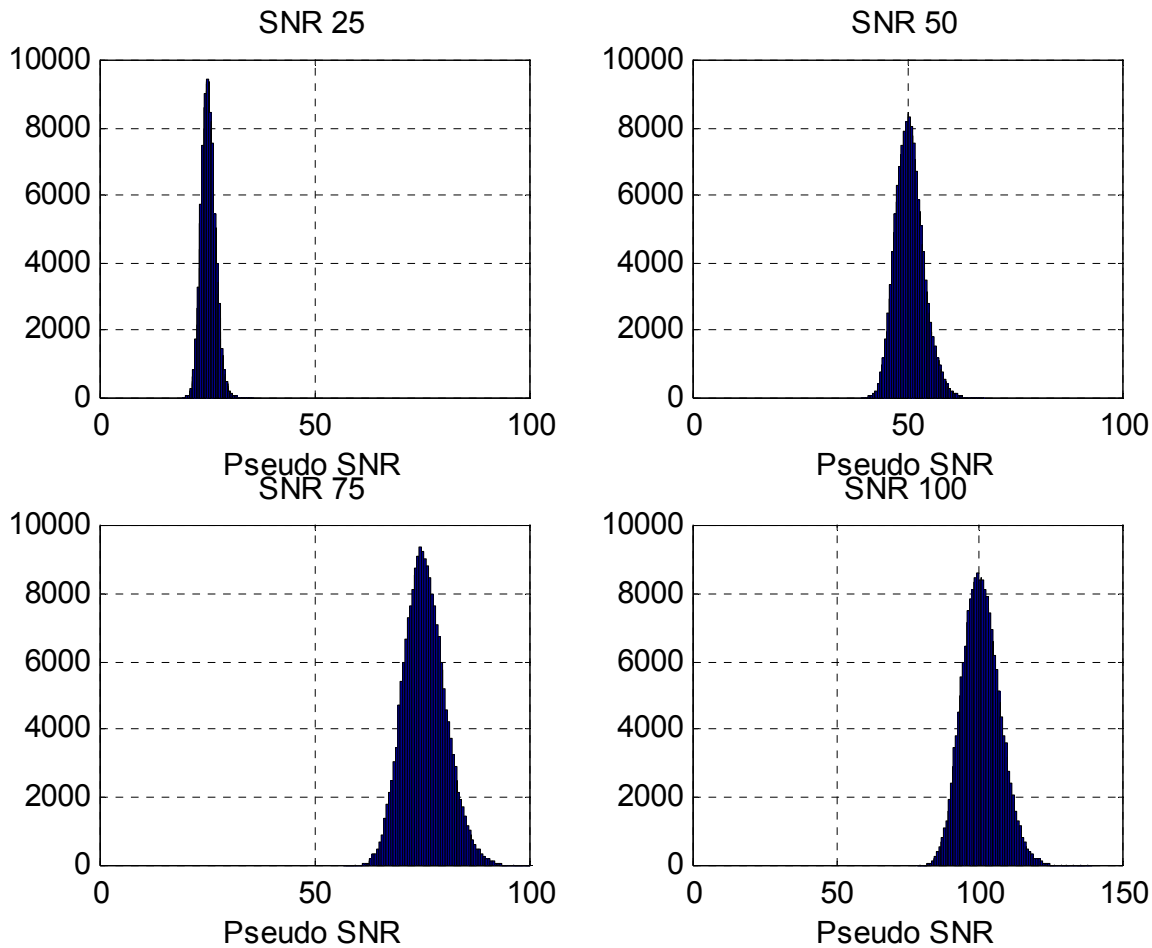
Simulated SNR Estimates

30x30 Pseudo SNR Histograms



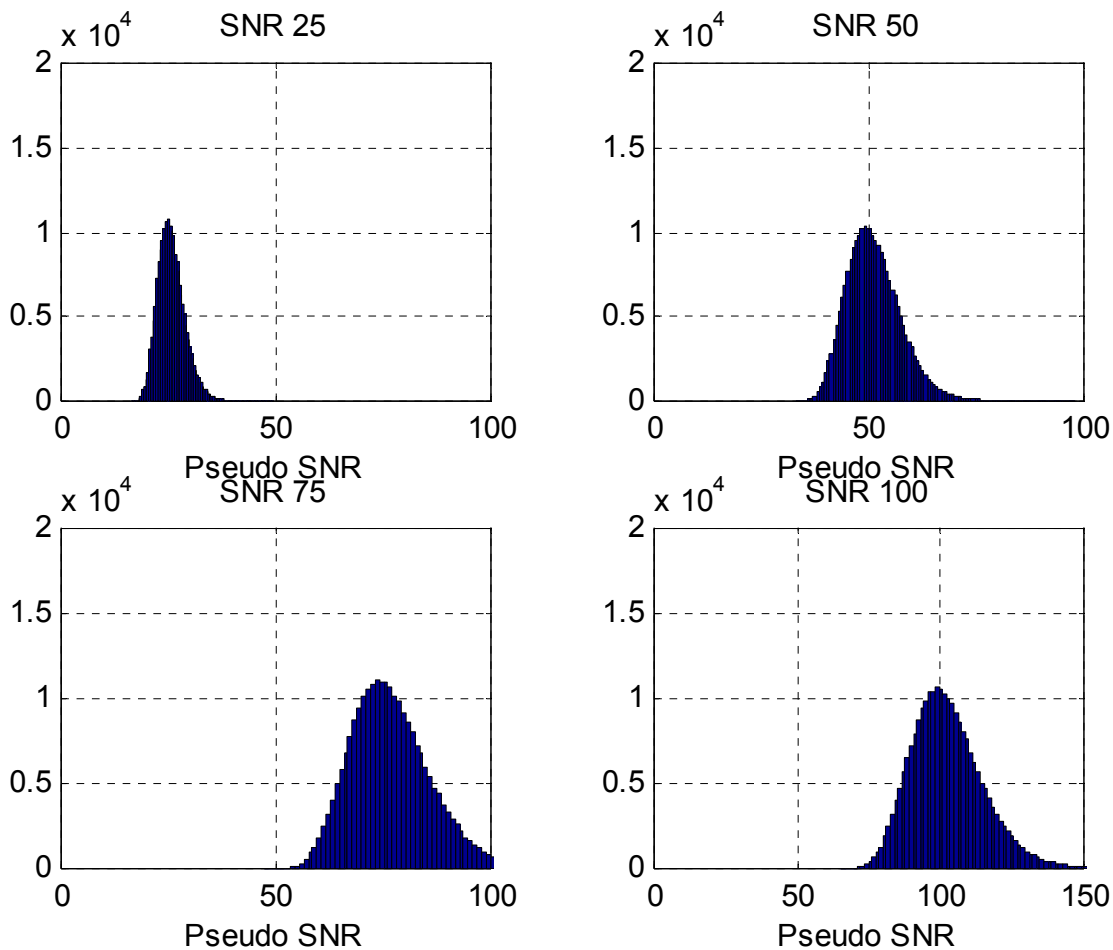
Simulated SNR Estimates

10x10 Pseudo SNR Histograms



Simulated SNR Estimates

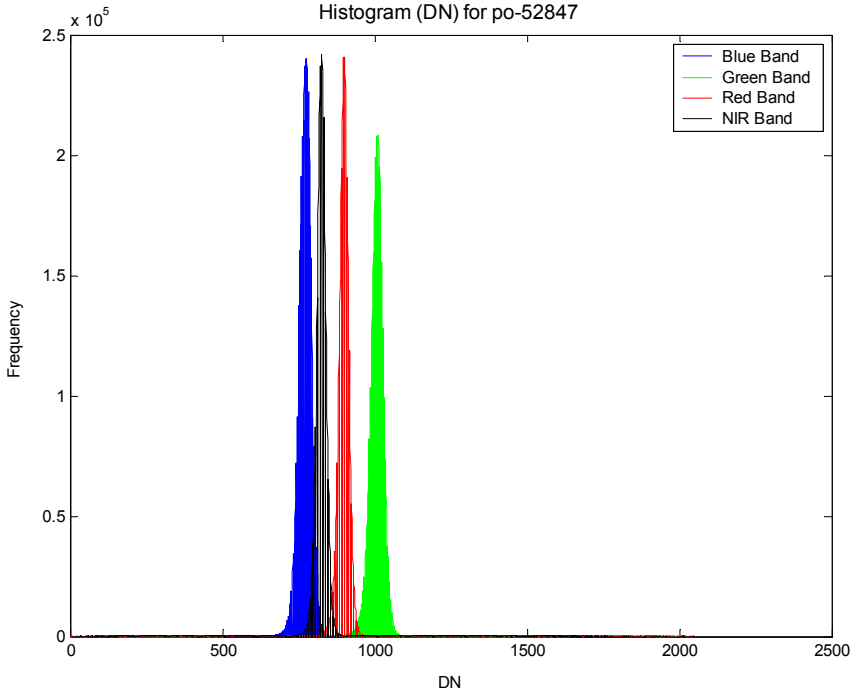
5x5 Pseudo SNR Histograms



IKONOS SNR Estimates

Antarctica Site 1 Uniformity

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

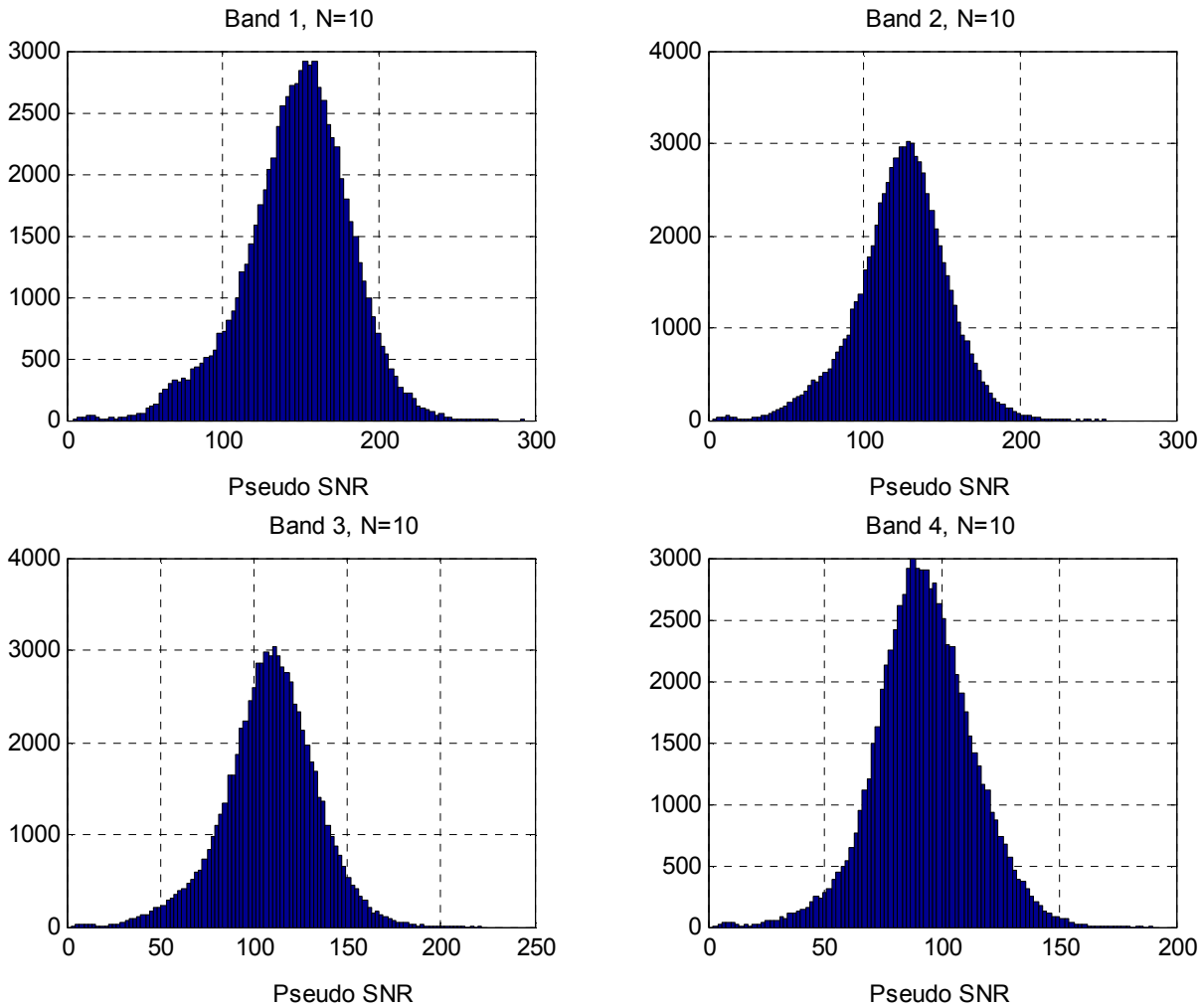


Band	Mean Radiance Value $W/(m^2sr)$	Standard Deviation / Mean (Radiance Values)
1	17.3671	0.0147
2	19.3374	0.0167
3	12.5021	0.0190
4	11.7009	0.0214

FOM = 0.0181

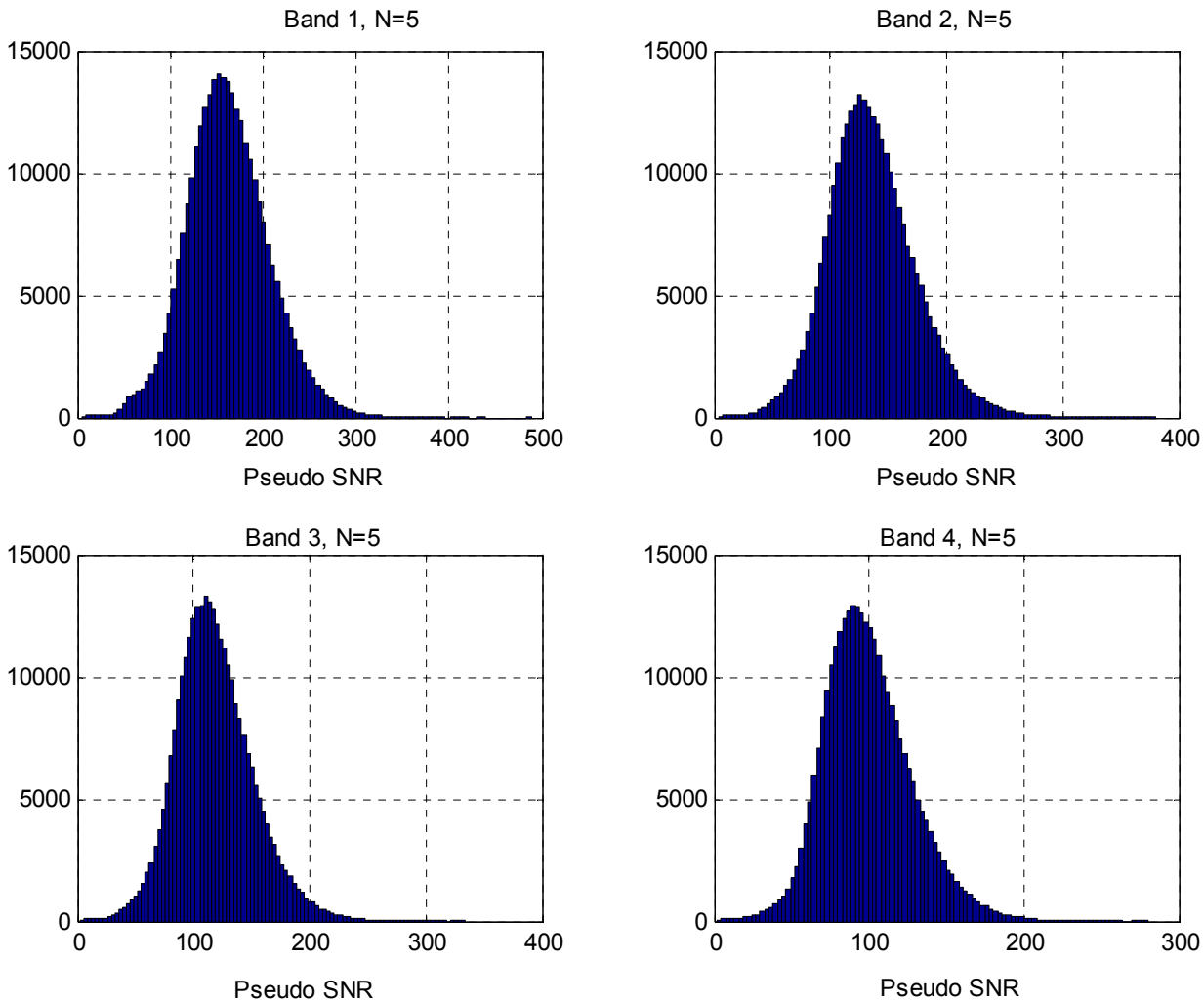
Antarctica Site 1 SNR Estimates

Task 627, PO ID#52847
10 X 10 Window SNR Estimates



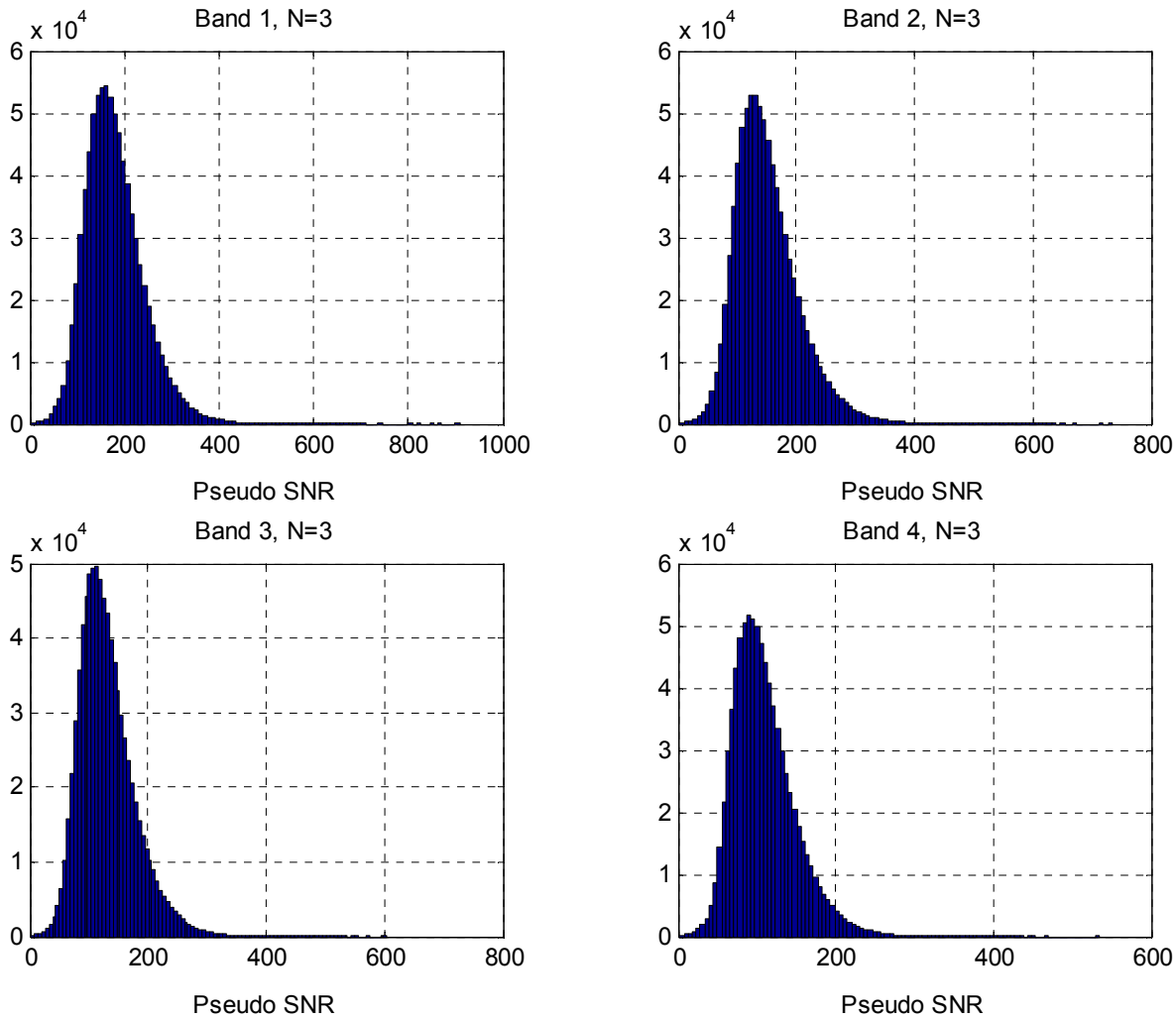
Antarctica Site 1 SNR Estimates

Task 627, PO ID#52847
5 X 5 Window SNR Estimates



Antarctica Site 1 SNR Estimates

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



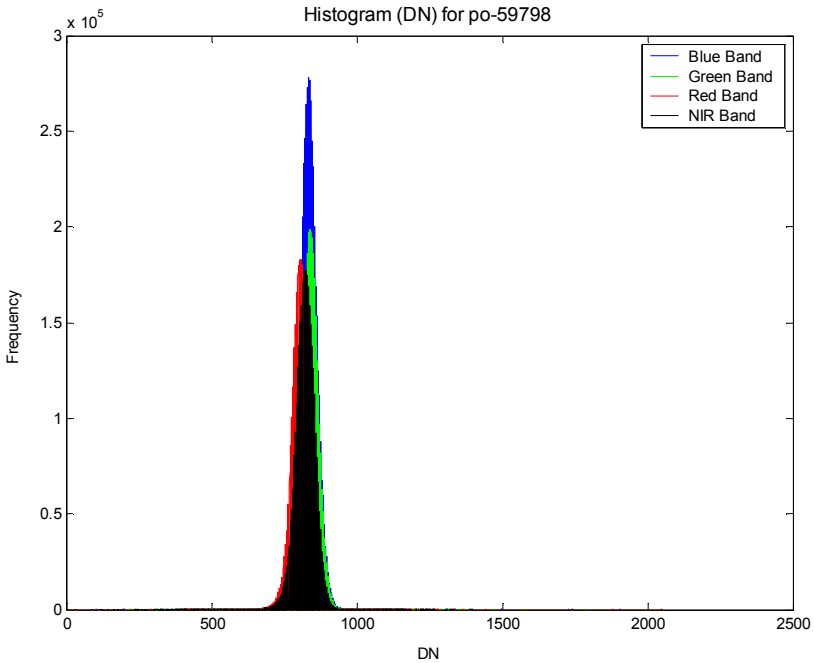
Antarctica Site 1 SNR Summary

Task 627, PO ID#52847

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	17.3671	158.9590	152.3217	162.1035	0.1093	0.1140	0.1071
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

Antarctica Site 2 Uniformity

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

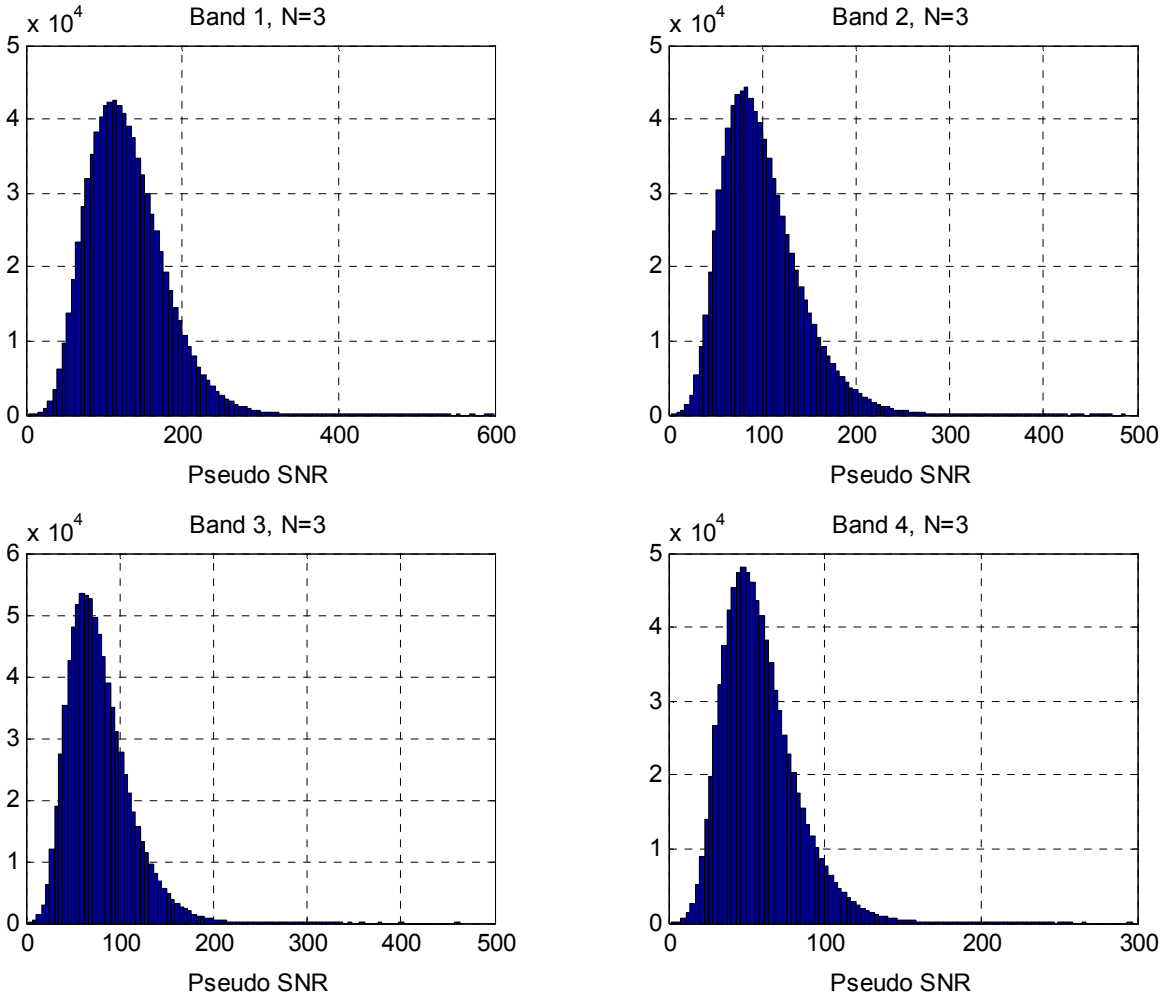


Band	Mean Radiance Value $W/(m^2sr)$	Standard Deviation / Mean (Radiance Values)
1	12.4096	0.0154
2	13.0841	0.0196
3	8.6197	0.0248
4	8.1926	0.0300

FOM = 0.0231

Antarctica Site 2 SNR Estimates

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



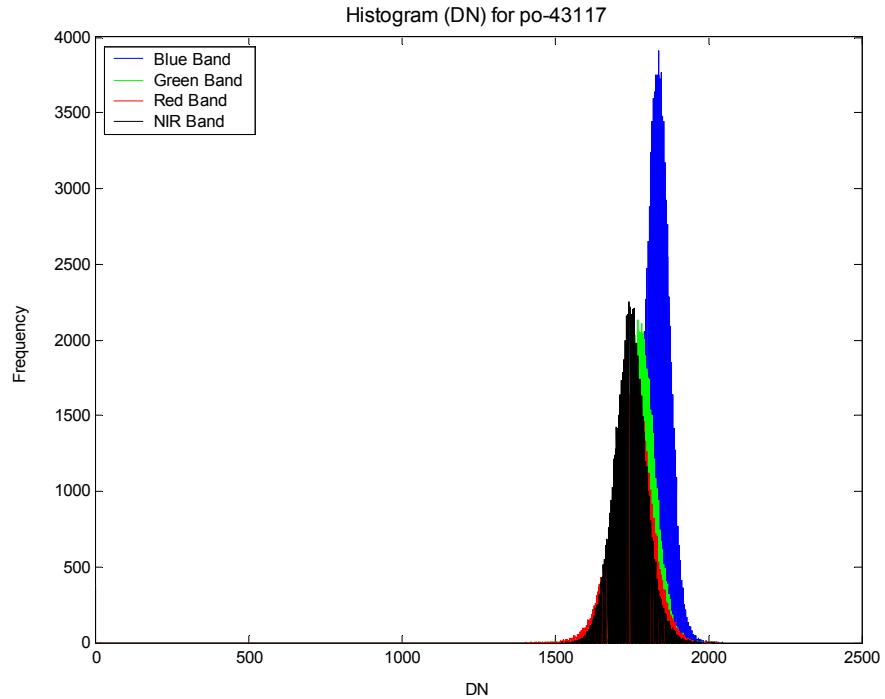
Antarctica Site 2 SNR Summary

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	12.4096	105.1424	106.6267	114.0335	0.1180	0.1164	0.1088
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

Ivanpah, CA Site Uniformity

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



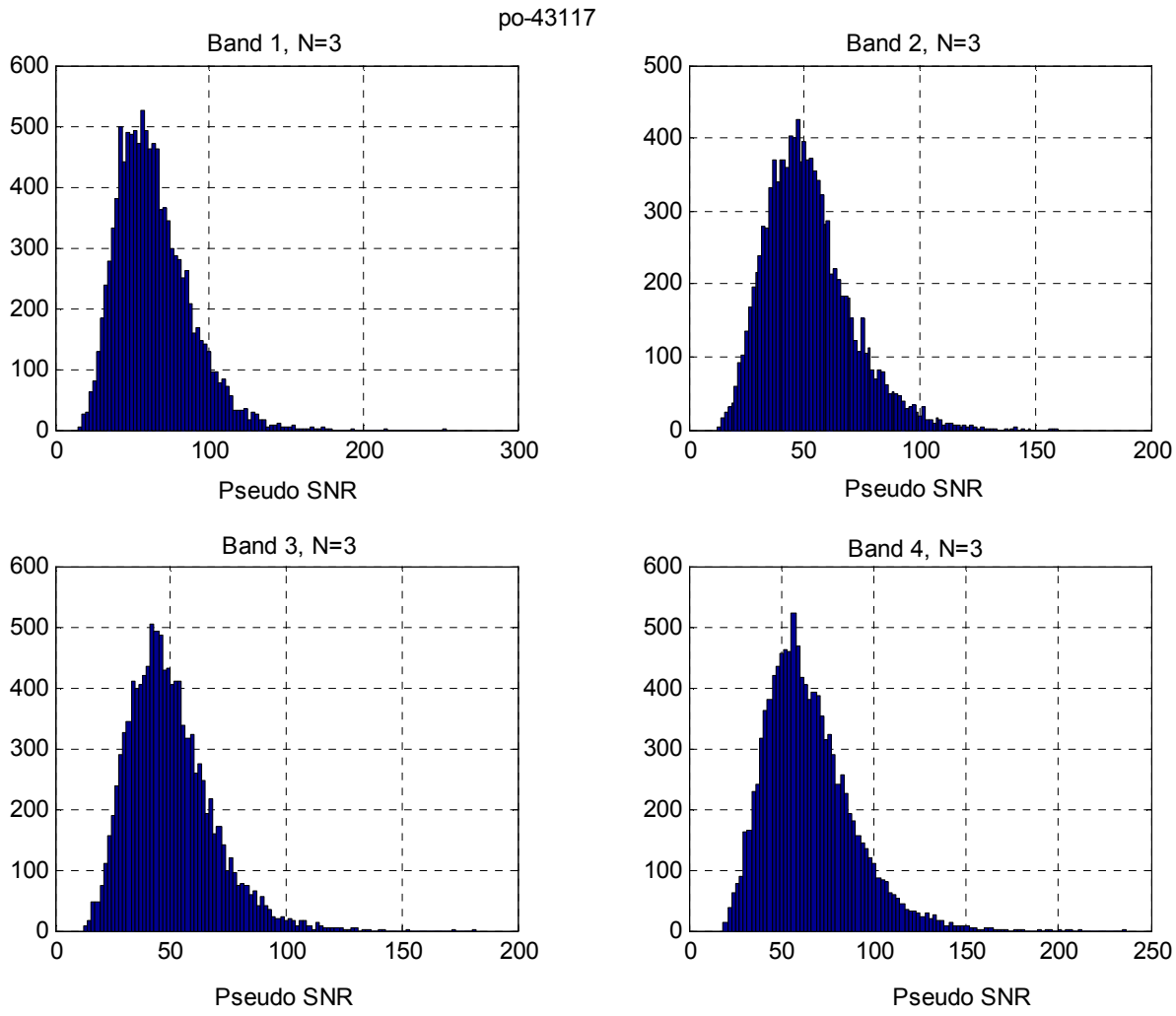
Band	Mean Radiance Value W/(m^{2}sr)	Standard Deviation / Mean (Radiance Values)
1	7.9765	0.0652
2	10.6203	0.0683
3	8.4575	0.0708
4	9.0073	0.0679

FOM = 0.0681

Ivanpah, CA Site SNR Estimates

Stennis Space Center

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



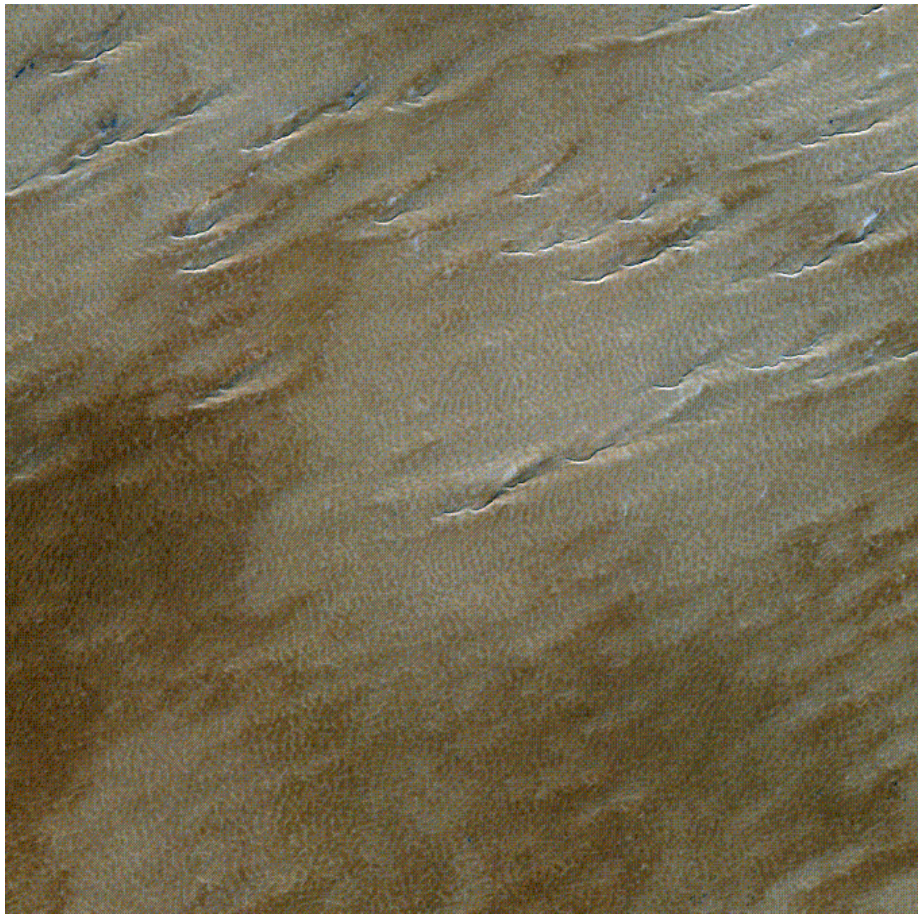
Ivanpah, CA Site SNR Summary

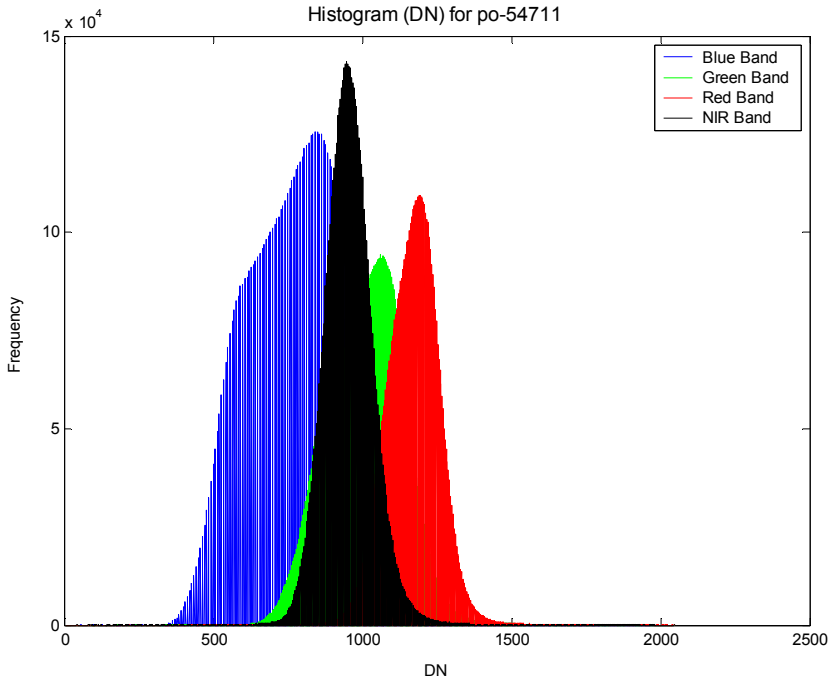
Task 789, PO ID#43117

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	7.9765	53.1855	55.5864	56.6186	0.1500	0.1435	0.1409
Band 2	10.6203	43.0584	43.2196	47.1574	0.2466	0.2457	0.2252
Band 3	8.4575	42.4880	44.3659	42.0815	0.1991	0.1906	0.2010
Band 4	9.0073	55.7761	52.9028	56.8210	0.1615	0.1703	0.1585

Mali Site Uniformity

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





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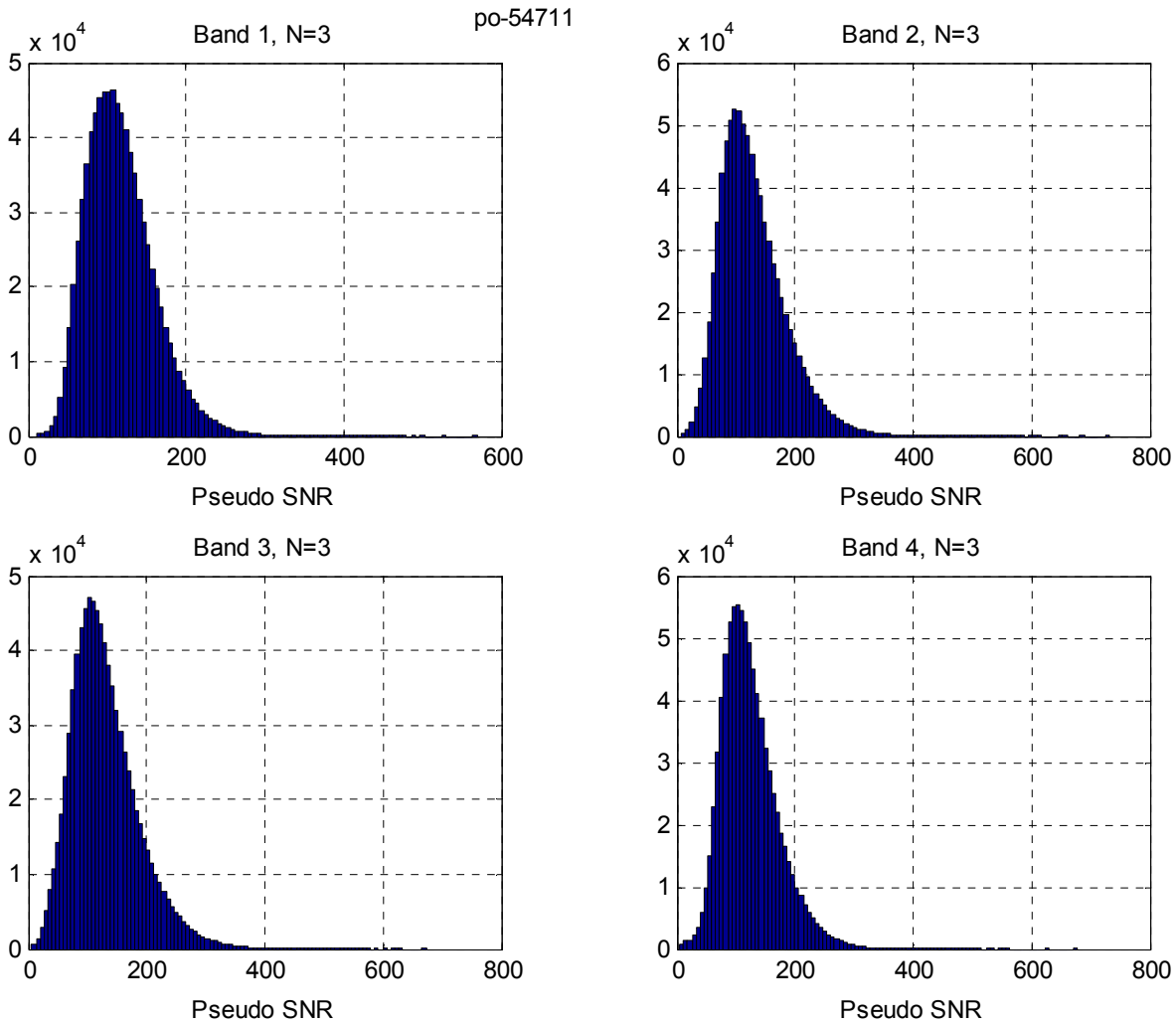
3	13.4130	0.0268
4	14.3605	0.0230

FOM = 0.0313

Mali Site SNR Estimates

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



Mali Site SNR Summary

Task 895, PO ID#54711

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	9.3836	68.2870	82.5735	107.7011	0.1374	0.1136	0.0871
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

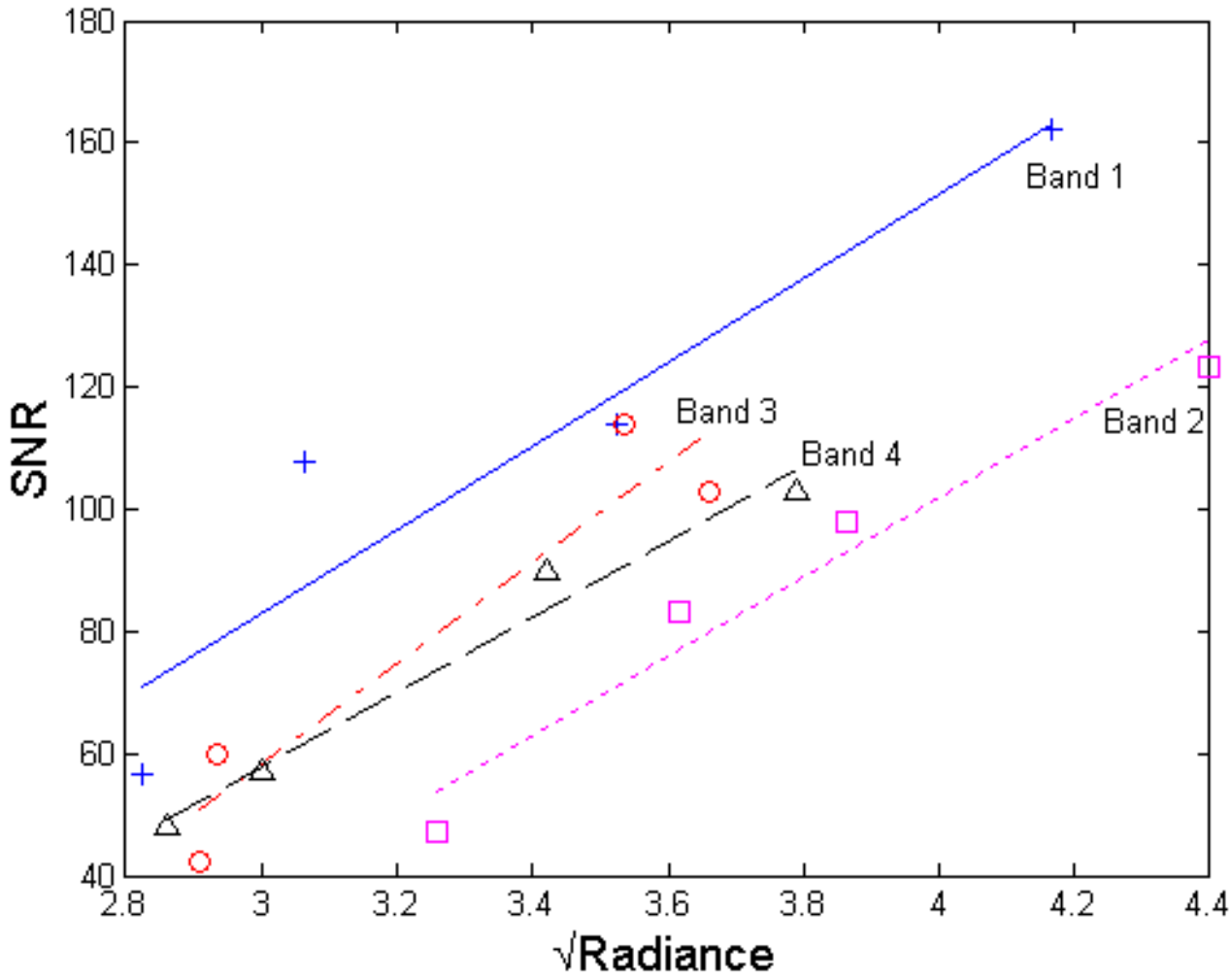
SNR of Photon Noise Limited Systems

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

- **SNR proportional to Sqrt of radiance**

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

SNR vs. Square Root of Mean Radiance



Summary

- **EarthSat Africa data shows < 3% non-uniformity for IKONOS size scenes (11 Km X 1 Km windows)**
  - Uniform site selection algorithm will be modified and applied to IKONOS imagery
- **IKONOS SNR estimates require further analysis**
  - SNR vs. target reflectance must be determined and compared against IKONOS specification
  - Effects of MTFC will be investigated; MTFC Off data is expected to have higher SNR
  - Comparison with Space Imaging models/estimates is desired
- **IKONOS will be tasked periodically over uniform sites to monitor the system stability and SNR**
  - Coincident collects with L7, EO1 are desirable