Relative Gain Characterization and Correction for Pushbroom Sensors Based on Lifetime Image Statistics

Joint Agency Commercial Imagery Evaluation

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Objectives

- Develop improved estimates of detector relative gains for pushbroom scanners using an optimized subset of data from sensor imagery
- Develop techniques for on-orbit estimation of sensor relative gains for OLI based on precursor ALI image database
    - Based on ALI Assessment System
    - 2602 scenes from 8 year period (Nov 26, 2000 to May 28, 2008)

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Background

- Image data from pushbroom sensors typically contains striping due to mismatch in response between individual detectors in an array
- Detector Relative gains for pushbroom sensors can be characterized using various methods
    - Pre-Launch Calibration
    - Using Diffuser Panel
    - Yaw Maneuver
    - Using Scene Data
- Characterization using image data only requires statistics from scenes it collected

Background

- For pushbroom sensors, relative gains can be estimated from image data if the statistics from a sufficiently large number of scenes are averaged to obtain composite detector statistics

- Composite Histogram approach can be used to estimate relative gains from lifetime image statistics

- Relative gains based on this approach can be calculated using either the ratio of detector means or standard deviations

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Relative Gain Estimation

- Equations involved are

$$RG_i = \frac{\mu_i}{\mu_r}$$

$$RG_i = \frac{\sigma_i}{\sigma_r}$$

- **RG_i : Relative Gain for i^{th} detector**
- **μ_i : Global Mean of i^{th} detector**
- **σ_r: Global Standard Deviation of i^{th} detector**
- **μ_r : Mean of a reference detector**
- **σ_r : Standard Deviation of a reference detector**

- Global detector statistics (mean and standard deviation) are calculated using detector data from all the scenes

Algorithm Development

Step 1: Calculate Scene Statistics

- Equations used to calculate the scene mean and standard deviations are

$$\mu_s = \frac{\sum_{i=1}^{N_d} n_{is}\,\mu_{is}}{\sum_{s=1}^{N_d} n_{is}}$$

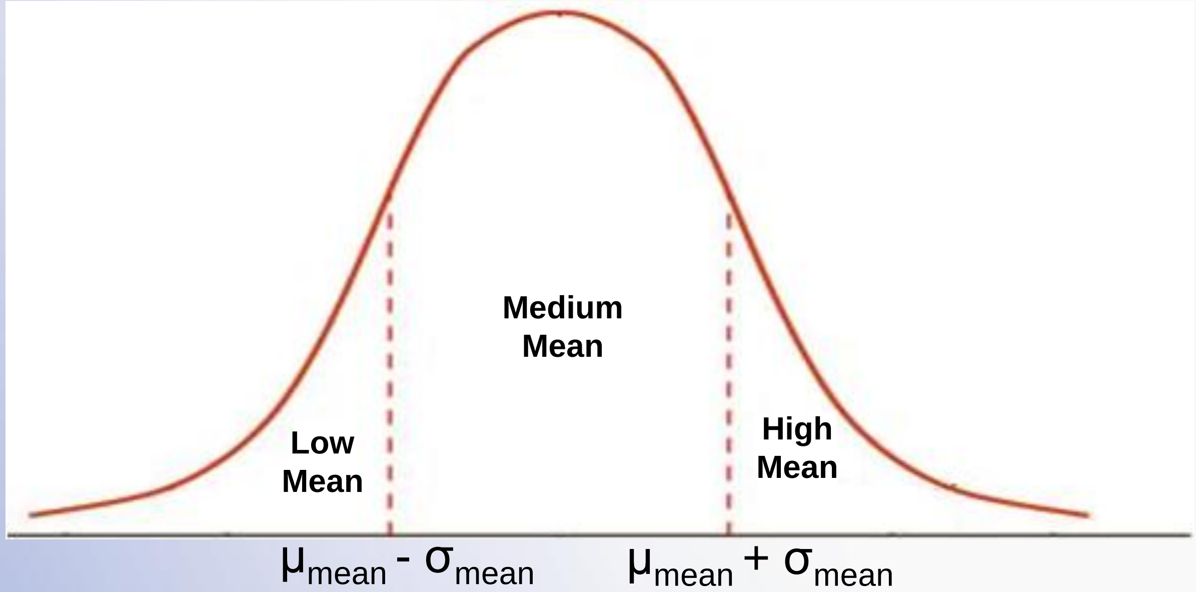
$$\sigma_s = \sqrt{\frac{\left(\sum_{i=1}^{N_d} n_{is}\left(\sigma_{is}^2 + \mu_{is}^2\right) - \left(\sum_{i=1}^{N_d} n_{is}\right)\mu_s^2\right)}{\sum_{i=1}^{N_d} n_{is}}}$$

- **μ_s : Scene Mean**
- **σ_s : Scene Standard Deviation**
- **N_d : Total Number of Detectors**
- **μ_{is} : Mean of i^th Detectors for s^th Scene**
- **σ_{is} : Standard Deviation of i^th Detectors for s^th Scene**
- **n_{is} : Number of Frames of i^th Detectors for s^th Scene**

Step 1: Calculate Scene Statistics Cont.

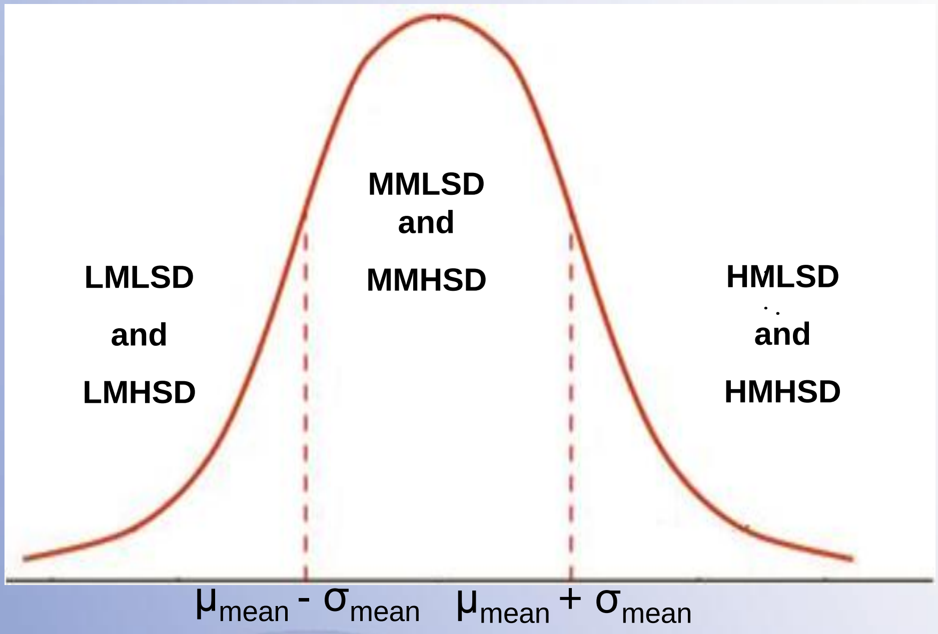
- During the calculation
    - ➢Subtract bias from the mean DN of each detector, for every scene
    - ➢Avoid the use of saturated detectors data

Step 2: Calculate Scene Mean Thresholds



- Once the mean for all the available test scenes is determined, calculate average and standard deviation (μ_{mean} , σ_{mean}) of scene means
- Based on μ_{mean} and σ_{mean}, divide the distribution of scene means into three different segments: Low Mean (LM), Medium Mean (MM) and High Mean (HM)
- From available scenes, group scenes lying in each of the three regions. Note: all 4 SCAs of a ALI scene need to lie in one region to accept the scene

Step 3: Calculate Scene Std. Dev. Thresholds



Band	Dataset_2 (2602 Scenes)				
	Mean Thresholds		Standard Deviation Thresholds		
	μ - σ	μ + σ	LM	MM	HM
PAN	148	1206	36	213	311
MS-1p	136	765	4	117	210
MS-1	122	844	5	145	248
MS-2	140	1100	11	207	314
MS-3	157	1369	30	237	287
MS-4	317	1686	74	259	215
MS-4p	318	1719	73	267	211
MS-5p	215	933	83	198	194
MS-5	185	1040	74	235	237
MS-7	117	910	50	199	235

Table: Scene Mean and Std. Dev. Thresholds

- Calculate average Standard Deviation for all three regions
- Break each region into two sub-regions based on image std. dev. above or below average std. dev. for that region
- Resulting 6 different sub-regions

  Low Mean, low and high standard deviation (LMLSD and LMHSD)

  Mean High, low and high standard deviation (MMLSD and MMHSD)

  High Mean, low and high standard deviation (HMLSD and HMHSD)

Step 4: Estimate Relative Gain

Table: Total Number of Scenes Available in each of 6 sub-regions for Dataset_2.

Band	Low Mean		Medium Mean		High Mean	
	LMLSD	LMHSD	MMLSD	MMHSD	HMLSD	HMHSD
PAN	23	8	666	423	84	69
MS-1p	87	24	884	553	125	93
MS-1	87	22	893	555	124	91
MS-2	90	34	865	533	117	85
MS-3	99	47	642	411	89	64
MS-4	105	56	409	242	77	49
MS-4p	100	52	379	229	74	48
MS-5p	156	105	674	457	150	120
MS-5	155	84	596	444	118	103
MS-7	97	56	514	399	66	54
Average	**100**	**49**	**652**	**425**	**102**	**78**

- **As expected, there are far more medium-mean (76%) scenes than low-mean (11%) and high-mean scenes (13%)**
- **Relative Gain is estimated for 6 sub-regions: LMLSD, LMHSD, MMLSD, MMHSD, HMHSD, and HMHSD**
- **These 6 sets of relative gains are applied to a set of test scenes**

Striping Metric

- A Striping metric is needed to provide a quantitative measurement of the amount of striping present in an image

- To calculate the amount of striping present in the image, a difference between every pixel and its two left and right neighbors (D_{CT}) is calculated

$$D_{CT}(m,n) = x_{m,n} - \frac{x_{m,n-1} + x_{m,n+1}}{2}$$

- To avoid the detection of scene content as stripes, a homogeneity filter is used. Homogeneity filter is evaluated using cross-track (H_{CT}) and along-track homogeneity (H_{AT})

Striping Metric

$$H_{CT}(m,n) = x_{m,n-1} - x_{m,n+1}$$

$$H_{AT}(m,n) = x_{m,n} - \frac{x_{m-1,n} + x_{m+1,n}}{2}$$

These two factors are quite noisy. Thus, the H_{CT} was averaged over five pixels, while the H_{AT} was averaged over three pixels

- The homogeneity filter *H* was calculated from H_{CT} and H_{AT} *using*

$$H(m,n) = \frac{1}{1 + \left(\frac{\left(\frac{abs\left(H_{AT}(m,n) + H_{CT}(m,n)\right)}{2} \right)}{StripingMetricCutoff} \right)^4}$$

'StripingMetricCutoff' is a band dependent-factor which is 2% of the average standard deviation of all the scenes from the database

- The scene striping metric, absolute value of the product of the cross-track difference D_{CT} and homogeneity filter *H*, shows where, spatially in the image, stripes are located
- A detector striping metric for each detector is computed by taking the mean of each column of the scene striping metric

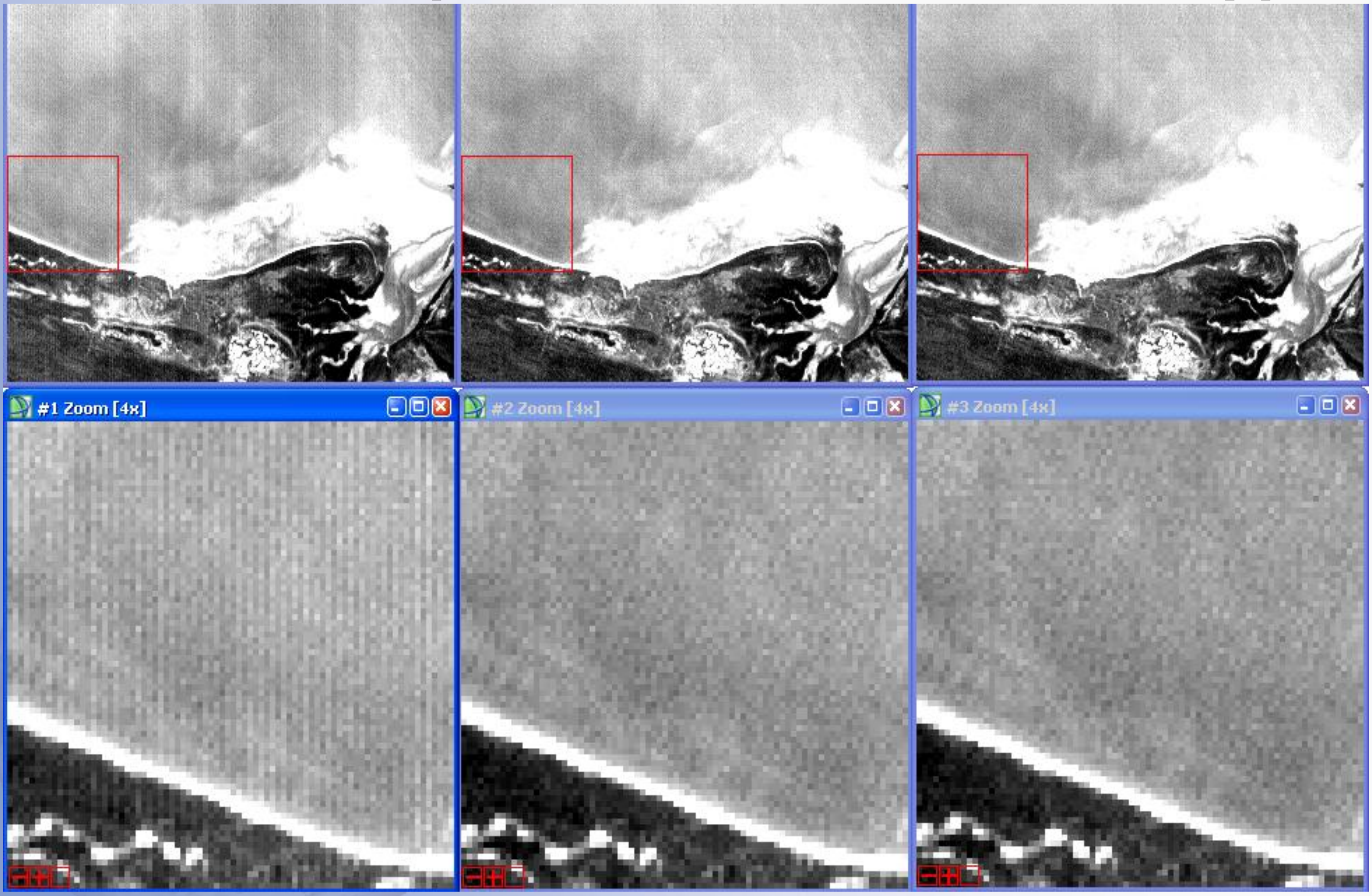
Striping Metric

- Three different factors derived from detector striping metric are used to calculate the striping metric, a single number
  - First factor is the mean of the overall detector striping metric and provides an estimate of the overall striping intensity
  - Second factor is the maximum peak above a baseline from the detector striping metric. This provides an estimate of a peak striping intensity
  - The last factor is the mean of the top 15 peaks (including the maximum peak) above baseline. This provides an estimate of striping severity from worst case detectors.
- The cube root of the product of these three factors is then the overall striping metric of an image

Results

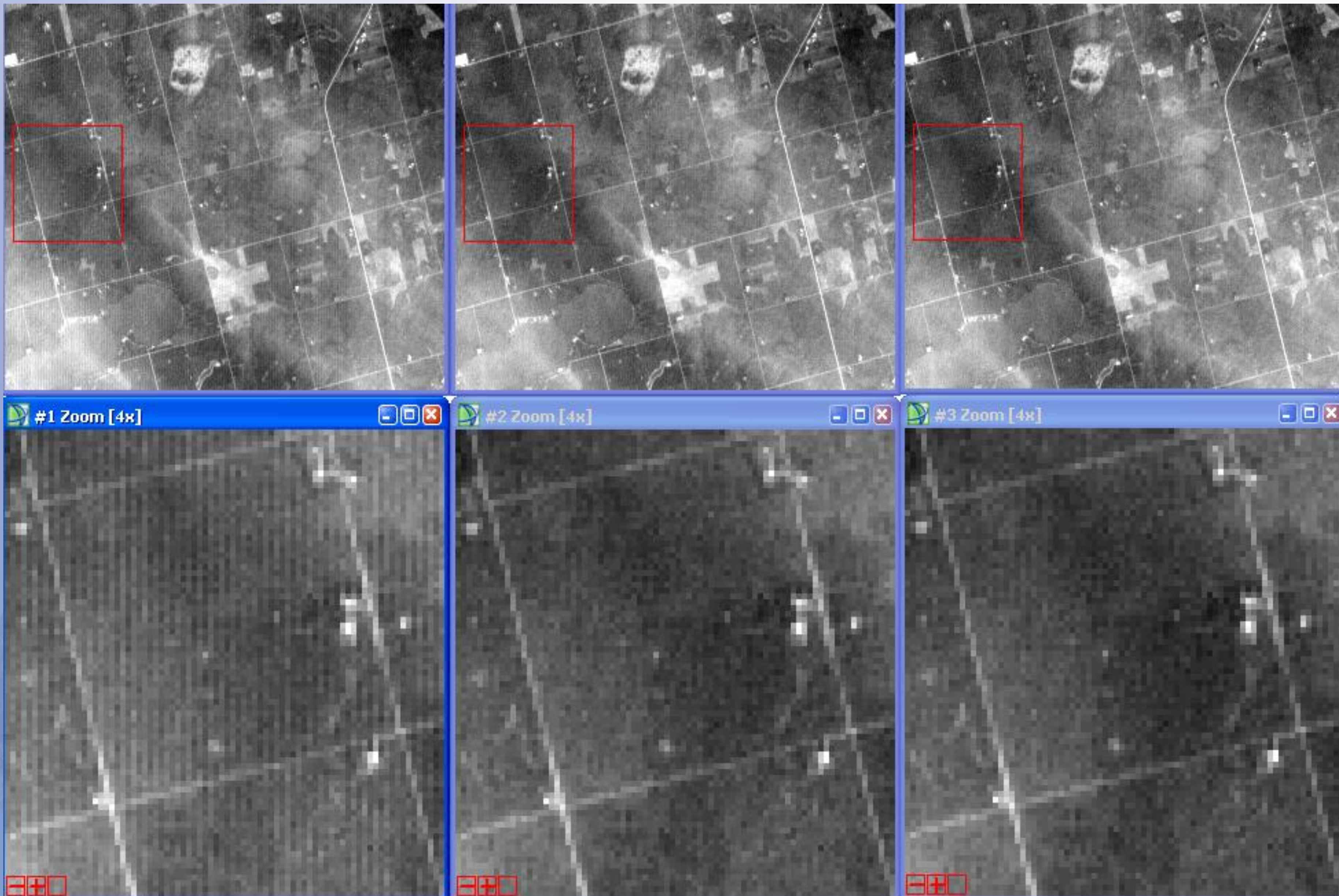
- Qualitative Analysis
  - Visual Assessment

Low Mean (Australia, SCA-1, Band-1p)



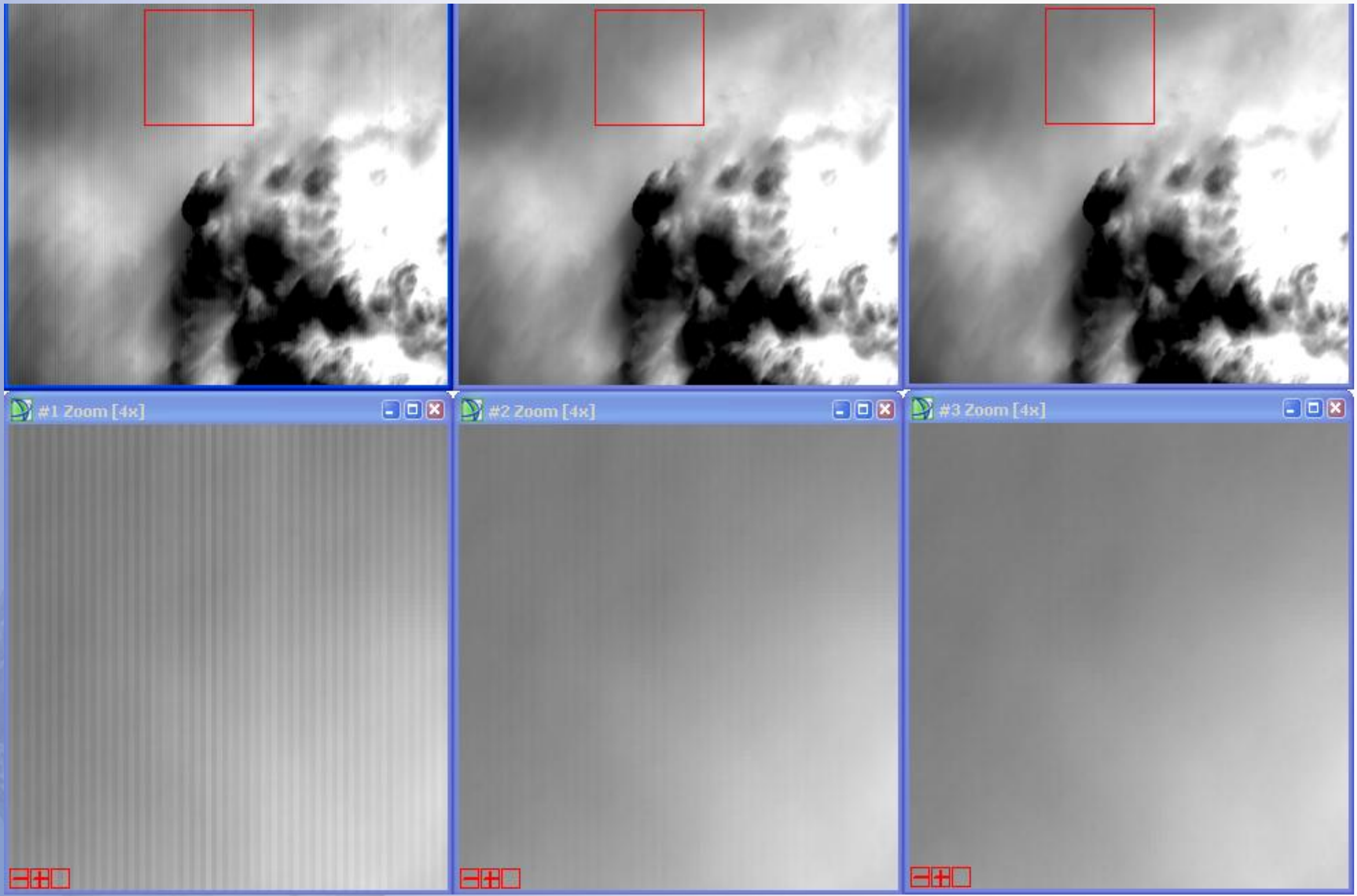
(a) LMHSD (0.89) (b) MMLSD (0.27) (c) HMHSD(0.31)

Medium Mean (Brookings, SCA-1, Band-1p)



(a) LMHSD (0.93) (b) MMLSD (0.45) (c) HMHSD(0.5)

High Mean (New Guinea, SCA-1, Band-2)



(a) LMHSD (12.60) (b) MMLSD (3.00) (c) HMHSD(1.05)

Results

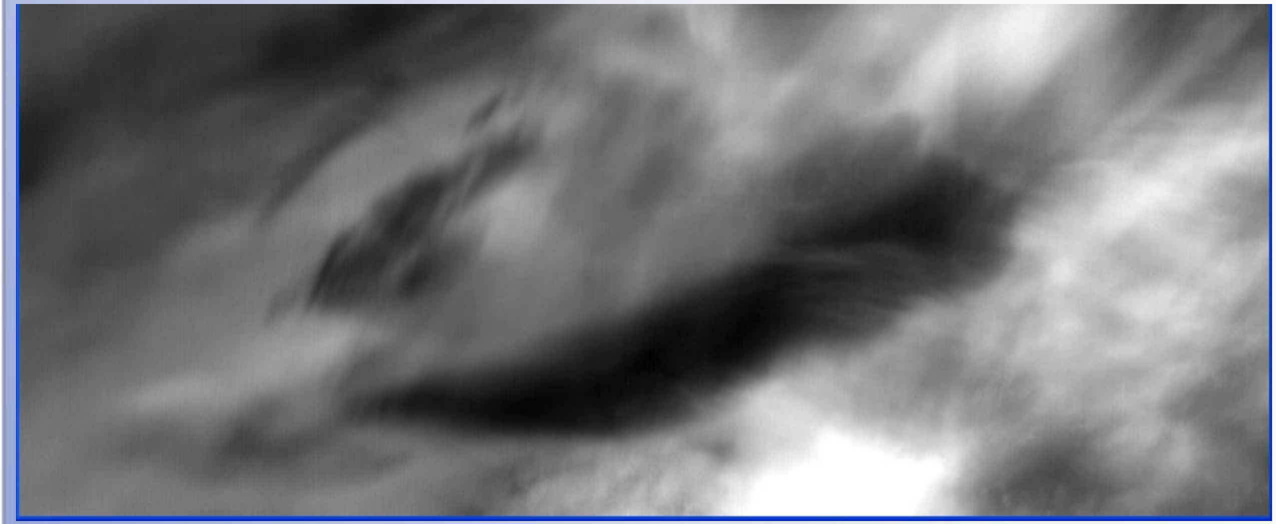
- Quantitative Analysis
  - Striping Metric

Test Scenes

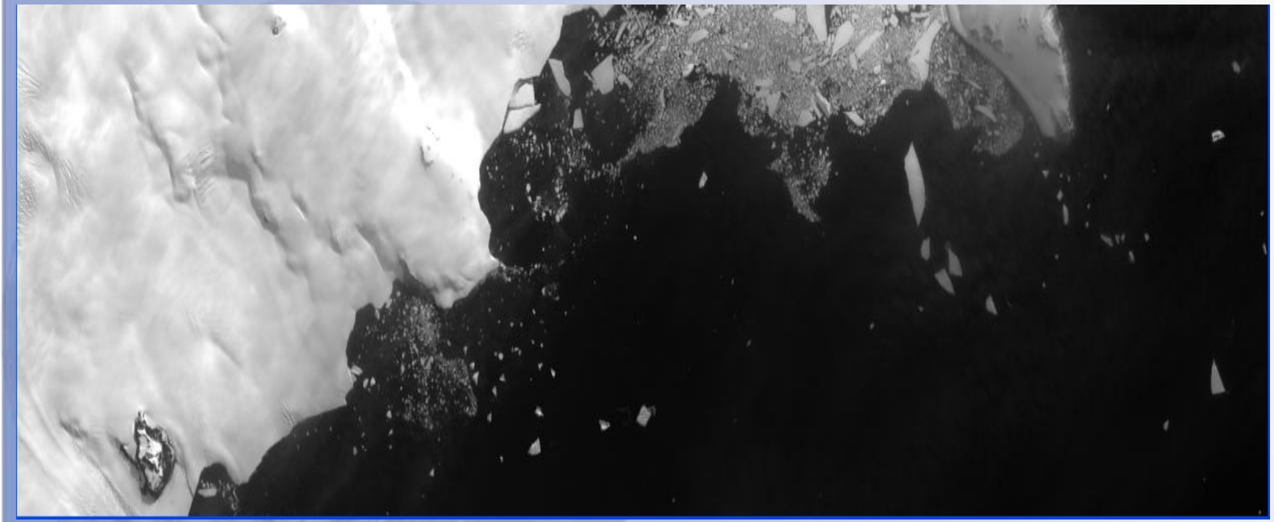
Scene	Location	Scene Characteristics	Scene Mean
1	Antarctica	Cloudy Scene	Low
2	Antarctica-2	Water/Ice	Low
3	Australia	Primarily Water	Low
4	Brookings	Rural Farmland	Medium
5	Brookings	Rural Farmland	Medium
6	Brookings	Rural Farmland	Medium
7	India	Cityscape	Medium
8	New Guinea	Cloudy	High
9	Mauritania	Desert	High
10	Sonara	Desert	High

- Set of test scenes used in the analysis contain ten level zero-R (L0R) scenes
  - ❑ L0R scenes are only nominally aligned with respect to typical detector offsets and have no radiometric correction applied
- The scenes are quite diverse
- 3 Brookings Scenes selected to test repeatability at one location

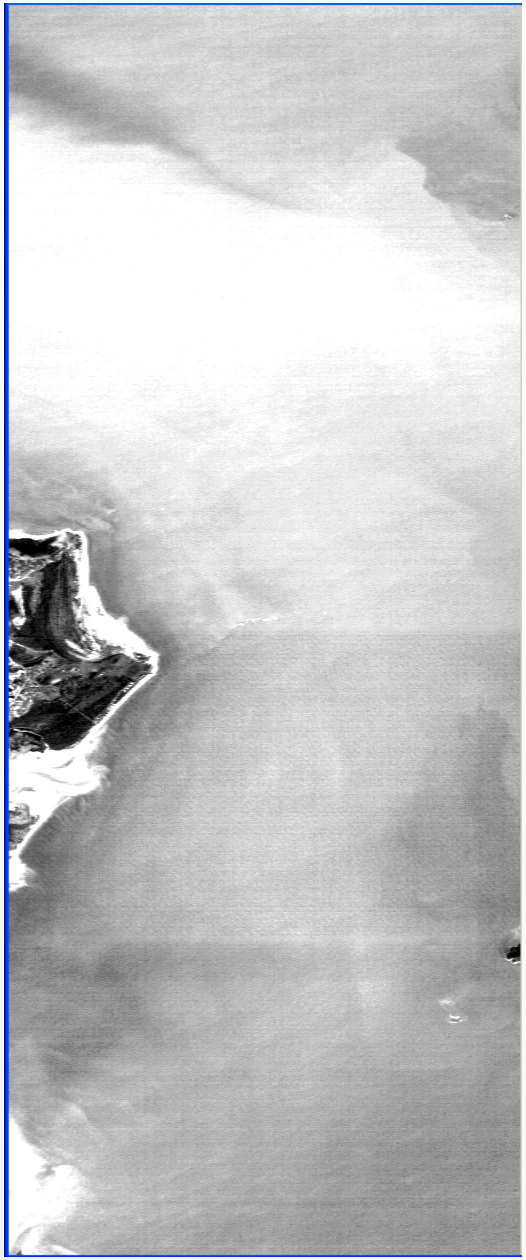
Low Mean Test Scenes



Scene 1: Cloudy Scene (Antarctica)

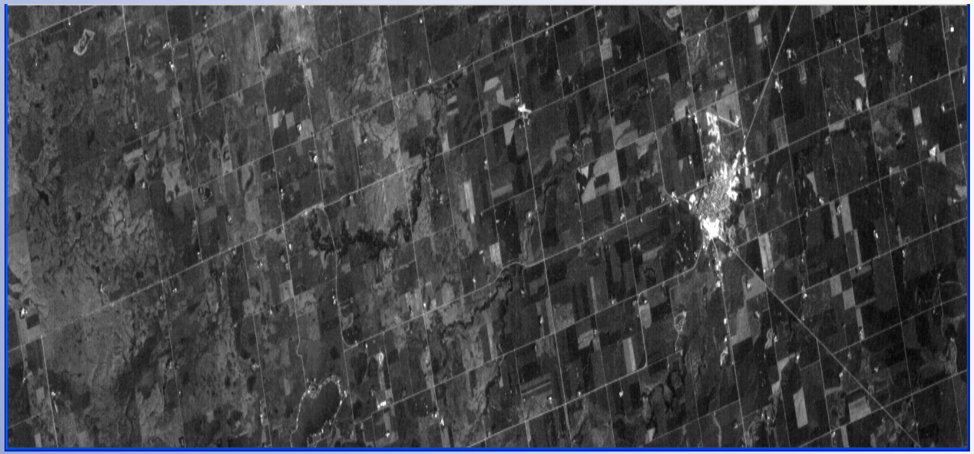


Scene 2: Water/Ice (Antarctica-2)



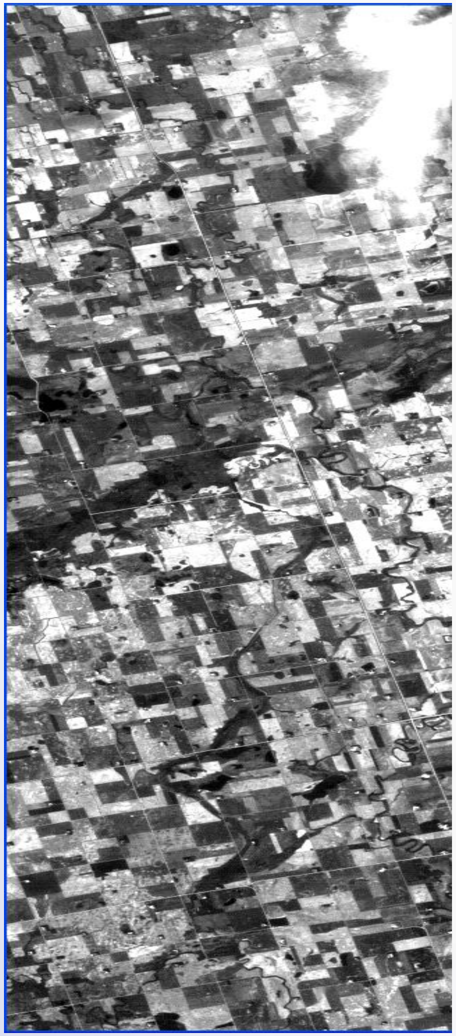
Scene 3: Australia (Primarily Water)

Medium Mean Test Scenes

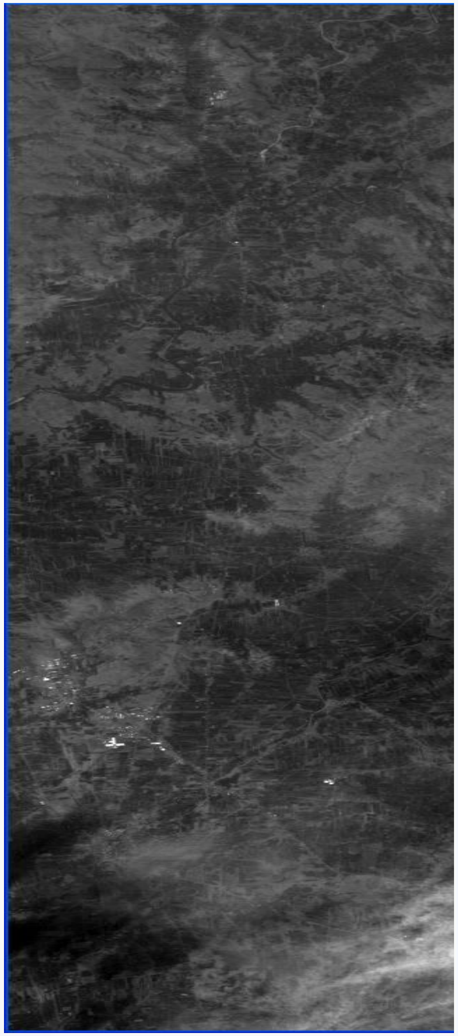


Scene 4: Rural/Farmland (Brookings)

Scene 5: Rural/Farmland (Brookings)

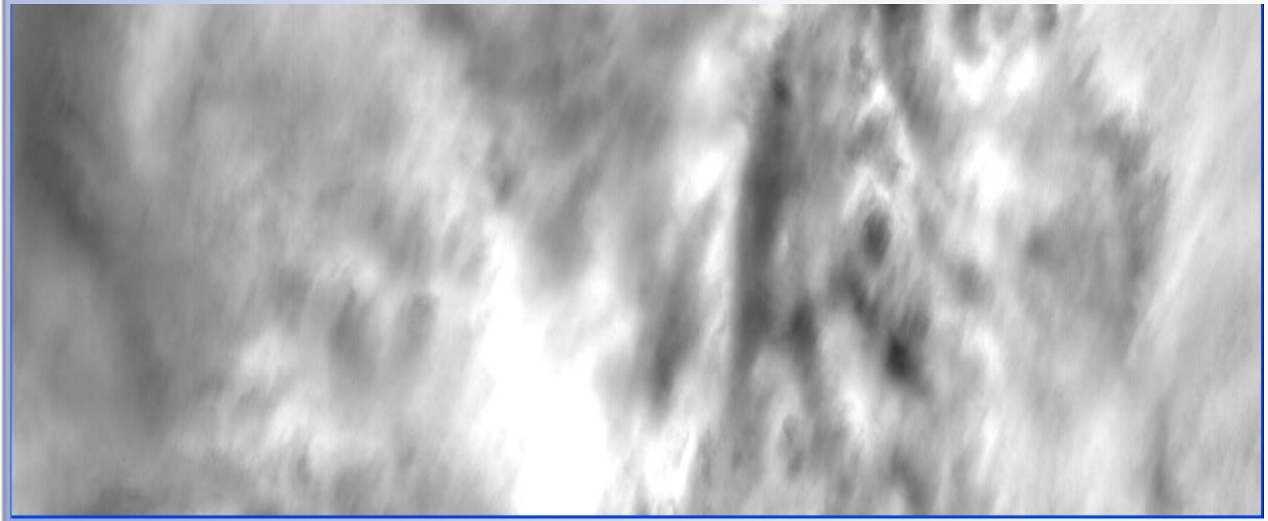


Scene 6: Rural/Farmland (Brookings)

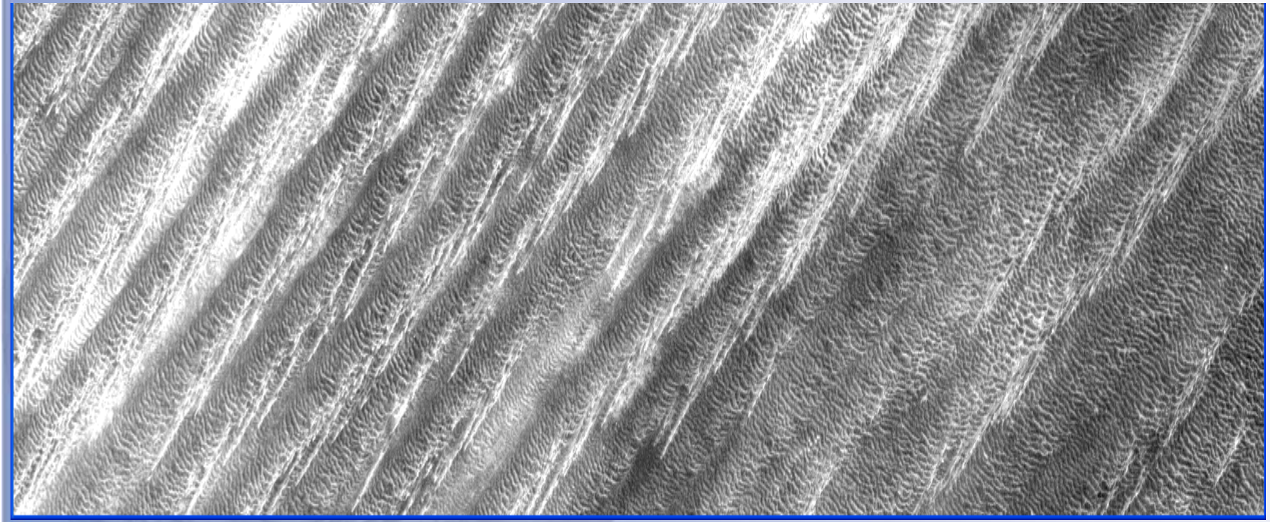


Scene 7: Cityscape (India)

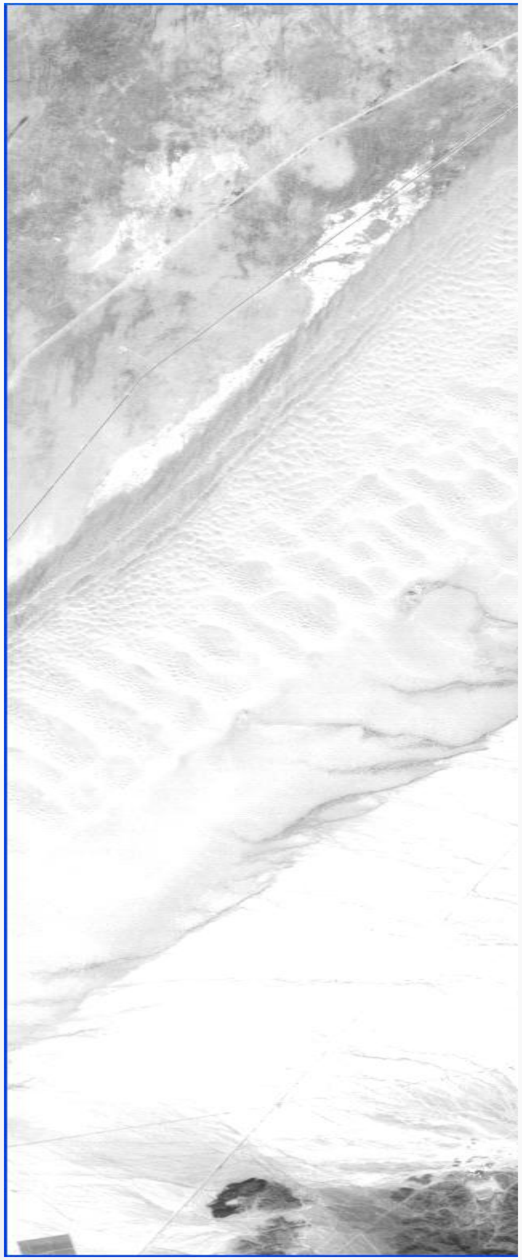
High Mean Test Scenes



Scene 8: Cloudy Scene (New Guinea)



Scene 9: Desert (Mauritania)



Scene 10: Desert (Sonora)

Overall Striping Metric

Scene	Scene Characteristics	Scene Striping Metric						
		Bias Subtracted	LMLSD	LMHSD	MMLSD	MMHSD	HMLSD	HMHSD
1	LM	4.84	3.64	1.53	**0.70**	0.81	0.78	**0.79**
2		1.99	1.62	0.81	**0.65**	0.68	0.66	**0.69**
3		1.66	1.64	0.82	**0.74**	0.77	0.77	**0.80**
4	MM	1.42	1.15	0.36	**0.21**	0.25	0.25	**0.26**
5		1.04	0.84	0.25	**0.22**	0.24	0.25	**0.25**
6		0.68	0.64	0.20	**0.16**	0.18	0.18	**0.18**
7		0.47	0.49	0.19	**0.16**	0.18	0.17	**0.17**
8	HM	14.36	13.84	6.36	**3.32**	3.33	2.89	**2.68**
9		1.81	1.20	0.45	0.20	0.24	0.18	**0.19**
10		0.87	0.71	0.25	0.18	0.18	0.18	**0.18**
Mean Based	**Average**	**2.91**	**2.58**	**1.12**	**0.66**	**0.69**	**0.63**	**0.62**
Std. Dev. Based	**Average**	**2.91**	**1.25**	**1.68**	**0.63**	**0.72**	**0.87**	**0.76**

- Overall striping metric indicates that the estimates from HMHSD generated the minimum striping metric
- If HMHSD is given preference, mean-based estimates are better than the standard-deviation-based estimates (indicated by a lower striping metric than std. dev.-based estimates)

Occurrence of Minimum Striping Metric for One Test Scene

Band	Different Approach					
	LMLSD	LMHSD	MMLSD	MMHSD	HMLSD	HMHSD
PAN	0	0	0	0	4	0
MS-1p	0	0	0	1	2	1
MS-1	0	0	0	1	3	0
MS-2	0	0	1	0	3	0
MS-3	0	0	0	0	0	4
MS-4	0	0	0	0	0	4
MS-4p	0	0	0	2	0	2
MS-5p	0	0	0	1	1	2
MS-5	0	0	2	0	1	1
MS-7	0	0	1	0	0	3
Total	**0**	**0**	**4**	**5**	**14**	**17**

Minimum Striping Metric Occurrences by Bands For New Guinea Test Scene

- Highlighted cells suggest that RG estimated from high mean scenes generated the highest occurrence of minimum striping metric

Occurrences of Minimum Striping Metric Over 10 Test Scenes

Scene	Scene Characteristics	LMLSD	LMHSD	MMLSD	MMHSD	HMLSD	HMHSD
1	**LM**	1	1	18	6	5	12
2		7	11	11	9	6	5
3		9	16	7	7	2	6
4	**MM**	0	8	28	20	6	11
5		2	14	21	18	7	17
6		5	12	25	24	17	20
7		10	12	33	24	28	27
8	**HM**	0	0	4	5	14	17
9		0	0	17	10	19	18
10		0	5	14	17	12	21
Total		**34**	**79**	**178**	**140**	**116**	**154**
Test Scenes		**13**	**37**	**236**	**56**	**49**	**9**

- MMLSD produces lowest striping metric most often based on 226 test scenes
- HMHSD produces 2nd best result based on only 5 test scenes
- Strongly suggests HMHSD is better on a per test scene basis

Identifying Best Calculation Method for Relative Gains

Data	RG Estimates	LMLSD	LMHSD	MMLSD	MMHSD	HMLSD	HMHSD
Dataset_2	**Mean**	34	79	178	140	116	154
	Std. Dev.	90	39	214	90	110	77
	Test Scenes	**13**	**37**	**236**	**56**	**49**	**9**

Occurrences of Minimum Striping Metric

- Given HMHSD is preferred, ‘mean-based’ RG estimates may also be superior to ‘std dev-based’ estimates

Validation

- Additional data sets from the ALI archive were used to validate these results
- ALI exhibited focal plane contamination problem
  - Particulate buildup occurred gradually and was monitored by detector response to calibration lamps
  - When a 2% reduction in response to cal lamps occurred, focal plane was heated (‘bake-out’) to remove contamination
- Original dataset used for this study exhibited minimal contamination effects
- Additional datasets for validation study exhibit greater degrees of contamination

Scenes Available in ALIAS Database

- Table below lists datasets used in validation study
- Dataset_2 was used for original study due to large volume of scenes and minimal effect from contamination effect

Dataset Name	Collect Period	Number of Scenes Available
Dataset_1	1 Day after Bakeout	**1485**
Dataset_2	2 Days after Bakeout	**2602**
Dataset_3	3 Days after Bakeout	**2670**
Dataset_4	4 Days after Bakeout	**2638**
Dataset_5	5 Days after Bakeout	**2618**

- Datasets span 8 year period (2000-2008)
- Datasets collected on dates farther removed from bakeout exhibit greater contamination

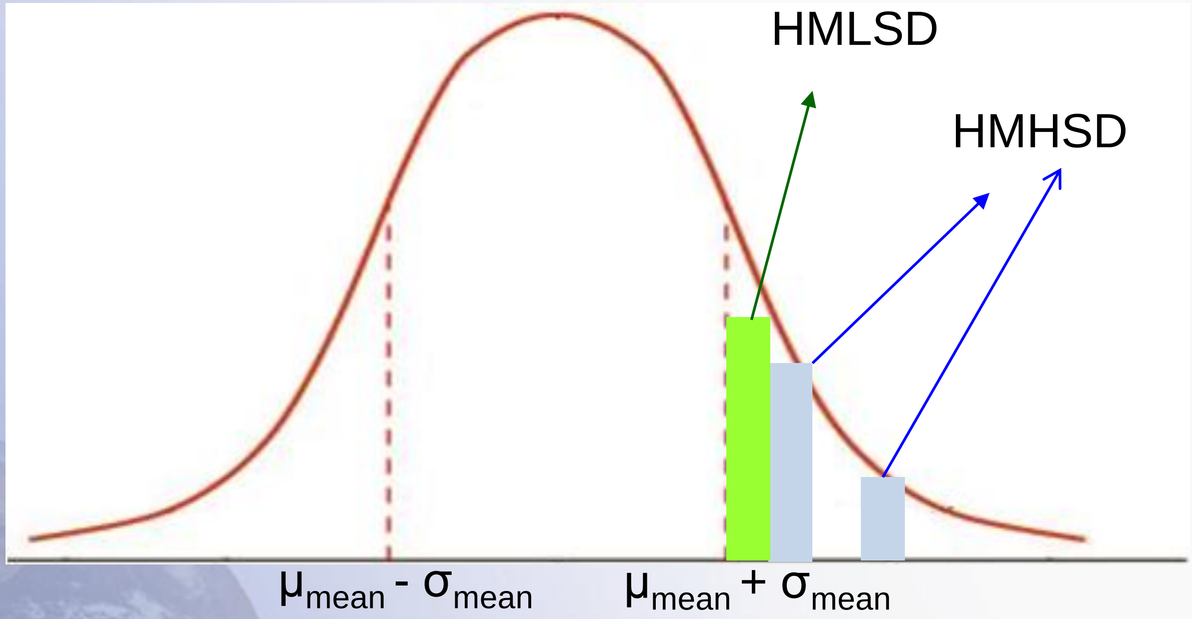
Optimal Image Type (Striping Metric)

Dataset Name	RG Estimates	Bias Subtracted	LMLSD	LMHSD	MMLSD	MMHSD	HMLSD	HMHSD
Dataset_1	Mean	2.91	3.68	1.08	0.69	0.64	0.64	**0.58**
	Std. Dev	2.91	2	1.58	0.7	0.63	1.15	**0.67**
Dataset_2	Mean	2.91	2.58	1.12	0.66	0.69	0.63	**0.62**
	Std. Dev	2.91	1.25	1.68	0.63	0.72	0.87	**0.76**
Dataset_3	Mean	2.91	8.23	1.53	1	0.98	0.93	**0.95**
	Std. Dev	2.91	3.61	2.36	0.95	0.97	0.96	**1.07**
Dataset_4	Mean	2.91	8.64	1.15	0.68	0.61	0.64	**0.55**
	Std. Dev	2.91	4.82	1.36	0.67	0.63	1.06	**0.64**
Dataset_5	Mean	2.91	4.69	1.05	0.63	0.61	0.62	**0.55**
	Std. Dev	2.91	2.31	1.51	0.59	0.62	0.92	**0.63**

- However, validation results were not greatly affected by contamination.
- HMHSD RG estimates provides minimum striping metric
- Mean-based RG again superior to Std. Dev.-based RG estimates

Conclusions

- Estimated relative gains from HMHSD are superior to other image types



  - ➢ It is likely that a larger number of brighter scenes exists in the HMHSD subset than in the HMLSD subset. This will lead to better RG estimates due to greater signal-to-noise effect.
- For HMHSD, relative gain estimates from scene means are superior to scene std. dev.