A Comparison of Relative Gain Estimation Methods for High Radiometric Resolution Pushbroom Sensors

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Outline

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- Methodology
- Results
- Conclusions

INTRODUCTION

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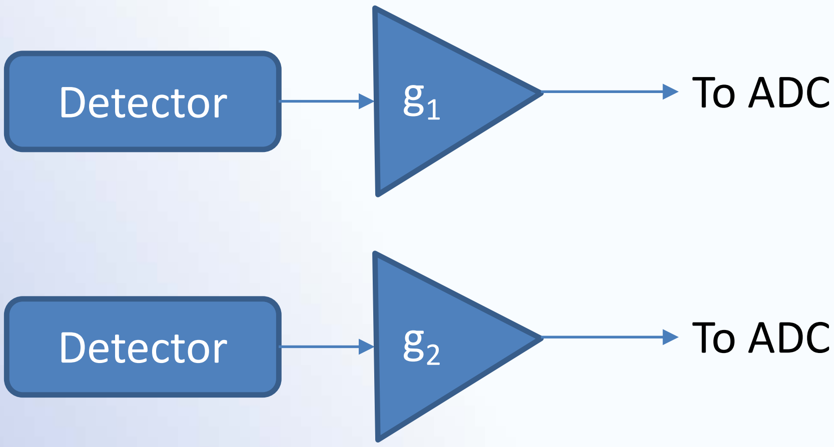
What are Relative Gains?

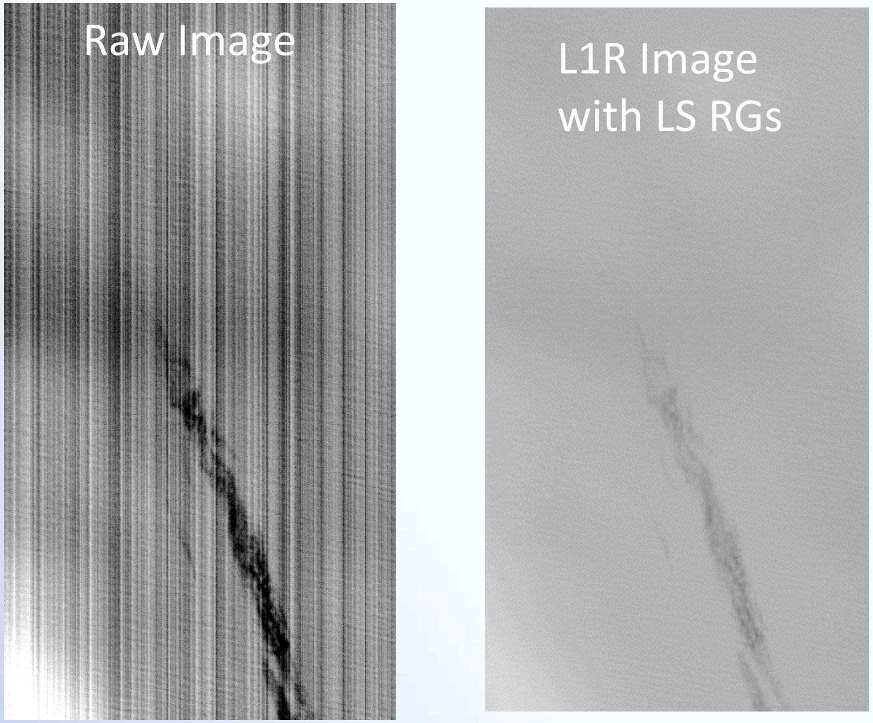
- When two detectors sense the same radiance, they should generate the same digital number (DN): $DN = g_i L_\lambda + b$
- Due to real world constraints, the DN will not be the same because $g_i \neq g_j$
  - This causes visible striping in an image
- A relative gain (RG), $RG = \frac{g_i}{\bar{g}}$, is applied to each detector so that the resulting DNs are the same when the detectors sense identical values



MOVTIVATION

- Landsat 8 (L8) uses a pushbroom style sensor array with nearly 70,000 detectors
- Difficulty increases with 12 (actually 14) bit dynamic range
- Relative gains are calculated using an onboard solar diffuser.

- Do data-driven alternative relative gain estimation methods, “lifetime statistics” and “side-slither,” provide equivalent or better accuracy?

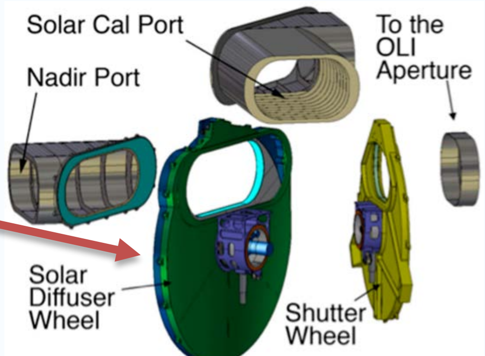


Landsat 8 Example: LC81101102015335LGN01, B3, FPM1

METHODOLOGY

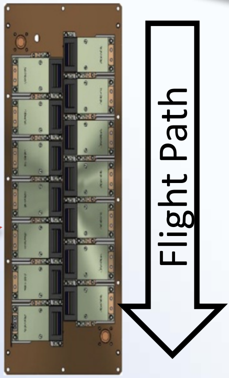
How are Relative Gains Calculated?

- Three methods are currently being used to calculate Landsat 8 RGs:
  1. Solar Diffuser (DIFF)

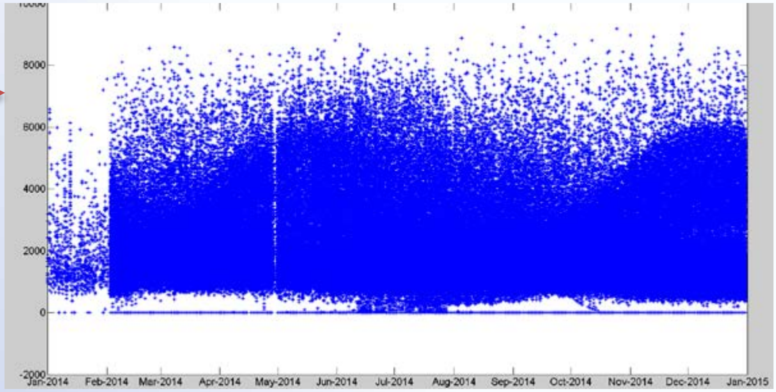


http://www.mdpi.com/2072-4292/6/12/12275/htm

  2. Side Slither (SS)



  3. Lifetime Statistics (LS)



Solar Diffuser

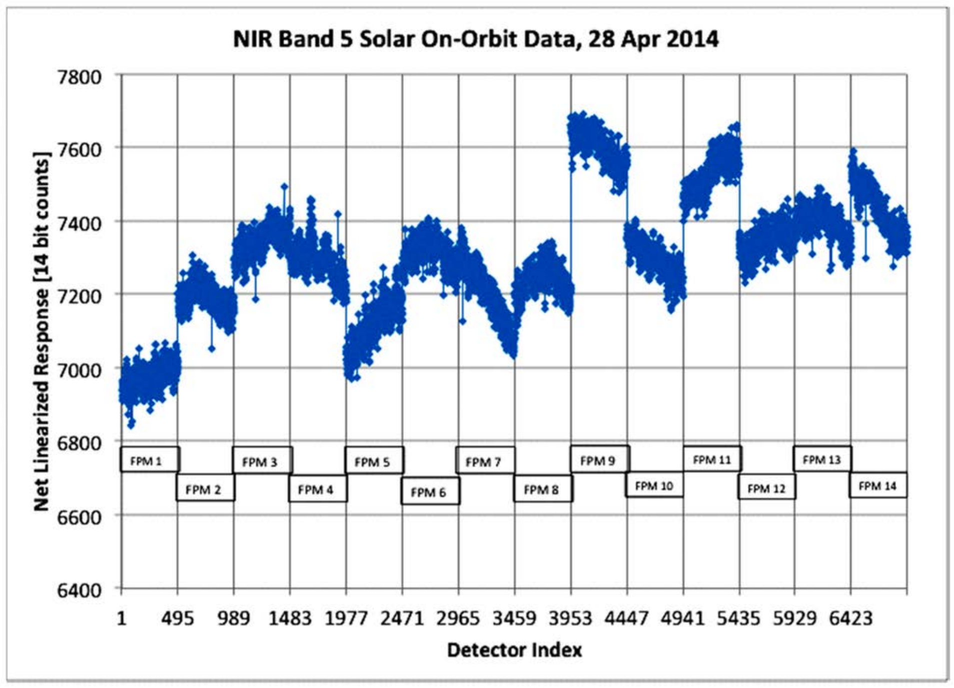
- Diffuser collects are processed the same way standard OLI images are processed in order to correct any bias and linearize the response
- The following equation is then used to derive the RGs for each detector

$$RG_i = \frac{\overline{DN_i}}{\overline{\overline{DN}}}$$

Where:

- RG_i = RG for the i^th detector
- $\overline{DN_i}$ = Average DN for the i^th detector
- $\overline{\overline{DN}}$ = Average DN for all detectors within a focal plane module (FPM)

Sample Solar Diffuser Collect



http://www.mdpi.com/2072-4292/6/12/12275/htm

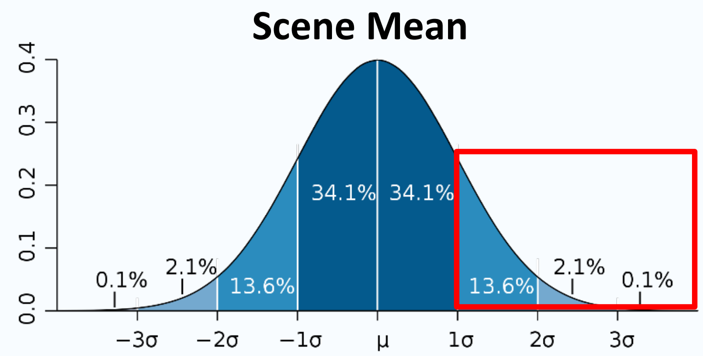
Lifetime Statistics

- Basic idea:
  - Each detector statistically sees about the same value (means and standard deviations) when given a “long enough” period of time
  - These means can then be used to derive relative gains

Scene Filter

- Rel Gains calculated on 16 day intervals
- Scenes within the **16 day interval** are filtered by scene mean and by scene standard deviation

$$RG_i = \frac{\overline{DN_i}}{\overline{DN}}$$



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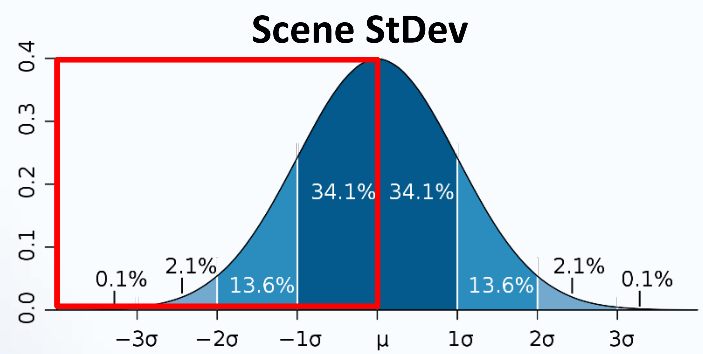

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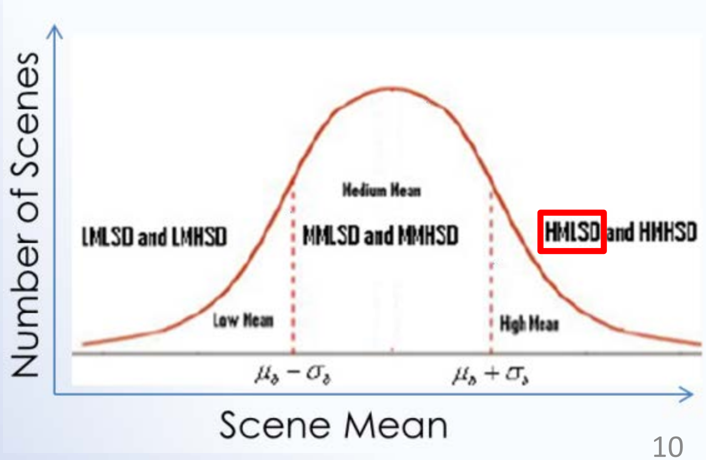


Side Slither

- Over a radiometrically flat and uniform area, the satellite is rotated 90^o on its yaw axis
- As the sensor passes over its target, each detector theoretically measures the same radiance

Pushbroom Scan

Scan Motion

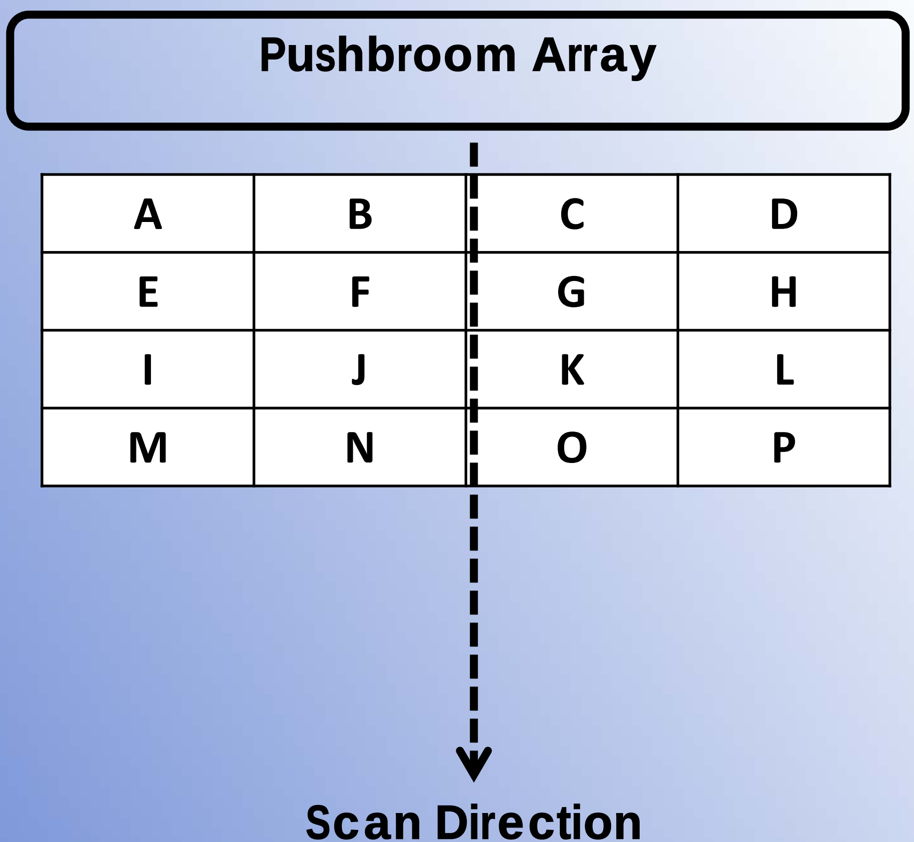


Image Formed

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P

Side-Slither Scan

Scan Motion

Yaw array 90 degrees

Pushbroom Array

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P

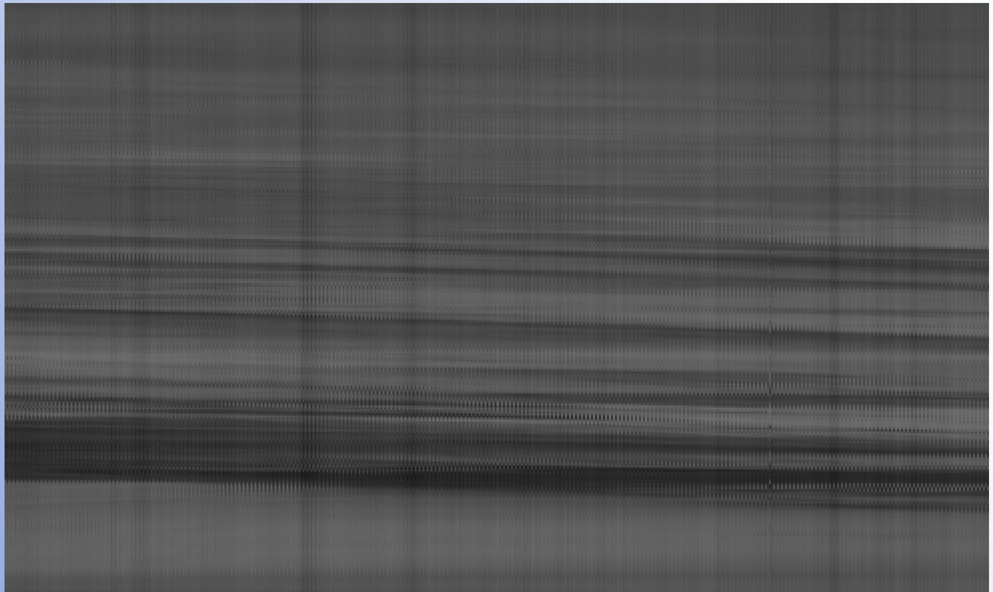
Scan Direction

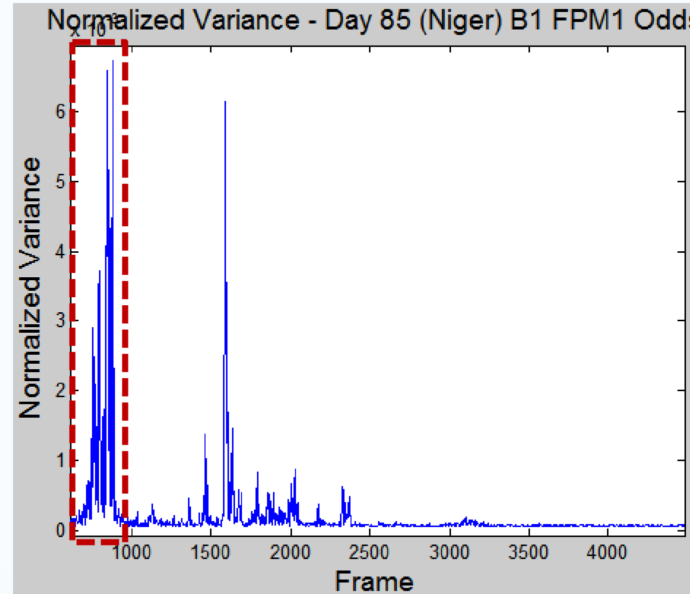
Image Formed

B			
F	B		
J	F	B	
N	J	F	B
	N	J	F
		N	J
			N

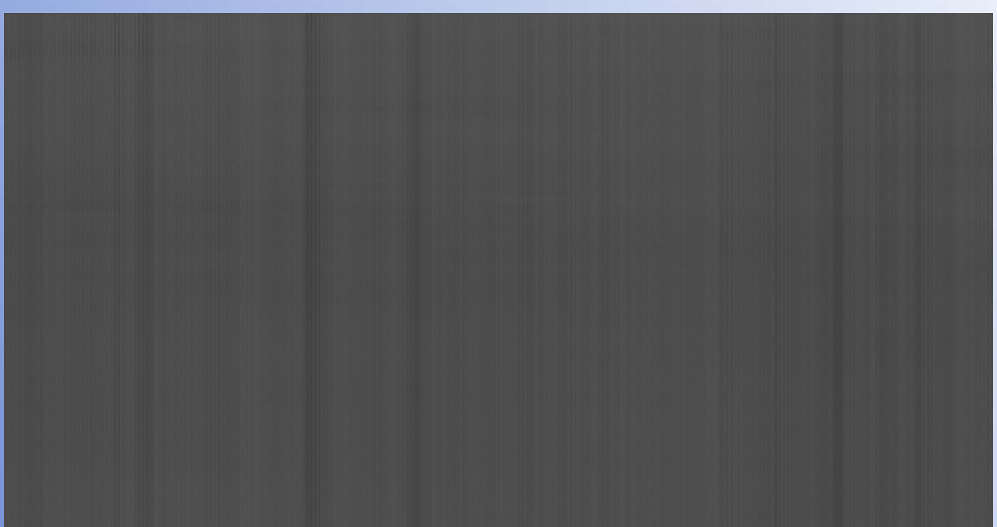
Frame Variance

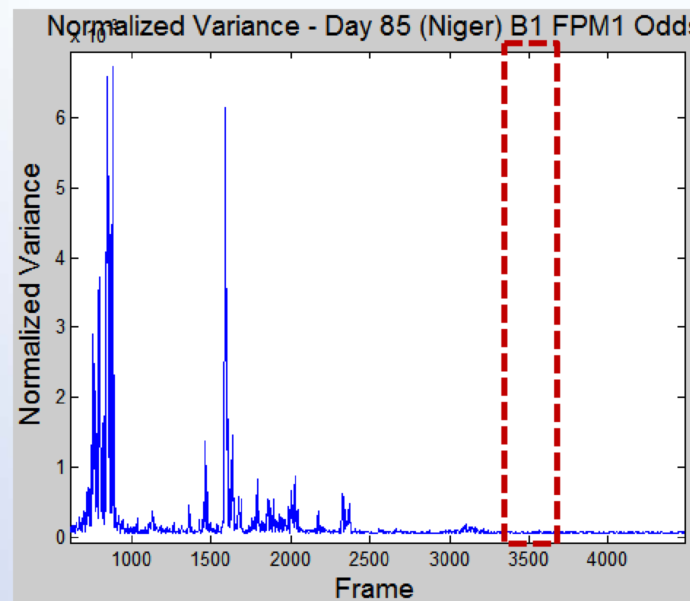
‘Bad’ SS data





‘Good’ SS data





Test Scenes

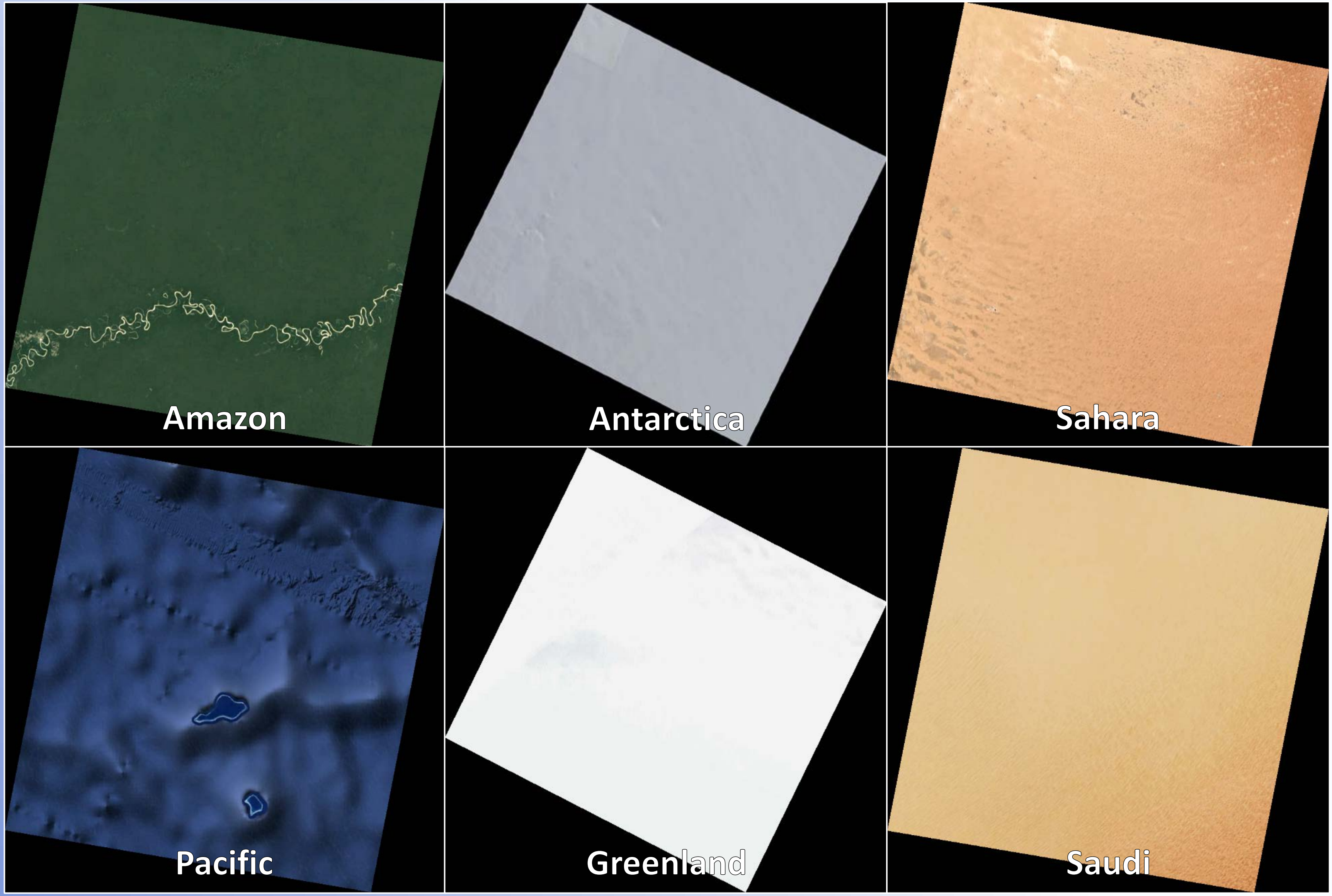
- Six different regions of interest (ROIs) were chosen, 10 scenes/ROI, spanning the lifetime of Landsat 8:
  - Amazon Rainforest
  - Pacific Ocean
  - Antarctica
  - Greenland
  - Sahara Desert
  - Saudi Arabia

Amazon Rainforest, Pacific Ocean: Dark Scenes

Antarctica, Greenland: Bright at Short Wavelengths

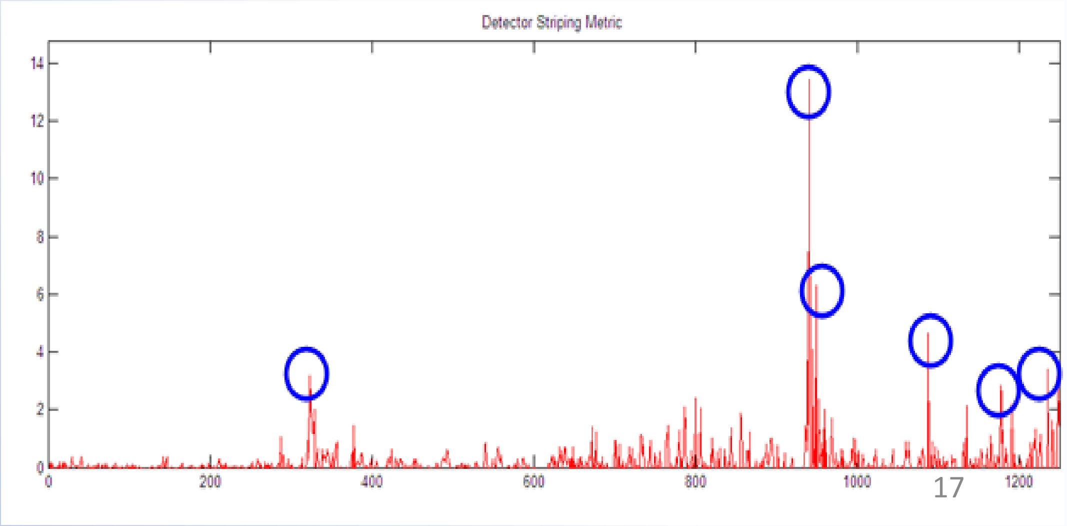
Sahara Desert, Saudi Arabia: Bright at Long Wavelengths

Test Scenes



Quantitative Assessment: A Striping Metric

- For all detectors in an FPM (except for the two edge detectors), a detector and its two neighboring detectors are compared to determine the level of striping.
- $S_i = \frac{\left|\overline{L_l} - \frac{1}{2}\left(\overline{L_{l-1}} + \overline{L_{l+1}}\right)\right|}{\overline{L_l}}$ S_i = striping metric
  $\overline{L_l}$ = mean of a detector column
- The overall striping metric is the cube root of the product of the mean, maximum peak, and mean of the top 15 peaks:
- $\sqrt[3]{\begin{matrix} mean \cdot max \cdot \\ mean\ of\ top\ fifteen \end{matrix}}$



Differences on Average: Pairwise Difference Test

- Determines if two methods are statistically different from each other for a given band.
- $t = \frac{\overline{x_i - y_i}}{s/\sqrt{n}}$, where
  - t = test statistic
  - $\overline{x_i - y_i}$ = sample mean of the difference between two methods
    - i = same detector in the scene
  - s = standard deviation of $\overline{x - y}$
  - n = sample size

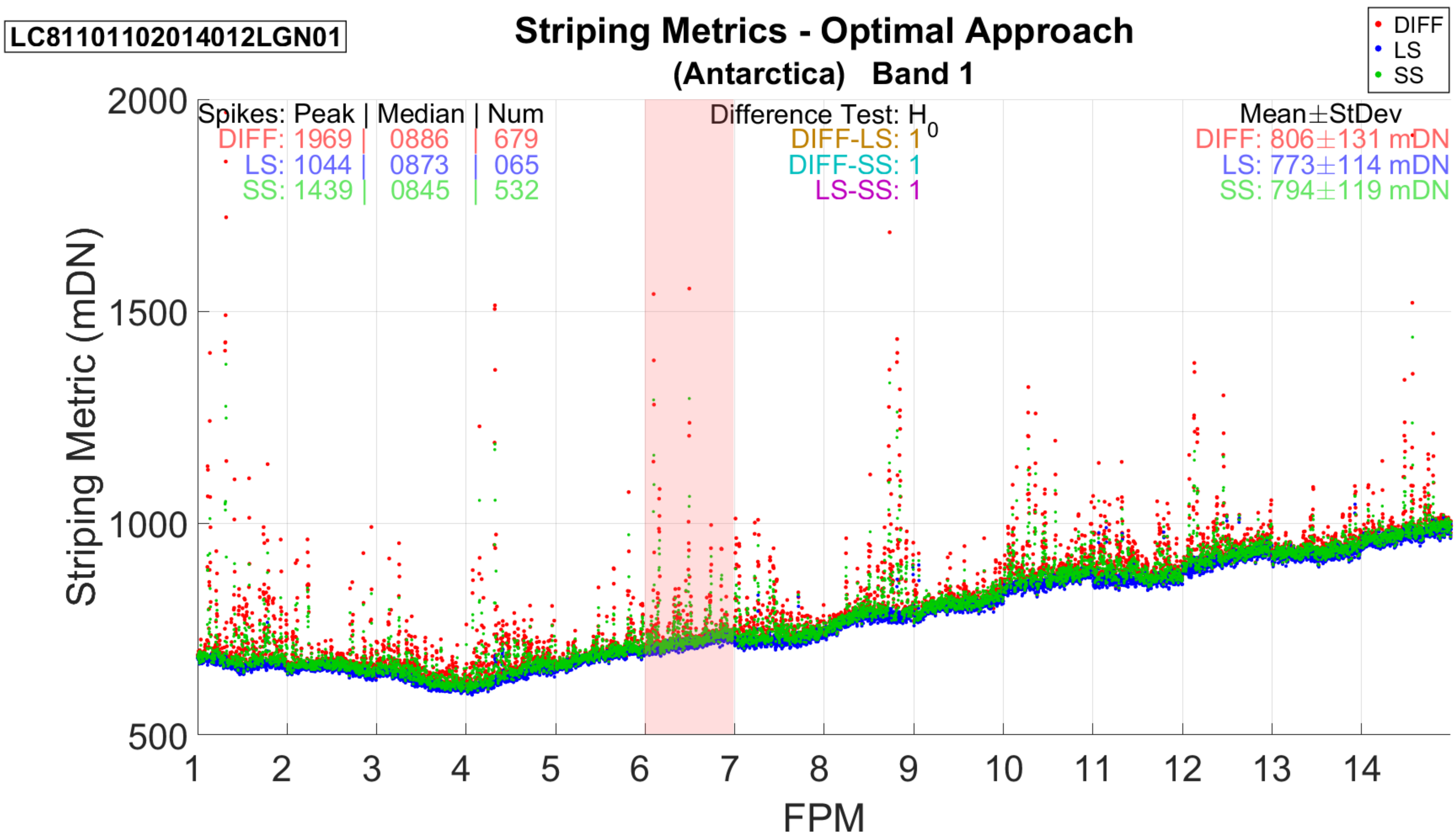
Extreme Stripes: Counting 'Spike' Data

- A Hampel filter was used to identify significant "outliers", or spikes, in an FPM for each of the three methods.
  - Moving window median filter
  - For a given data sequence,
  - Spike if: $x_i \geq 3MAD(x_{i-l}, \ldots, x_{i+l})$
  - The data point at the center of the window is considered a spike if it is more than three times the median absolute deviation of the data points in the window.

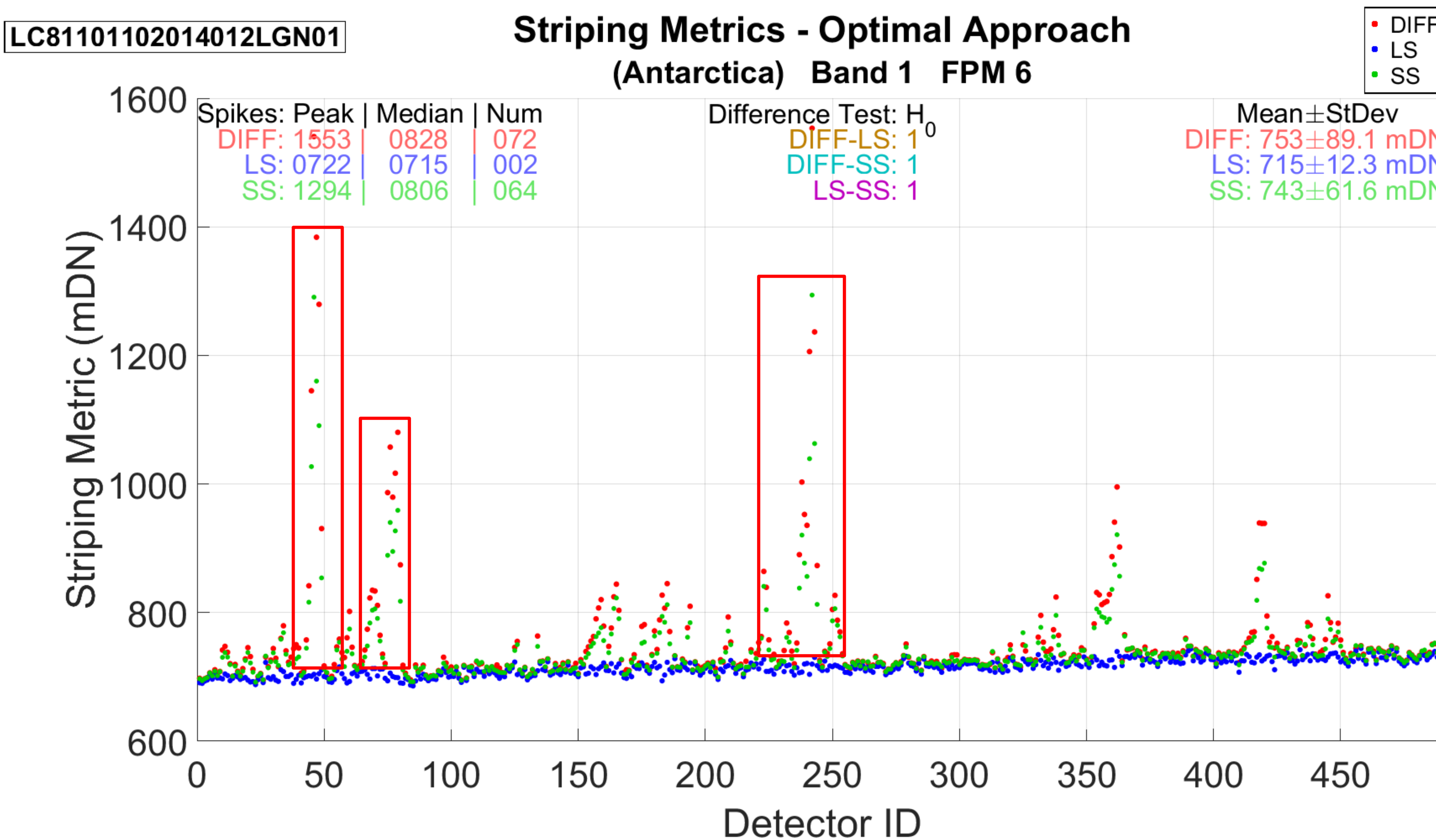
- The peak spike was recorded, along with the median of spikes and number of spikes.

RESULTS

Visible Spikes (DIFF & SS)

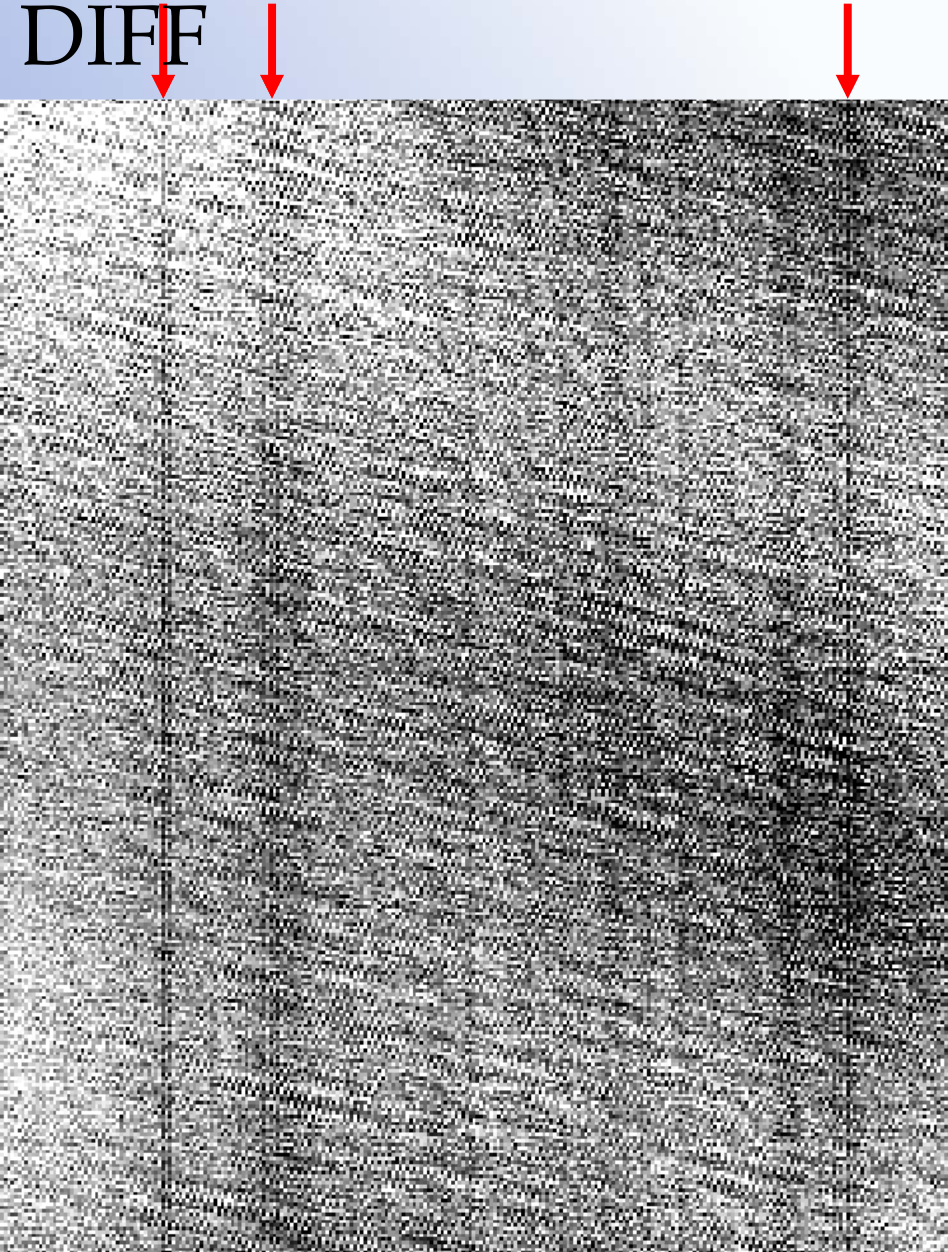


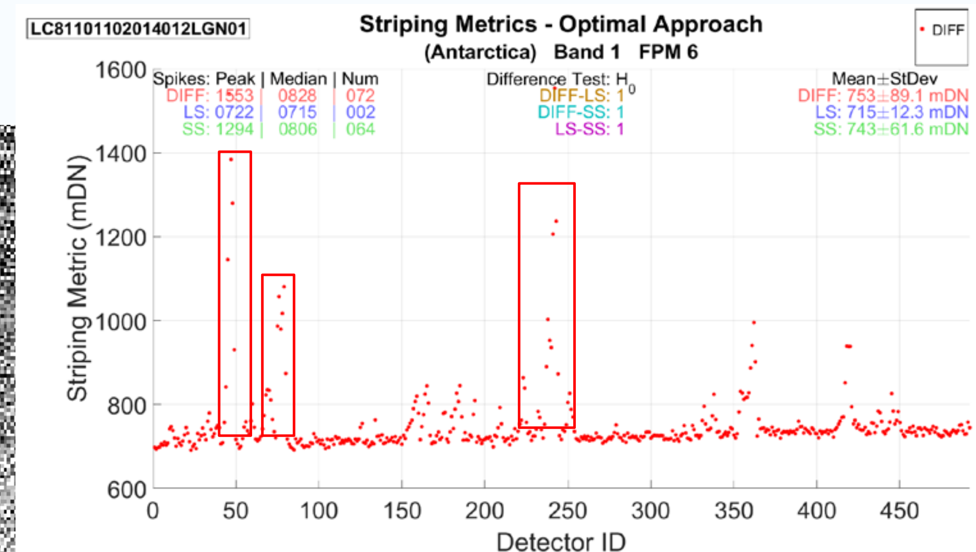
Visible Spikes (DIFF & SS)



Antarctica Band 1 FPM 6

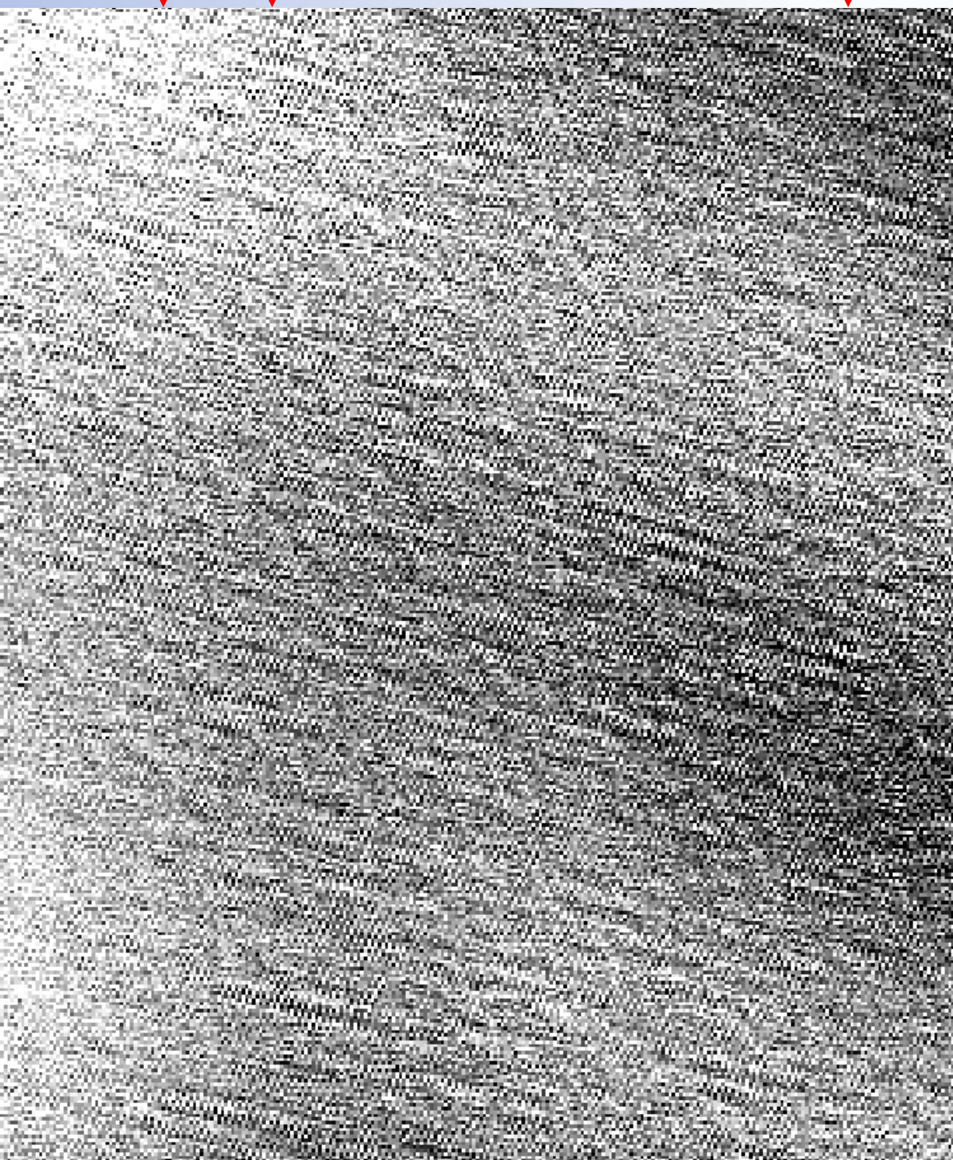
DIFF

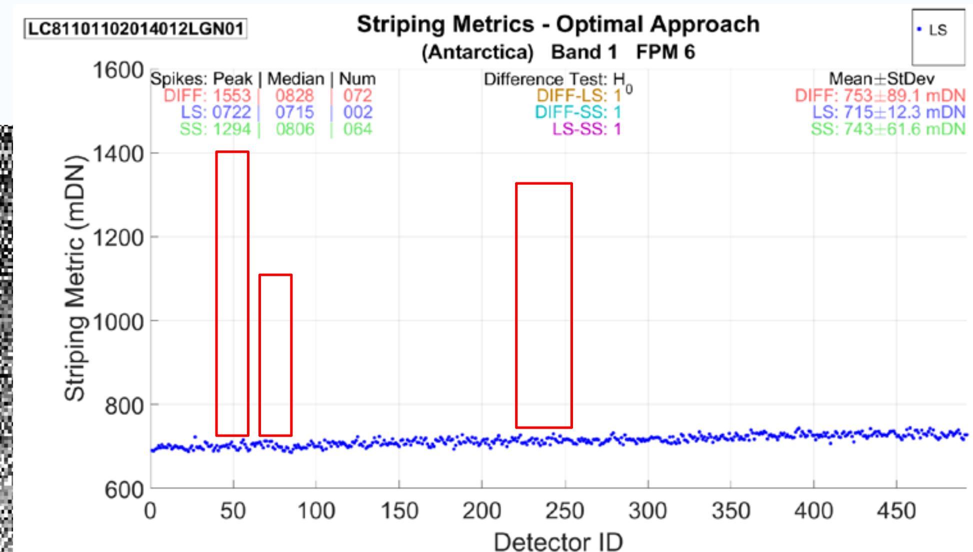




Antarctica Band 1 FPM 6

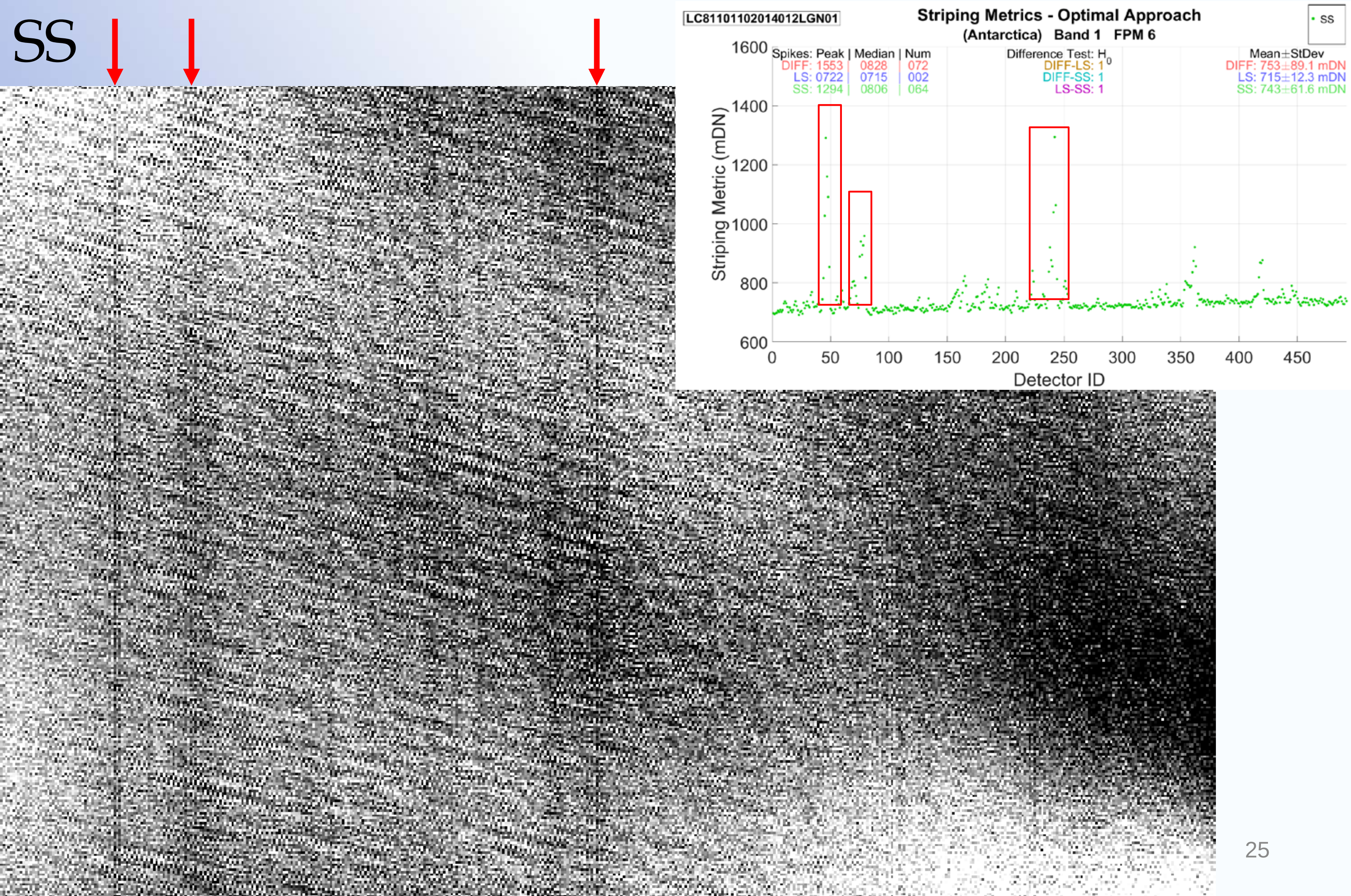
LS



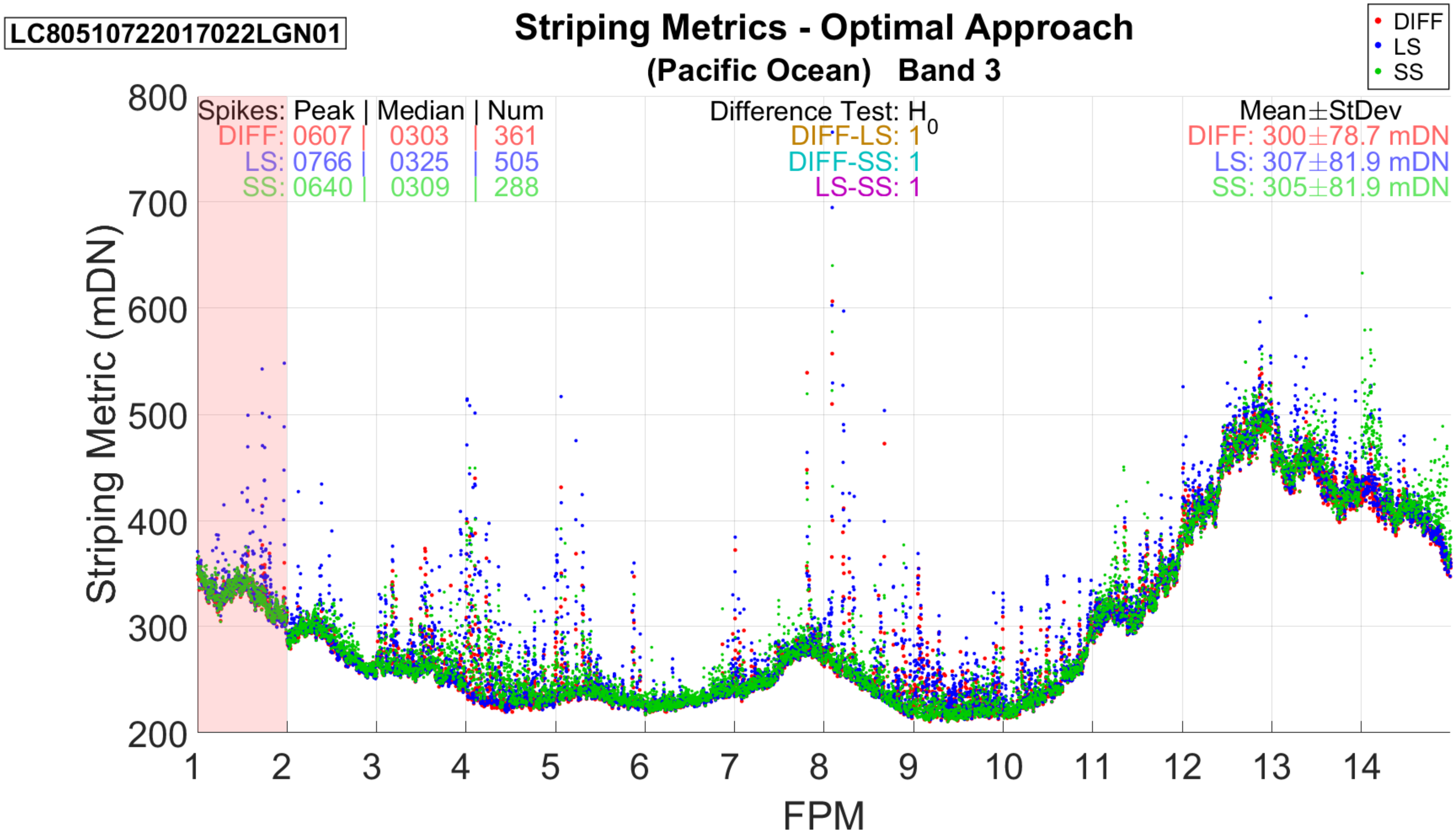


Antarctica Band 1 FPM 6

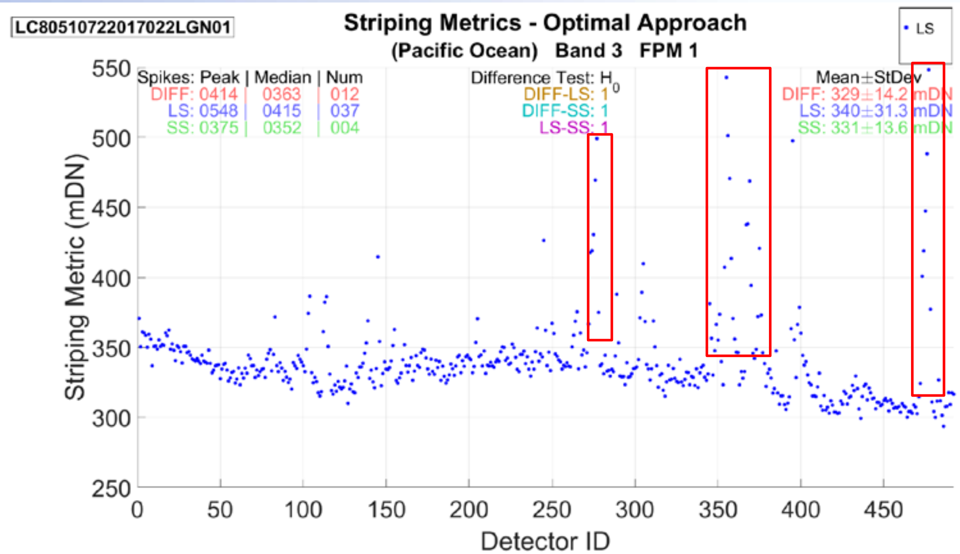
SS

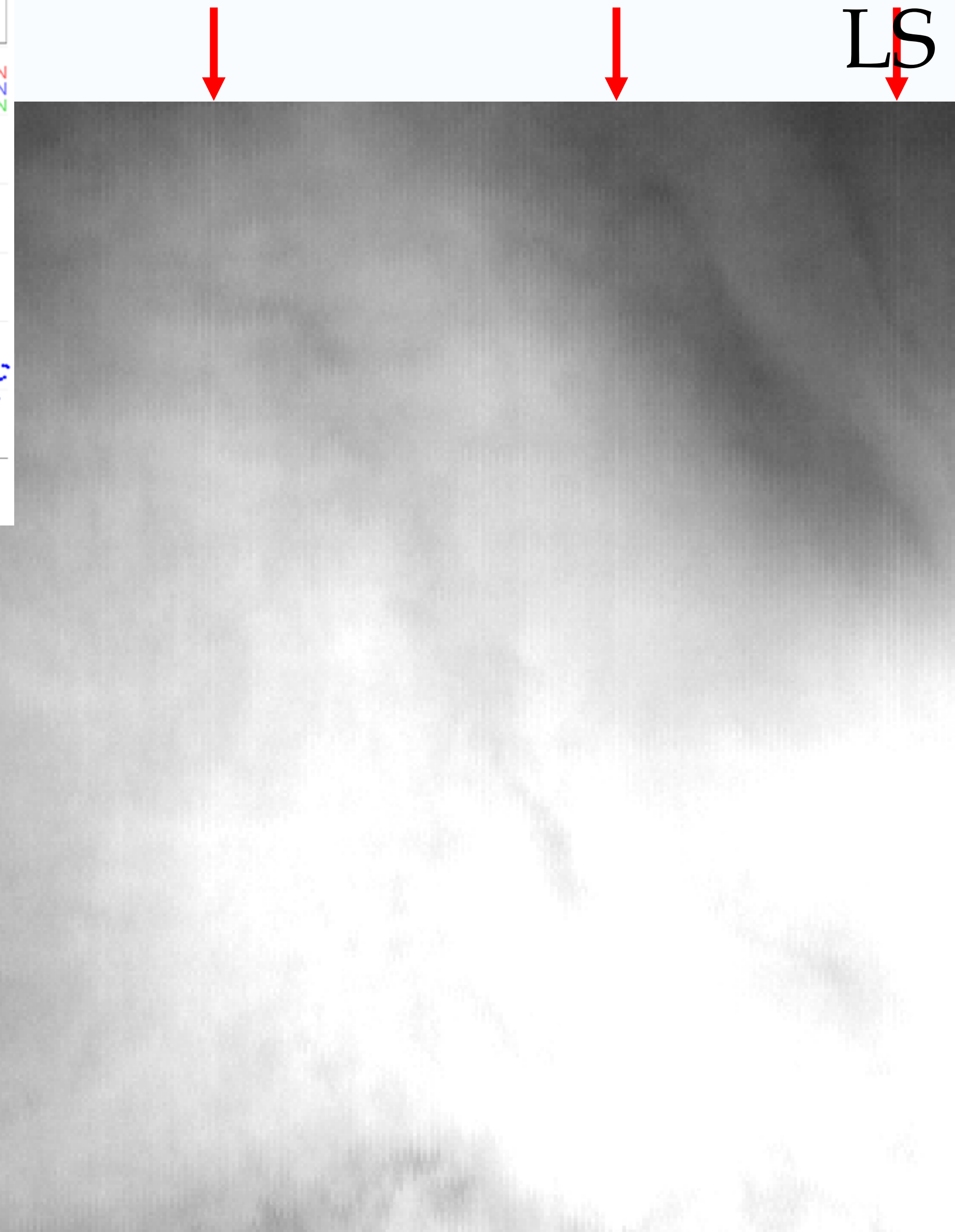


Visible Spikes (LS)

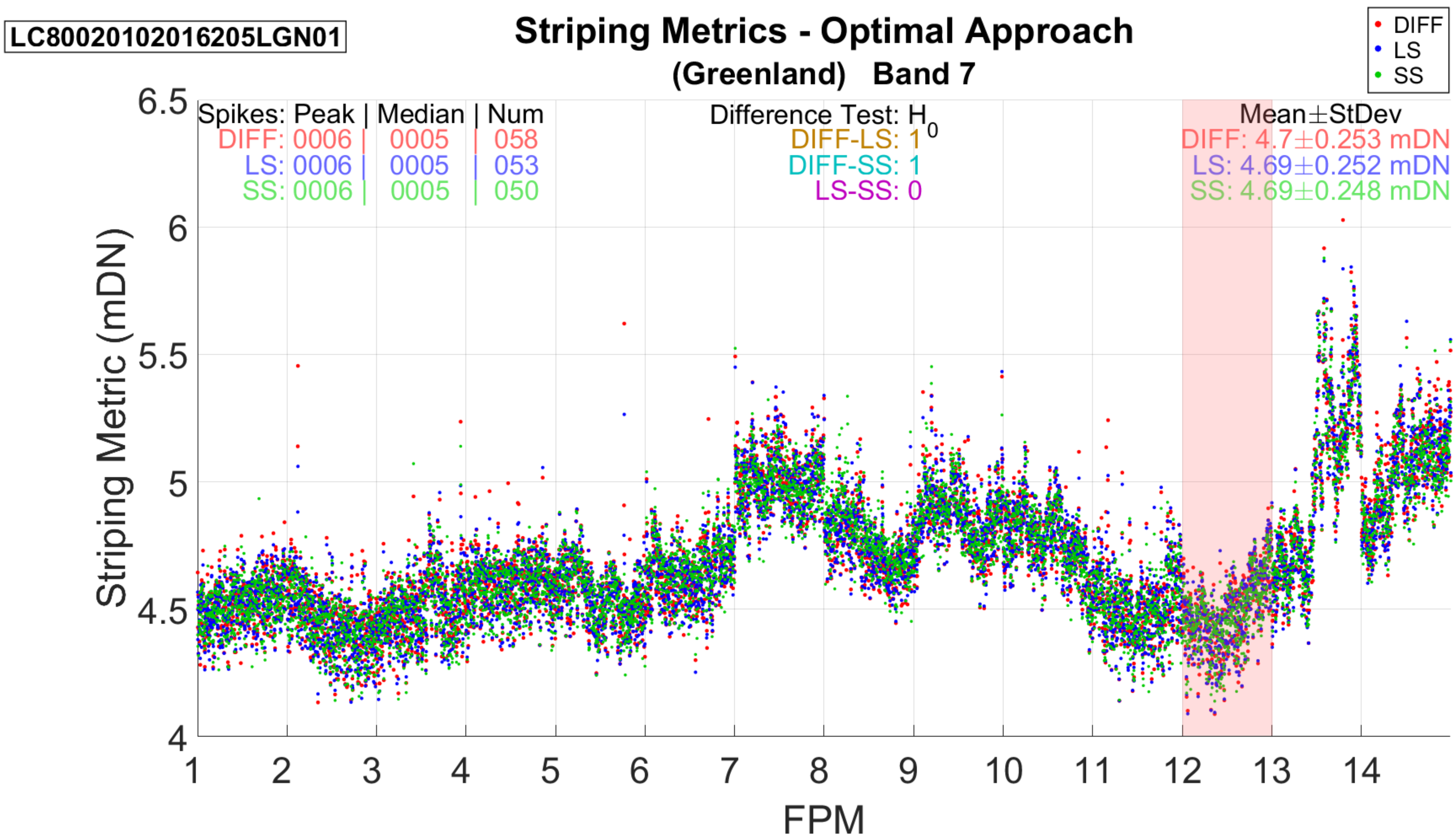


Pacific Ocean Band 3 FPM 1



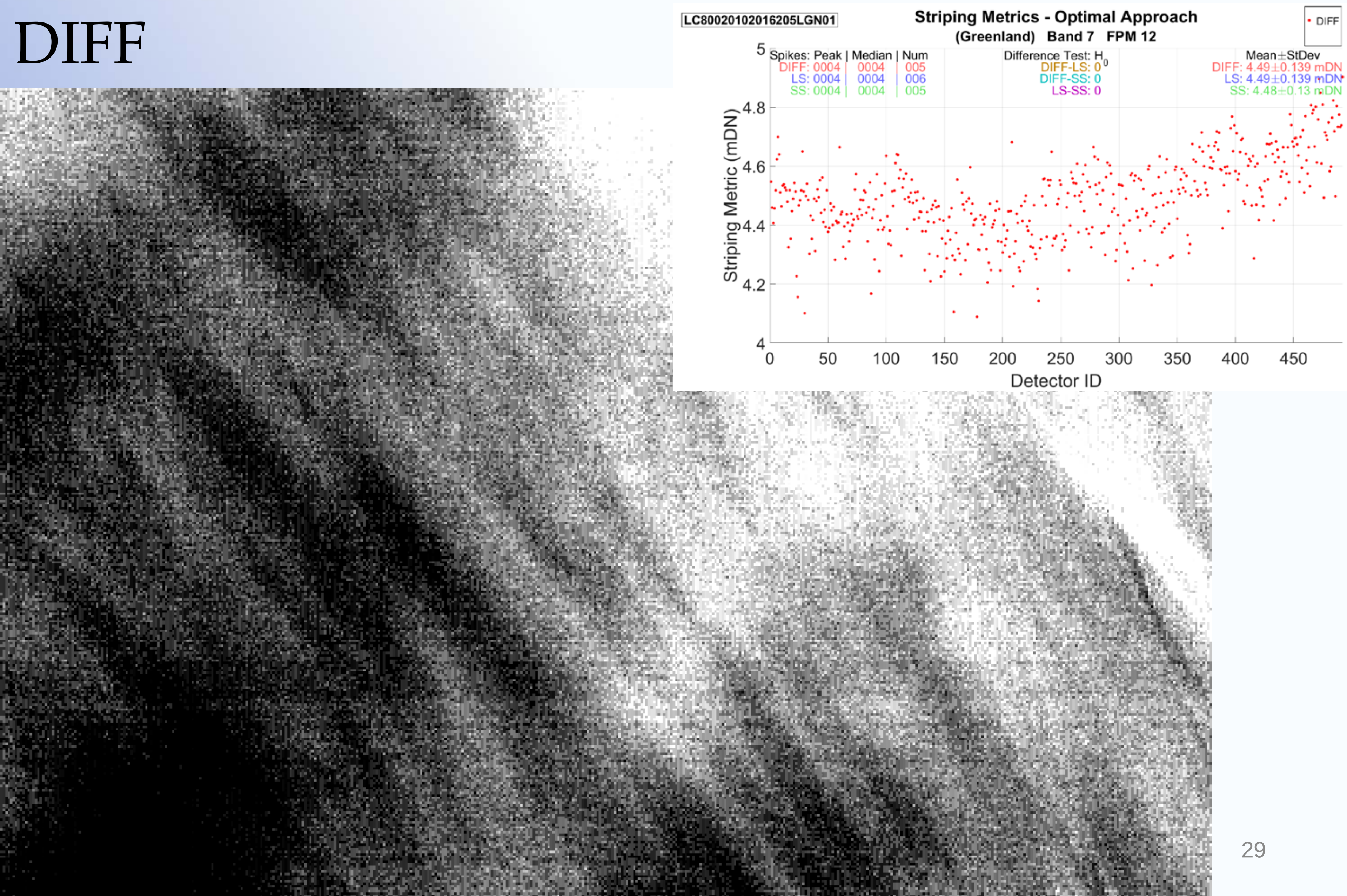


Lowest Striping Metrics

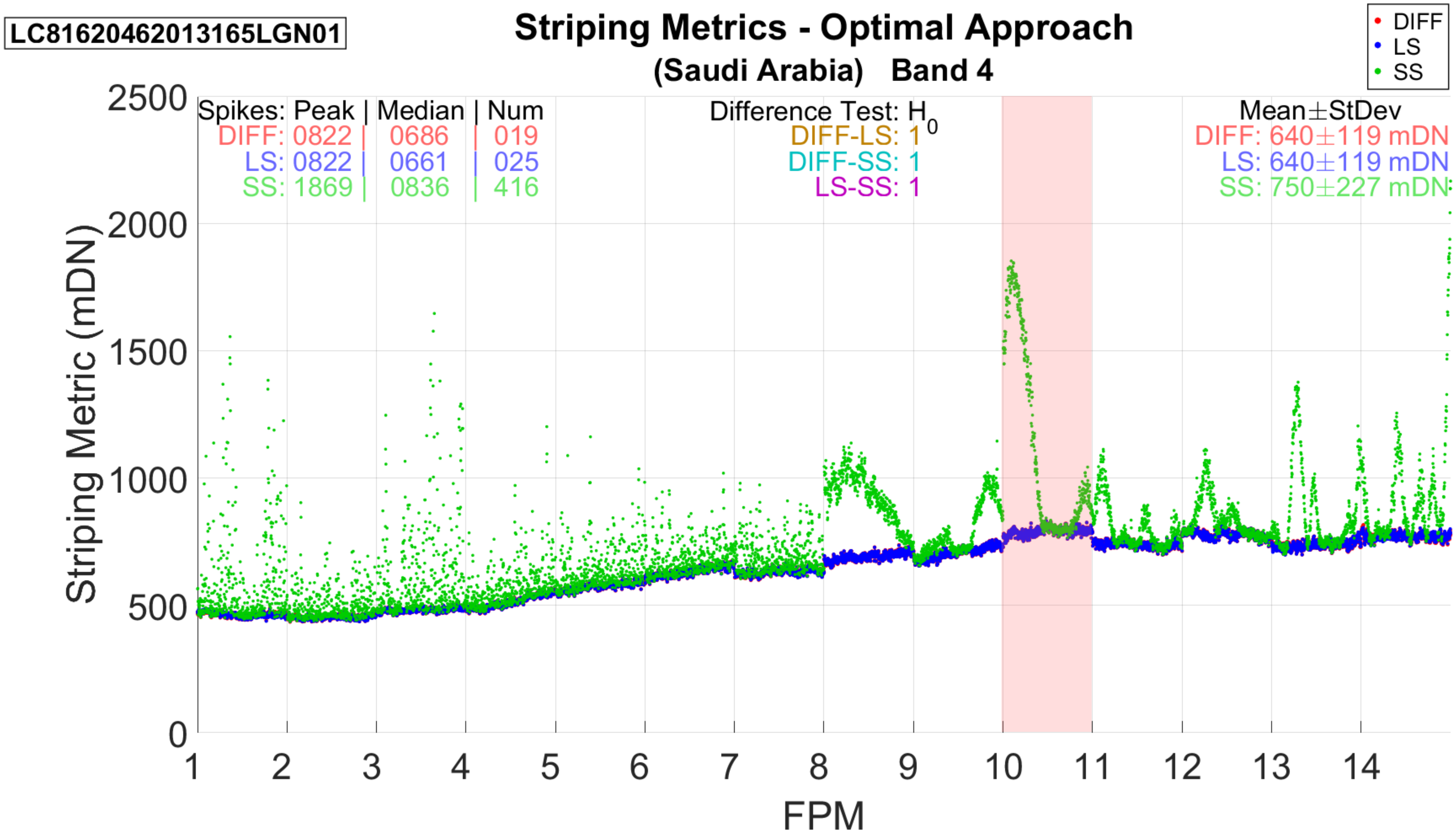


Greenland   Band 7   FPM 12

DIFF



Side Slither Anomaly



Summary: Pairwise Difference Tests

Band	Test	Amazon	Pacific	Antarctica	Greenland	Sahara	Saudi	Totals
1	DIFF	0	0	0	0	0	0	0
	LS	**7**	**9**	**10**	**10**	**9**	**9**	**54**
	SS	2	0	0	0	0	0	2
2	DIFF	0	0	0	0	0	0	0
	LS	**9**	**10**	**10**	**9**	**9**	**8**	**55**
	SS	1	0	0	1	1	0	3
3	DIFF	0	1	0	0	0	0	1
	LS	**7**	**7**	**10**	**10**	**8**	**8**	**50**
	SS	1	0	0	0	1	0	2
4	DIFF	**1**	**1**	0	0	0	0	2
	LS	0	0	**10**	**10**	**10**	**10**	**40**
	SS	0	0	0	0	0	0	0
5	DIFF	**2**	**2**	0	0	0	0	4
	LS	0	0	**4**	**10**	**8**	**6**	**28**
	SS	0	0	0	0	0	0	0
6	DIFF	0	**1**	0	0	0	0	1
	LS	**2**	**1**	**7**	**7**	**10**	**10**	**37**
	SS	0	0	2	2	0	0	4
7	DIFF	0	0	0	0	0	0	0
	LS	0	**1**	**9**	**8**	**8**	**8**	**34**
	SS	0	**1**	0	1	0	0	2
8	DIFF	1	0	2	2	0	0	5
	LS	0	2	1	1	0	0	4
	SS	**5**	**6**	**3**	**5**	0	**2**	**21**
Totals	DIFF							13
	LS							**302**
	SS							34

Summary: Spike Results

Band	Amazon		Pacific		Antarctica		Greenland		Sahara		Saudi		Totals	
1	DIFF	**10**	DIFF	**9**	DIFF	**10**	DIFF	**10**	DIFF	**9**	DIFF	**10**	DIFF	**58**
	LS	0	LS	1	LS	0	LS	0	LS	0	LS	0	LS	1
	SS	0	SS	0	SS	0	SS	0	SS	0	SS	0	SS	0
2	DIFF	**10**	DIFF	**10**	DIFF	**10**	DIFF	**10**	DIFF	**8**	DIFF	**10**	DIFF	**58**
	LS	0	LS	0	LS	0	LS	0	LS	1	LS	0	LS	1
	SS	0	SS	0	SS	0	SS	0	SS	0	SS	0	SS	0
3	DIFF	**3**	DIFF	**4**	DIFF	**9**	DIFF	**9**	DIFF	**3**	DIFF	**7**	DIFF	**35**
	LS	2	LS	3	LS	0	LS	0	LS	**3**	LS	1	LS	9
	SS	1	SS	2	SS	0	SS	1	SS	**3**	SS	2	SS	9
4	DIFF	0	DIFF	0	DIFF	1	DIFF	4	DIFF	1	DIFF	2	DIFF	8
	LS	**3**	LS	**8**	LS	0	LS	1	LS	**5**	LS	1	LS	18
	SS	2	SS	2	SS	**4**	SS	**5**	SS	3	SS	**5**	SS	**21**
5	DIFF	**2**	DIFF	2	DIFF	1	DIFF	0	DIFF	0	DIFF	2	DIFF	7
	LS	1	LS	**3**	LS	**2**	LS	0	LS	3	LS	**3**	LS	12
	SS	1	SS	1	SS	1	SS	**7**	SS	**5**	SS	2	SS	**17**
6	DIFF	0	DIFF	0	DIFF	**3**	DIFF	4	DIFF	3	DIFF	0	DIFF	10
	LS	**4**	LS	1	LS	**3**	LS	0	LS	0	LS	2	LS	10
	SS	**4**	SS	**2**	SS	1	SS	**5**	SS	**5**	SS	**7**	SS	**24**
7	DIFF	1	DIFF	**2**	DIFF	2	DIFF	3	DIFF	2	DIFF	1	DIFF	11
	LS	**5**	LS	1	LS	**3**	LS	0	LS	3	LS	2	LS	14
	SS	2	SS	**2**	SS	2	SS	**4**	SS	**5**	SS	**7**	SS	**22**
8	DIFF	1	DIFF	1	DIFF	**3**	DIFF	**4**	DIFF	0	DIFF	0	DIFF	9
	LS	0	LS	0	LS	2	LS	3	LS	0	LS	0	LS	5
	SS	**4**	SS	**4**	SS	2	SS	2	SS	**5**	SS	**7**	SS	**24**
												Totals	DIFF	**196**
													LS	70
													SS	117

Conclusions

- All three methods work well—Diffuser, Lifetime Statistics, and Side Slither
- Statistically significant differences exist between the mean striping levels of the three methods
  - Significant differences are extremely small due to the large number of detectors
  - Lifetime Statistics generally has the smallest values, although this is somewhat wavelength dependent
- Large striping metric "spikes," which generally indicate visual stripes, are present for all three methods
  - Spikes in Diffuser method most prevalent at short wavelengths
  - Side Slither striping spikes exist, however many appear to be induced by processing error
  - Lifetime Statistics approach generates substantially fewer spikes
- Both data driven methods, Lifetime Statistics and Side Slither, produce results equivalent to or better than Diffuser method
  - Suggests that these methods can readily be a backup to onboard methods
  - However, each has a significant requirement:
    - Lifetime statistics method requires developing a database of information
    - Side Slither requires a maneuver that may not be possible for some systems and impacts operational imaging
  - Lifetime Statistics appears to outperform Side Slither; however, additional investigation needed to resolve this comparison