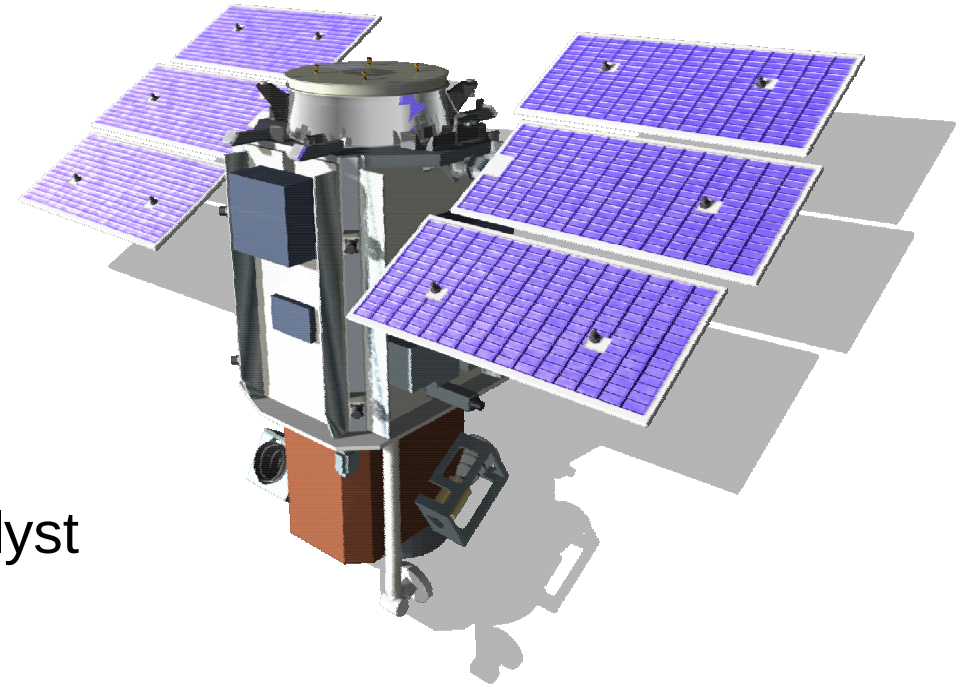
QuickBird Radiometric Calibration



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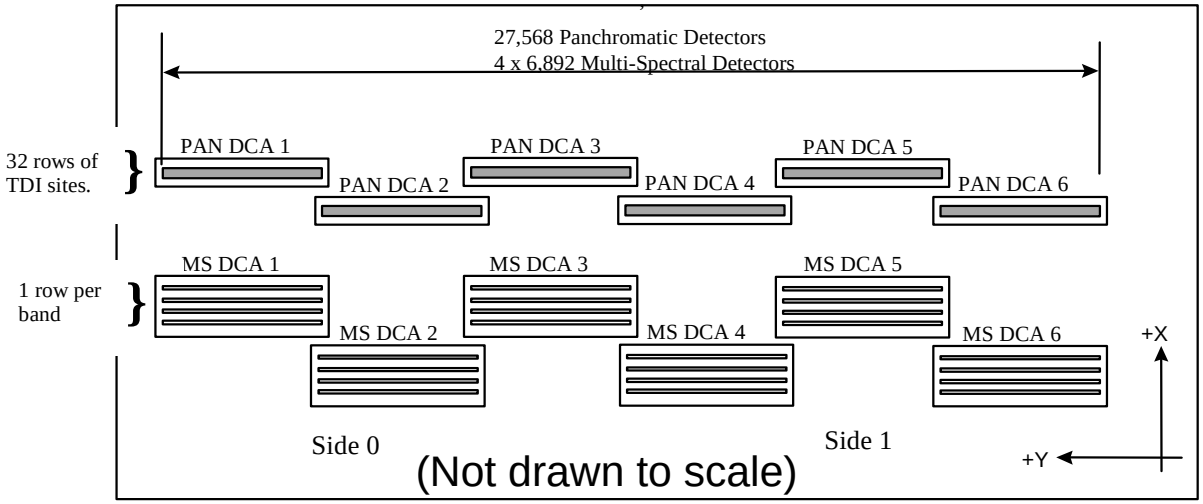
Radiometric Calibration Analyst

Outline

- General radiometric correction
  - Basic theory
  - Techniques used by DigitalGlobe
- Color Banding
  - Problem in low dynamic range imagery (ocean, forest, and desert scenes)
  - A new method of coefficient generation was developed
  - Banding and streaking results
- Absolute Calibration Discrepancy

Focal Plane Array (FPA)



- Comprised of staggered detector chip arrays (DCAs), 6 Pan and 6 MS (4 bands each)
- Each DCA is a CCD array of 4736 detectors (Pan) or 1184 detectors (MS) – includes masked, invalid, and overlap detectors
- 27888 pan and 6972 detectors per MS band must be calibrated
- Pan DCAs have up to 32 rows of detectors for Time Delay Integration (TDI) giving 5 different exposure levels (each of which must be calibrated)

Radiometric Correction

- Relative radiometric correction

$$q_{Det,Band} = \frac{p_{Det,Band} - A(T,t)_{Det,Band}}{B_{Det,Band}}$$

- Where $p_{Det,Band}$ is the raw DN in counts, $q_{Det,Band}$ is the corrected DN value, $A(T,t)_{Det,Band}$ is the dark offset and is a function of temperature and time, and $B_{Det,Band}$ is the relative gain

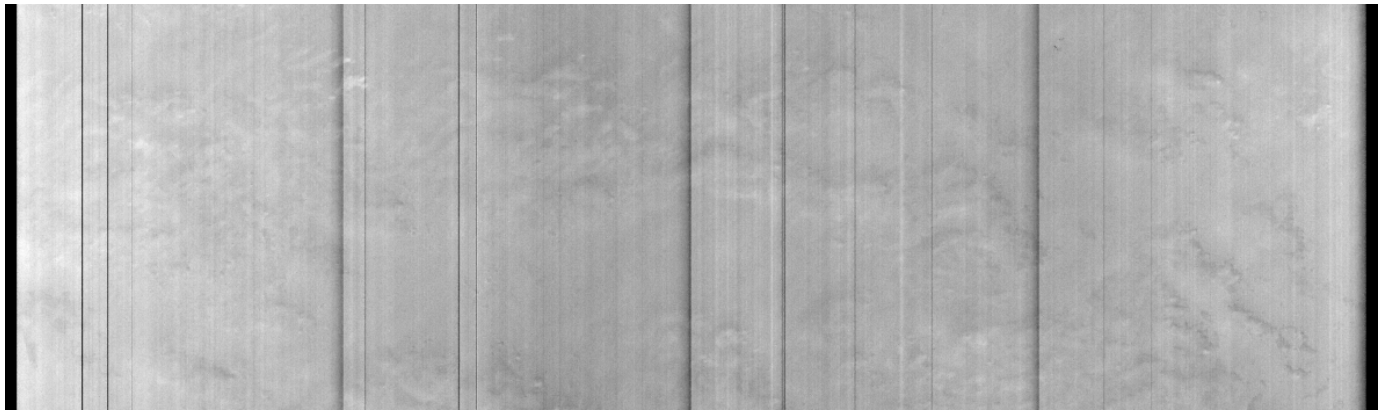
- The conversion to absolute radiance is preformed by the following equation:

$$L_{Det,Band} = K_{Band} q_{Det,Band}$$

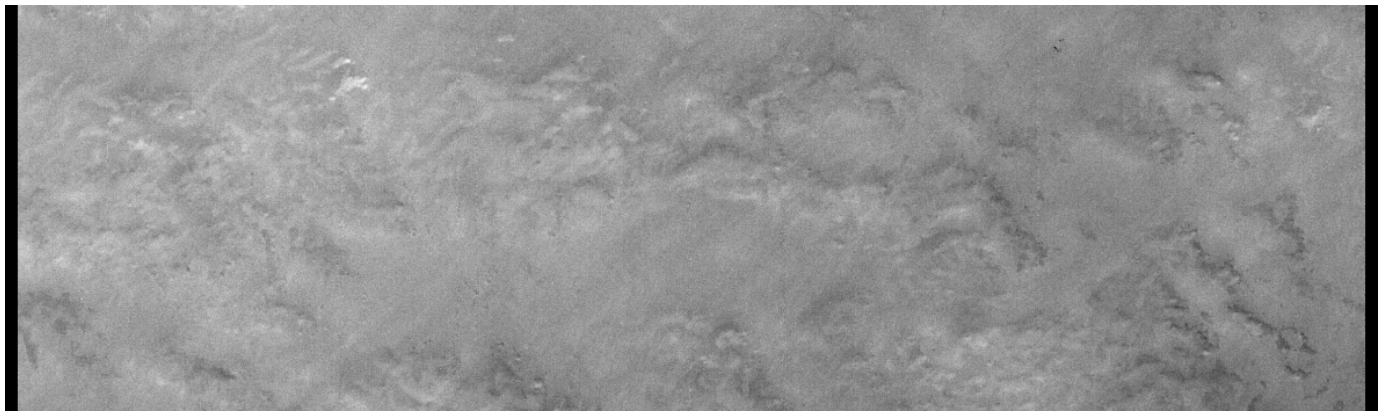
- Where $L_{Det,Band}$ is the absolute radiance in units of W/m^2-ster and K_{Band} is a constant calculated for each band. Multiplying the corrected counts $q_{Det,Band}$ by K_{Band} gives the absolute radiance at the telescope aperture for a given detector

Why Perform Relative Radiometric Correction?

- A uniform scene does not create a uniform raw image



- Major causes of non-uniformity include variability in detector response, variability in electronic gain and offset, lens falloff, and particulate contamination
- All of these can be removed from imagery through radiometric correction as seen below:



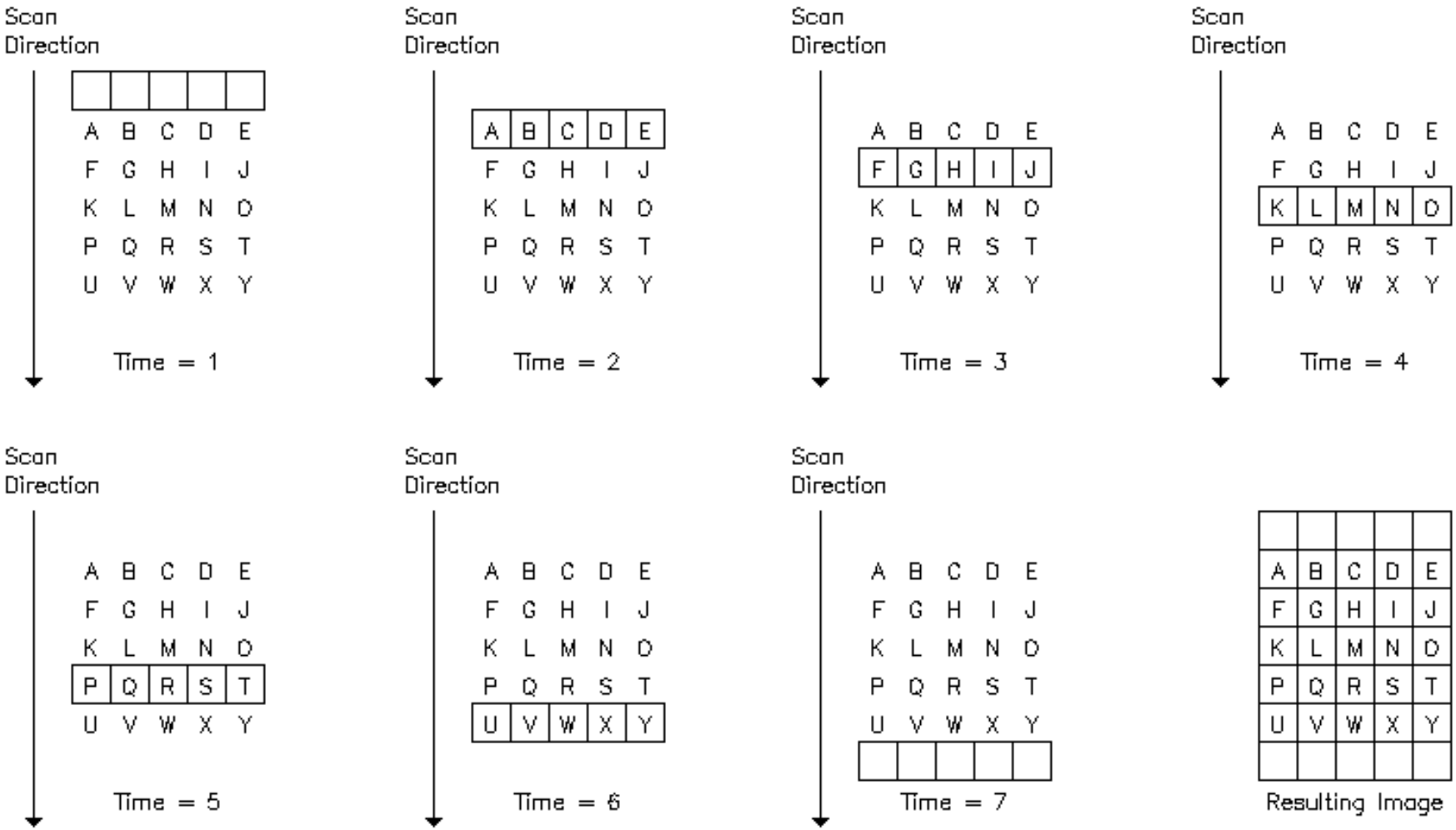
Relative Gain

- Methodology - Divide individual detector response by average response for a given band:

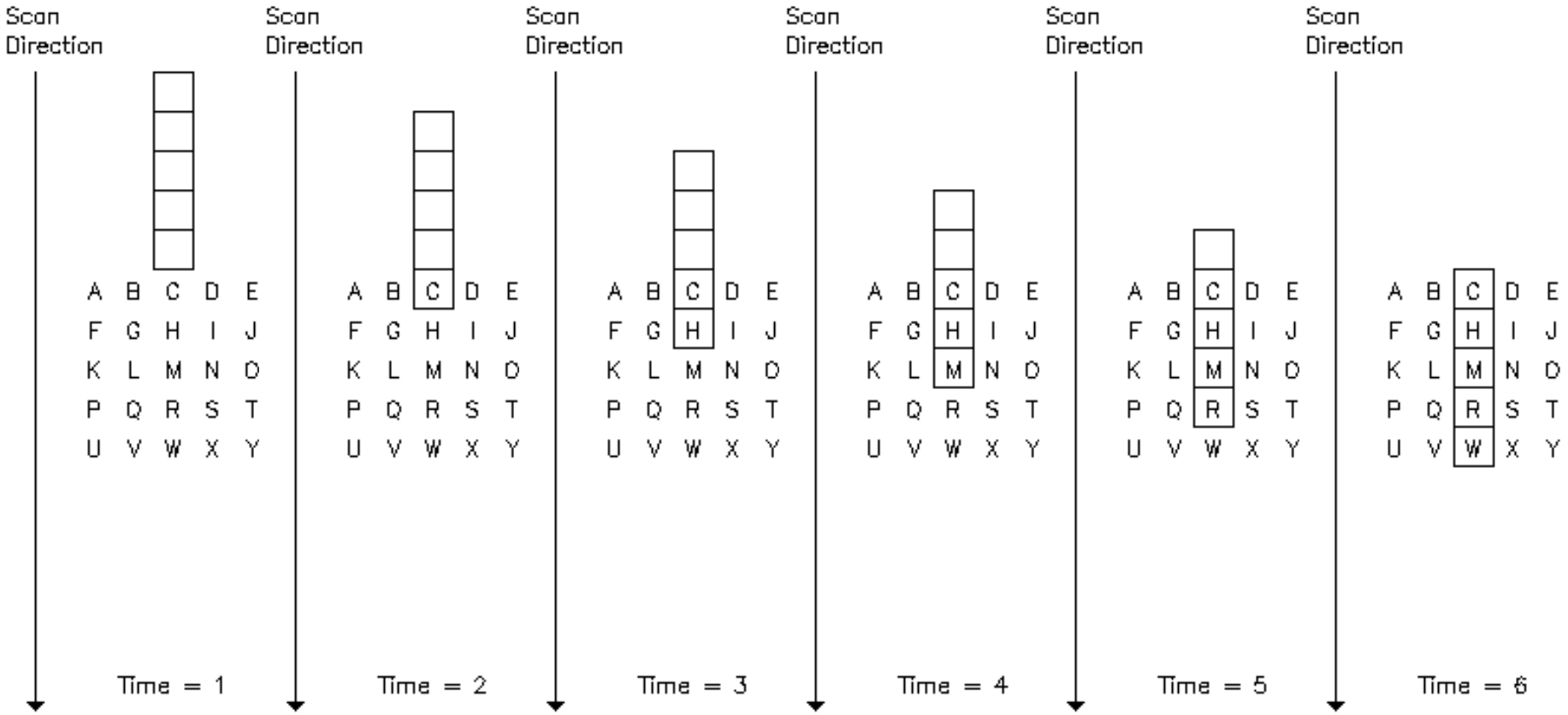
$$B_{Det,Band} = \frac{gain_{Det,Band}}{\langle gain_{Det,Band} \rangle}$$

- Assume target presents a constant radiance across FOV
- Pre-launch relative gain typically performed by looking at an integrating sphere or large diffuser panel
- These coefficients cannot account for changes up through launch unless some reliable on-board device is available
- On-orbit relative gain typically performed by looking at a large desert target (cloud free, spatially uniform, lambertian) using normal or side-slither imaging

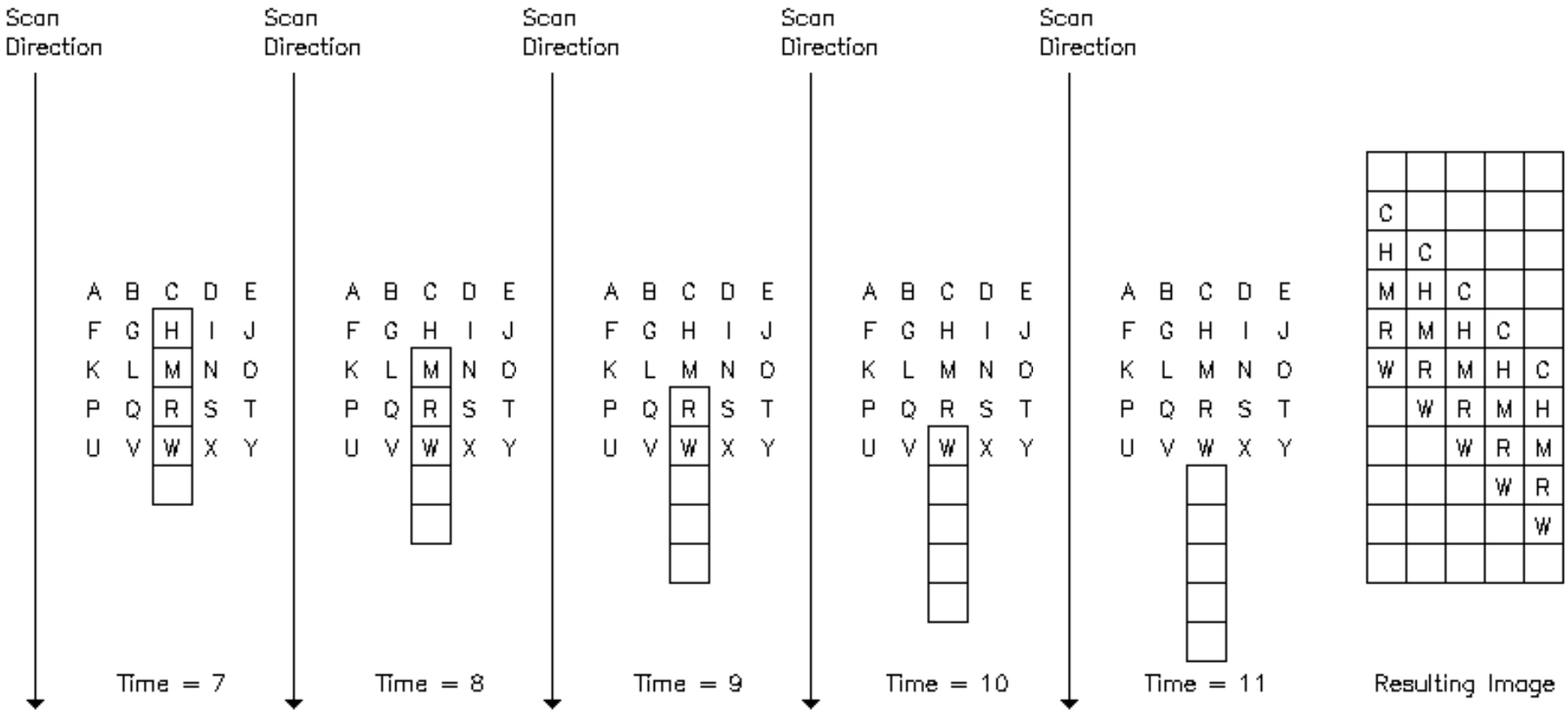
Normal Imaging Configuration



Side-Slither Configuration

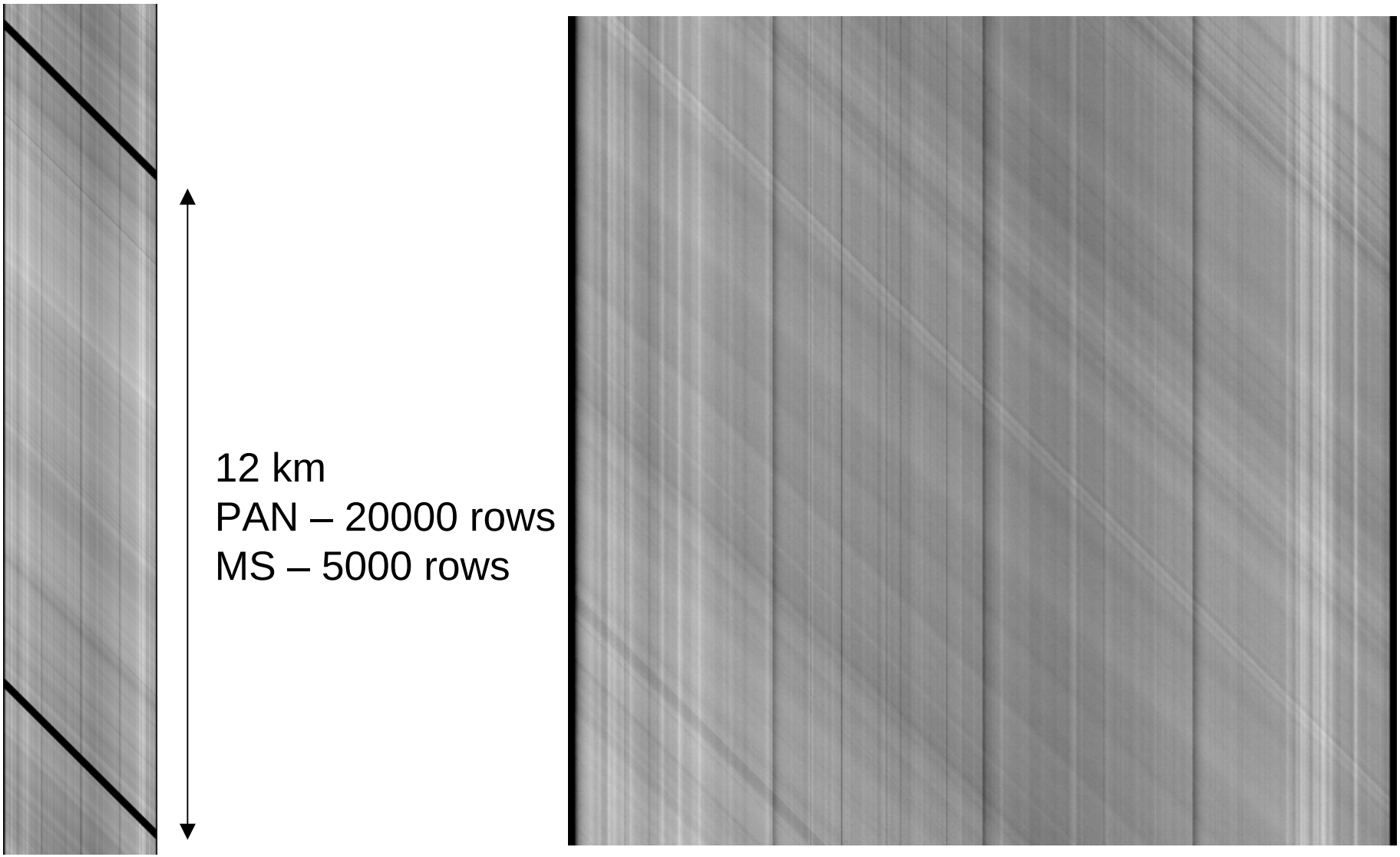


Side-Slither Configuration Cont.



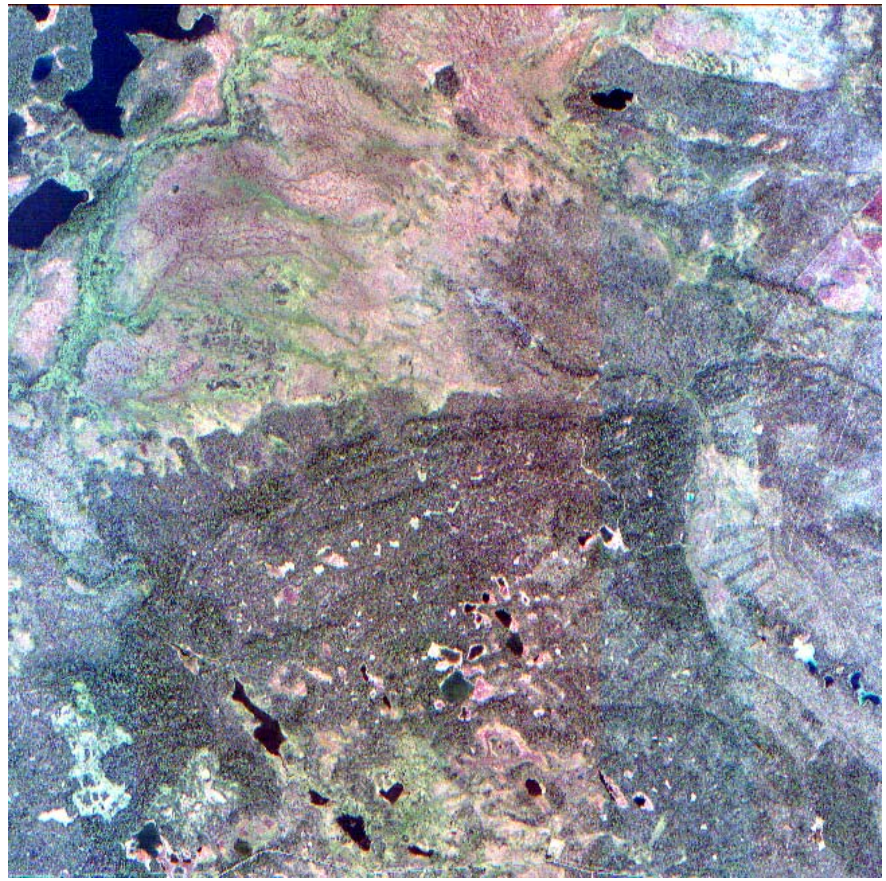
- The goal is to present a constant radiance across FOV to all detectors
- Using the side-slither technique, every detector views the same set of points on the ground for improved statistics

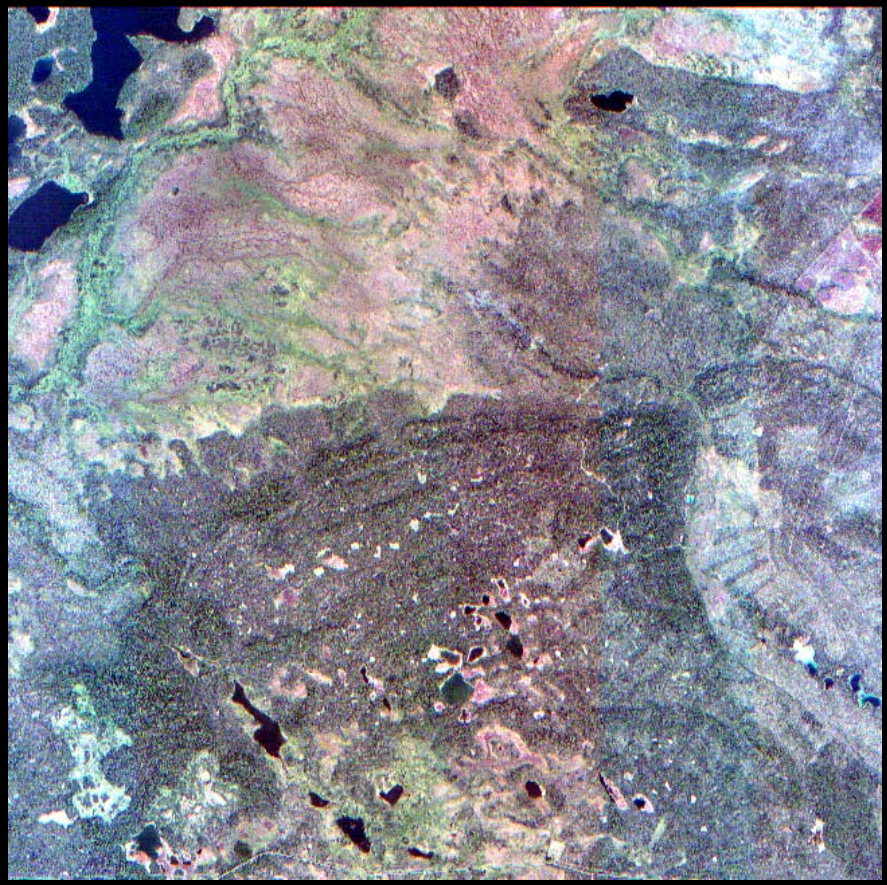
Side-Slither Region of Interest



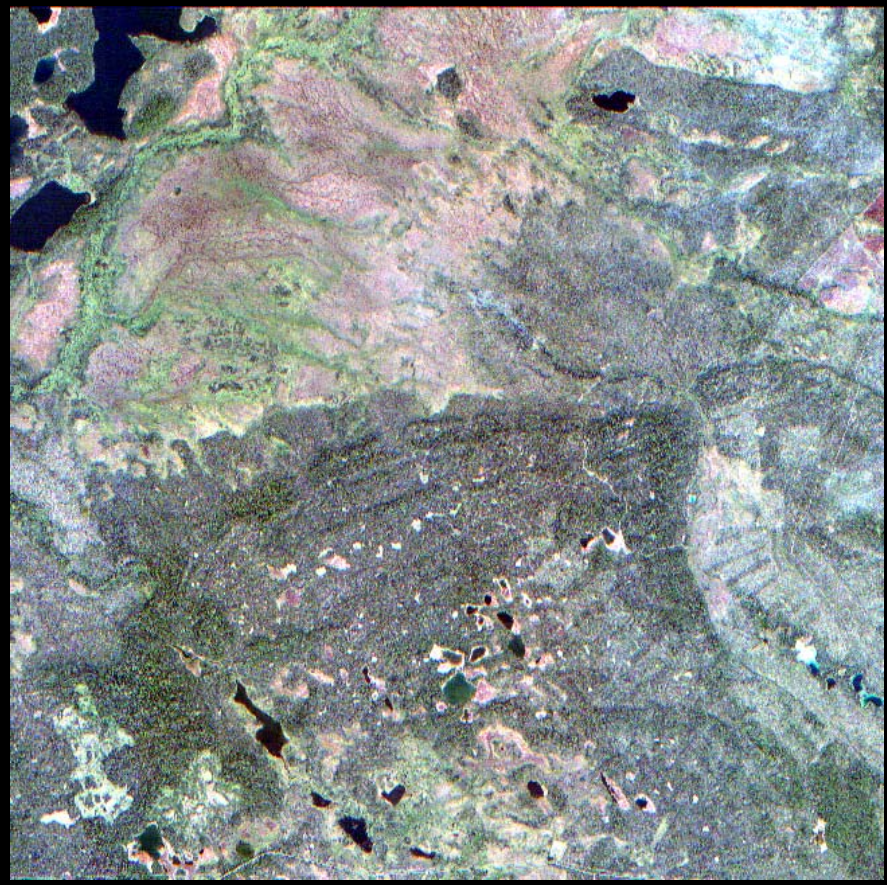
Color Banding in QuickBird Imagery

- Color banding is a problem in low dynamic range imagery such as ocean, forest, and desert scenes
- Potential causes of banding include:
  - offset stability/estimation
  - gain stability/estimation
  - non-linear detector/electronic response
  - other biases (compression noise)
  - spectral differences between DCAs
- Most noticeable in color images
- Banding only affects a small number of images in our archive
- Images shown are worst-case examples
- A new method for relative radiometric coefficient generation was developed for MS only (Pan coefficients in progress)
- New method is a two point calibration using side-slither and ocean scenes





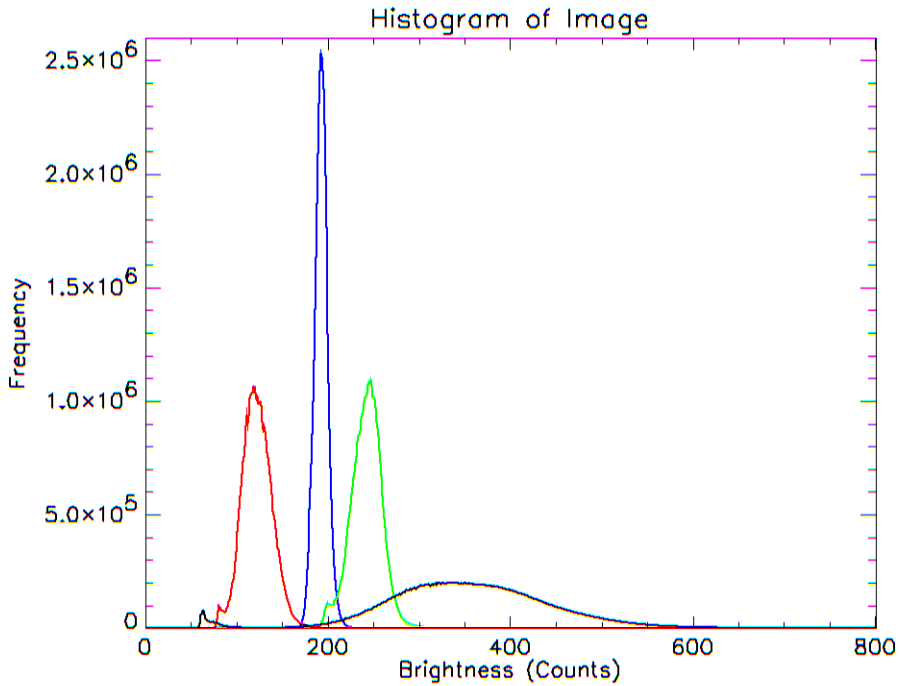
Before



After

Dynamic Range Example

- Histogram of the image from the previous slide
- Notice the large peaks and narrow widths of the data
- FWHM are approx. 26, 40, and 46 counts in the blue, green, and red bands respectively out of 1800
- Typical city scenes have FWHMs greater than 140 for blue and 200 for green and red
- Banding defined as percent difference of one DCA to the previous DCA in a corrected image
- The mean value of the blue band is 193 counts. Adjacent DCAs must be within 3.86 counts to meet the 2% spec



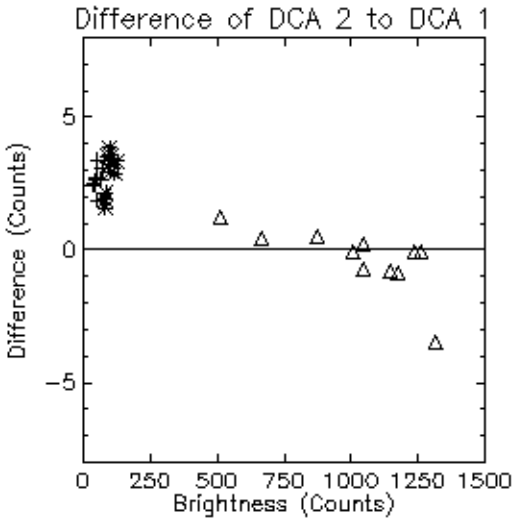
- However, the mean of the red band is only 122 counts meaning DCAs must be within 2.44 counts to meet spec

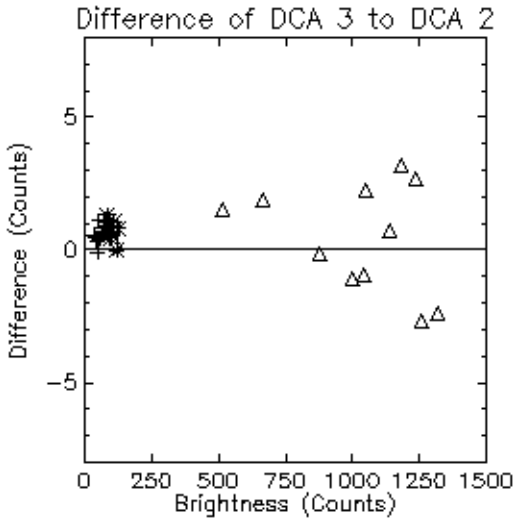
Analysis of Banding

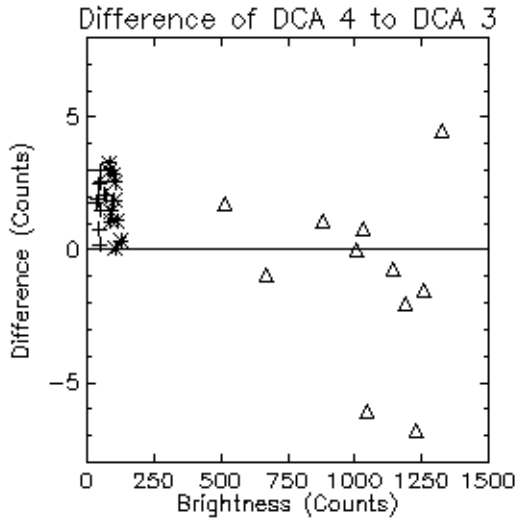
- A new set of coefficients was generated using data acquired between 6/01/2002 and 8/31/2002
- New relative gains were calculated using 12 side-slither and 10 ocean scenes (every combination of the two scene types was calculated and averaged to get an average system result)
- New offsets were calculated using the 10 ocean images ($A_{Det,Band}$ was calculated for each scene and then the average was found)

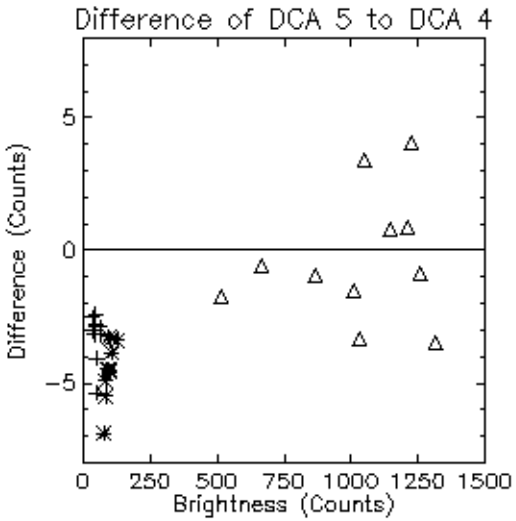
- To evaluate the new coefficients, 10 ocean (same as before), 10 forest, and 10 desert (normal scan) scenes were radiometrically corrected
- The mean value was calculated for each overlap region in each DCA and adjacent DCA overlap regions were compared
- Plotted is the banding difference (counts) vs. scene brightness (counts)
- Ideally, all of the data points should have a zero difference

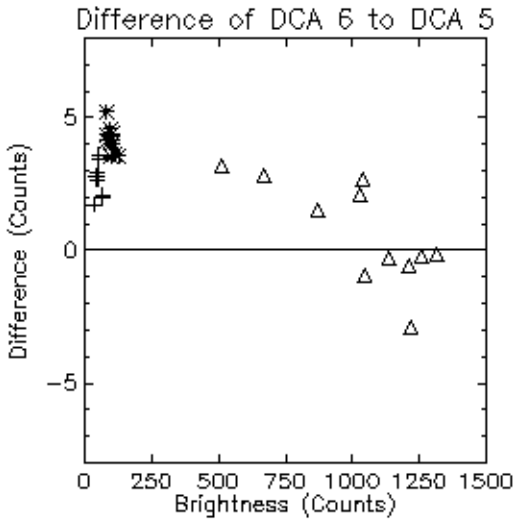
Banding Differences In Red Band Using Old Calibration Coefficients











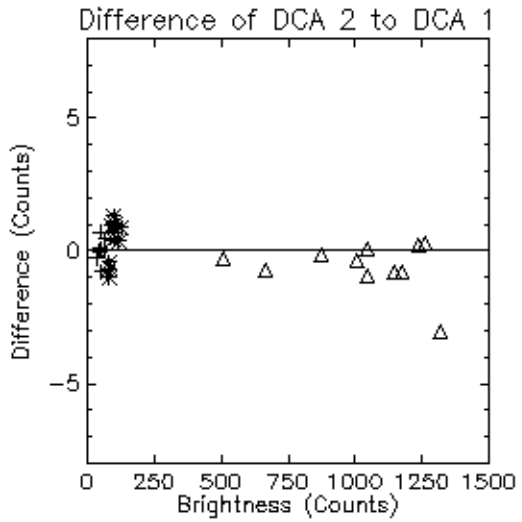
\+ Ocean

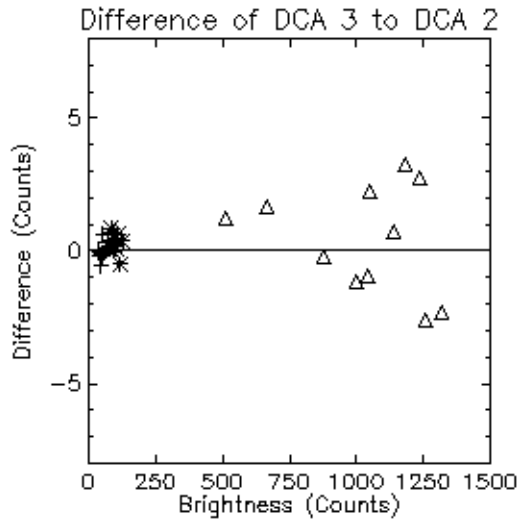
* Forest

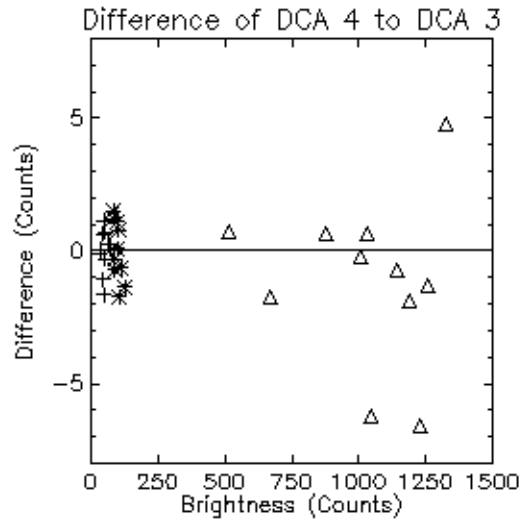
Δ Desert

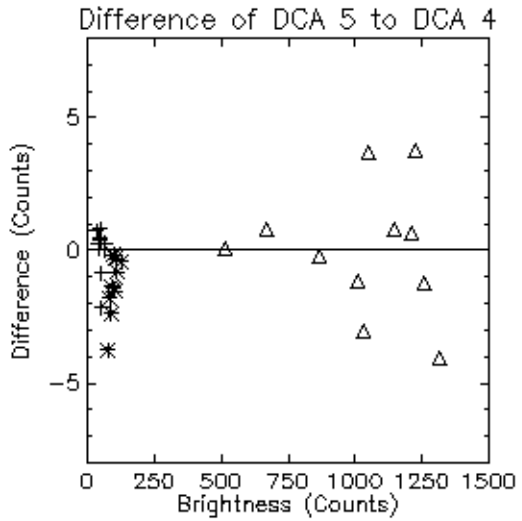
Differences calculated using the mean value of the overlap pixels

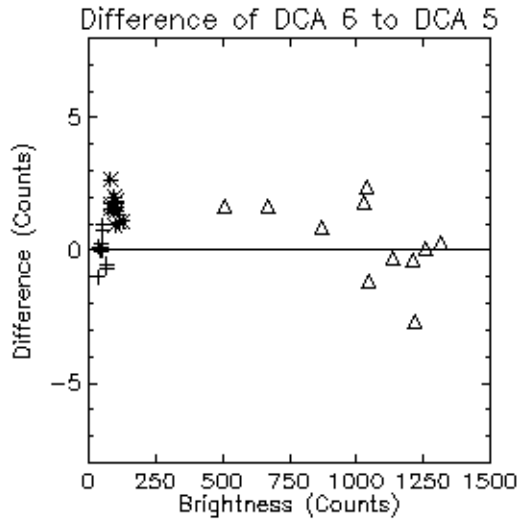
Banding Differences In Red Band Using New Calibration Coefficients









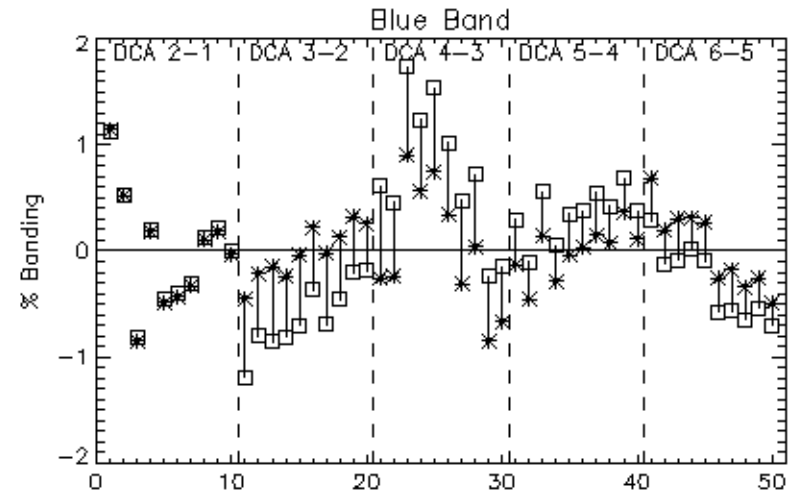


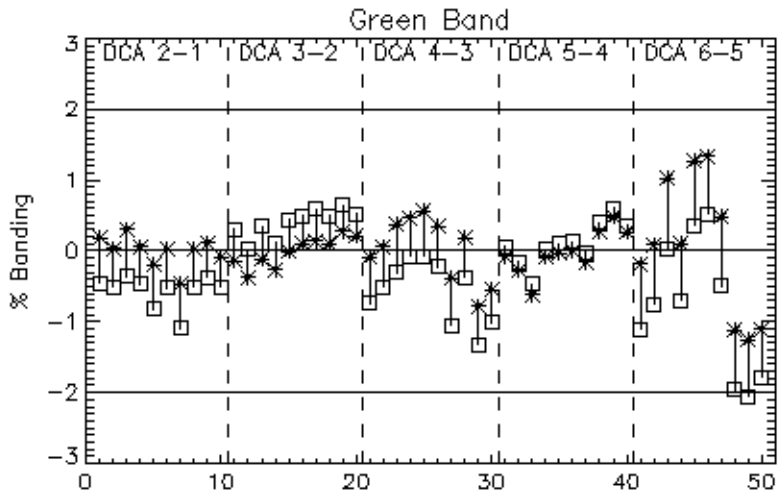
\+ Ocean

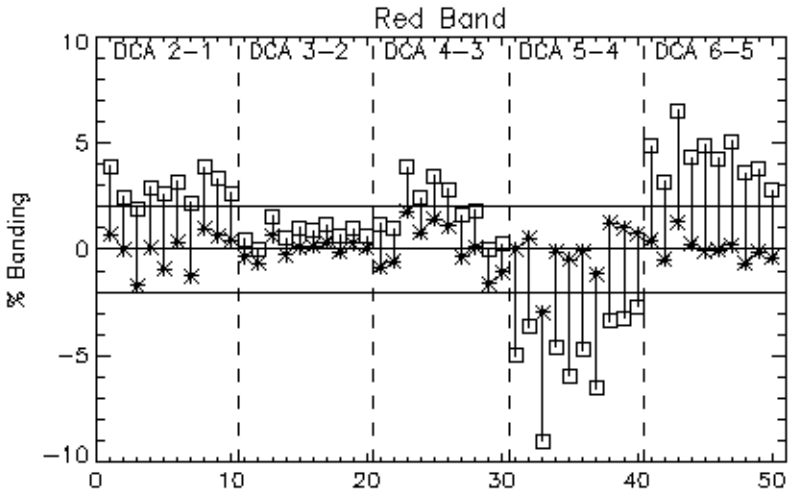
∗ Forest

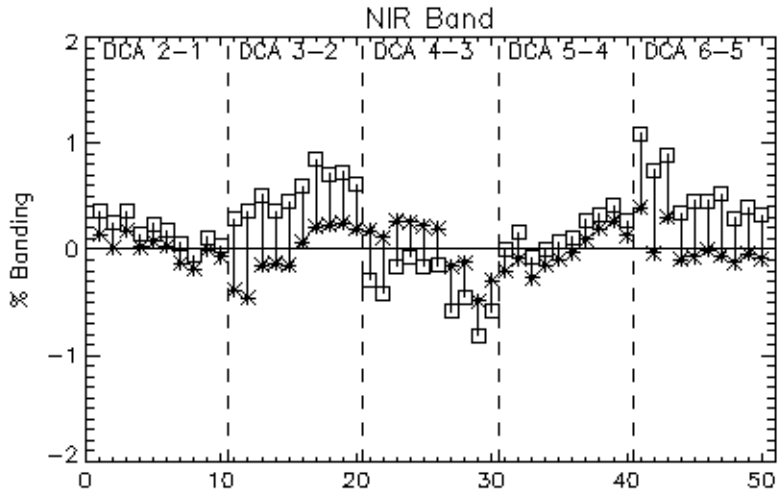
Δ Desert

Testing Forest Banding Improvements

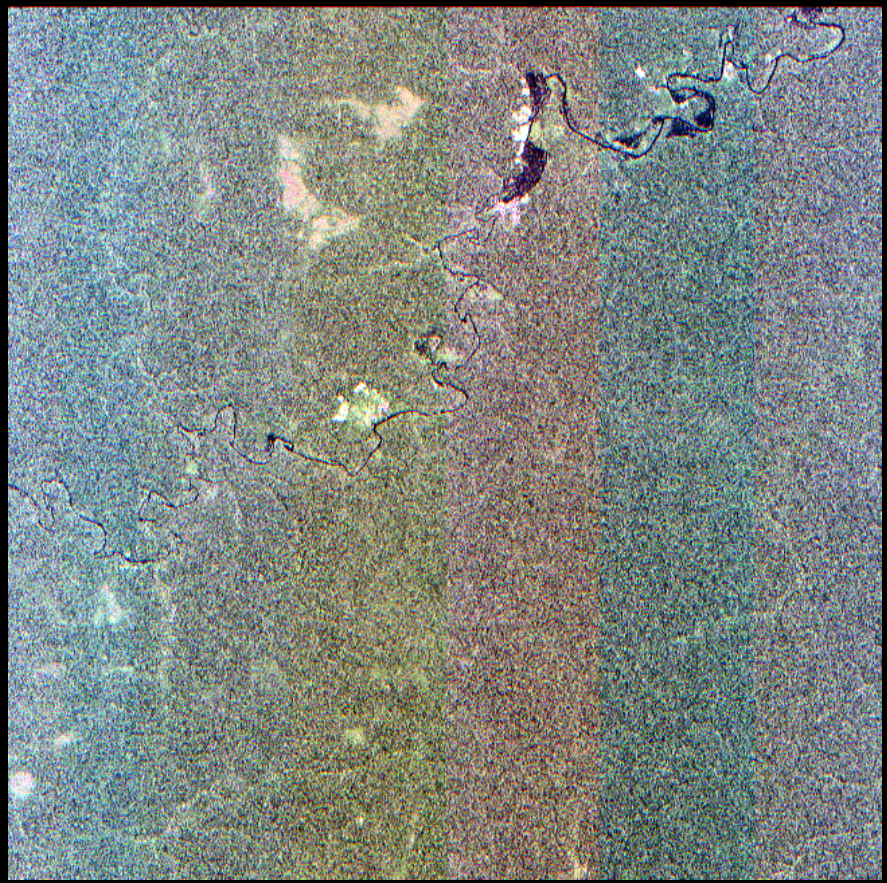




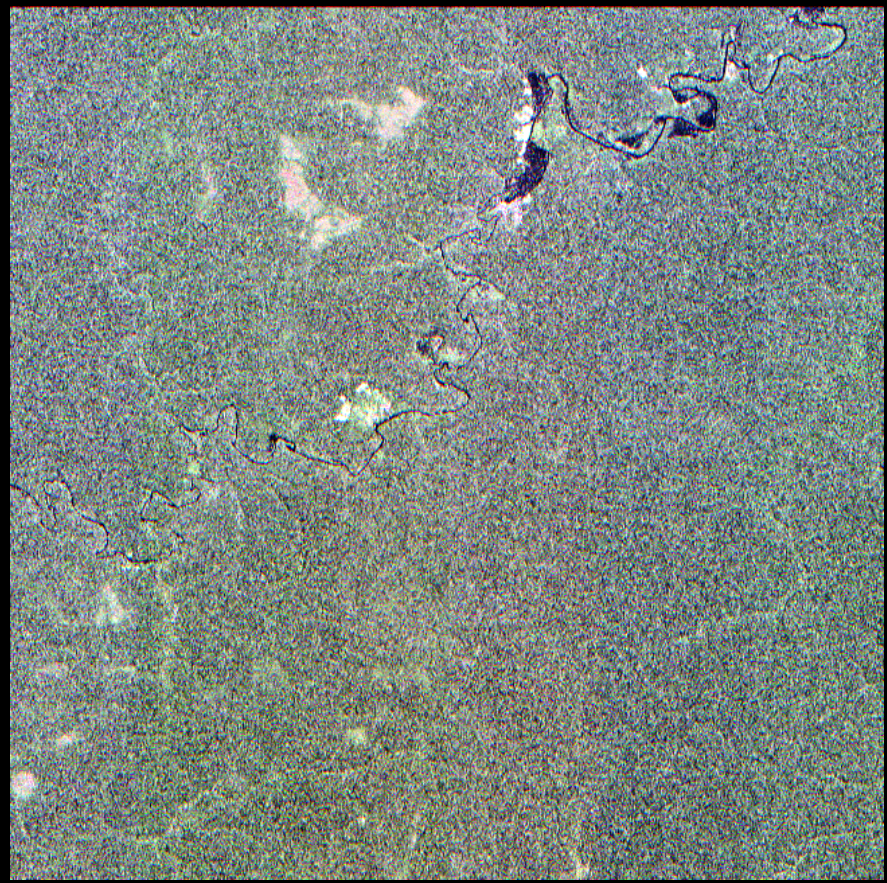




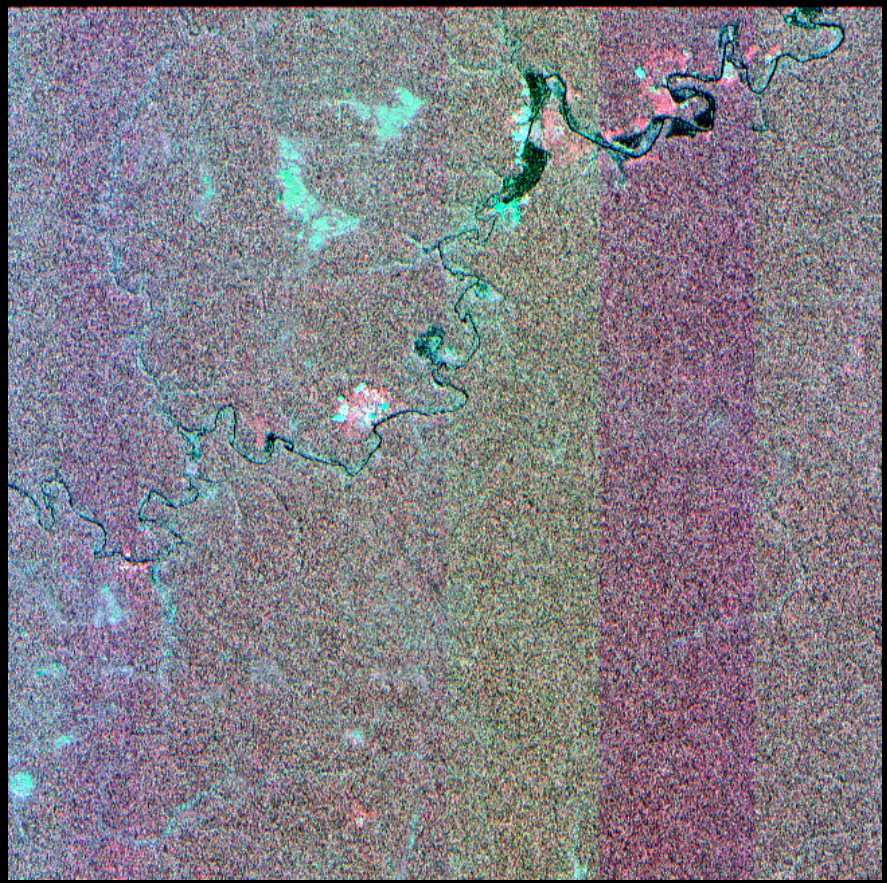
□ Old Coefficients * Coefficients in Development



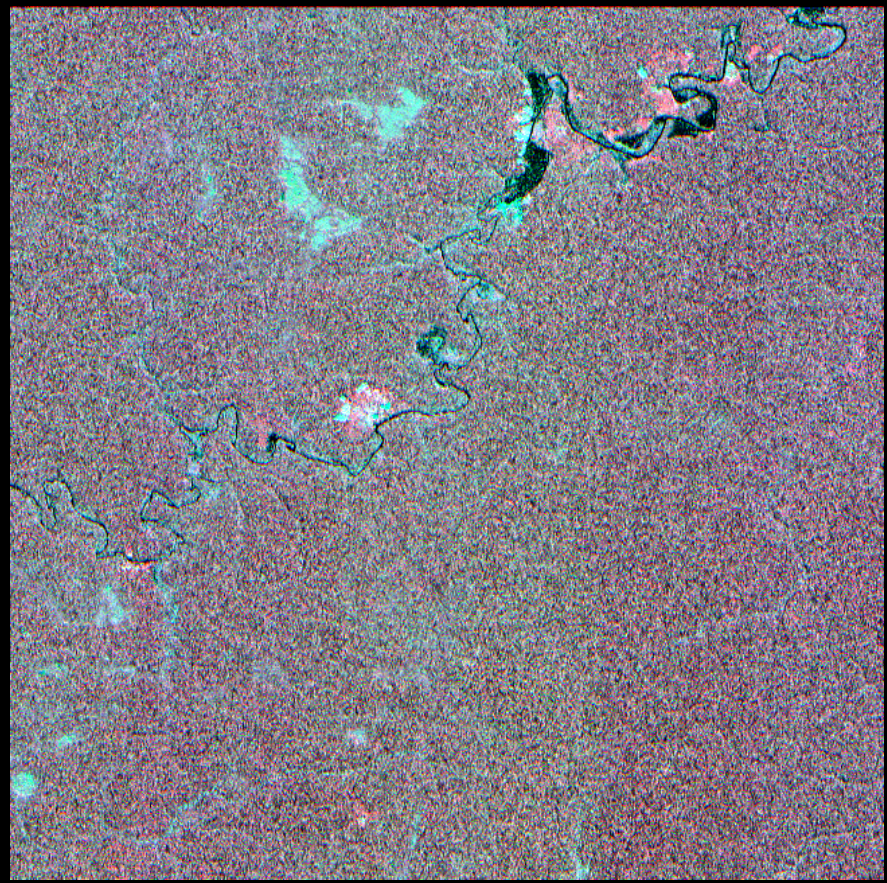
Before



After



Before

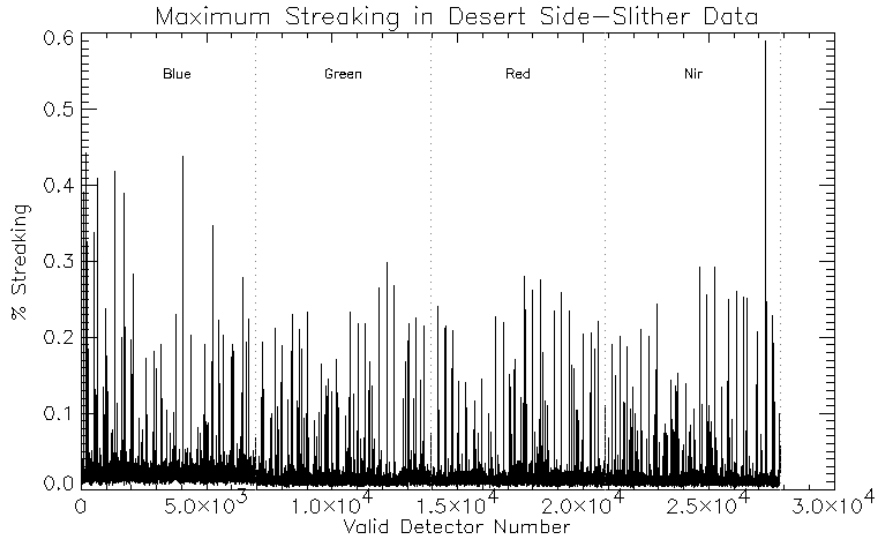


After

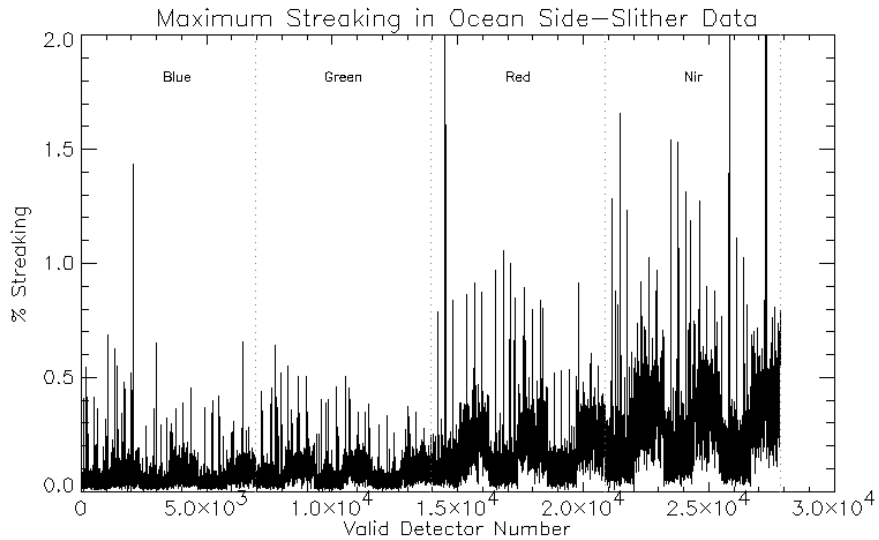
Streaking Results

$$\text{Streaking}_N = \frac{\left| q_N - \left(\frac{q_{N-1} + q_{N+1}}{2} \right) \right|}{\left(\frac{q_{N-1} + q_{N+1}}{2} \right)}$$

- 8 desert images (not used in calibration)
- For all bands:
  - 99% detectors have streaking < 0.11%
  - 99.9% have streaking < 0.27%
  - Maximum streaking – 0.59%
- Mean values range:
  - Blue: 426-571 Green: 826-1045
  - Red: 842-1072 NIR: 944-1195



- 4 ocean images
- For all bands:
  - 99% detectors have streaking < 0.59%
  - 99.9% have streaking < 1.29%
  - 13 detectors are > 2%
- Mean values range:
  - Blue: 125-245 Green: 117-238
  - Red: 44-93 NIR: 24-57



Absolute Calibration Discrepancy

- Sensor level irradiance calibration at Kodak
- System level integrating sphere calibration at Ball
- Ball absolute coefficients currently given to customers

Ball Vs Kodak				
	Kodak	Ball		
	W/m^2-ster-um per DN	W/m^2-ster-um per DN	**% Diff**	
Blue	0.2359	0.2015	**-14.582**	
Green	0.1453	0.131	**-9.842**	
Red	0.1785	0.162	**-9.244**	
NIR	0.1353	0.1163	**-14.043**	
Ball Vs Arizona				
	Arizona	Arizona	Ball	
	DN per W/m^2-ster-um	W/m^2-ster-um per DN	W/m^2-ster-um per DN	**% Diff**
Blue	4.018	0.249	0.2015	**-19.037**
Green	6.493	0.154	0.131	**-14.942**
Red	5.447	0.184	0.162	**-11.759**
NIR	7.446	0.134	0.1163	**-13.403**
Kodak Vs Arizona				
	Arizona	Arizona	Kodak	
	DN per W/m^2-ster-um	W/m^2-ster-um per DN	W/m^2-ster-um per DN	**% Diff**
Blue	4.018	0.249	0.2359	**-5.215**
Green	6.493	0.154	0.1453	**-5.657**
Red	5.447	0.184	0.1785	**-2.771**
NIR	7.446	0.134	0.1353	**0.744**

Summary

- Relative radiometric calibration is excellent
  - Banding in desert scenes is less than 0.5% in pan, green, red, and NIR bands and less than 1% in the blue band
  - Banding was a problem in low dynamic range imagery
  - All imagery meets the less than 2% banding spec except low-radiance scenes, when calibrated with the new radiometric coefficients
  - Previous analysis has shown that streaking is less than 0.25% in the pan band
  - Streaking in MS bands < 0.59% for all detectors except low-radiance scenes where all but 13 detectors meet spec
  - New coefficients effective for MS imagery acquired after 12/01/2002
  - Pan and MS coefficients for entire archive under development
- The absolute calibration discrepancy is still being investigated