RapidEye
geo facts
turned into knowledge

The RapidEye Calibration Approach and Current Results

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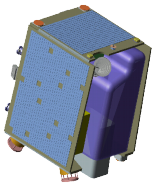
Content of the Presentation

- RapidEye System Overview
- RapidEye Calibration Approach
- Results of the Initial Post-launch Calibration
- Planned Mid- and Long-term Calibration Activities

RapidEye System Overview

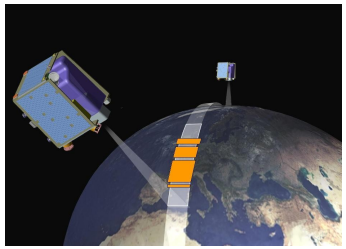


Constellation of 5 identical satellites with a 5 band multi-spectral pushbroom scanner

Image data download in Svalbard (Norway), Satellite Control, Image data processing and Archiving in Brandenburg (Germany)

Launch at August 29, 2008, in Kazakhstan; Operational since February 01, 2009

Flight Altitude 630 km, Ground Sampling Distance 6.3 m, Swath Width 77 km, Image take length 1,500 km, Imaging Capacity up to 4 Mio km² per day



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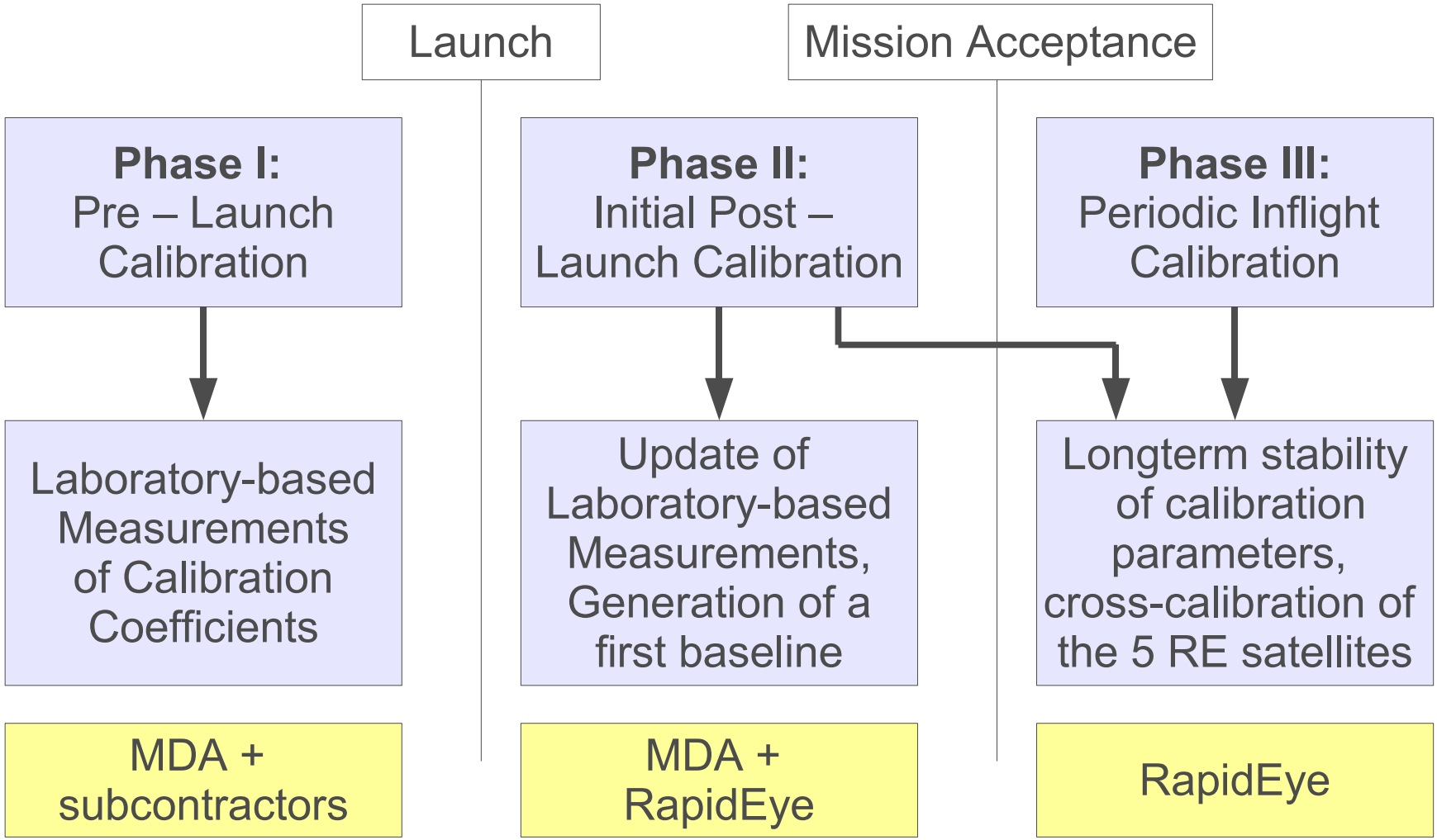
Cornerstones of the RapidEye Calibration Approach

- **Primary Markets for RapidEye Data and Services: Agriculture, Forestry, Environmental Monitoring, Insurance, Mapping**
  - Vegetation – related spectral features and indices are of major importance
- **Temporal stability, spatial homogeneity, and cross calibration** between the 5 satellites are the most important calibration goals
- **Absolute Radiometric Calibration** is as well important to ensure the derivation of vegetation-related features from the multi-spectral image data
- **Geometric Calibration** is required to meet the mapping accuracy requirements according to the customer's expectations

RapidEye Calibration Phases



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Main Objectives of the Three Phases

- **Phase I: Determination of the initial absolute calibration coefficients**
  - Initial absolute radiometric calibration, Initial determination of the gain and offset tables (GOT), Spectral band response function determination
  - Determination of the geometric camera model, Measurement of the correct position of each sensor element
- **Phase II: Relative radiometric calibration based on image statistics**
  - Generation of an initial radiometric baseline
  - Improved spatial calibration (homogeneous response over the whole image)
- **Phase III: Periodical Update of the Calibration Parameters**
  - Temporal stability based on the image statistics of all collected data and on selected globally distributed calibration test sites

Phase I: Initial Laboratory Calibration

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- **Determination of the spectral transmission and the system response function**
  - Response tables for all 5 spectral bands
- **Radiometric noise determination based on absolute calibrated sources**
  - Initial absolute calibration tables
  - Initial GOT for spatial homogeneity
- **Initial camera model and MTF determination**
  - Geometric camera parameter adjustment

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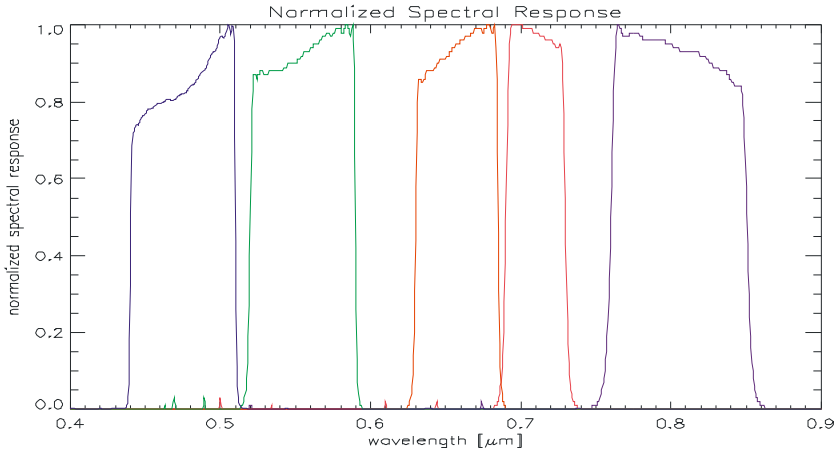
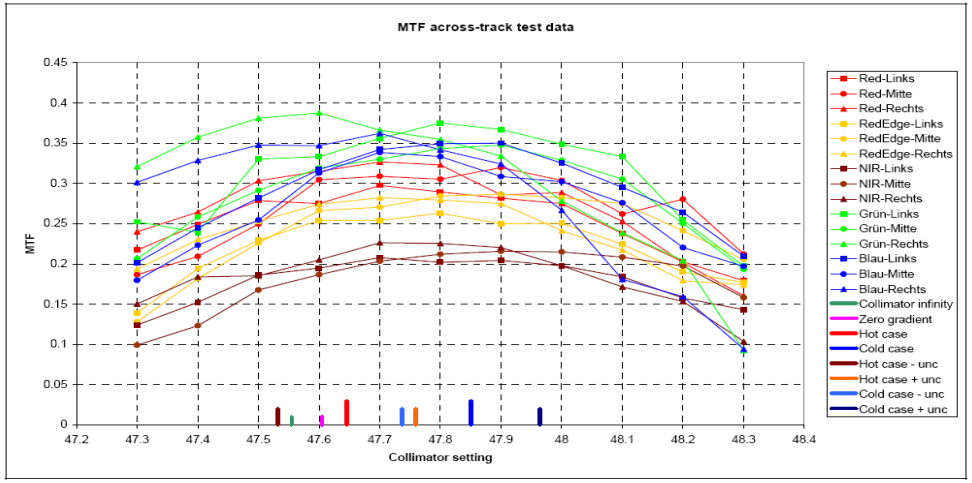


Table 4-1: PFM Red Band Performance w/ 937 Calibration

Radiance Case	Effective Radiance [W/m ^2/sr /um]	Delta L [W/m ^2/sr /um]	NER [W/m ^2/sr /um]
CDARK	0	0.303	0.452
CMIN	13.109	-0.267	0.628
CO4	103.672	-0.097	0.989
CO1	244.401	0.054	1.342



Phase I: Preliminary Estimation of the Relative Stability

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Relative accuracy between Payloads:

Table 6-6: Summary of worst-case payload variability

Band	Radiance [W/m2/sr/µm]	Measured Variation	E		Total Variation
			Thermal Correction Residual	Payload Repeatability	
Blue	72.5	0.68%	1.05%	0.20%	**1.93%**
Green	25.2	1.42%	0.83%	0.23%	**2.48%**
Red	14.2	1.34%	1.05%	0.58%	**2.97%**
Red Edge	55.2	0.63%	1.22%	0.85%	**2.70%**
NIR	58.1	1.34%	0.72%	1.63%	**3.69%**

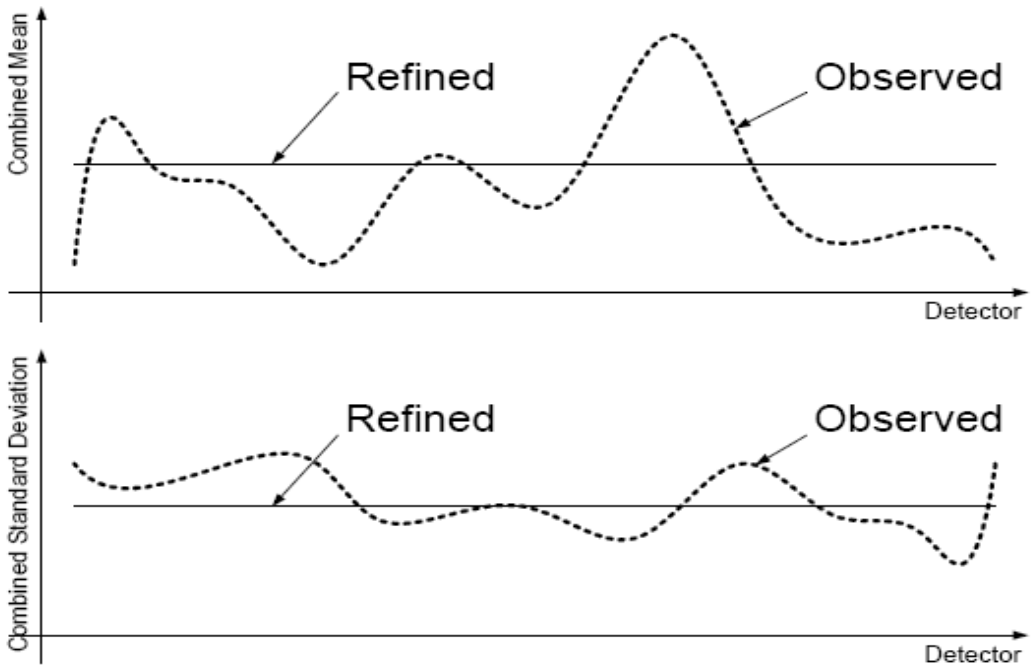
Phase II: Initial Post Launch Calibration

Spatial Homogeneity: Relative radiometric calibration based on image statistics

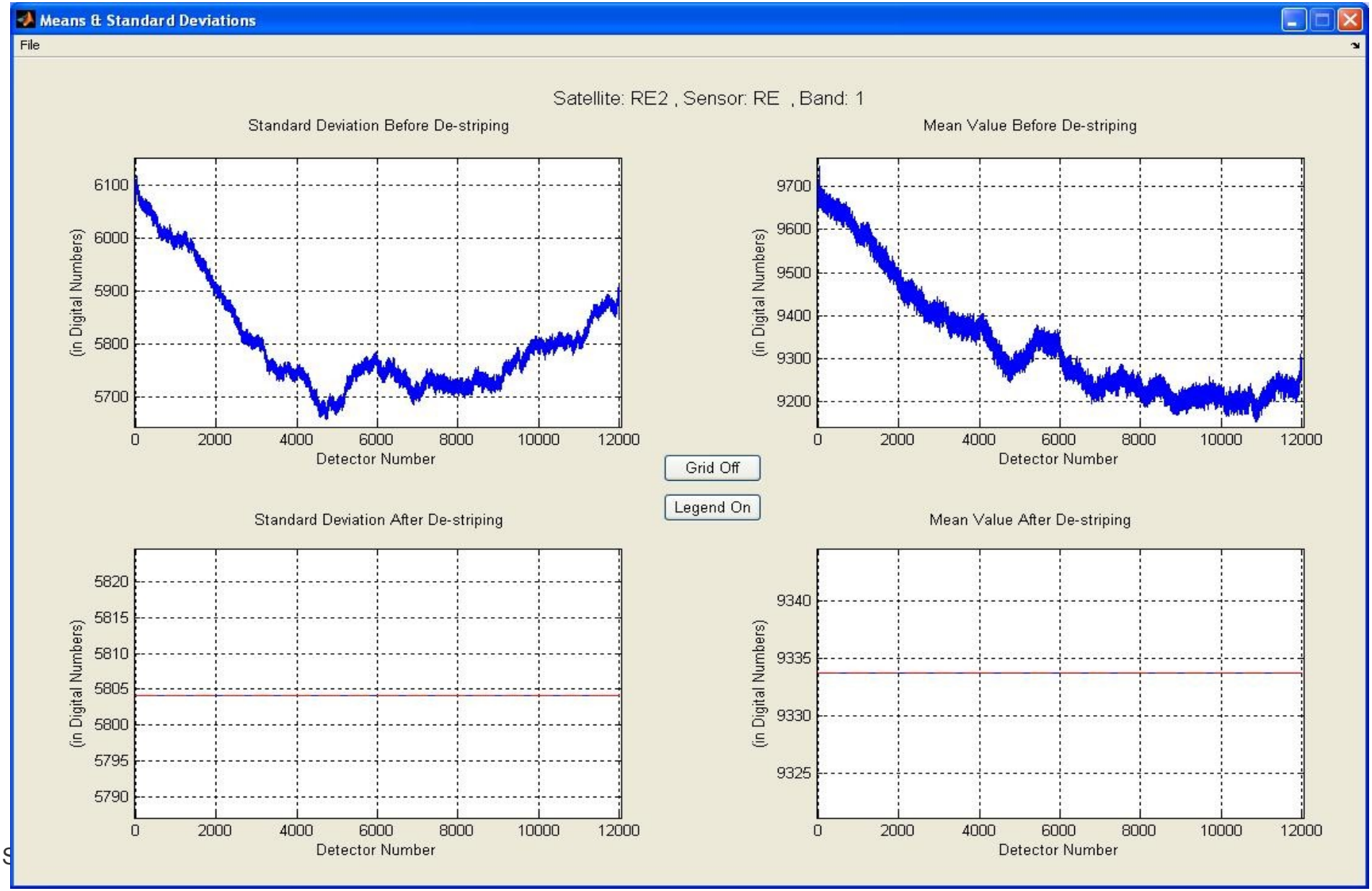
- No ground truth measurements in this phase
- Improves spatial calibration
  - For all scheduled and planned image takes the “per detector” mean and standard deviation is gathered over all image takes
    - for each detector
    - each band
    - each spacecraft

$$gain_i' = gain_i \cdot \left(\frac{\bar{\sigma}}{\sigma_i} \right)$$

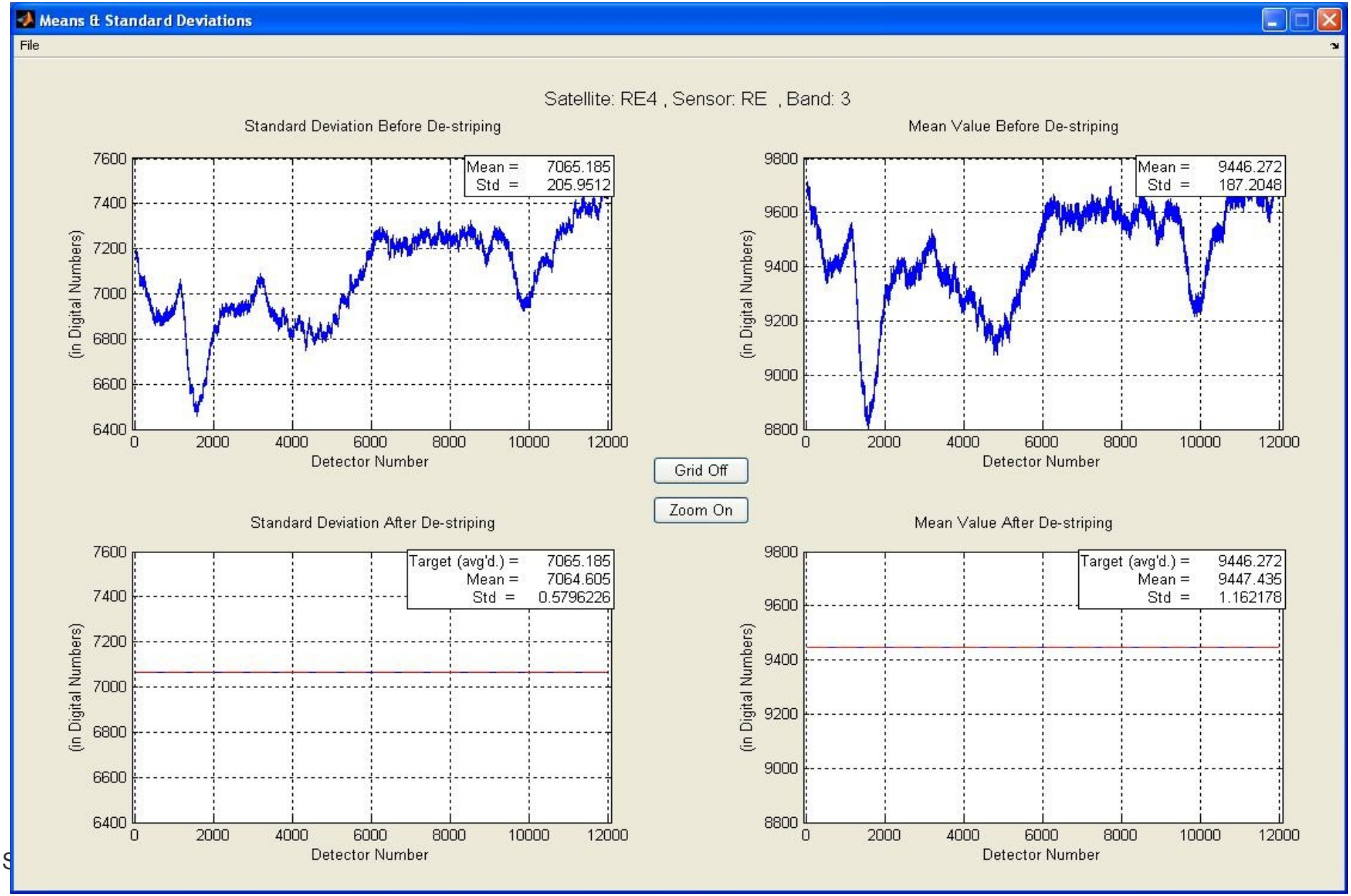
$$offset_i' = offset_i + \bar{\mu} - \left(\frac{\bar{\sigma}}{\sigma_i} \right) \cdot \mu_i$$



Phase II: GOT table update (1)

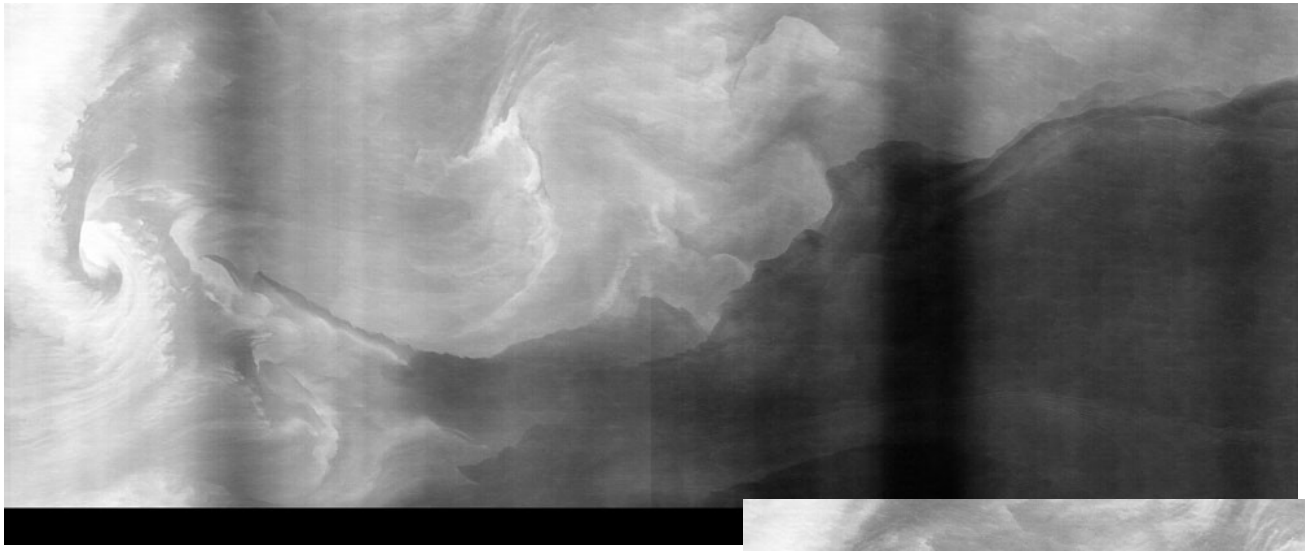


Phase II: GOT table update (2)

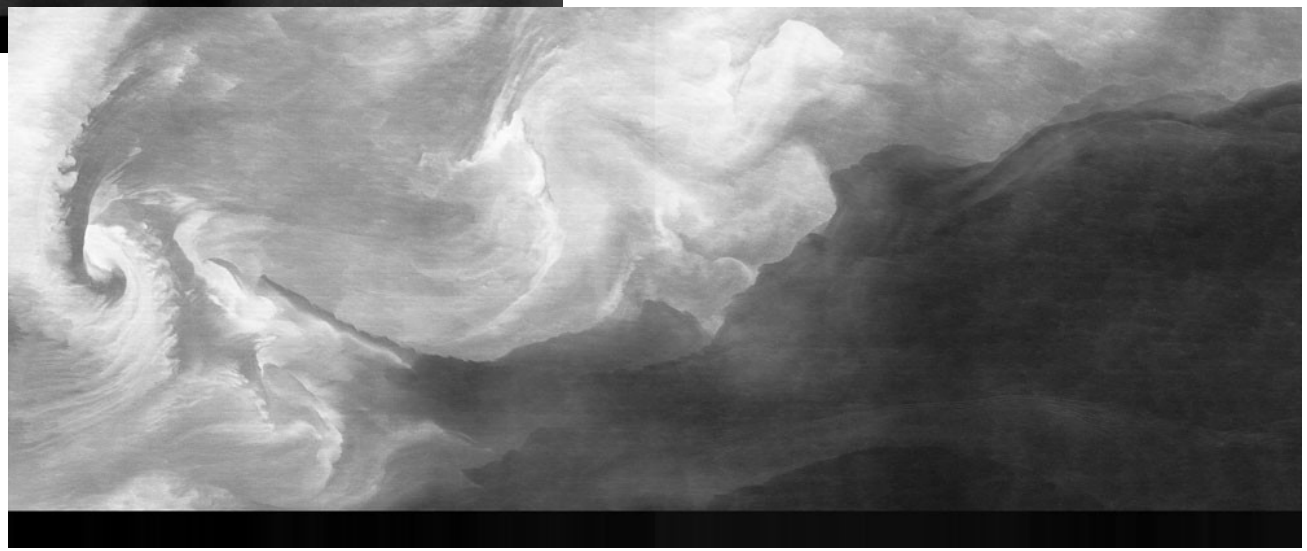


Phase II: GOT table update (3)

Image example showing the result of the GOT table update (exaggerated contrast stretch)



Before GOT update



After GOT update

Phase II: Baseline Determination for In-flight Temporal Calibration

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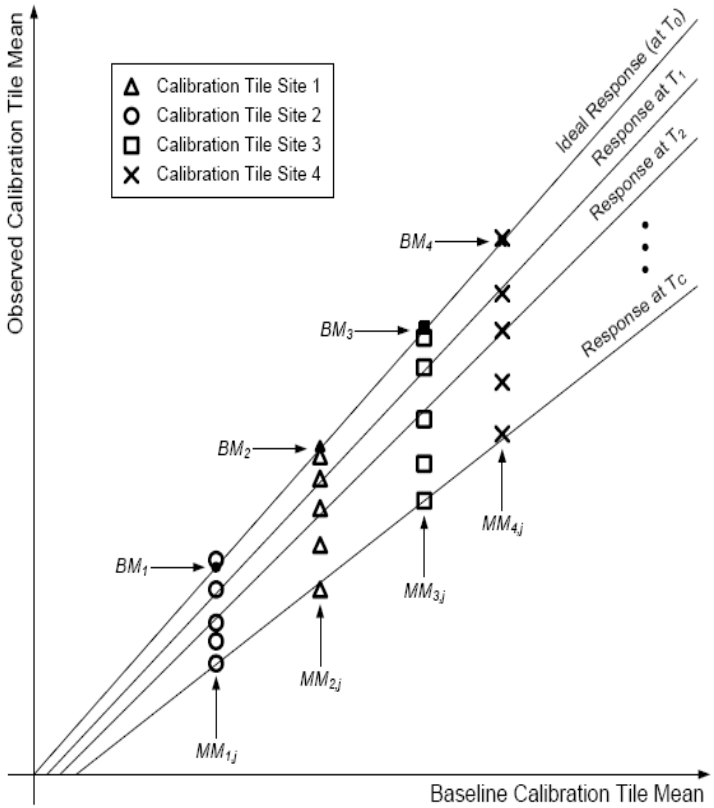
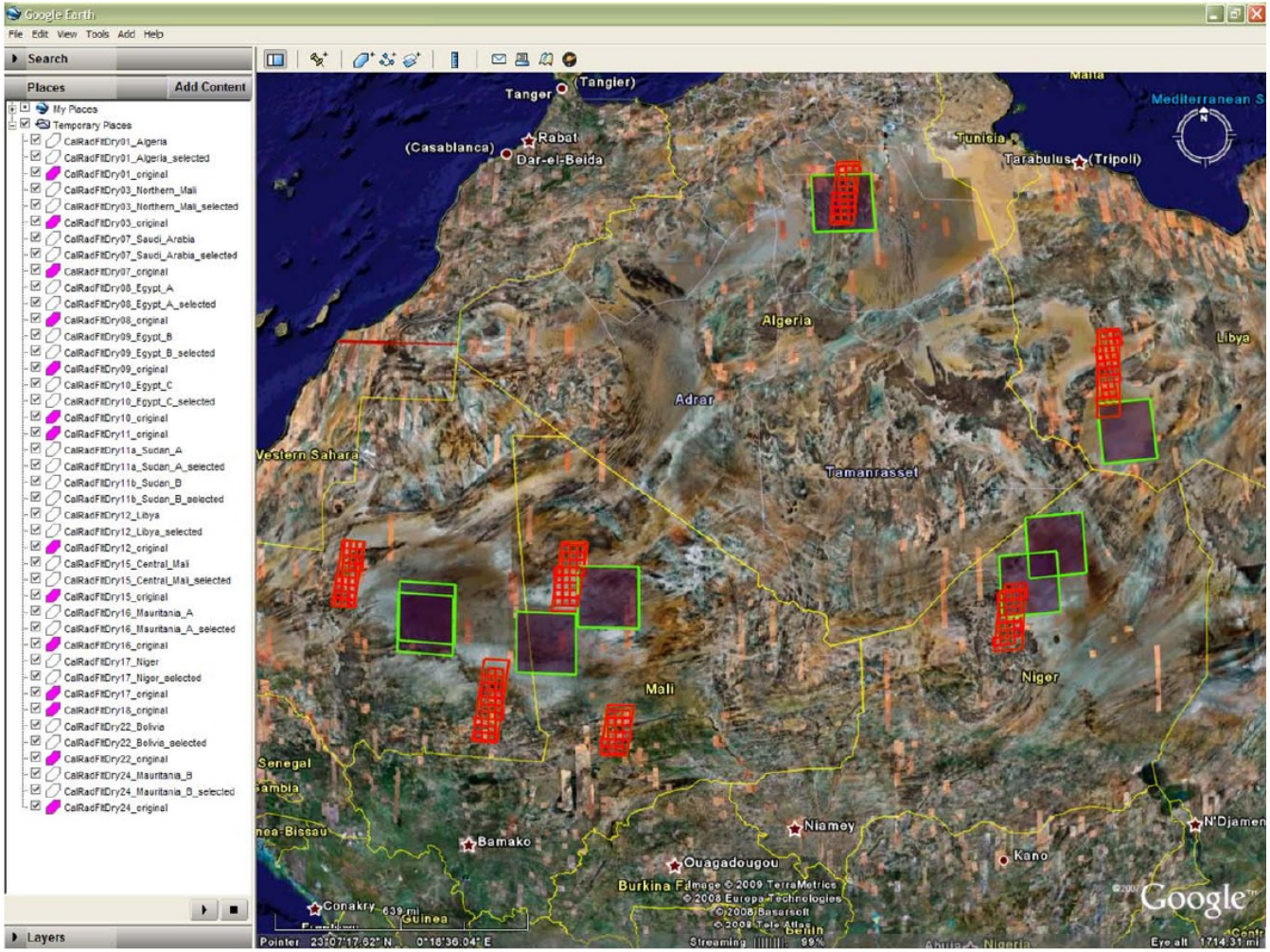
Principles of the radiometric baseline determination

- Collection of imagery over a small number (currently 14) of selected homogeneous ground calibration test sites → determination of the initial radiometric parameters
- The image acquisition for the calibration sites is repeated on a reasonably frequent basis (roughly once every fortnight, currently weekly)
- The radiometric baseline is mainly used as reference to determine any trends in the long-term radiometric behavior of the satellite cameras
- The radiometric baseline is used furthermore for the cross-calibration between the 5 RapidEye satellites



CCD detector performance changes over time

Phase II: Relative Temporal Radiometric Calibration



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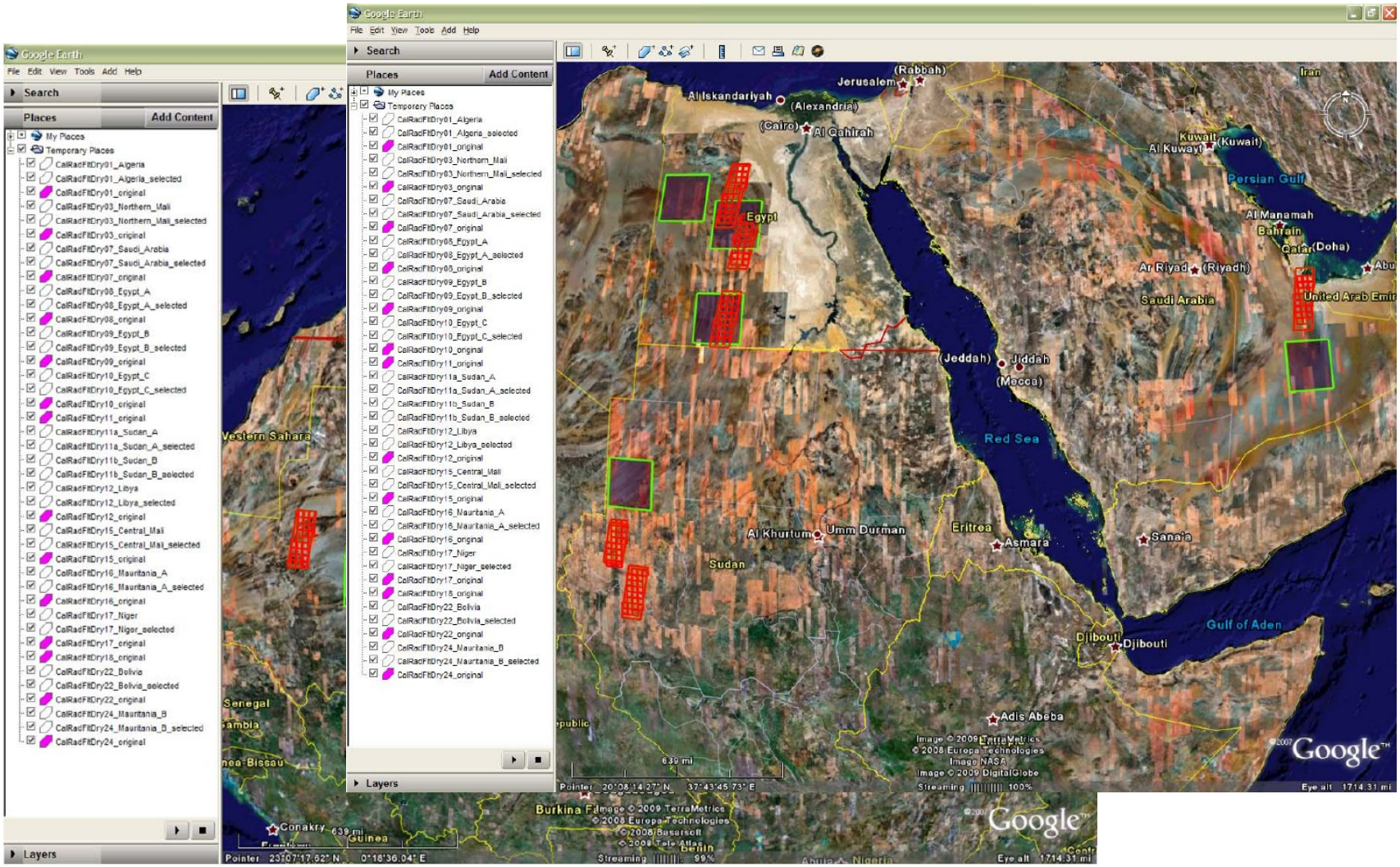
Phase II: Relative Temporal Radiometric Calibration



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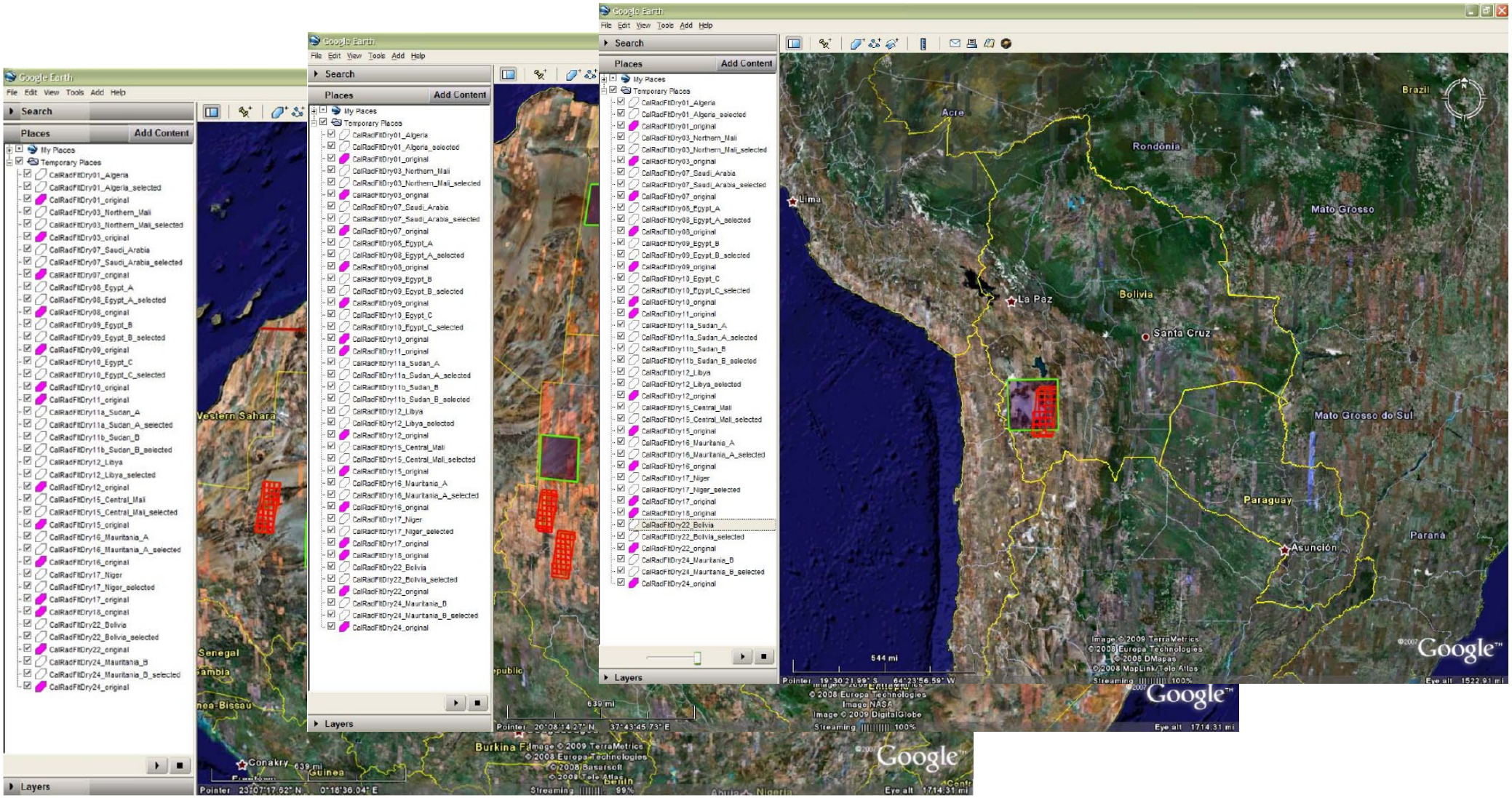
Phase II: Relative Temporal Radiometric Calibration



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Phase II: Relative Temporal Radiometric Calibration

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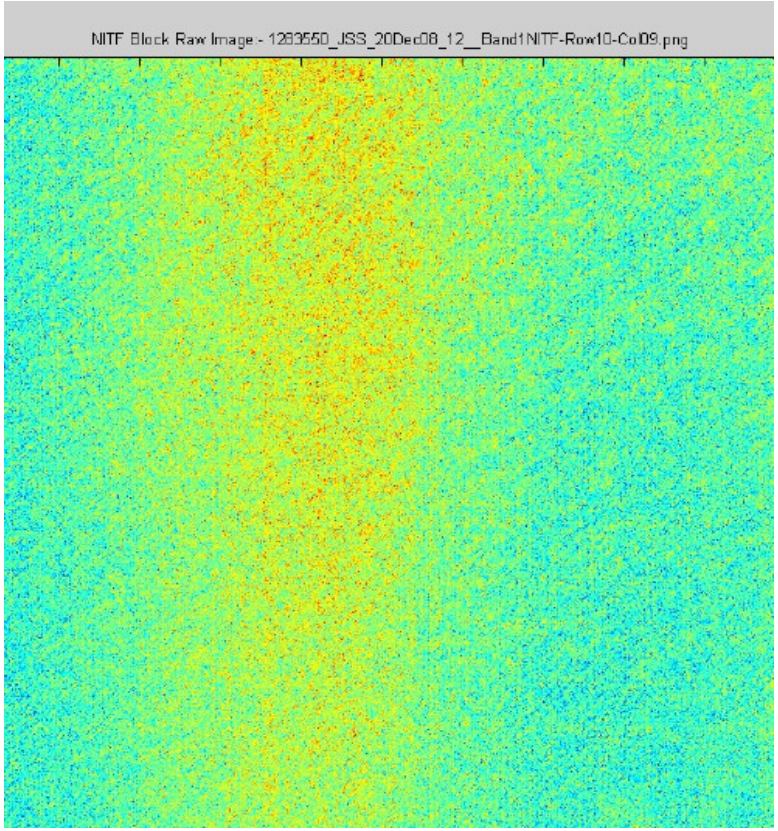
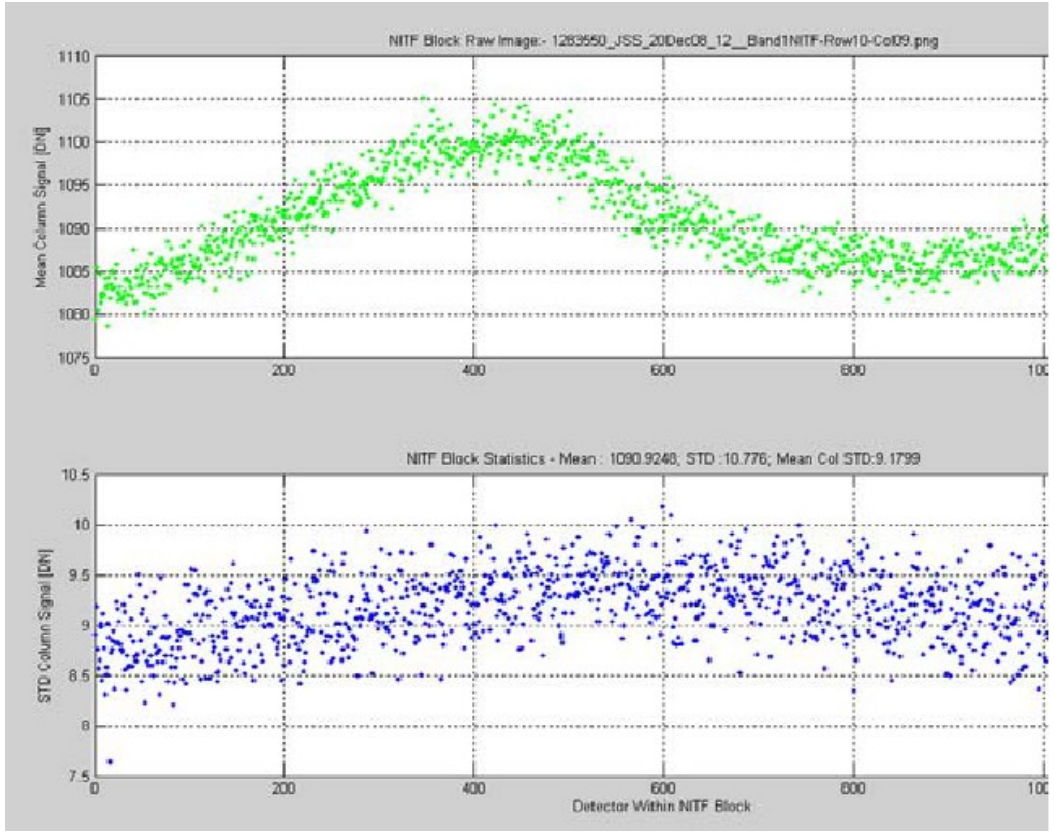
Estimate of Initial Relative Radiometric Accuracy at MPAR (Mission Preliminary Acceptance Review) End of January 2009 done by MDA

	RE1	RE2	RE3	RE4	RE5
Blue	-15.7%	2.00%	1.02%	-3.41%	1.46%
Green	-6.56%	1.33%	1.04%	-3.42%	1.10%
Red	-0.22%	-4.43%	2.09%	-0.46%	-2.68%
Red Edge	-0.86%	-1.91%	1.99%	-1.95%	-2.00%
NIR	0.44%	-1.47%	1.15%	-1.24%	-10.29%

Phase II: Post Launch Noise Estimation



Homogeneous snow field for Noise estimation – Due to structure not perfect for this task



Line Statistics for Noise Estimation

Phase II: Post Launch Noise Estimation Results

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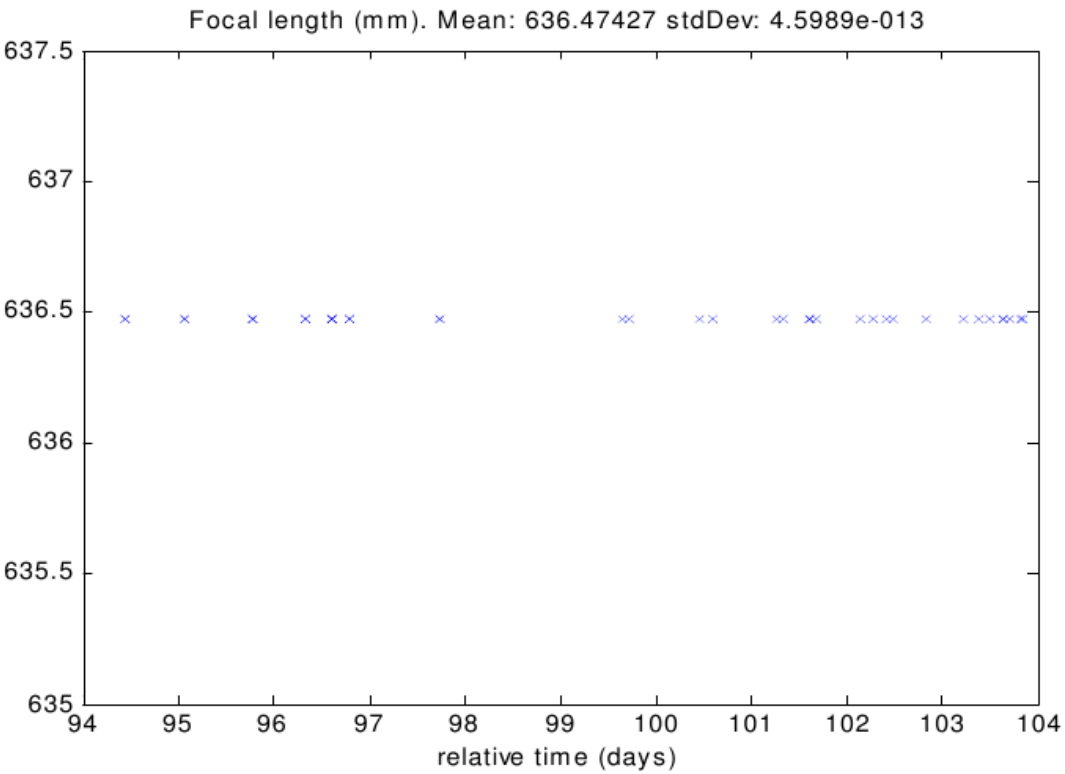
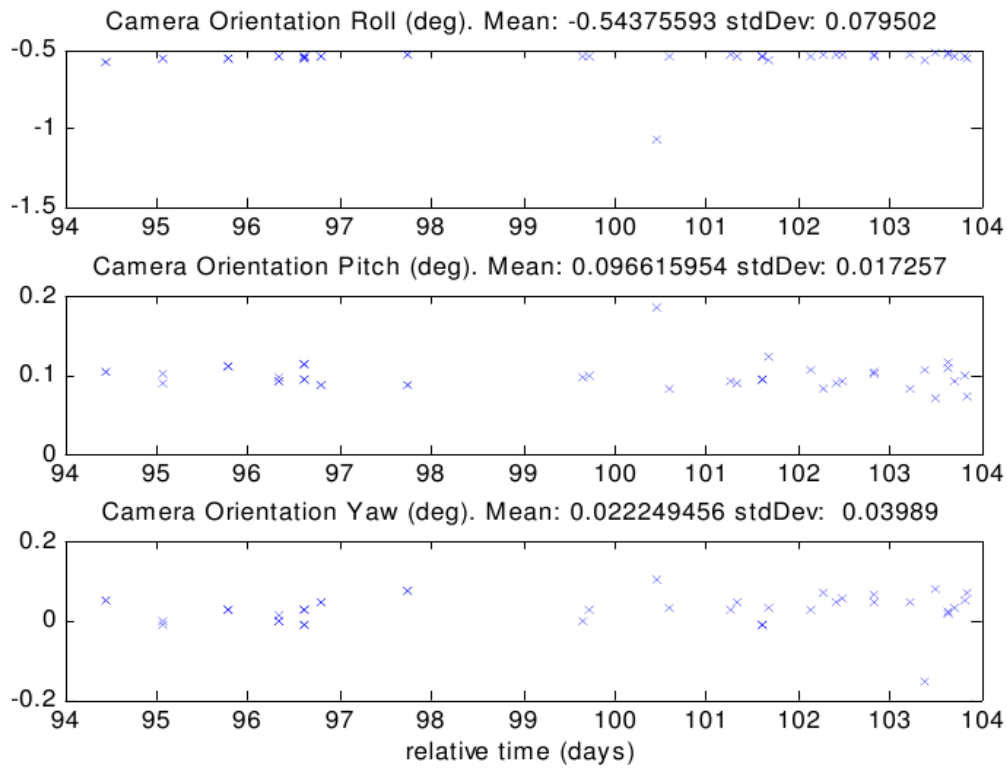
RE1			Radiance	NER meas.	NER spec.
	Band1 - Blue	Mean Values	97.6	1.38	2.04
	Band2 - Green	Mean Values	121.3	1.61	1.78
	Band3 - Red	Mean Values	151.1	2.03	2.13
	Band4 - RedEdge	Mean Values	130.4	1.84	1.97
	Band5- NIR	Mean Values	116.2	1.32	0.88
RE2					
	Band1 - Blue	Mean Values	82.7	1.41	1.93
	Band2 - Green	Mean Values	91.20	0.94	1.45
	Band3 - Red	Mean Values	97.30	1.22	1.54
	Band4 - RedEdge	Mean Values	87.60	1.09	1.49
	Band5- NIR	Mean Values	75.15	0.85	0.65
RE3					
	Band1 - Blue	Mean Values	99.8	1.32	2.06
	Band2 - Green	Mean Values	138.5	1.20	1.97
	Band3 - Red	Mean Values	186.2	1.27	2.53
	Band4 - RedEdge	Mean Values	170.2	1.25	2.40
	Band5- NIR	Mean Values	151.5	0.93	1.08
RE4					
	Band1 - Blue	Mean Values	97.4	0.92	2.04
	Band2 - Green	Mean Values	130.4	0.98	1.88
	Band3 - Red	Mean Values	168.5	0.99	2.33
	Band4 - RedEdge	Mean Values	152.1	1.04	2.20
	Band5- NIR	Mean Values	142.5	0.79	1.03
RE5					
	Band1 - Blue	Mean Values	108.1	0.90	2.13
	Band2 - Green	Mean Values	146.3	0.77	2.06
	Band3 - Red	Mean Values	180.3	0.99	2.46
	Band4 - RedEdge	Mean Values	167.8	0.85	2.38
	Band5- NIR	Mean Values	146.4	0.79	1.06

Geometric Calibration

Two Step Approach

1. Camera Alignment and Scale Calibration
2. Optical/thermal Distortion Calibration





Example of Focal Length and Camera Orientation Results for RE-3

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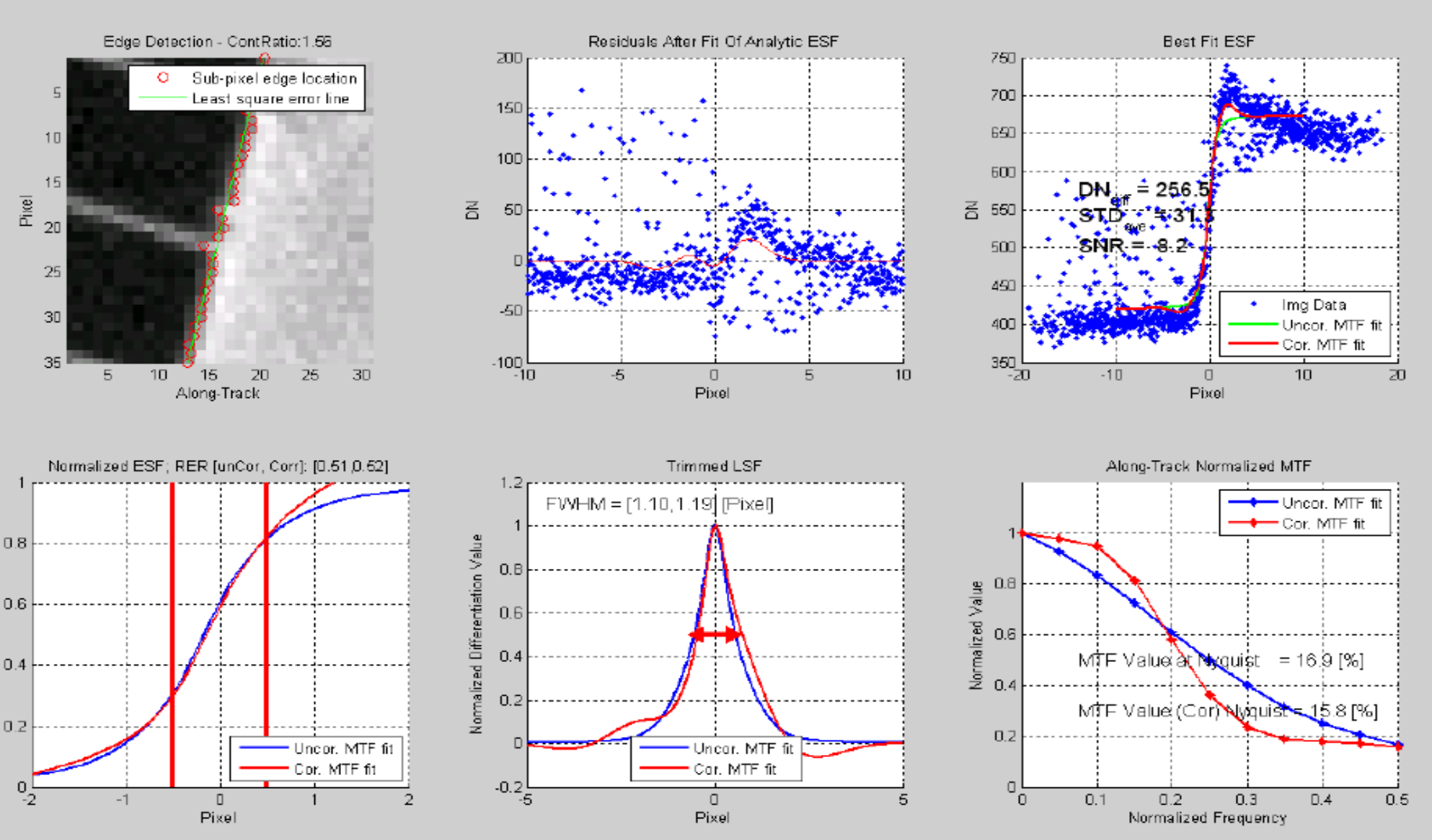
MTF Calculation Based on the Edge Response Function



MTF Results

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SC	Band	Image ID	ChipID	MTF Along-Track	MTF Across-Track
RE1					
	Band1 - Blue		Mean Values	17.9	26.5
	Band2 - Green		Mean Values	14.2	20.9
	Band3 - Red		Mean Values	17.6	18.9
	Band4 - RedEdge		Mean Values	17.3	17.9
	Band5- NIR		Mean Values	14.7	13.8
RE2					
	Band1 - Blue		Mean Values	28.5	14.8
	Band2 - Green		Mean Values	12.9	15.8
	Band3 - Red		Mean Values	10.0	21.2
	Band4 - RedEdge		Mean Values	9.1	14.7
	Band5- NIR		Mean Values	12.7	13.0
RE3					
	Band1 - Blue		Mean Values	10.3	12.5
	Band2 - Green		Mean Values	14.3	12.5
	Band3 - Red		Mean Values	15.2	9.3
	Band4 - RedEdge		Mean Values	18.1	8.2
	Band5- NIR		Mean Values	16.2	12.1
RE4					
	Band1 - Blue		Mean Values	15.2	16.9
	Band2 - Green		Mean Values	14.3	14.2
	Band3 - Red		Mean Values	11.9	12.4
	Band4 - RedEdge		Mean Values	9.1	14.2
	Band5- NIR		Mean Values	12.6	16.5
RE5					
	Band1 - Blue		Mean Values	19.8	28.7
	Band2 - Green		Mean Values	19.9	29.8
	Band3 - Red		Mean Values	28.4	20.1
	Band4 - RedEdge		Mean Values	29.5	19.0
	Band5- NIR		Mean Values	16.2	14.5

Outlook: Absolute Radiometric Calibration and Cross-Calibration

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Principles

- Vicarious calibration approach based on parallel ground truth measurements over a very few (1-3) selected radiometric calibration test sites
- Ground truth data acquisition requires absolute calibrated ground spectrometers, homogeneous flat terrain, stable weather conditions, and experienced ground staff
- RapidEye has currently contacted a number of ground calibration groups to establish a cooperation for absolute radiometric vicarious calibration
- It is intended to perform a first calibration campaign in spring 2009
- Potentially include a Lunar Radiometric Calibration Approach for the next phase
- Cross-Calibration activities with different other satellite systems