RapidEye Vicarious Calibration and Radiometric Performance Assessment_2009

Joint Civil Commercial Imagery Evaluation Workshop
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Contents

- RapidEye Mission and System Overview
- RapidEye Radiometric Calibration Strategy and Approach
- Absolute Vicarious Calibration Campaign_2009
  - Campaign Goals and Method
  - Ground and Sensor Measurements
- Comparison of Sensor Measured and TOA Predicted Radiance
- Conclusions and Future Work

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RapidEye Mission, Products and Services

- Provide reliable, current, cost-effective and high quality geo-spatial data and information
- Image Data and Services
  - Standard Image Products
    - Level 1B-Basic Product - Radiometric and sensor corrections, On-board attitude and ephemeris applied / band alignment
    - Level 3A – Ortho Product - Radiometric, sensor and geometric corrections, DTED Level 1 SRTM DEM or better
- Customer Services – Algorithms and specific products for fields such as
  - Precision Agriculture, Agro-Insurance, Forestry, Security & Emergency Services, Infrastructure Monitoring, Environment

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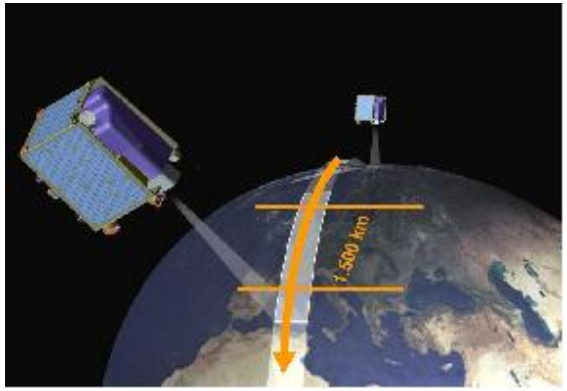
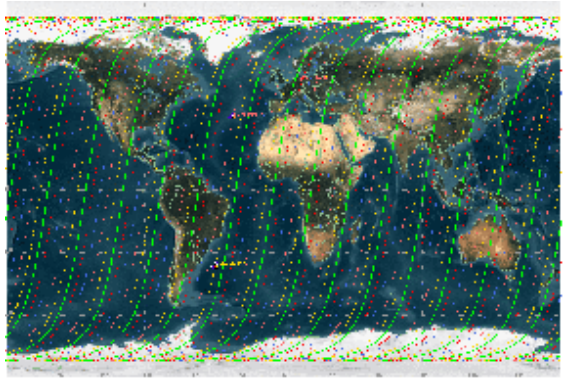
RapidEye System Parameters





Launch Date	29 August 2008
Operational Date	01 February 2009
Sun synchronous orbit	11:00 AM eq. crossing (descending node)
Altitude	630 km
GSD	6.5 m at nadir
Swath width	77 km
Image take length	~1,500 km(max)
Standard ortho-image tile	25 x 25 km^2
No. of orbits per day/SC	14.8
Image capture capacity	~4.4 Mkm^2/day(max)

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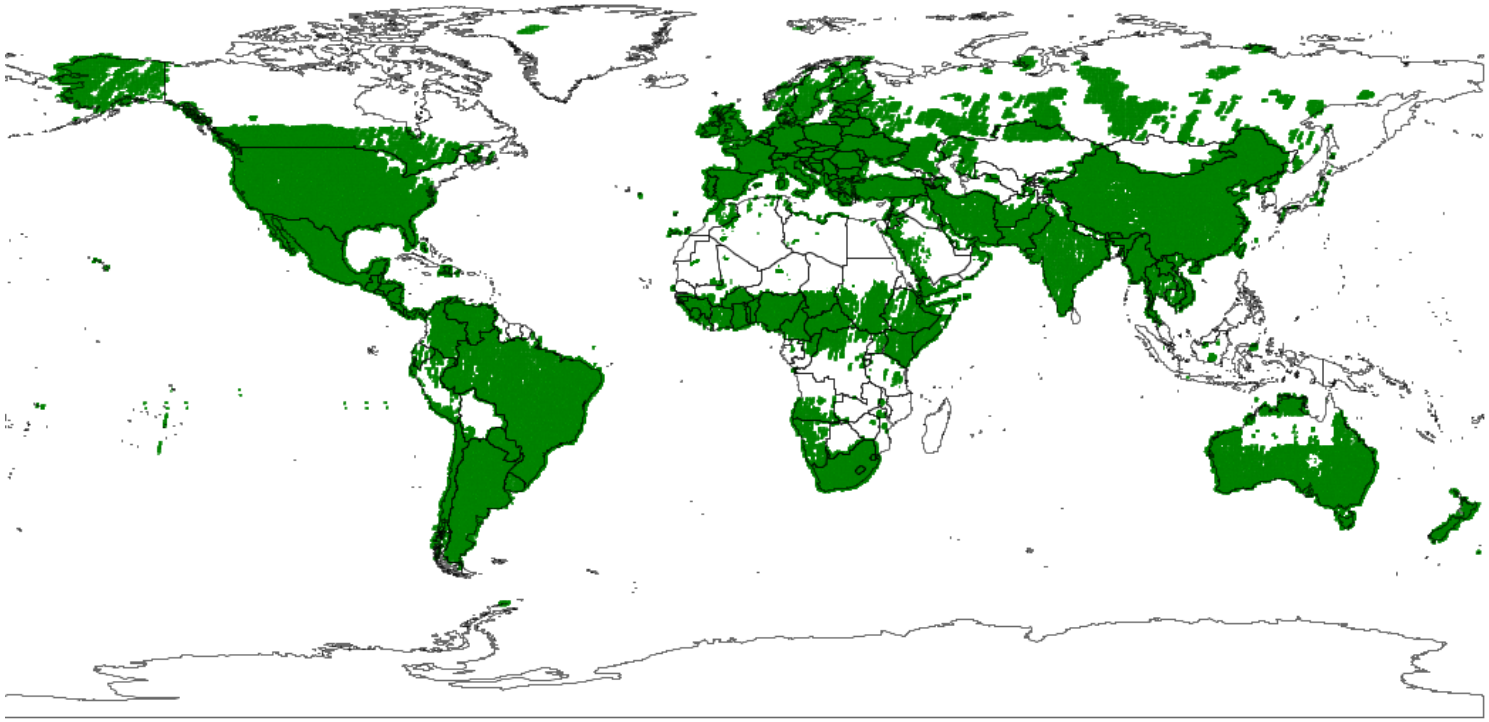
Coverage Since Start of Operations

RapidEye

Image Take Tiles – UDP < 20%



Total Coverage to date 400.109.722 sqkm (10_March_2010)

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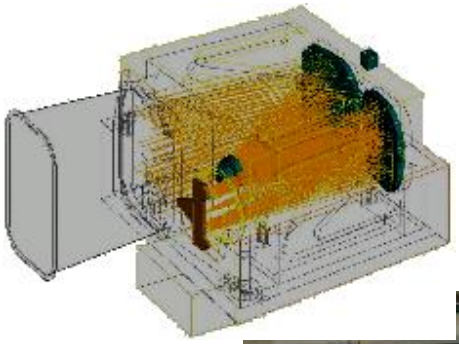
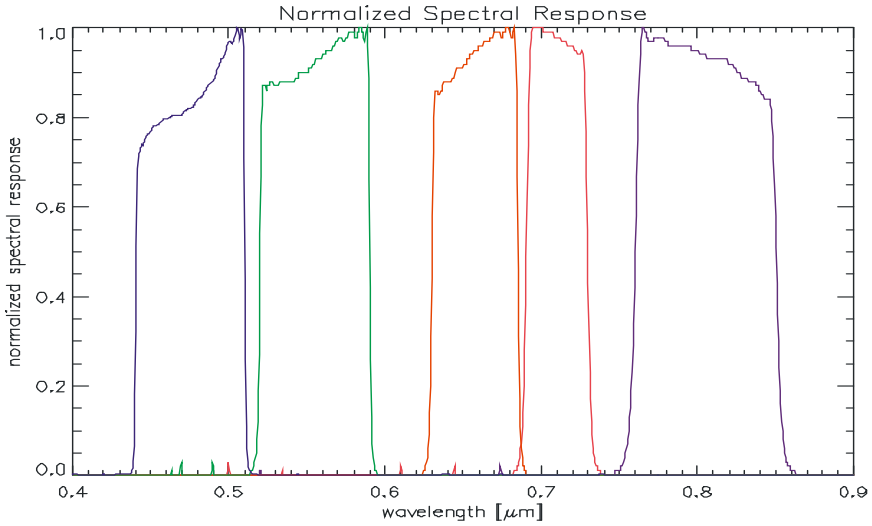
Multi-Spectral Imager (MSI) Parameters





Design	TMA (Al mirror)
Eff. focal length	633 mm
Entrance Pupil Dia.	147 mm
f-number	4.3
CCD	Atmel
(AT71544)	
Pixel Size	6.5 um
Pixels per line	12,000
Radiometric resolution	12 bit (prgm)
5 multi-spectral channels	
> Blue	440 - 510 nm
> Green	520 - 590 nm
> Red	630 - 685 nm
> Red_Edge	690 - 730 nm
> NIR	760 - 850 nm

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Radiometric Calibration Approach

- Relative Radiometric Accuracy between Spacecraft Cameras [RE_SY_0250]
  - “The radiometric relative accuracy between each of the cameras on the different spacecraft in the space segment shall be within 5%”.
- The primary objective is to make sure that the processing of the end product is not dependent on which specific spacecraft took the image.
- An absolute radiometric accuracy requirement was not specified for the RapidEye mission.
- However, there is a need to know the radiometric response of any MSI to a known radiance input.

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Radiometric Calibration Components

- **Spatial Calibration/Correction** – occurs on-board and on-ground- measure the pixel-to-pixel response in each CCD linear array and remove residual errors from pre-launch calibration and compensate for pixel-to-pixel response variations (striping, banding)

- **Temporal Calibration/Correction** – occurs on-ground - measure the in-band response across all five MSI in the constellation and corrects for MSI to MSI variations and thus keep the detector response stable over the constellation and over the mission life

- **Absolute Calibration** – reflectance based vicarious calibration campaign to provide known radiance input and produce individual sensor responsivity data

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Vicarious Calibration Campaign 2009

GOALS

- Detect changes to the pre-launch laboratory calibration
- Refine individual MSI radiometric performance and enhance capability to deliver accurate and reliable image products
- Establish an updated radiometric baseline for the constellation

METHOD

- Conduct a reflectance-based absolute vicarious calibration campaign for two of the five RapidEye spacecraft:
  - RE3 and RE4 and opportunistic overpasses of other spacecraft
- Compare MSI measured at aperture radiance to TOA predicted radiance based on ground measurements conducted by RSG
- Update gain and offset tables with absolute calibration parameters

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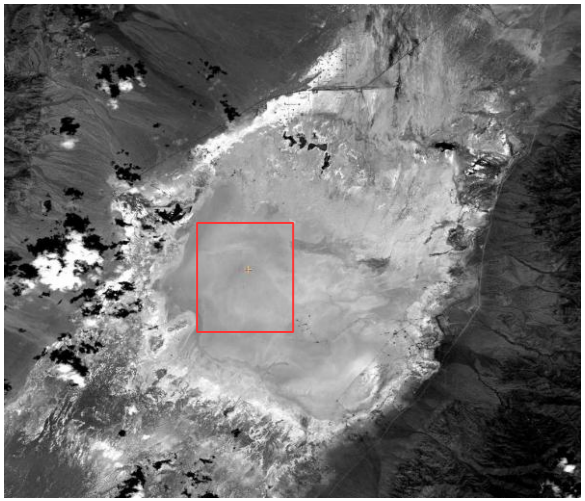
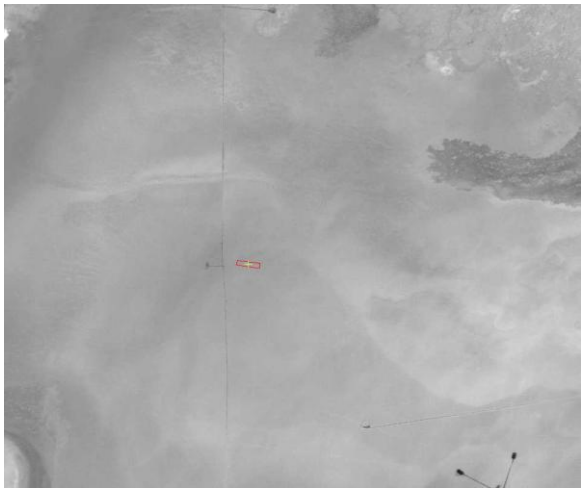
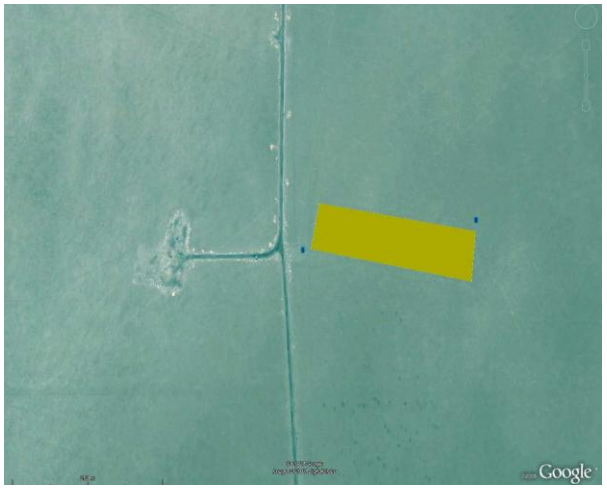
Calibration Sites

Rail Road Valley Playa, Nevada Lat 38.50473 / Lat -115.68696

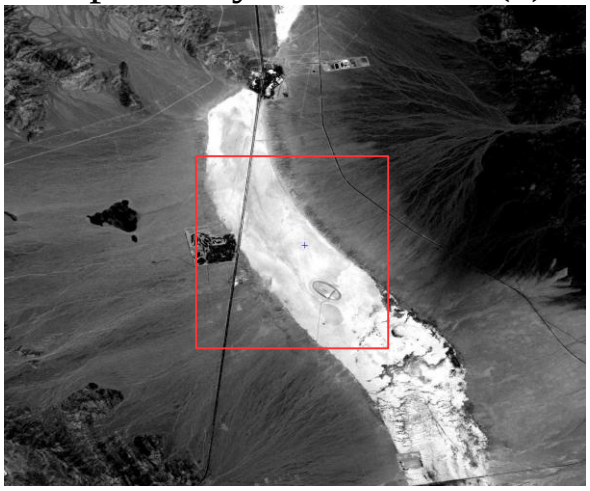


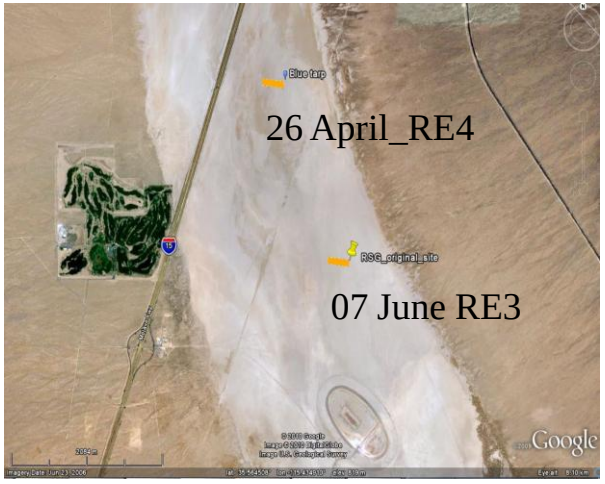




RE4_20 May_2009_Red_Edge

Ivanpah Playa California (1) Lat 35.55021/ Lon -115.38751 (2) Lat 35.56930/ Lon -115.39751





RE3_07 June_2009_Red_Edge

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Collection Parameter Summary

RapidEye

Collection DATE	Site (1,2)	S/C	Image Take Acquisition Start	Image Take Acquisition Stop	Tile Center Acquisition Time	Solar Zenith Angle	View Zenith Angle	Relative Azimuth (solar to view)	S/C Roll Angle	Solar Elev Angle
19.May.2009	RRV	RE3	2009-05-19 19:13:09.0	2009-05-19 19:13:48.0	2009-05-19 19:13:34.0	19.400	7.387	42.800	-6.600	70.784
07.Jun.2009	IVP(1)	RE3	2009-06-07 19:12:52.0	2009-06-07 19:13:53.0	2009-06-07 19:13:17.0	14.000	1.280	100.300	0.000	76.256
06.Sept.2009	RRV	RE3	2009-09-06 19:22:10.0	2009-09-06 19:22:31.0	2009-09-06 19:22:17.0	32.600	5.023	234.400	3.300	57.590
25.Sept.2009	RRV	RE3	2009-09-25 19:20:50.0	2009-09-25 19:21:12.0	2009-09-25 19:20:59.0	39.700	2.561	315.900	0.000	50.449
26.Apr.2009	IVP(2)	RE4	2009-04-26 19:10:11.0	2009-04-26 19:10:46.0	2009-04-26 19:10:42.0	22.700	3.743	15.000	0.000	67.565
20.May.2009	RRV	RE4	2009-05-20 19:13:16.0	2009-05-20 19:13:51.0	2009-05-20 19:13:46.0	19.200	5.910	76.600	-3.300	70.993
26.Jul.2009	RRV	RE4	2009-07-26 19:19:57.0	2009-07-26 19:20:57.0	2009-07-26 19:20:18.0	20.200	4.432	215.100	3.300	69.945
07.Sept.2009	RRV	RE4	2009-09-07 19:22:34.0	2009-09-07 19:23:21.0	2009-09-07 19:22:42.0	32.900	6.993	262.900	3.300	57.240
15.Oct.2009	RRV	RE4	2009-10-15 19:19:55.0	2009-10-15 19:20:51.0	2009-10-15 19:20:10.0	47.300	1.281	5.400	0.000	42.825
14 Jun.2009	*IVP(1)*	*RE5*	*2009-06-14 19:19:18.0*	*2009-06-14 19:20:10.0*		-	-	-	*10.000*	
02.May.2009	*IVP(2)*	*RE5*	*2009-05-02 19:16:20.0*	*2009-05-02 19:16:55.0*		-	-	-	*6.600*	

Vicarious Calibration Target Site (NE corner)

Rail Road Valley Playa,	Nevada, USA	Lat 38.50473 / Lat -115.68696
Ivanpah Playa (1)	California,USA	Lat 35.55021/ Lon -115.38751
Ivanpah Playa (2)	California, USA	Lat 35.56930/ Lon -115.39751

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Collection Summary Opportunistic Overpasses

- Minimal changes in surface reflectance and atmospheric characteristics at RRV and Ivanpah
- Searched for other RapidEye spacecraft images from the target areas around the scheduled ground measurement dates

Date	Spacecraft	Conditions	Days From Ground Collection
02 May	**RE5**	**Good**	**+5**
14 June	**RE5**	**Good**	**+7**
15 June	RE1	Cloud	+8
25 July	RE3	Cloud	-1
14 October	RE3	Cloud	-1
22 October	RE1	Cloud	+7

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Ground Based Measurements

Prediction of at-sensor radiance - Remote Sensing Group, University of Arizona

Date (mm/dd/yyyy) -- 09/06/2009
Site -- Railroad Valley

Latitude (pos. north) -- 38.4970
Longitude (pos. W of Greenwich) -- 115.691
Time (UTC) -- 19:22:12

Ground height (km) -- 1.43500
Sensor height (km) -- 100.000
Surface pressure (mb) -- 857.200

Solar zenith angle (degrees) -- 32.6000
View zenith angle (degrees) -- 5.02330
Relative azimuth (Solar - view) -- 234.400

Aerosol Angstrom exponent -- 1.79
Ozone (DU) -- 278
Water Vapor (cm) -- 1.37
Carbon dioxide (ppmv) -- 365

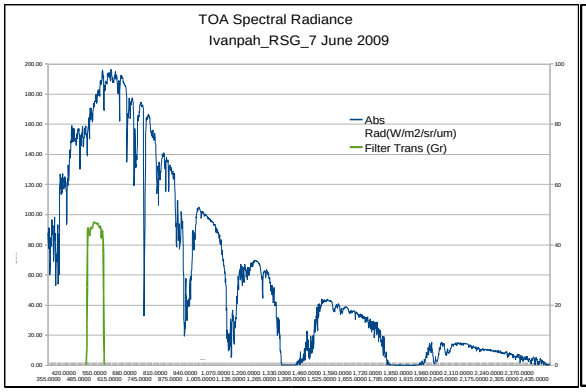
Earth-Sun Distance (AU) -- 1.00775

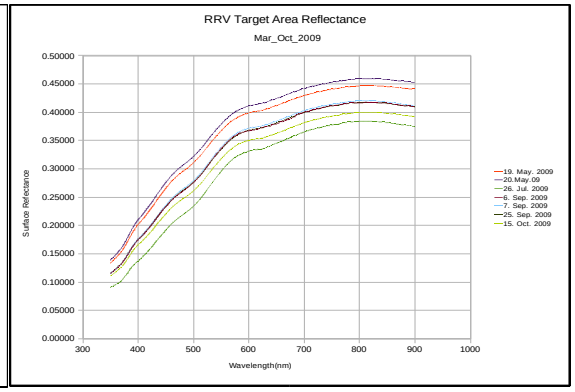
Gas transmittance is product of : Water vapor (gas and continuum)
Carbon dioxide
Oxygen
Nitrogen (N2)
HNO3
Trace gases

Headings are: Wavelength (nm)
Aerosol, molecular, and ozone optical depths,
Gas transmittance (species listed above),
Aerosol single-scattering albedo,
Measured surface reflectance,
Exoatmospheric solar irradiance,
- computed from Chance database, scaled by square of Earth-Sun distance
Relative radiance (reflectance of atmosphere containing no absorbing gases except ozone)
Reflected radiance (reflectance of atmosphere containing absorbing gases)
Absolute (top-of-atmosphere) radiance

TOA Radiance: In Band (W/m^2-sr-um) Univ of Ariz. RSG

Date	Blue	Green	Red	Red Edge	NIR
26. Apr. 2009	123.730	143.120	157.100	138.080	121.280
19. May. 2009	181.360	196.600	184.110	153.280	132.710
20. May. 2009	186.190	200.130	188.450	158.440	136.900
7. Jun. 2009	148.520	158.030	149.510	135.010	113.380
26. Jul. 2009	139.560	159.570	153.090	124.440	110.340
6. Sep. 2009	145.040	158.080	150.150	126.740	110.510
7. Sep. 2009	146.640	160.280	152.530	127.620	111.100
25. Sep. 2009	134.890	145.270	139.960	124.910	104.690
15. Oct. 2009	115.110	124.660	118.790	99.710	86.990





Wavel (nm)	---- Aerosol	Optical Molec.	Depths Ozone	Gas Trans.	Aerosol SSA	Surface Refl.	Solar Irrad. (W/m2/um)	Relative Radiance	Refl. Radiance	Absolute Radiance (W/m2/sr/um)	Radiance Uncertainty (units)	(%)
350.00000	0.38160	0.53430	0.00040	0.99490	0.96800	0.11430	95.70000	0.07410	0.07370	70.53000	0.00000	0.00000
351.00000	0.38050	0.52790	0.00080	0.99470	0.96800	0.11510	105.00000	0.07340	0.07300	76.61000	0.00000	0.00000
352.00000	0.37890	0.52160	0.00100	0.99480	0.96800	0.11580	92.50000	0.07330	0.07290	67.45000	0.00000	0.00000
353.00000	0.37730	0.51540	0.00050	0.99480	0.96790	0.11660	96.80000	0.07310	0.07270	70.35000	0.00000	0.00000
354.00000	0.37560	0.50940	0.00020	0.99410	0.96790	0.11740	110.00000	0.07290	0.07240	79.67000	0.00000	0.00000

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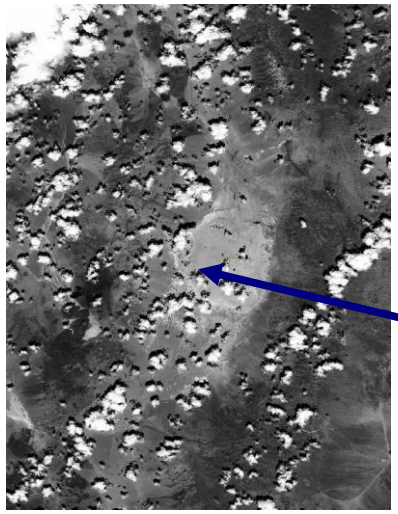
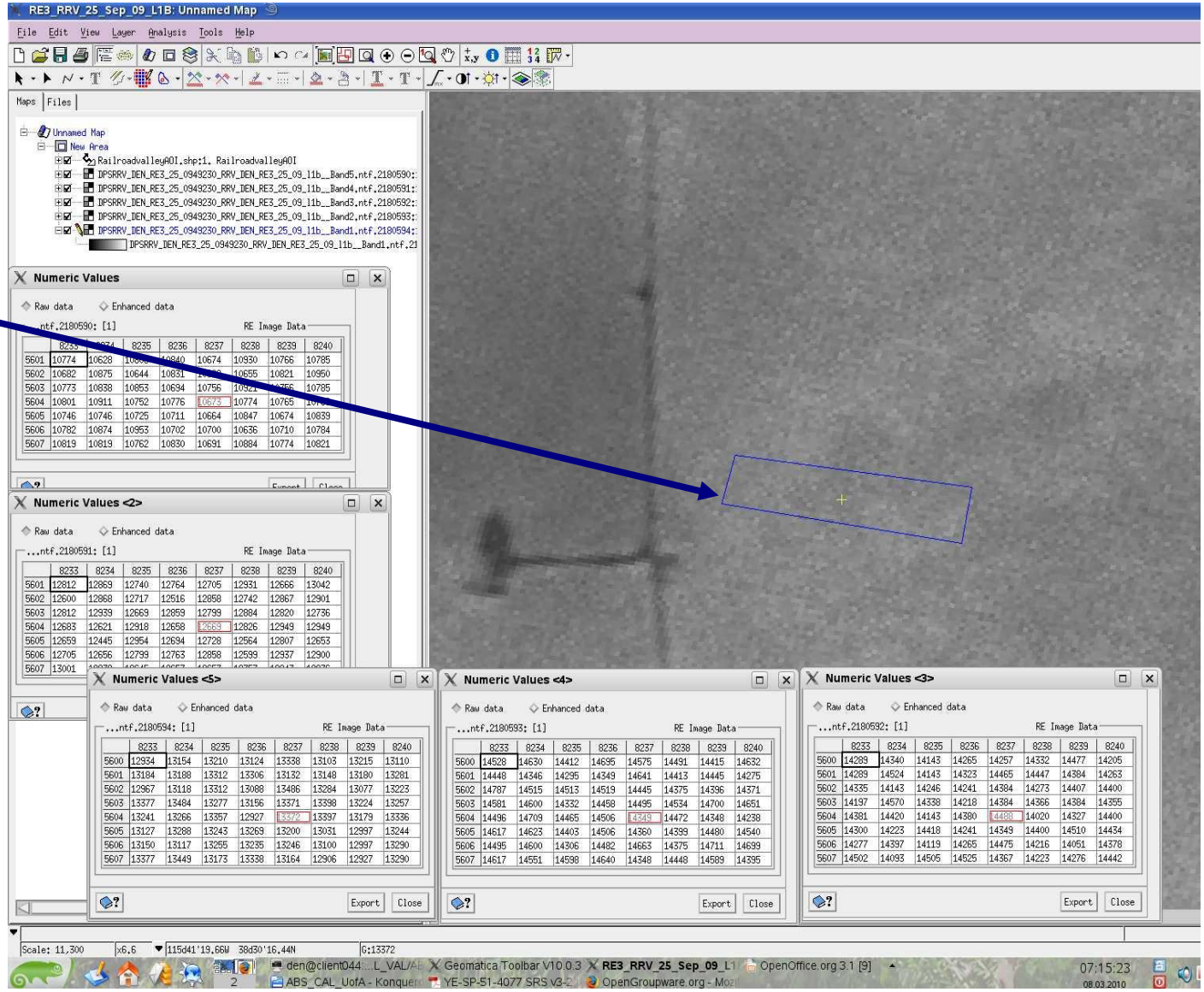
MSI Measured Radiance Extraction





- Extract pixel data using commercial image processing tools
  - PCI Geomatica
  - IDL
- Process to compute measured at aperture radiance

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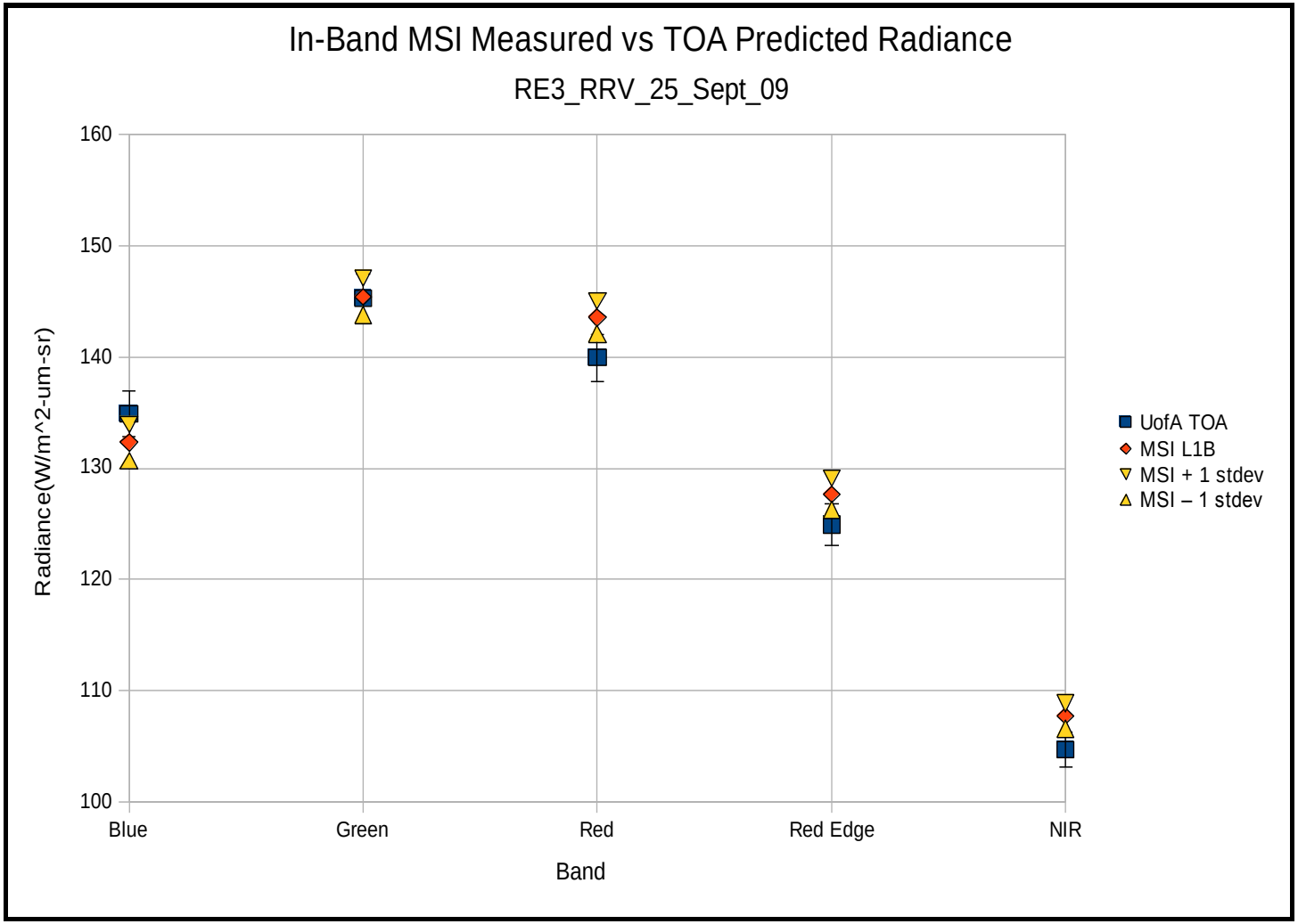
Calibration Results - RapidEye 3



MSI Measured Radiance computed from L1B Products. Uncertainty of in-situ reflectance based estimate for TOA Radiance for all bands is reported as 3%

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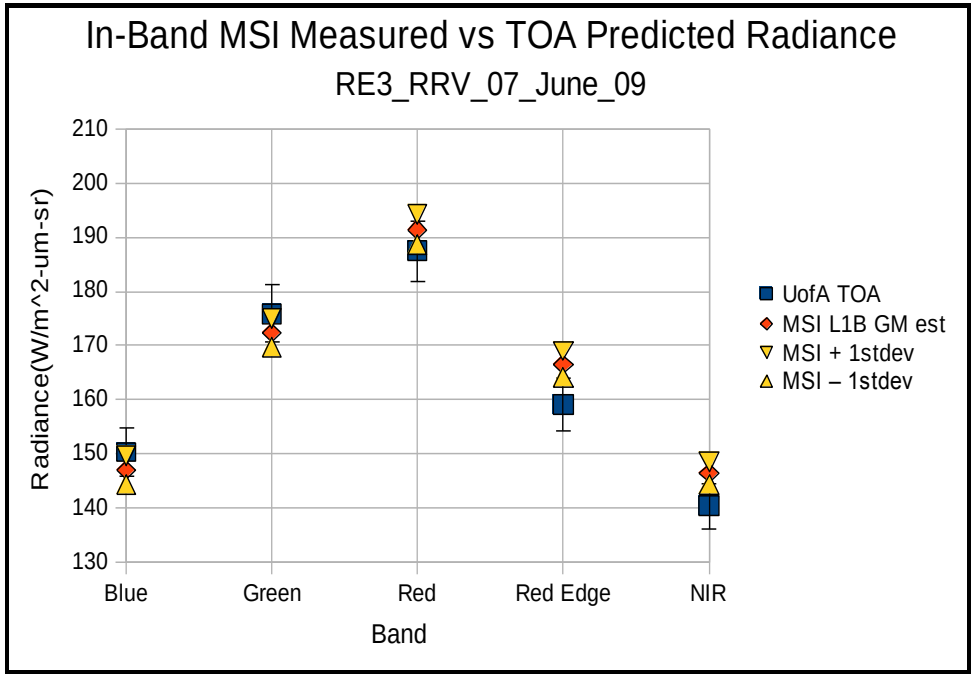
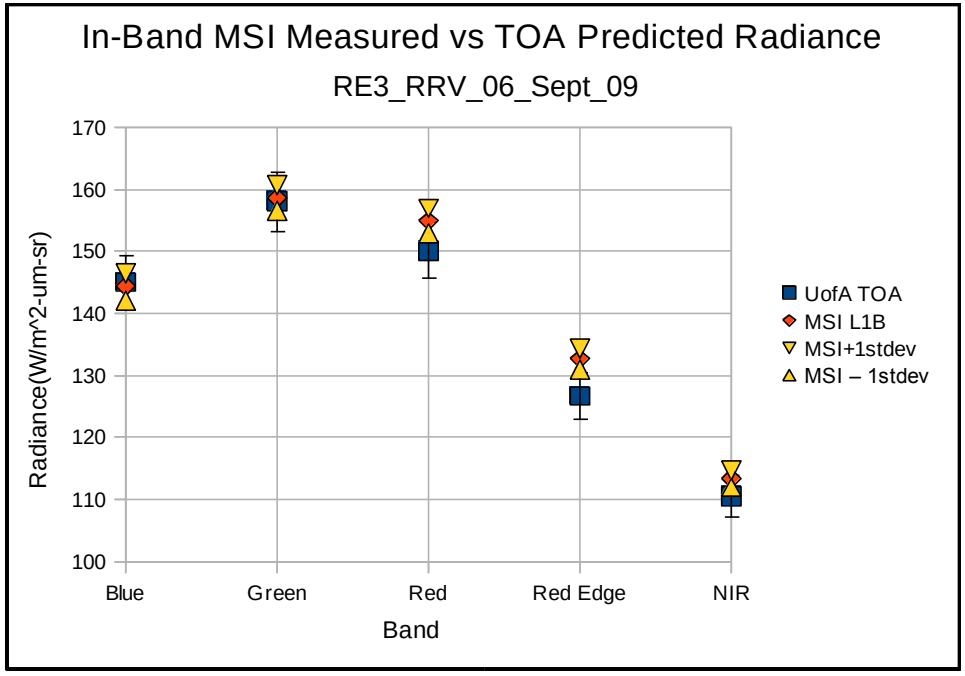
Calibration Results - RapidEye 3





Date\Band	Blue	Green	Red	Red_Edge	NIR
19 May	-	-	-	-	-
07 June	1.70	2.90	4.19	4.11	4.79
06 Sept	-0.48	0.38	3.18	4.68	2.59
25 Sept	-1.92	0.11	2.57	2.21	2.91
15 Feb	-	-	-	-	-
RMS Average	1.5	1.7	3.4	3.9	3.6

RE3 *% Error = (MSI Measured – TOA Estimate)/TOA Estimate*100*

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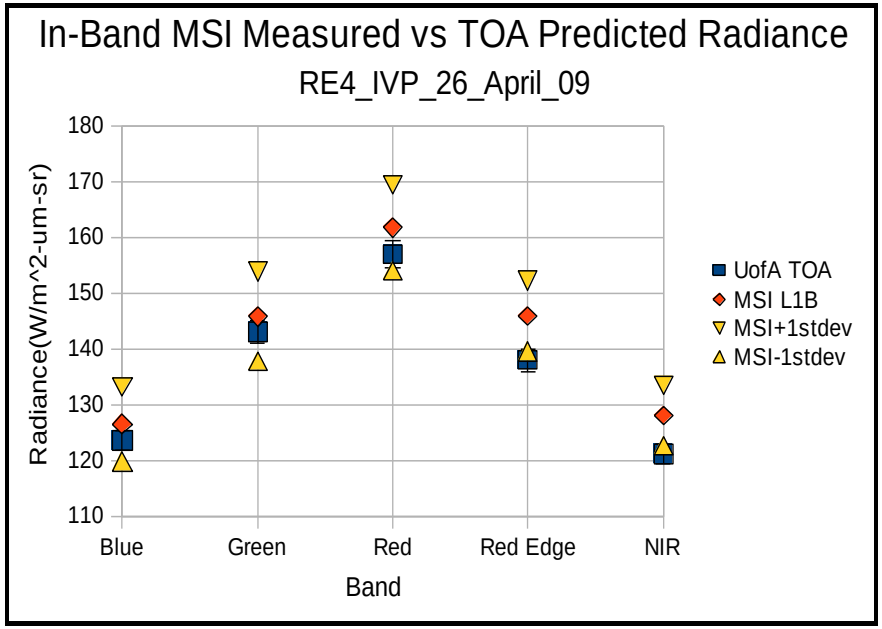
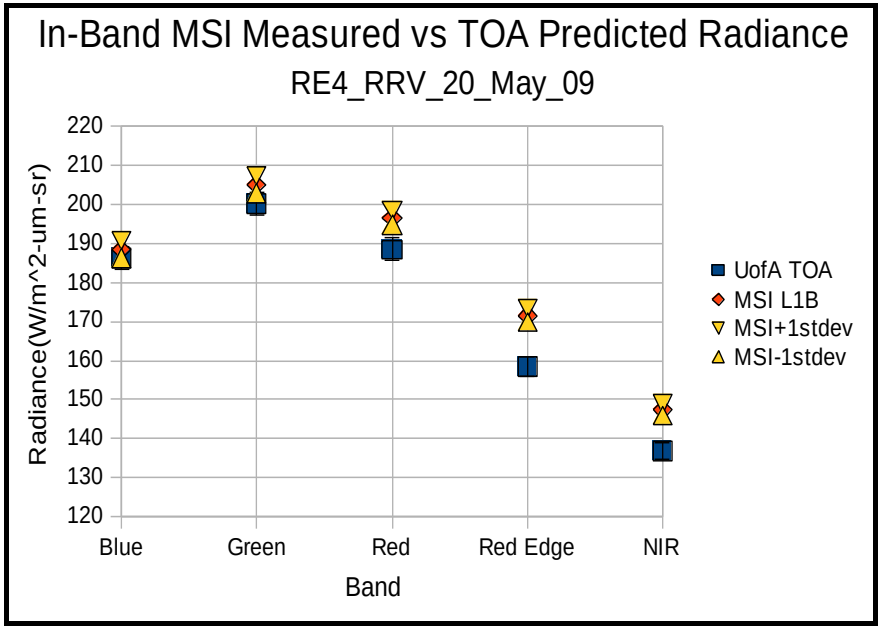
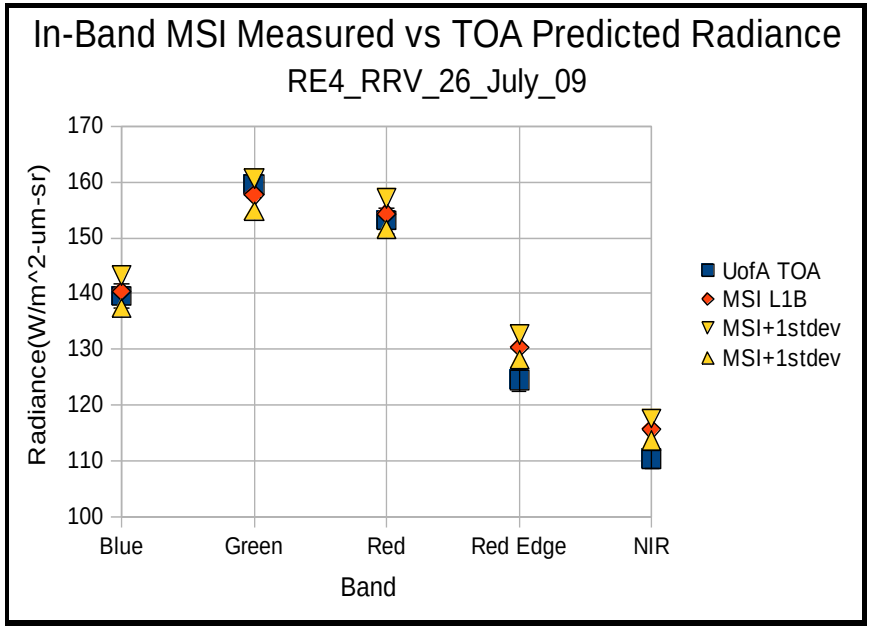
Calibration Results - RapidEye 4







Much larger standard deviation in MSI measured data in all bands on 26 April at IVP

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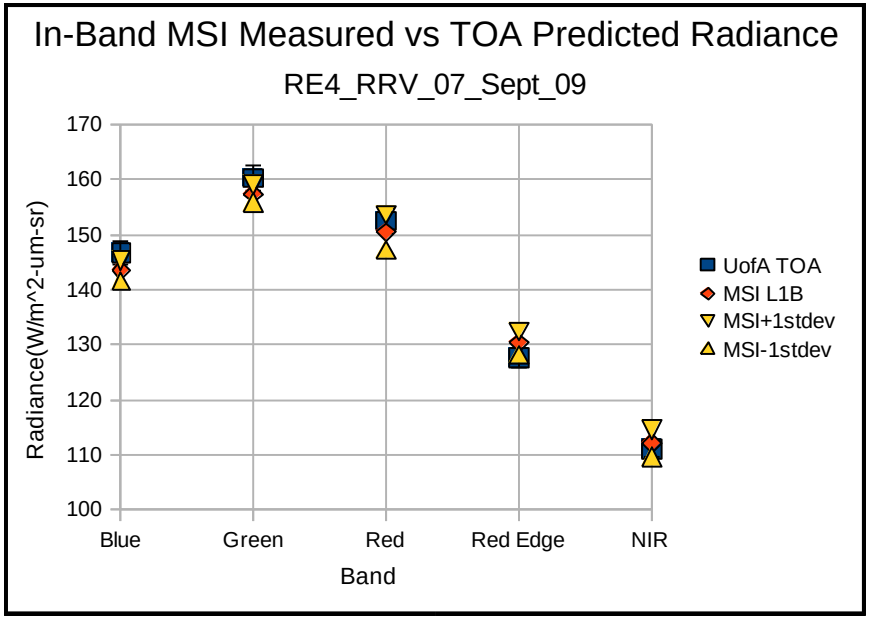
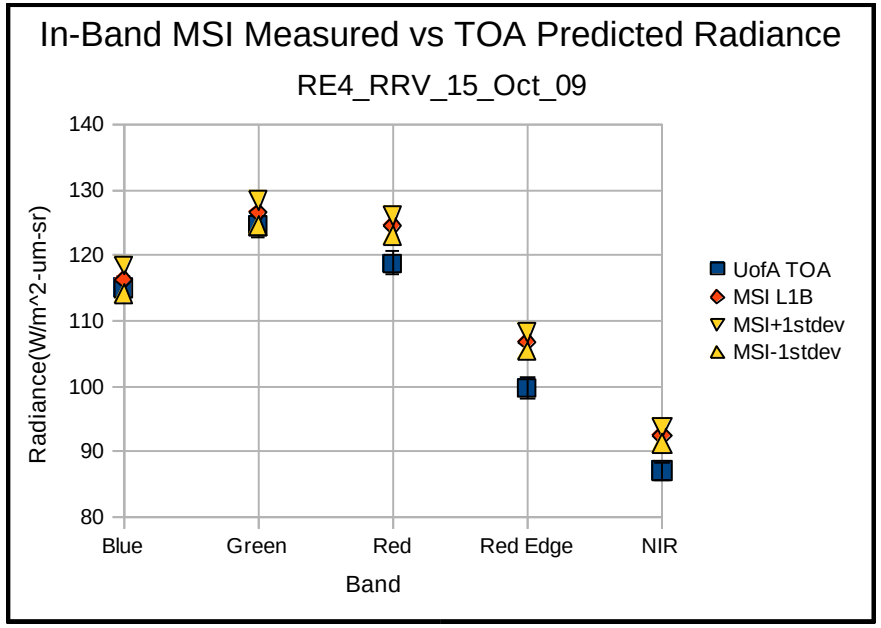
Calibration Results - RapidEye 4





Date-Site\Band	Blue	Green	Red	Red_Edge	NIR
26 April(IVP)	2.33	1.94	2.99	5.71	5.65
20 May(RRV)	1.21	2.43	4.30	8.26	7.63
26 July(RRV)	0.56	-1.22	0.79	4.76	4.75
07 Sept(RRV)	-2.18	-1.78	-1.39	2.10	1.93
15 Oct(RRV)	1.06	1.53	4.87	7.12	6.29
RMS Average	1.6	1.8	3.3	6.0	5.6

*RE4 % Error = (MSI Measured – TOA Estimate)/TOA Estimate*100*

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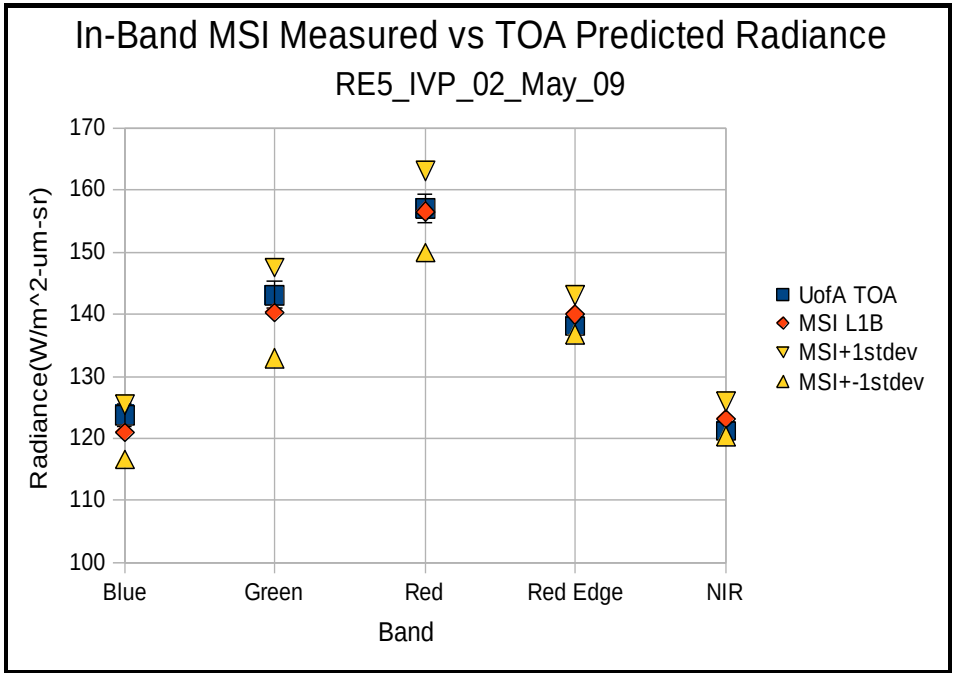
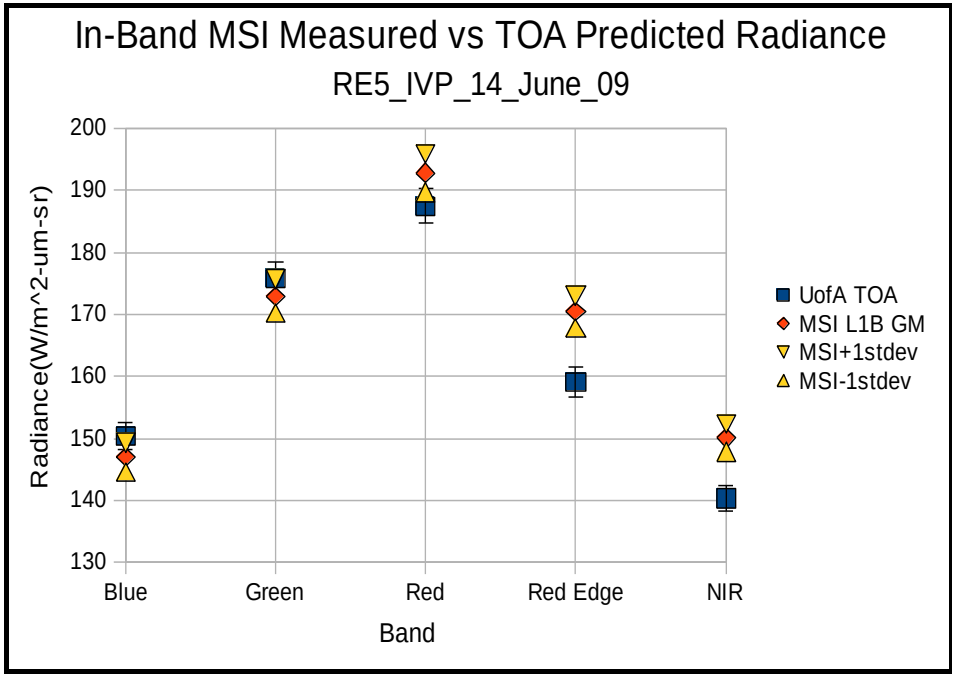
Calibration Results - RapidEye 5





Date-Site\Band	Blue	Green	Red	Red_Edge	NIR
02 May(IVP)	-2.17	-2.00	-0.35	1.36	2.69
14 June (IVP)	-2.27	-1.66	2.87	7.15	6.91
RMS Average	1.6	1.3	1.5	3.6	3.7

RE5 *% Error = (MSI Measured – TOA Estimate)/TOA Estimate*100*

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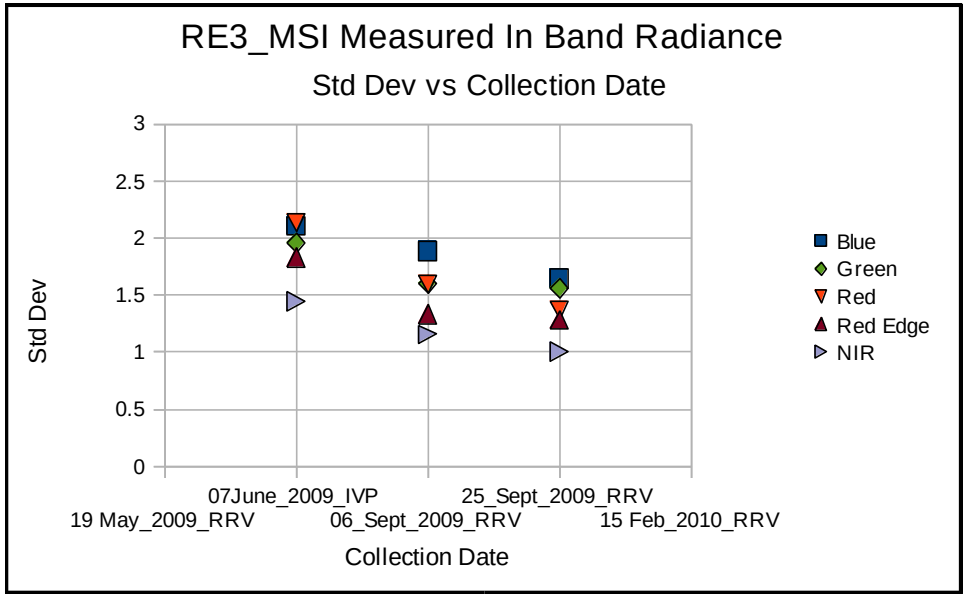
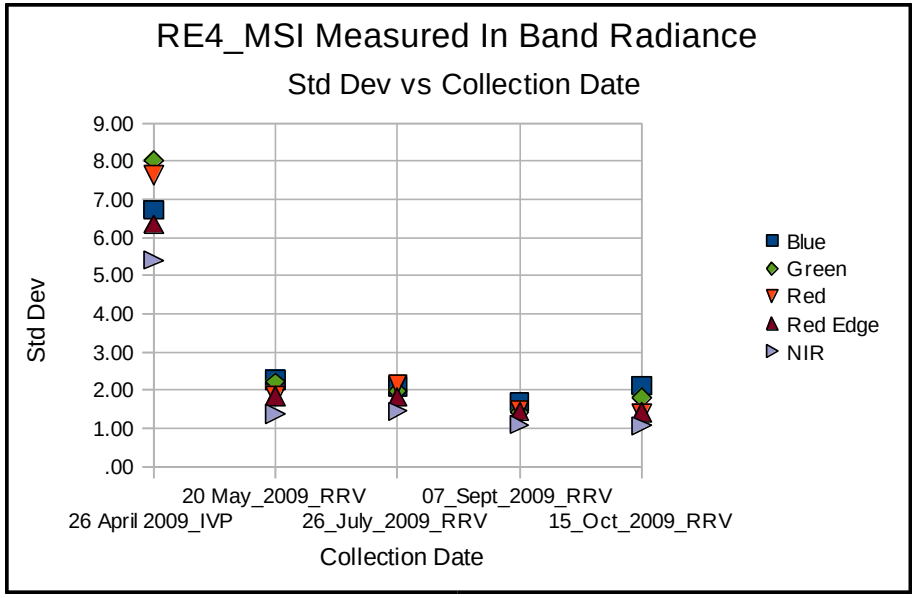
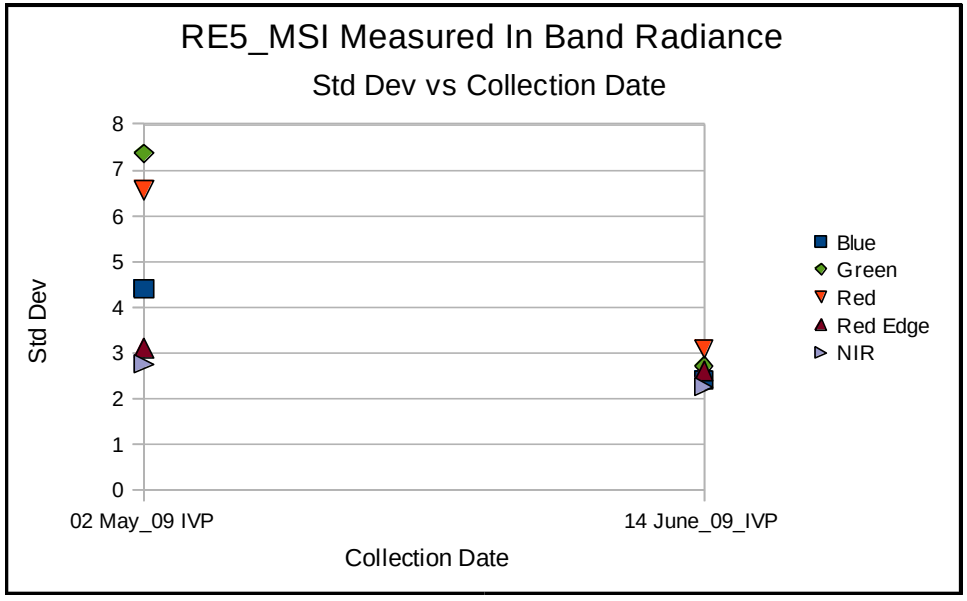
MSI Radiance - Standard Deviation







Uncertainty in MSI measured data is due to instrument and sampling error

The 26 April and 02 May IVP MSI data may be less reliable than that collected later in the year

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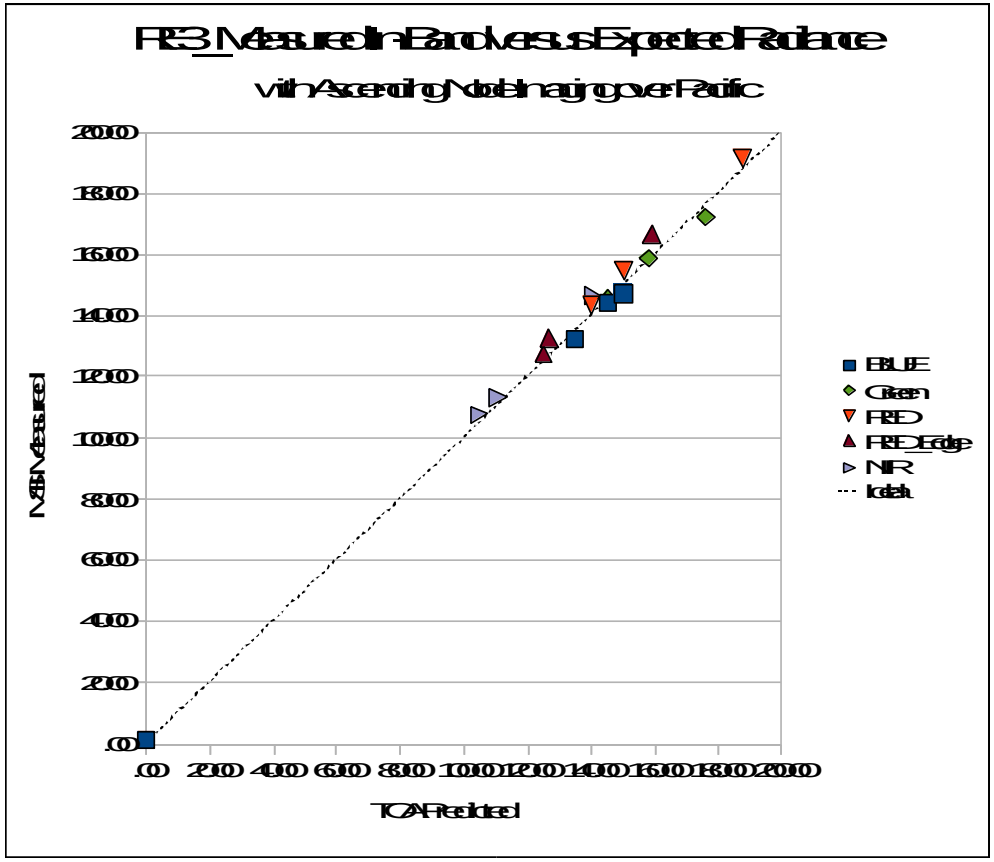
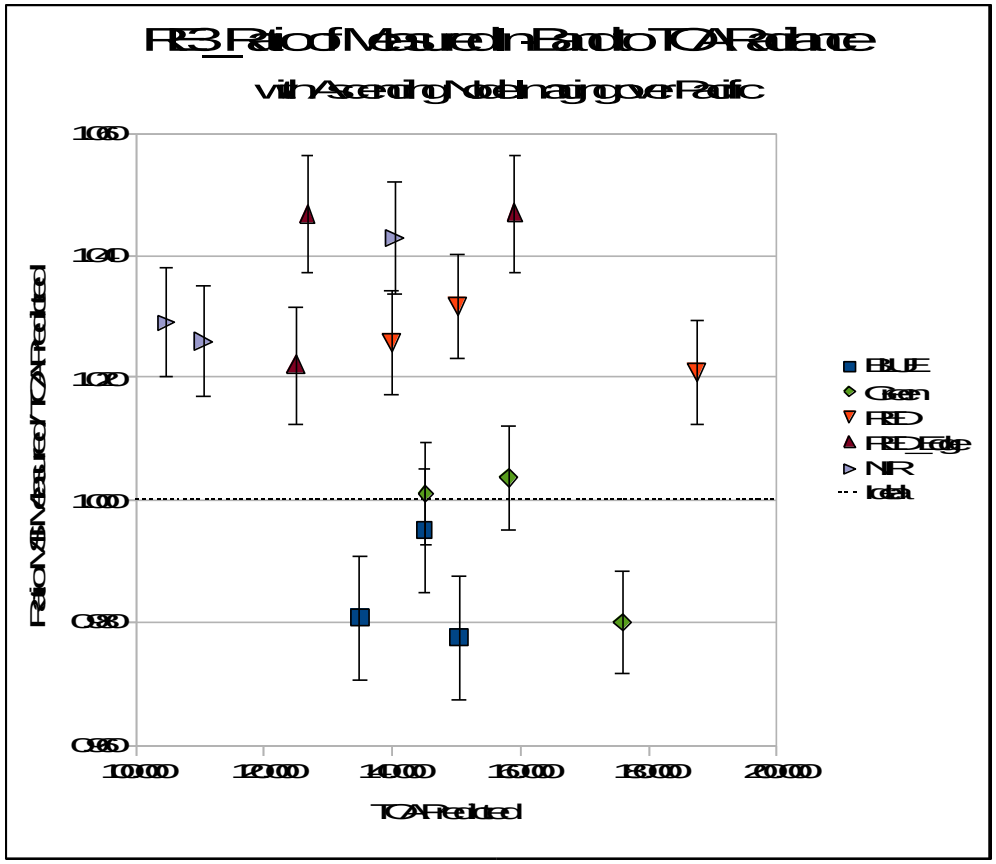
Measurement Analysis - RE3



MSI Measured compared to TOA predicted for all bands

Total uncertainty is the combination of uncertainty in the TOA prediction method, the uncertainty in the MSI instrument and limited number of pixels on target(sampling)



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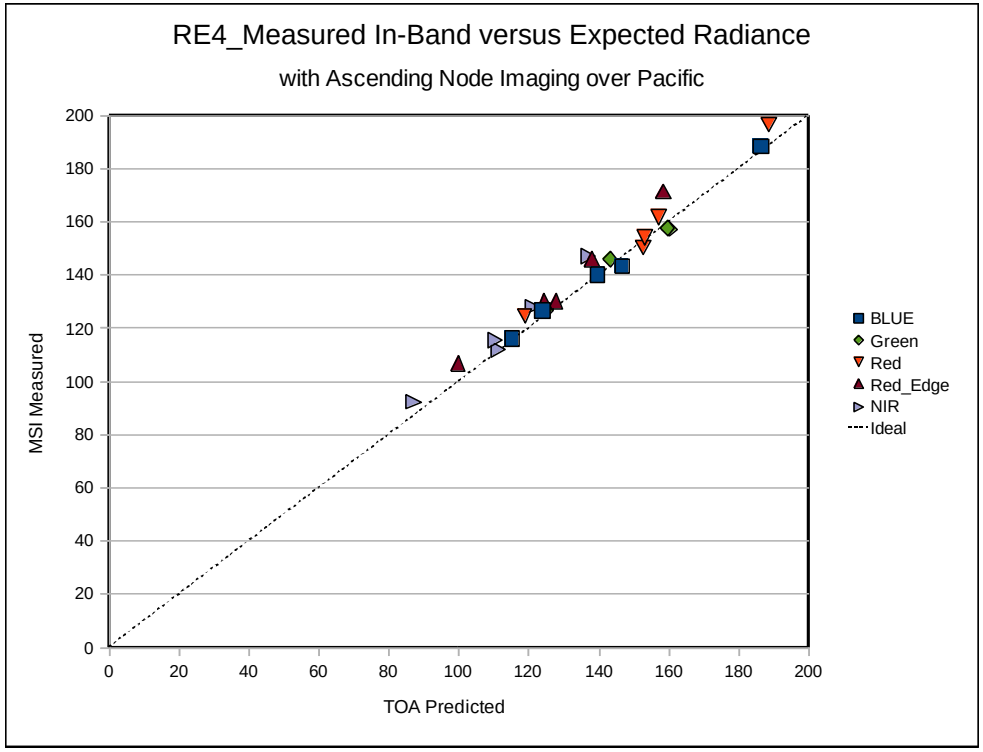
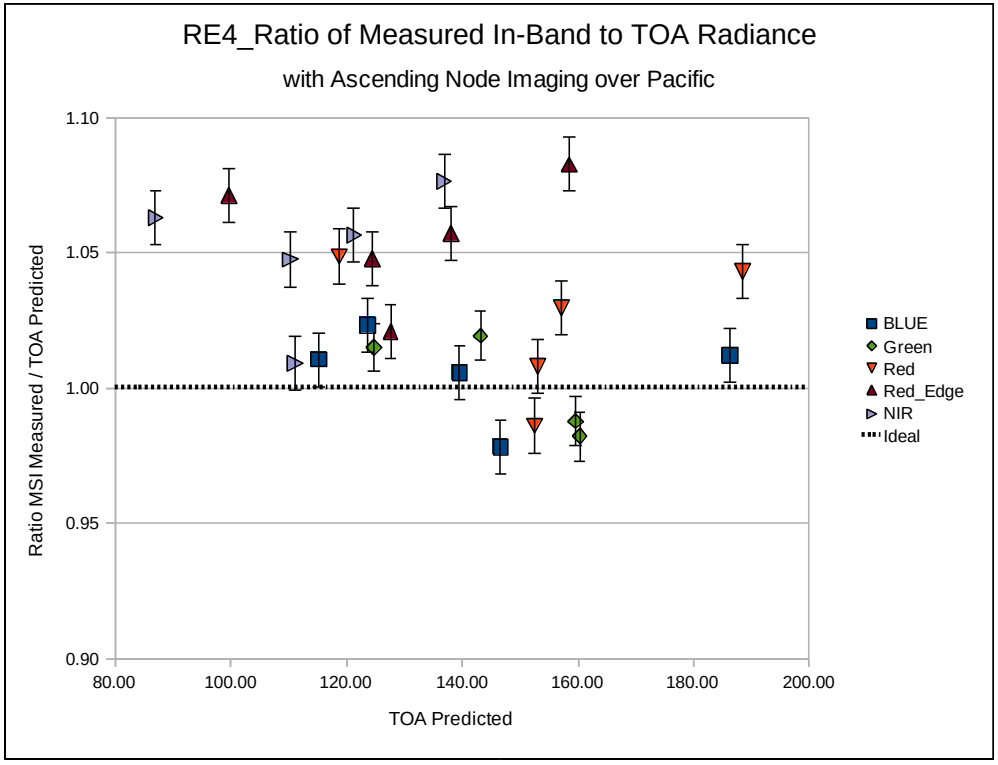
Measurement Analysis - RE4



MSI Measured compared to TOA predicted for all bands

Total uncertainty is the combination of uncertainty in the TOA prediction method, the uncertainty in the MSI instrument and limited number of pixels on target(sampling)

Uncertainty in 26 April IVP data is on the order of 0.05 – not included



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Conclusions and Future Work

- The MSI is linear for target brightness in the middle of the sensor dynamic range and for typically observed scenes
- The RE3, RE4 and RE5 absolute radiometric accuracy is quite good
- The MSI consistently measures higher than expected in most bands especially the Red, Red_Edge and NIR
- Ratios of measured to predicted radiance increase in the Red_Edge and NIR especially for RE4
- Use the 2009 absolute calibration data to create scaling factors and update on ground gain coefficients
- Plan for an Absolute VC Campaign for RE1, RE2 and RE5 in 2010
- Participate in Toz Golu trial in August 2010 with all spacecraft

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Acknowledgments

- Jeff Czapla-Myers and the RSG team at the University of Arizona
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- MDA (MacDonald Dettwiler and Associates) Keith Beckett; lead developer of the relative radiometric calibration concept and ground segment tools

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RapidEye

> Concepcion Airport region: 2010-01-22

Thanks for your attention!

Questions and Comments?

> Concepcion Airport region: 2010-02-27

BACKUP SLIDES

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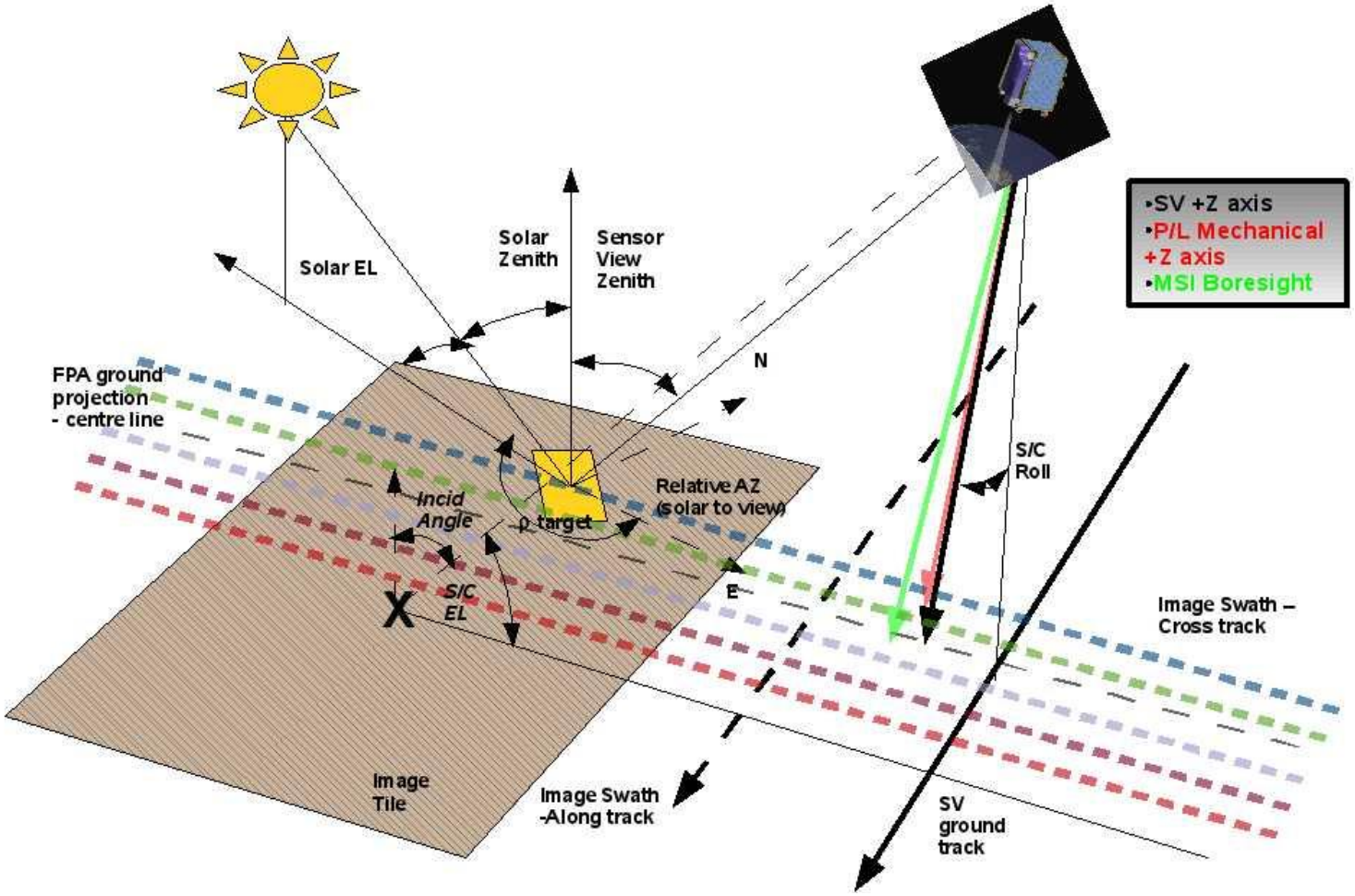
Site Acquisition Geometry_Backup



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