Landsat 8 Thermal Infrared Sensor (TIRS) Stray Light

Ron Morfitt — USGS / EROS
Matthew Montanaro — Rochester Institute of Technology
Aaron Gerace — Rochester Institute of Technology
Julia Barsi — NASA Goddard (Code 618)

U.S. Department of the Interior
U.S. Geological Survey

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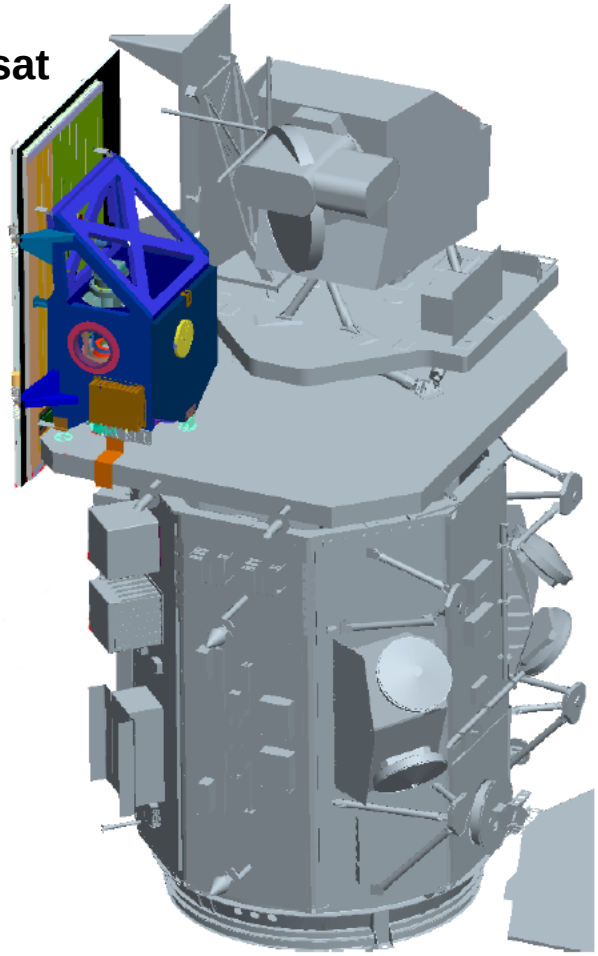
Landsat Science Team meeting
NASA Goddard Space Flight Center

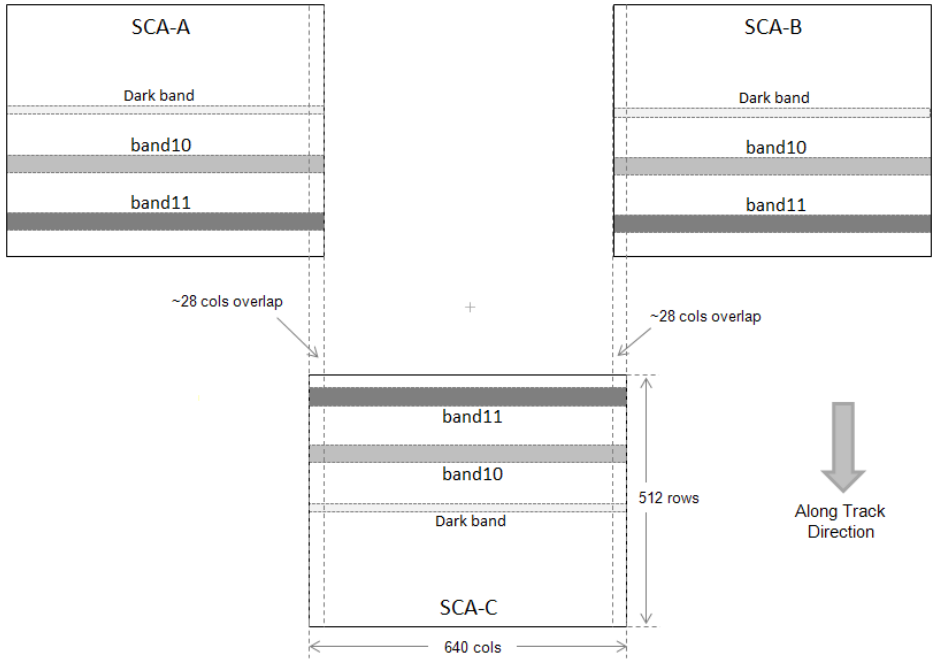
Instrument Overview

- **Launched on LDCM (now Landsat 8) on 11 Feb 2013**
- **Continue long wave infrared measurements for the Landsat program**
- **4 optical element refracting telescope**
- **Focal plane consists of 3 staggered QWIP arrays**
- **Two spectral channels:**
  - Band 10: 10.6 µm - 11.2 µm
  - Band 11: 11.5 µm - 12.5 µm
- **Dark band to monitor focal plane drift**
- **Push-broom configuration: ~1850 detectors across-track per band**
- **185 km ground swath; 100 meter pixel size on ground**
- **For calibration purposes, a Scene Select Mechanism (SSM) switches instrument view between nadir, deep space port, and blackbody**



Focal Plane Layout

- **Spectral filters over certain regions produce the two spectral channels; rest of array is masked.**
- **For normal ops: 2 rows from each of the three regions on each array are sent to the ground.**
- **Final image product contains combined image data from the three arrays stitched together.**



On-Orbit Performance Breakdown

- **Worst case measured values for selected TIRS requirements based on on-orbit image data**

Requirement	Measured Value		Required Value	Units
NEdT (@300K)	0.05		< 0.4	Kelvin
NEdL	0.008		< 0.059, < 0.049	W/m²/sr/µm
Saturation Radiances	28.4, 19.2		20.5, 17.8	W/m²/sr/µm
40 min. Radiometric Stability (1σ)	0.1		< 0.7	Percent
Inoperable Detectors	0		< 0.1	Percent
Swath Width	186.2		> 185	Kilometers
Ground Sample Distance	103.424		< 120	Meters
Band Registration Accuracy	10.4		< 18	Meters
TIRS-to-OLI Registration Accuracy	20.6		< 30	Meters
	Band 10	**Band 11**		
Absolute Radiometric Accuracy	~ 5 (~ 2*)	~ 10 (~ 5*)	< 2	Percent
Uniformity Field-of-View	~ 1 **	~ 2 **	< 0.5	Percent
Uniformity Banding RMS	~ 1 **	~ 2 **	< 0.5	Percent
Uniformity Banding St.Dev.	~ 2 **	~ 4 **	< 0.5	Percent
Uniformity Streaking	< 0.5	< 0.5	< 0.5	Percent

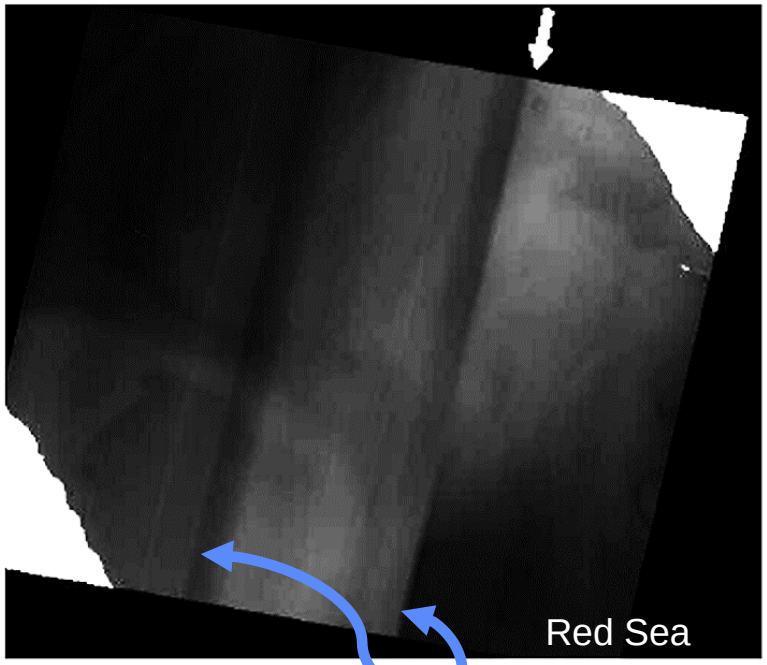
*After bias adjustment
** Scene dependent

Note: Worst case radiometric accuracy and uniformity performance occurs in band 11; band 10 approximately a factor of 2 better

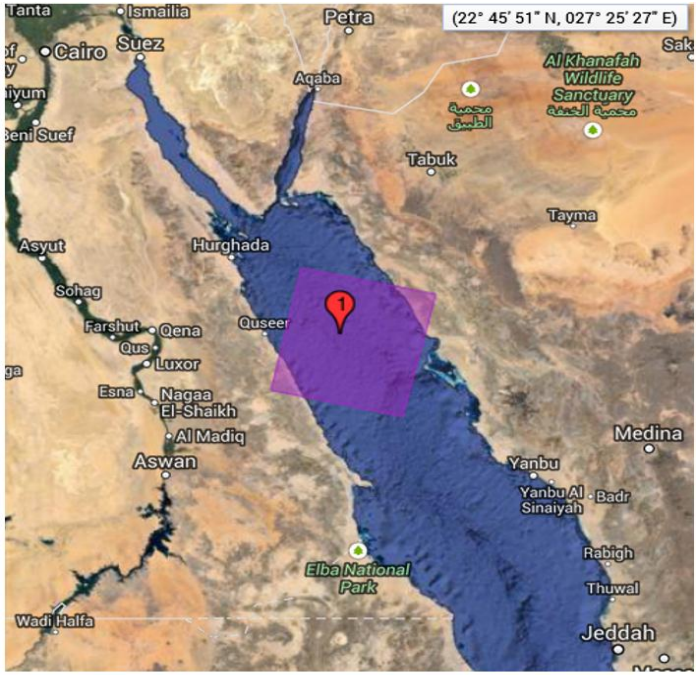
Instrument Issues: Non-Uniformity

- **Banding artifacts observed in certain Earth scenes expected to be uniform (e.g.- open water)**
- **Effect varies from scene-to-scene**
- **Effect varies within scene**

Example scene with varying along-track banding (band11)



Context view from EarthExplorer

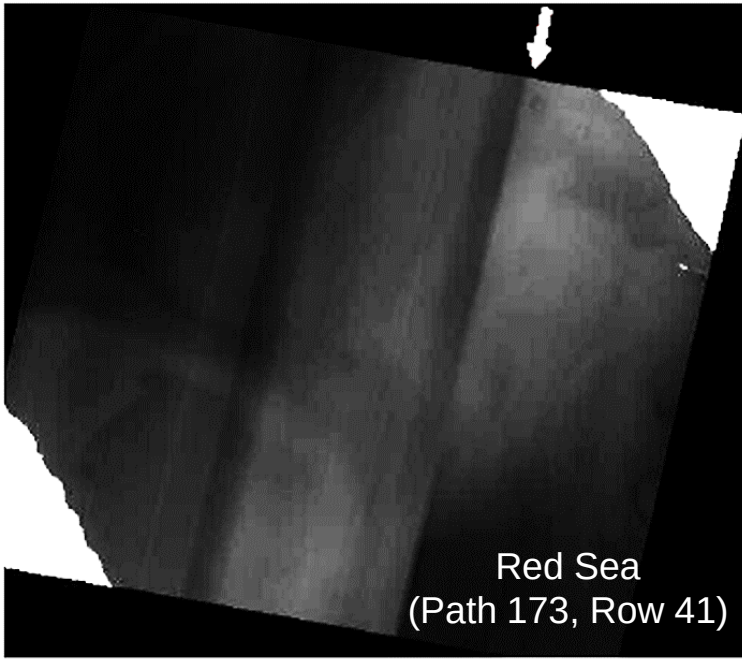


Banding observed especially near the boundary between adjacent focal plane arrays

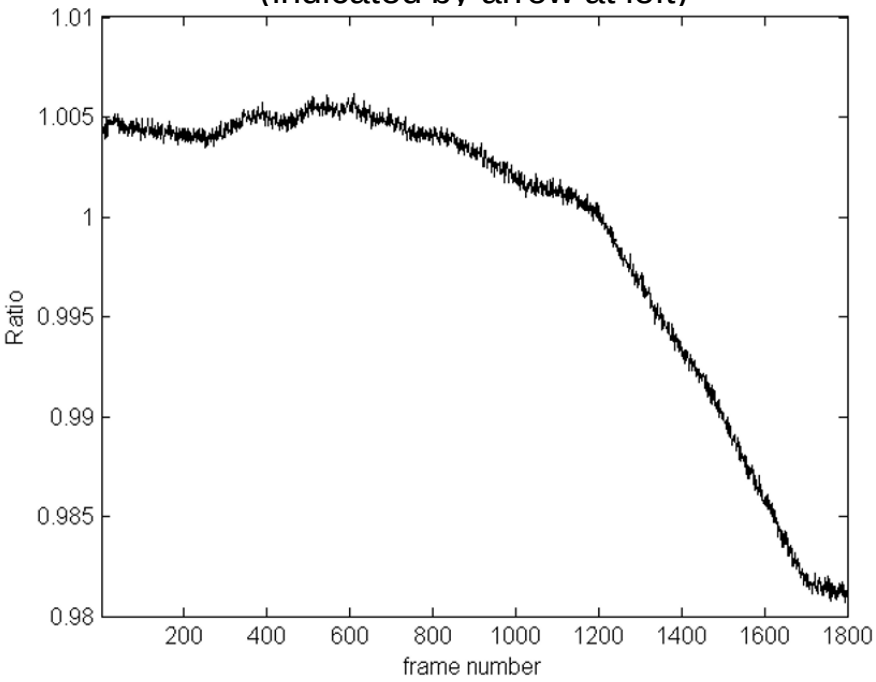
Instrument Issues: Non-Uniformity

- **Overlap ratio between arrays varies in the along-track direction (changes with push-broom frame number)**
- **Not the result of a mis-calibration of the detector since the effect changes with frame number & all indications show instrument is stable**

Example scene with varying along-track banding (band11)



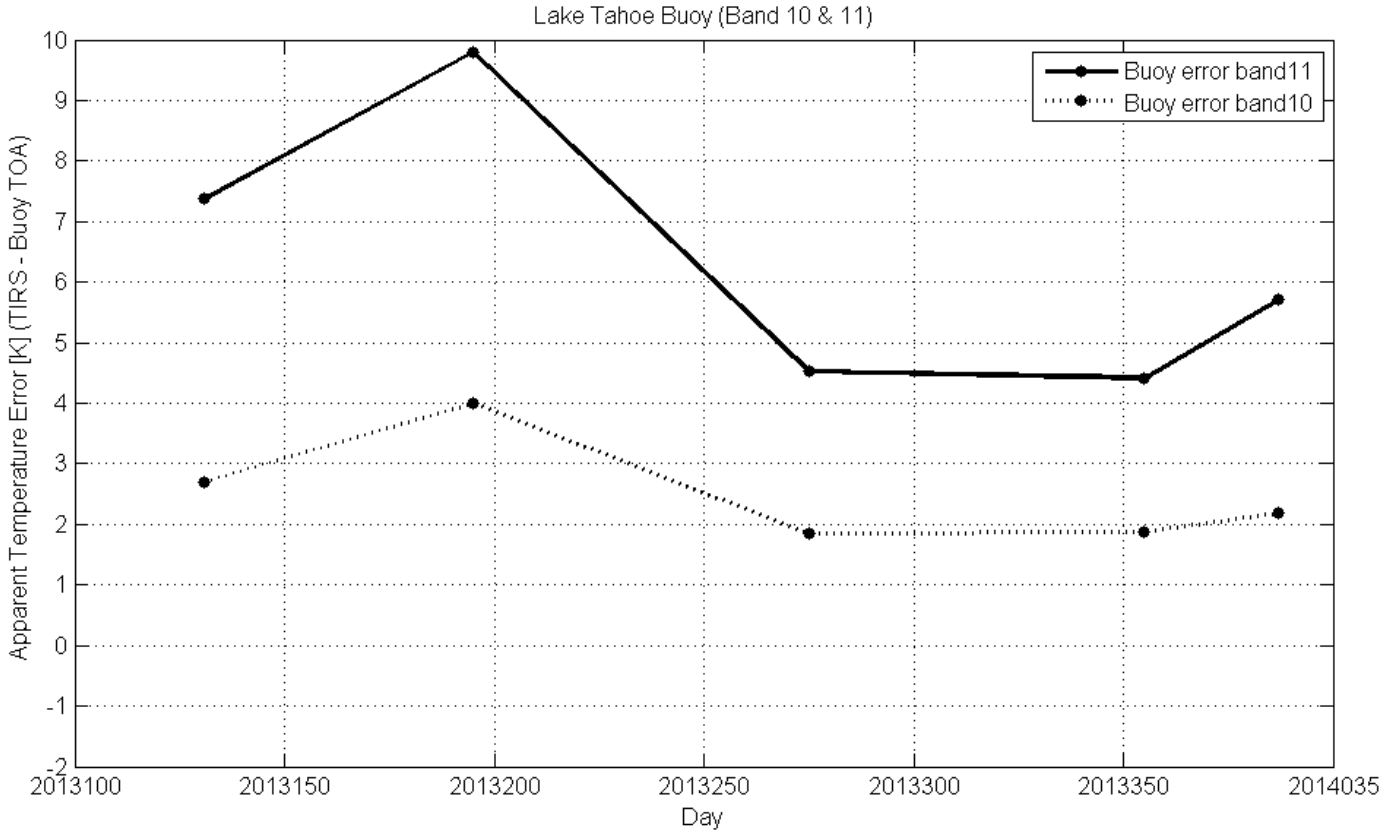
Ratio of signal on either side of array overlap (indicated by arrow at left)



Per our banding definition, this discontinuity would be a 1% band (versus a requirement of 0.5%)

Instrument Issues: Absolute Radiometry Calibration

- **Compare TIRS-derived temperature with in-situ temperature from water buoys*.**
- **Observed season-varying bias error between TIRS and buoys.**



Note:
these are values without the bias correction applied to TIRS image products in February 2014

* Assembled by Julia Barsi (NASA/GSFC) from buoy top-of-atmosphere radiances provided by NASA/JPL

The Cause: Stray Light/Ghosting

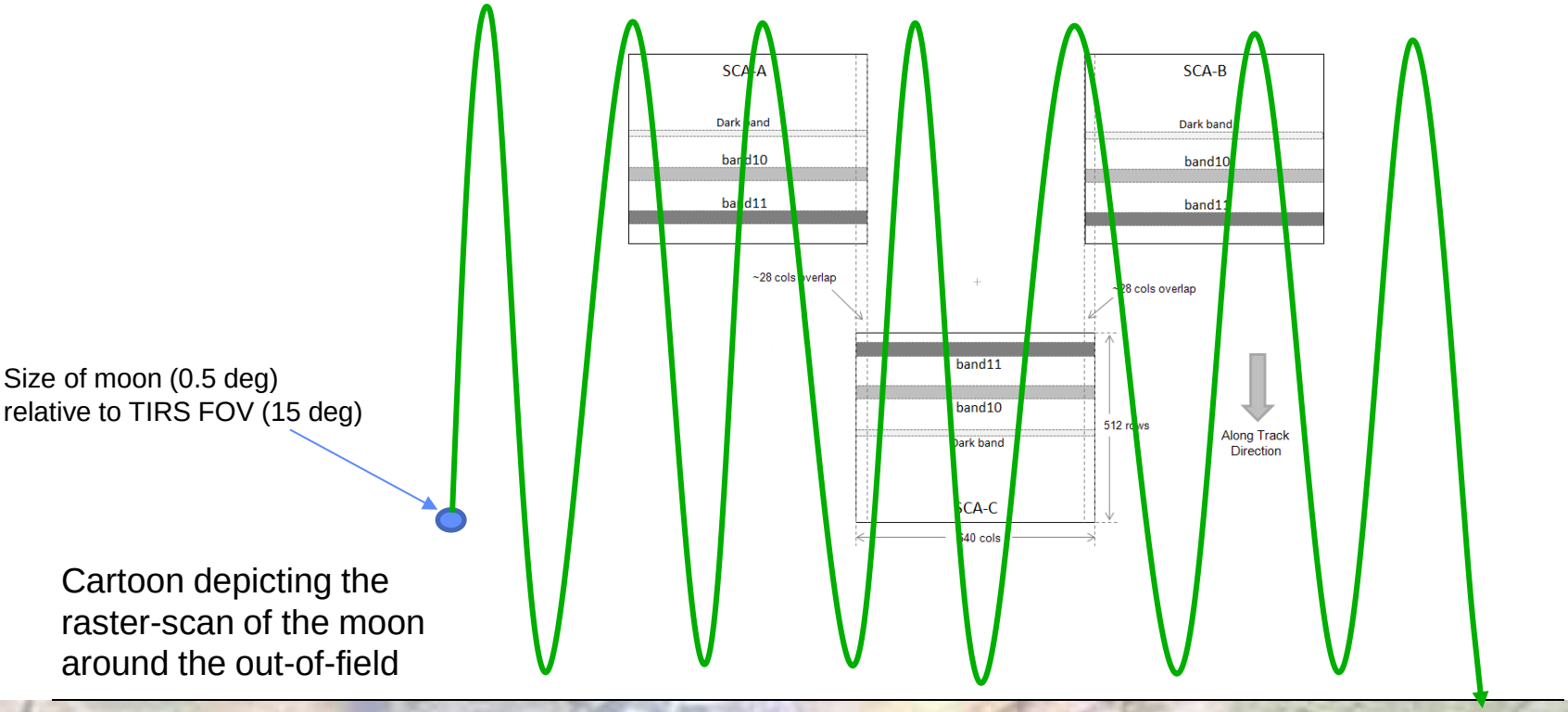
- **Known artifacts:**
  - Absolute Calibration error
    - TIRS always reports a higher temperature than in-situ measurements
    - Error based on lake buoys varies with season (i.e. - error is larger in summer)
    - Error proportional to surrounding area temperature (e.g., in band 10 about a 10 K change in surround temp induces ~1K change in target temp)
  - Banding
    - Magnitude and shape varies from scene-to-scene
    - Magnitude and shape varies within a scene

Suspected an out-of-field radiance (stray light) was adding a spatially varying signal to the focal plane (ghosting)

- **Would explain:**
  - Absolute cal error higher in summer since surrounding scene area is hotter and would therefore contribute higher magnitude of stray light signal on the detectors.
  - Banding magnitude and shape variation would depend on out-of-scene content.

Stray Light

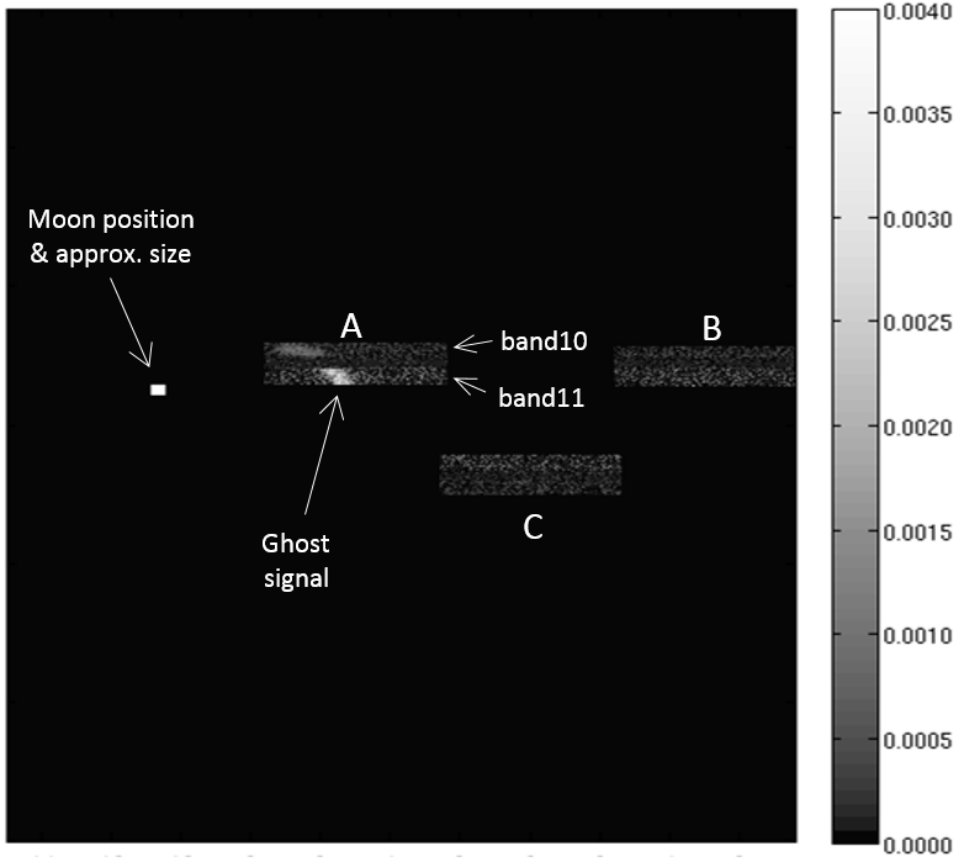
- **Investigate theory by slewing the observatory to raster-scan the moon outside the TIRS FOV**
- **Focal plane in “transmit-all” mode to read out the entire array (acts as a framing camera)**
- **Record any ghost signals on the arrays when the moon is outside the direct FOV**



Cartoon depicting the raster-scan of the moon around the out-of-field

Stray Light

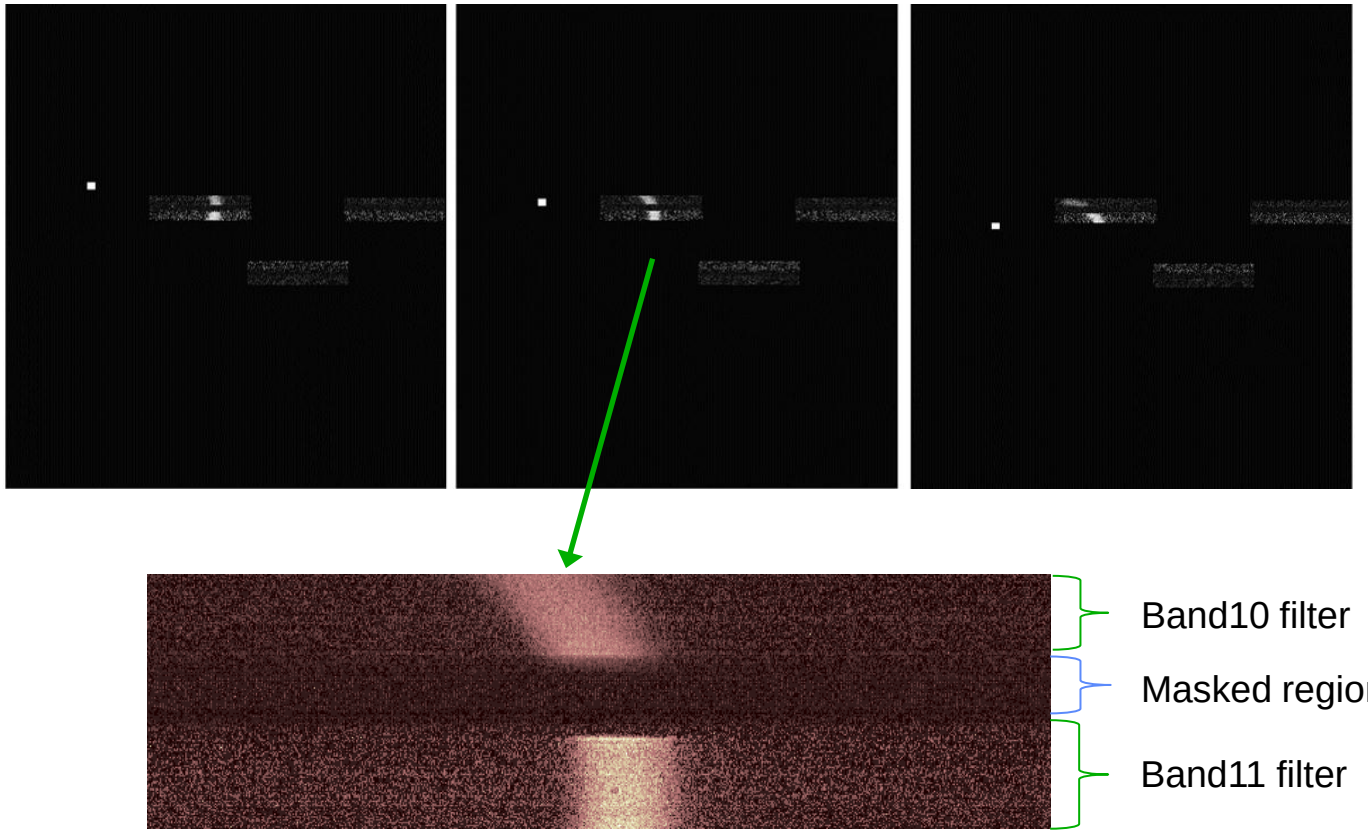
- Lunar position relative to boresight known from observatory pointing telemetry
- Signal on arrays expressed as a fraction of direct moon signal (when moon is directly imaged)



Video: moon322.mpg

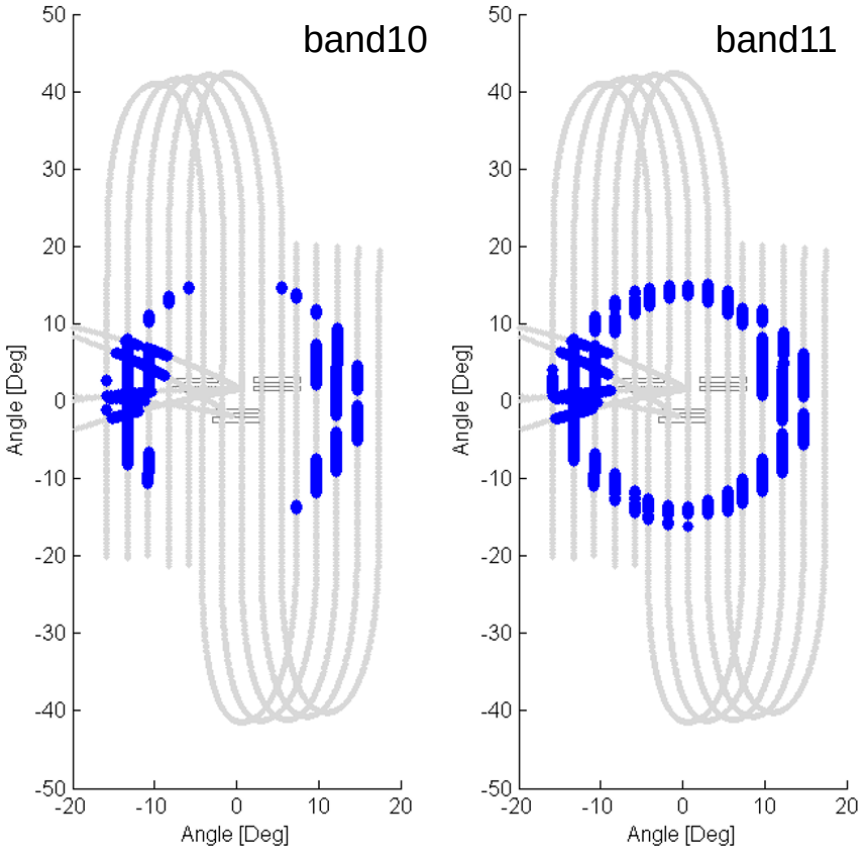
Stray Light

- **Ghost signal location and magnitude is a function of lunar position**



Stray Light

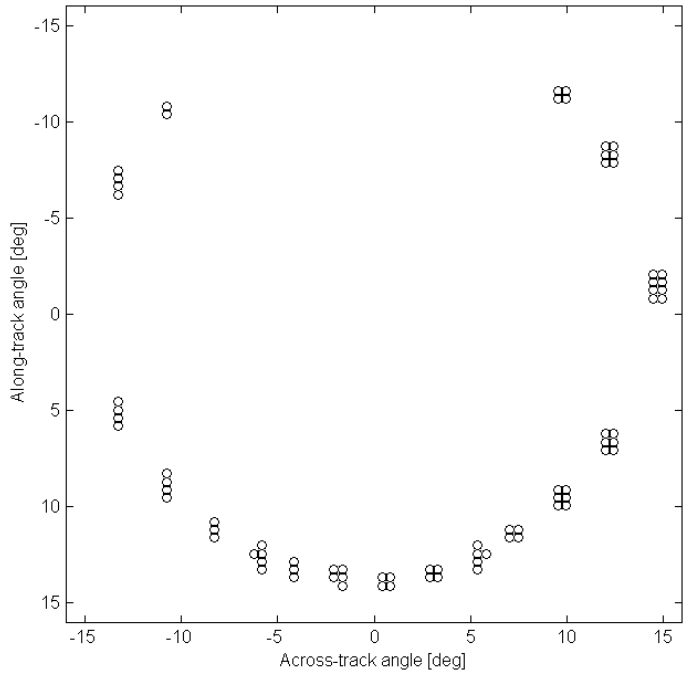
- **Can flag lunar locations (blue) in which a ghost appeared anywhere on the detectors**
- **Provides a sense of how far off-axis the offending signals are originating**



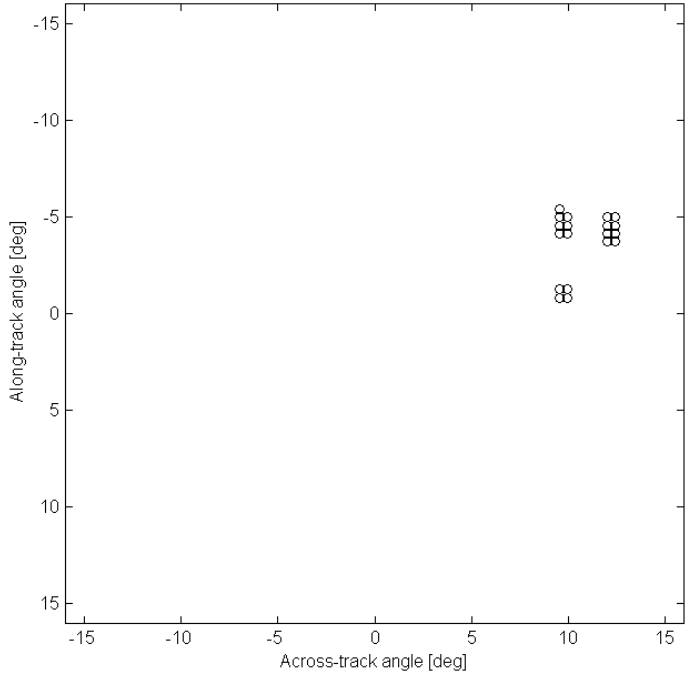
Stray Light

- **Able to produce a sparse map of lunar locations that produced a ghost for each detector**
- **Essentially have an out-of-field “Point-Spread Function (PSF)” for every detector**
- **Every detector has a different PSF (i.e.- the ghost signal is different for every detector)**

PSF for one detector on array -C

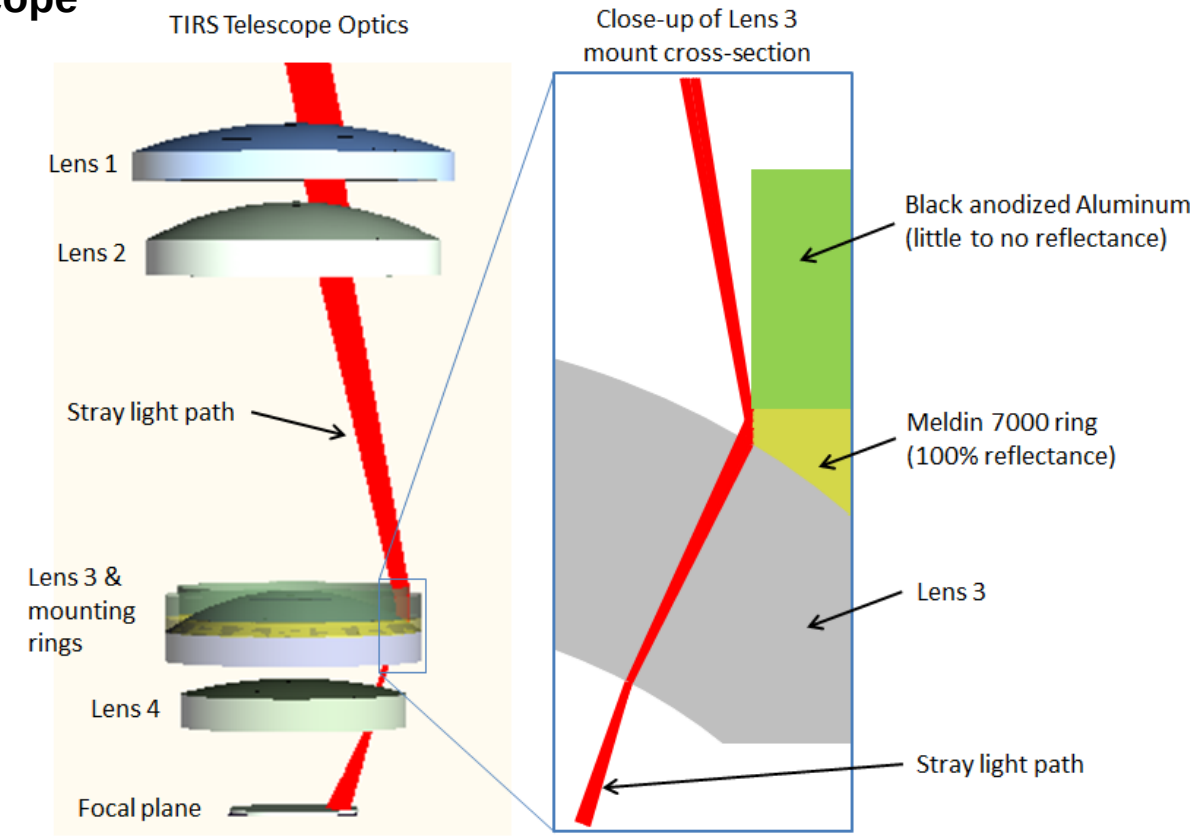


PSF for one detector on array -B



Stray Light Optical Modeling

- **Lunar stray light data provided to Optics group* at NASA/GSFC**
- **Stray light artifacts in TIRS have been correlated to far out-of-field light reflecting from the mounting ring contacting the first surface of Lens 3 in the TIRS Telescope**

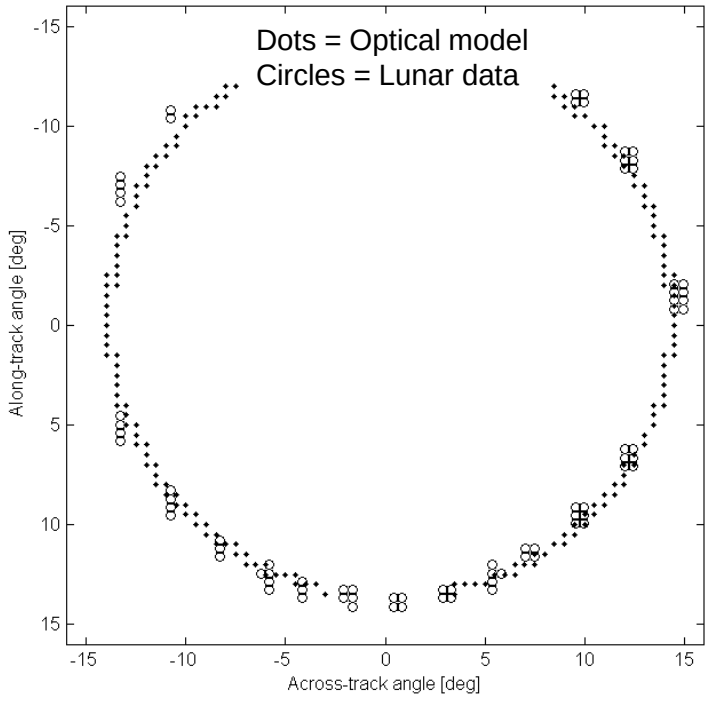


Note:
Optical model is being refined with new lab measurements of reflecting surfaces in the telescope assembly

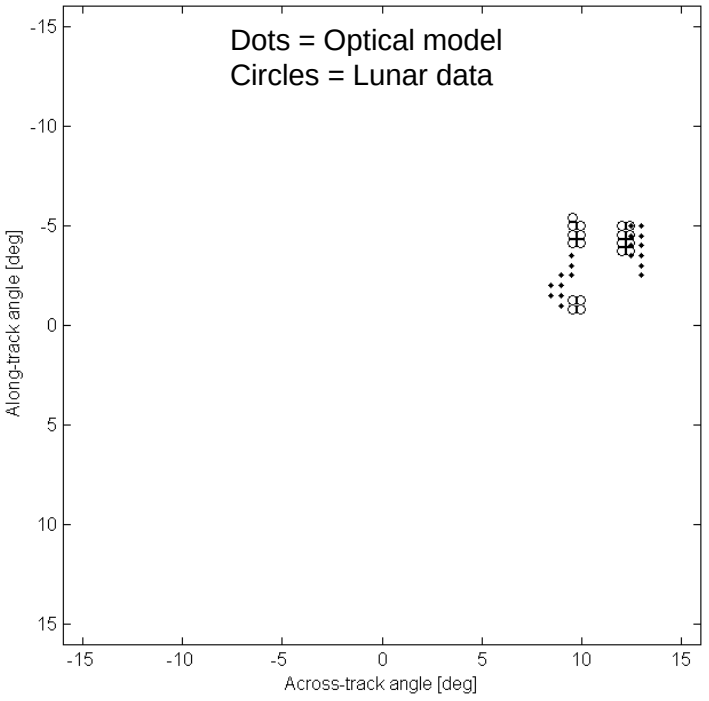
Stray Light Optical Modeling

- **Optical stray light model mostly fits observed lunar data**
- **Have a complete stray light PSF for every detector (i.e. – no gaps as in the lunar data)**
- **Optical model currently being refined based on lab measurement; initial run was 'good enough' to develop a stray light correction**

PSF for one detector on array -C

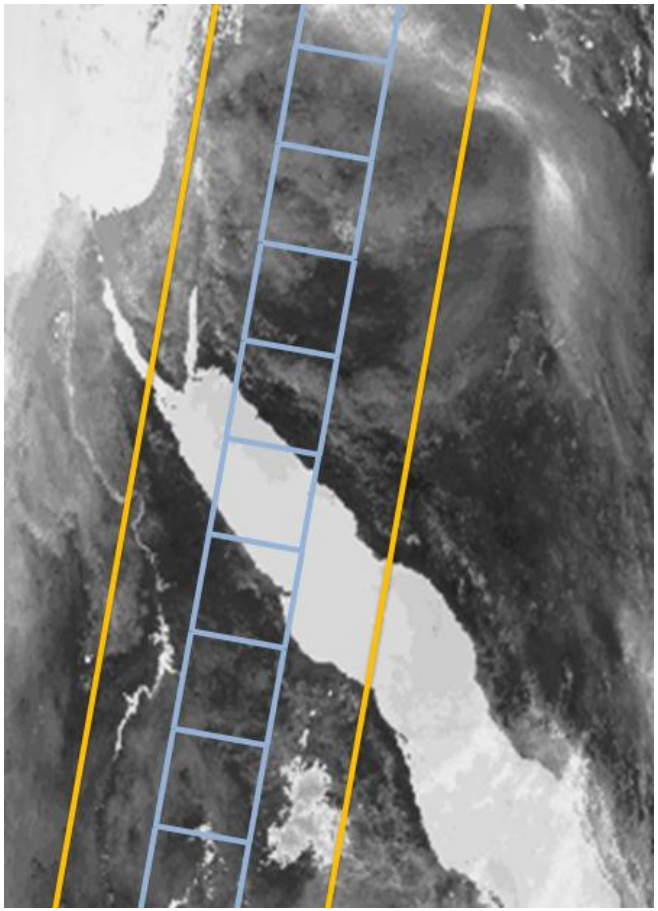


PSF for one detector on array -B



Possible Correction Strategies for TIRS

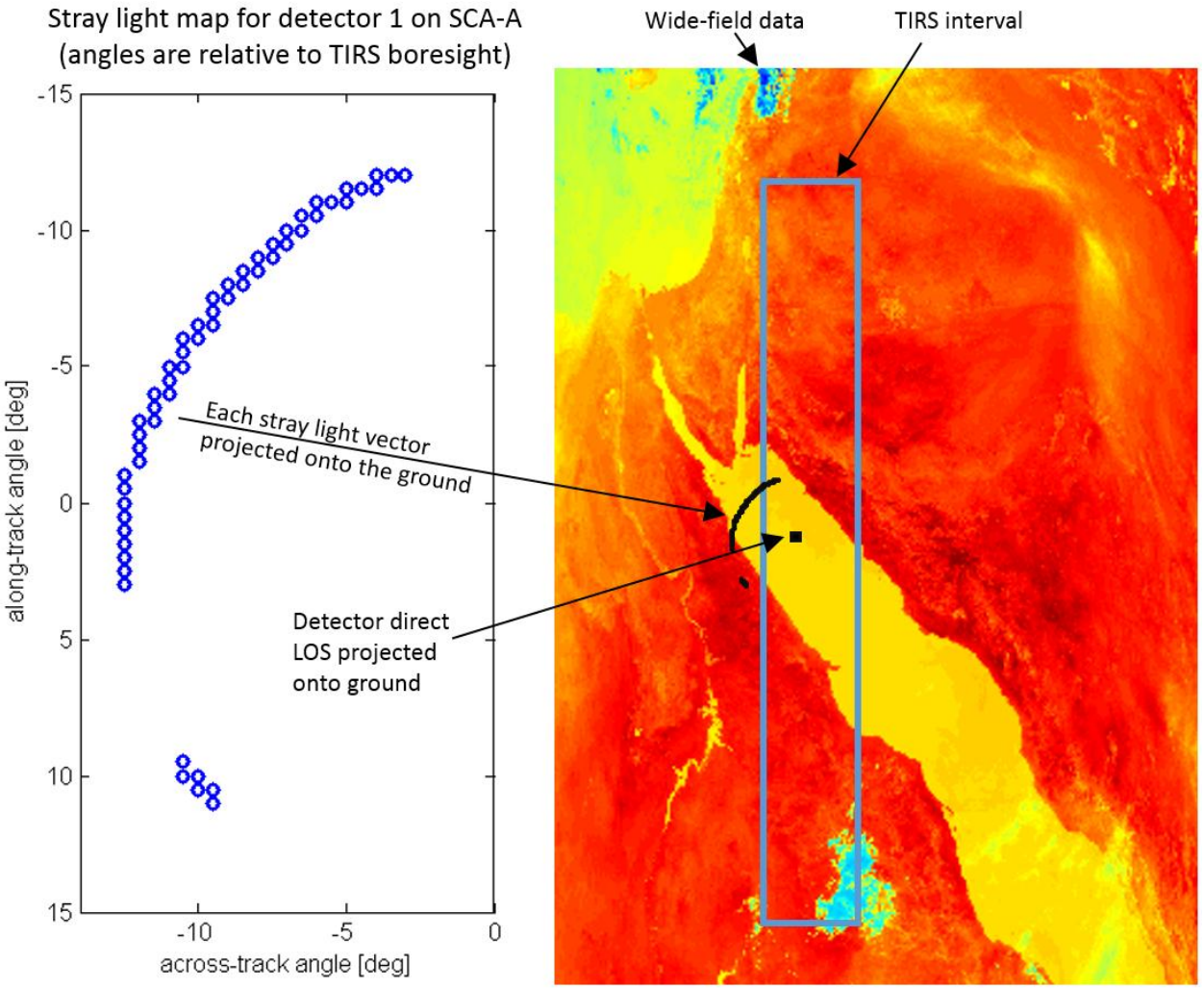
- **Use External Sensor Data:**
  - Coincident thermal band data (GOES, Meteosat, etc.) provides out-of-field radiance
  - Optical Stray Light Model provides locations of stray light sources
  - Most accurate (realtime clouds); Most computationally intensive (also requires external sensor data)
- **Use In-Scene Data:**
  - Use in-scene TIRS radiance as a surrogate for the out-of-field radiance
  - Making assumption than in-scene radiance correlates to out-scene radiance; only requires given TIRS scene (no other data necessary)
- Others



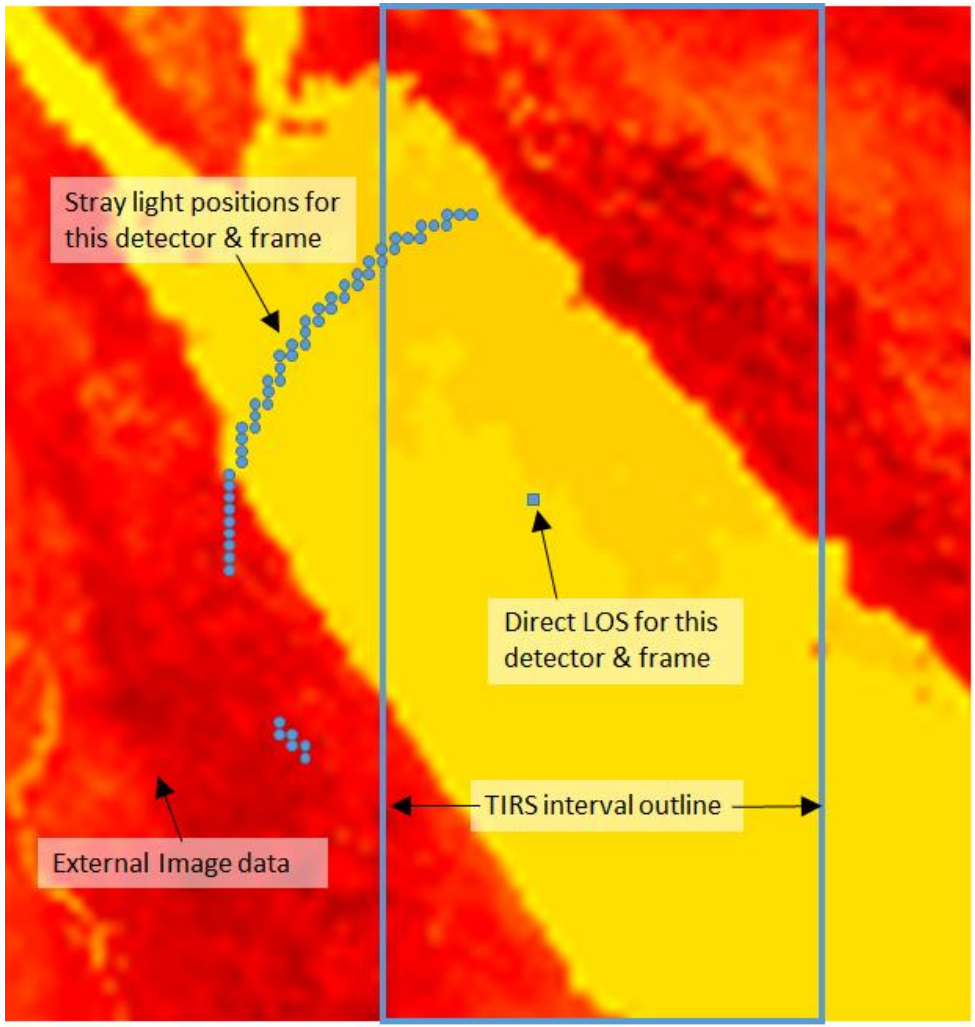
* All strategies depend on knowledge of out-of-field radiance

Total signal = direct signal + ghost signal

Stray Light Effect Correction Strategy: External Sensor Data



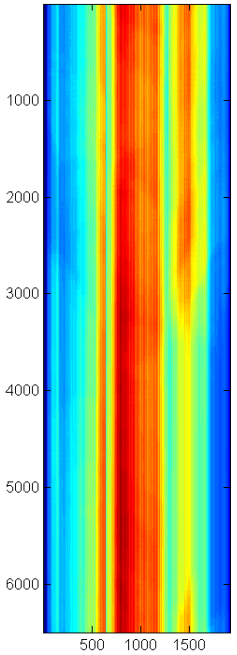
Stray Light Effect Correction Strategy: External Sensor Data



$$Ghost = a \cdot \left(Ext.Sampled\right) + b$$
$$= a \cdot \left(\sum L_{ext_i} \cdot w_i\right) + b$$

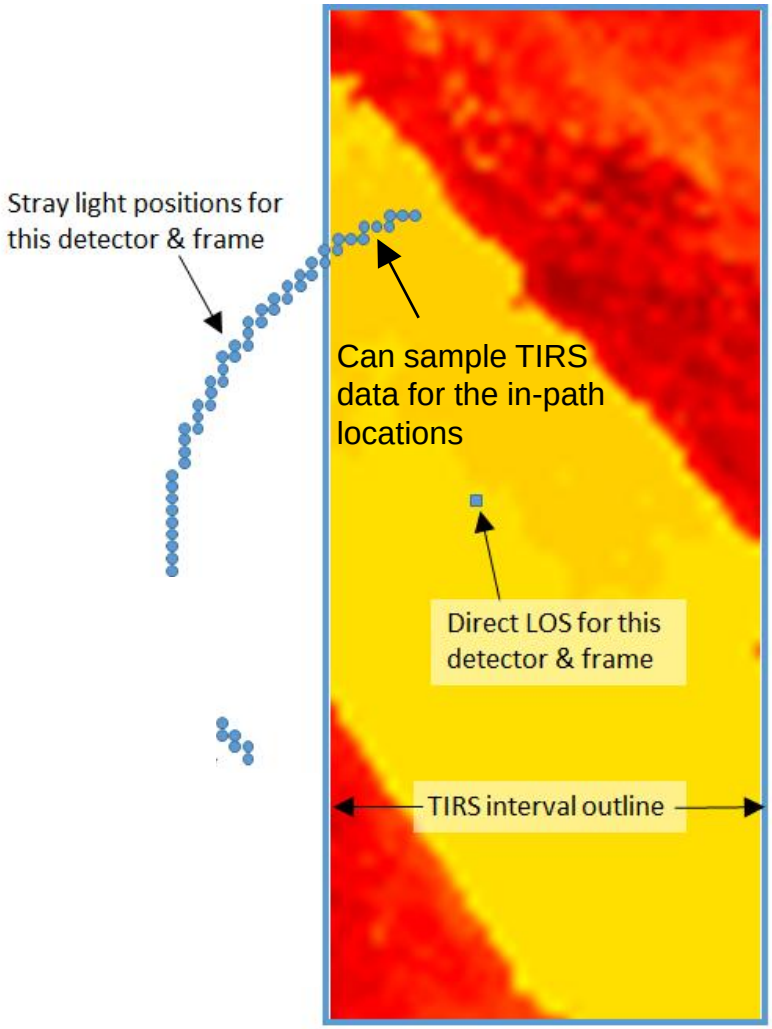
- Repeat for every frame
- repeat for every detector

Calculated ghost signal



Subtract this signal from the TIRS data to remove the stray light effects

Stray Light Effect Correction Strategy: TIRS Data ONLY



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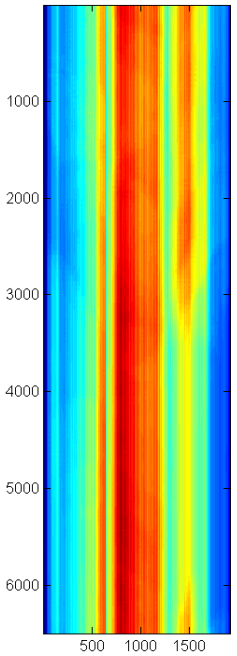

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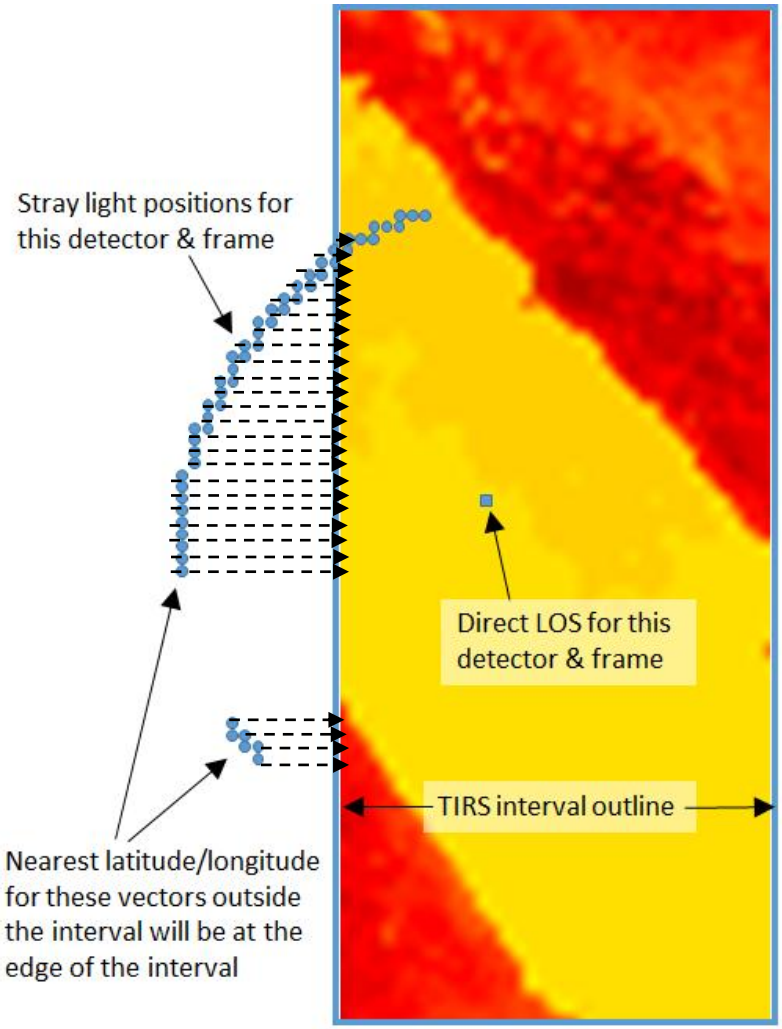

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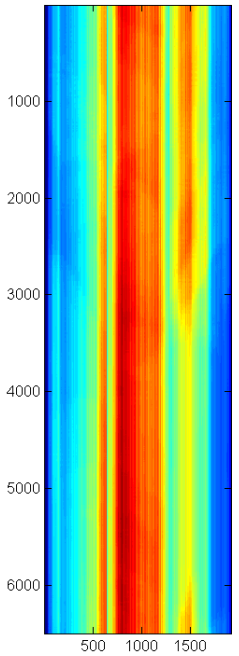


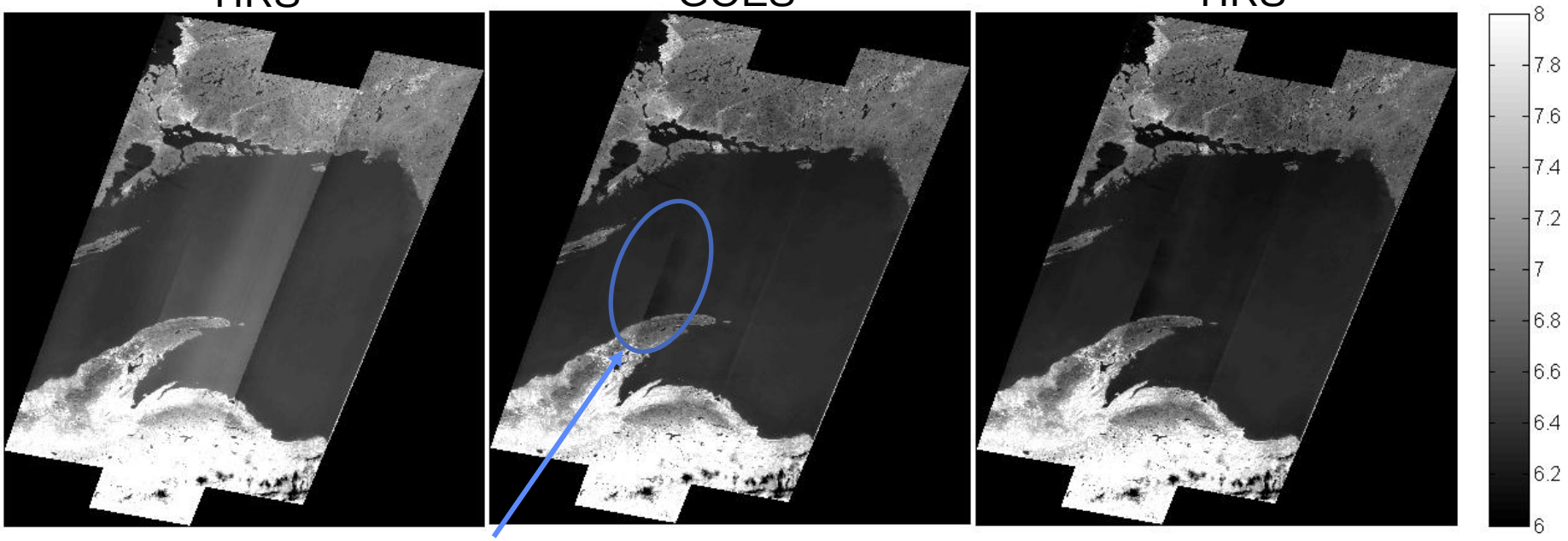
Subtract this signal from the TIRS data to remove the stray light effects

Results*: Banding

Original TIRS

TIRS Corrected with GOES

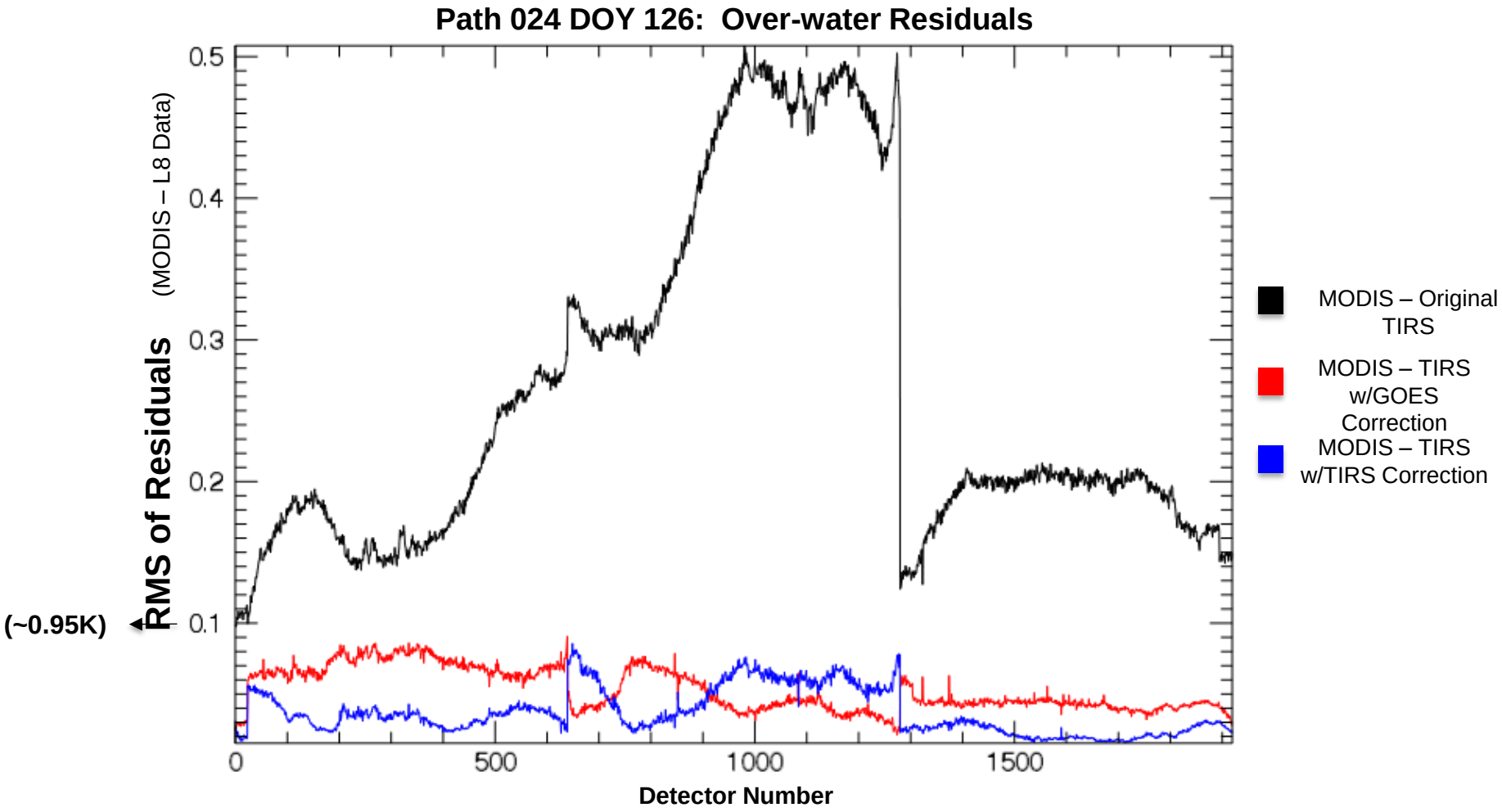
TIRS Corrected with TIRS



Residual banding traced to errors in optical model

* Note: These are preliminary results comparing the two correction methods. Analyses are ongoing to rigorously test the two methods and a determination will be made by Cal/Val as to how to correct for stray light in the standard image product generation system.

Results: Banding

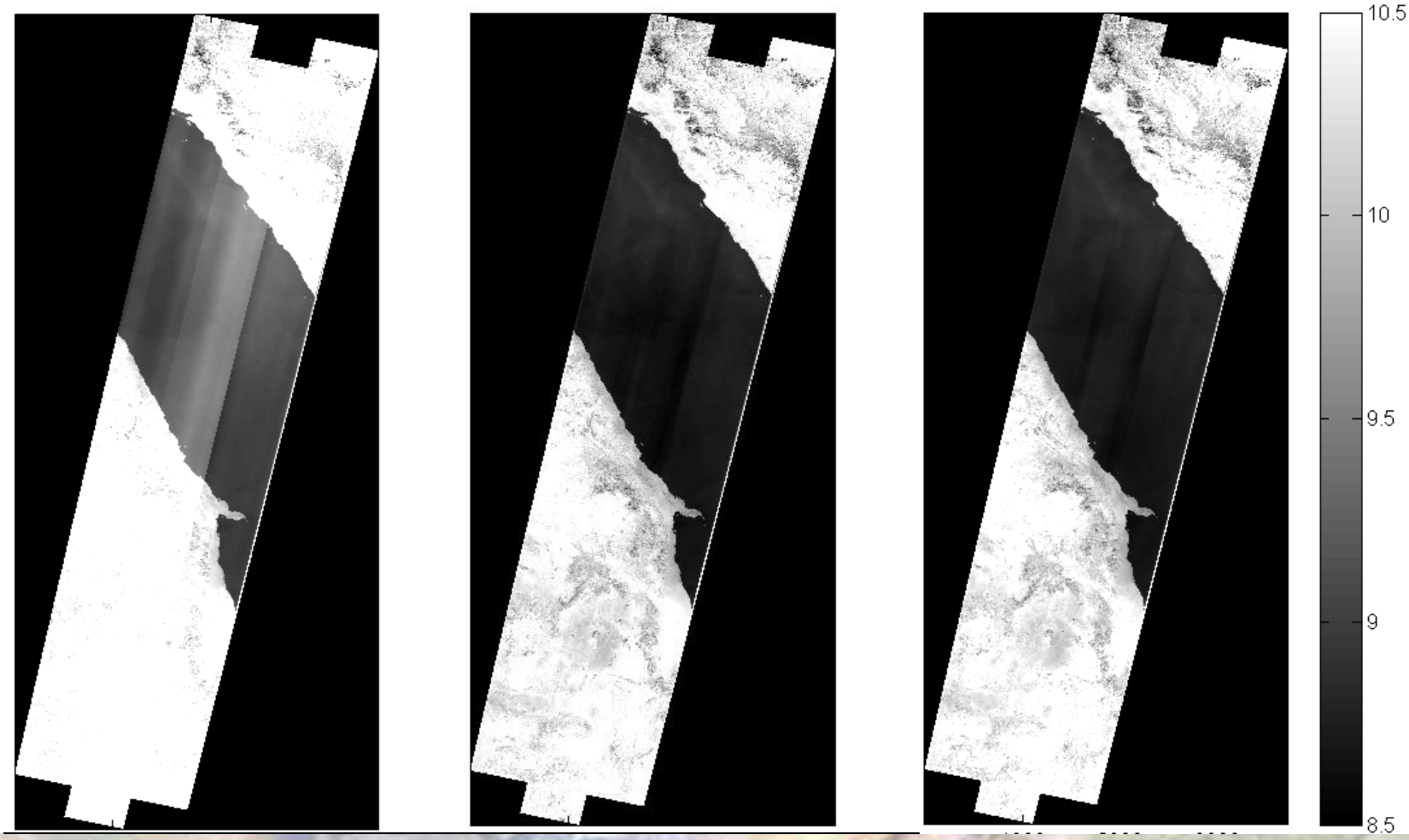


Results: Banding

Original TIRS

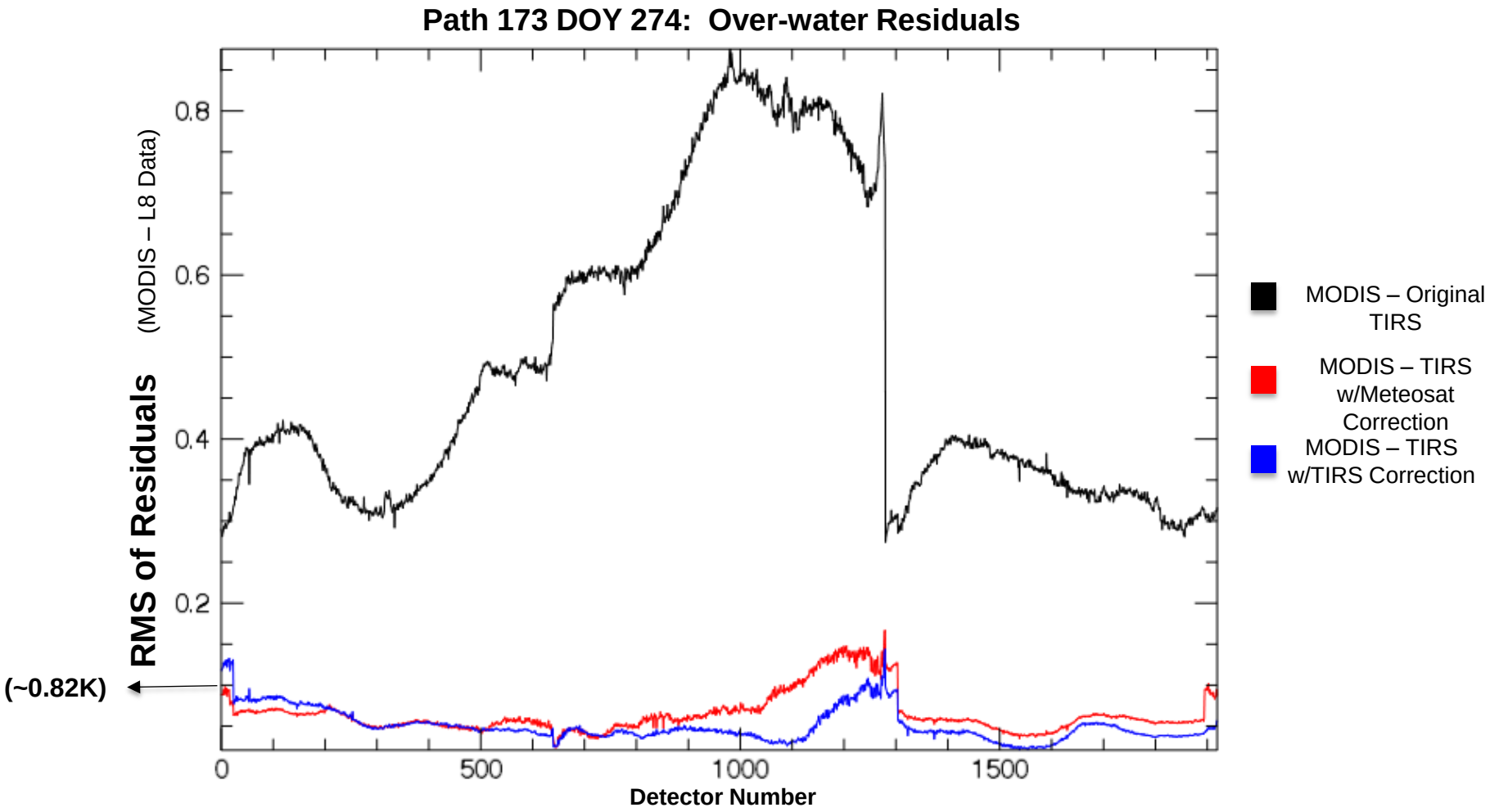
TIRS Corrected with GOES

TIRS Corrected with TIRS



Path173 DOY2013279

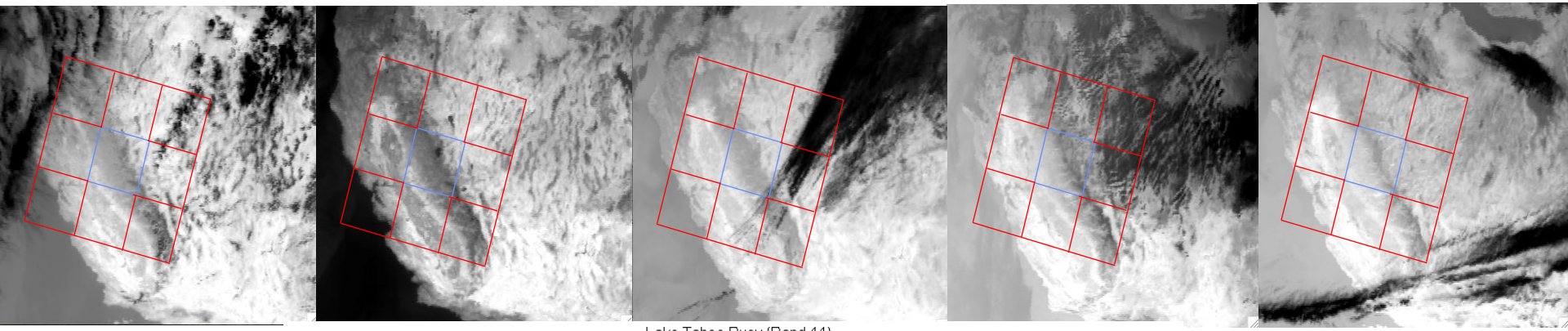
Results: Banding

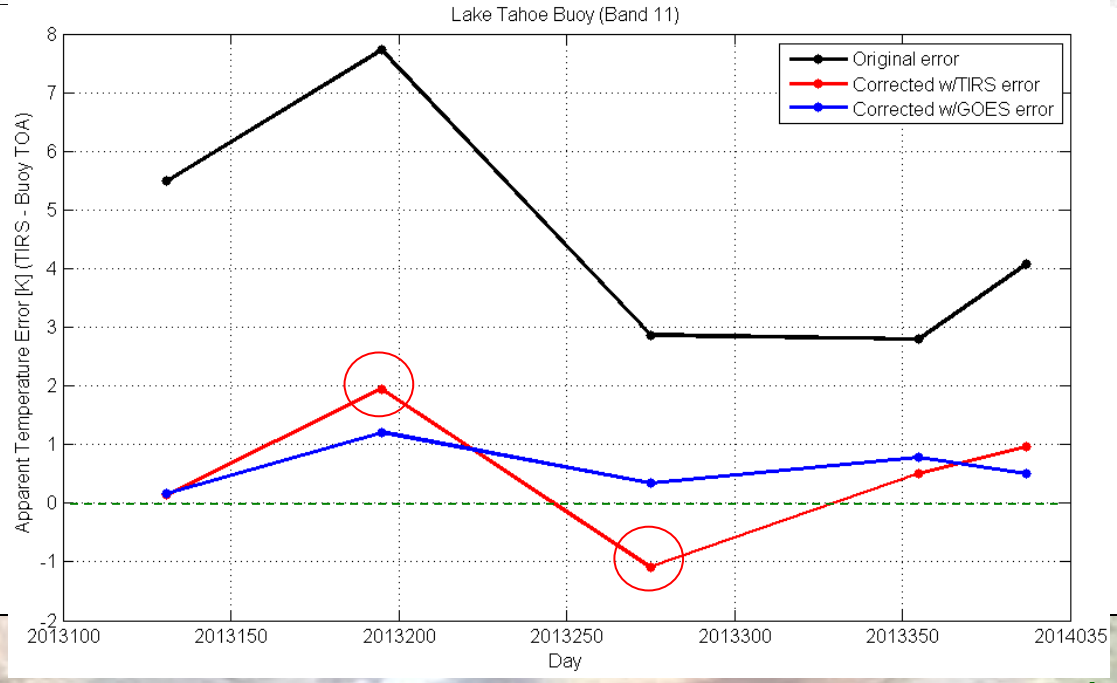


Path173 DOY2013279

Results: Absolute Radiometry Calibration (Lake Tahoe)

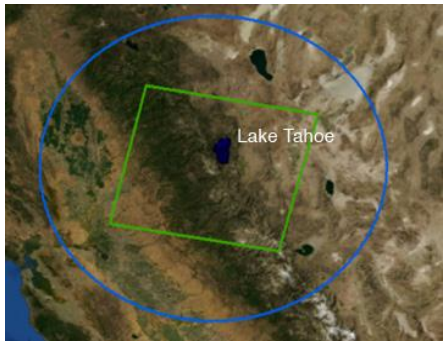
Day 131, 2013 | Day 195, 2013 | Day 275, 2013 | Day 355, 2013 | Day 22, 2014





Stray Light Source for Buoy Targets

JPL

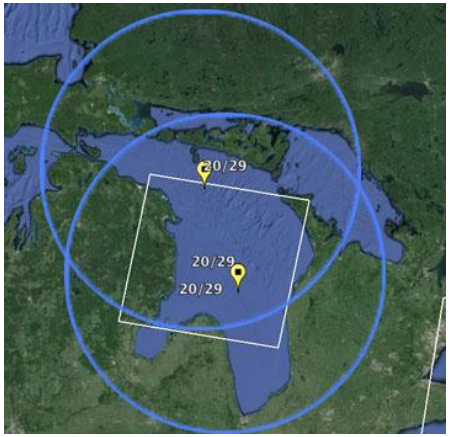


SCA2
N=13

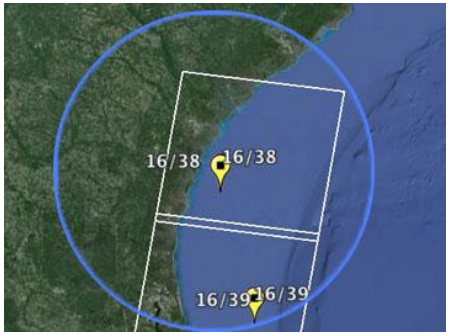
SCA2
N=5

JPL samples generated by Nina using GIS.
RIT samples generated by me using Nina's samples as a size guide and Photoshop

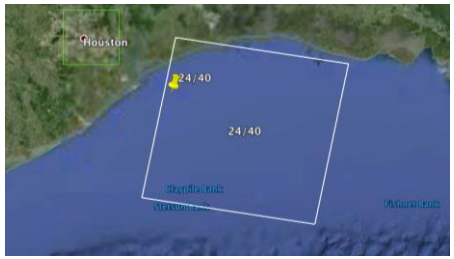
RIT



SCA1, 2
n=1 each



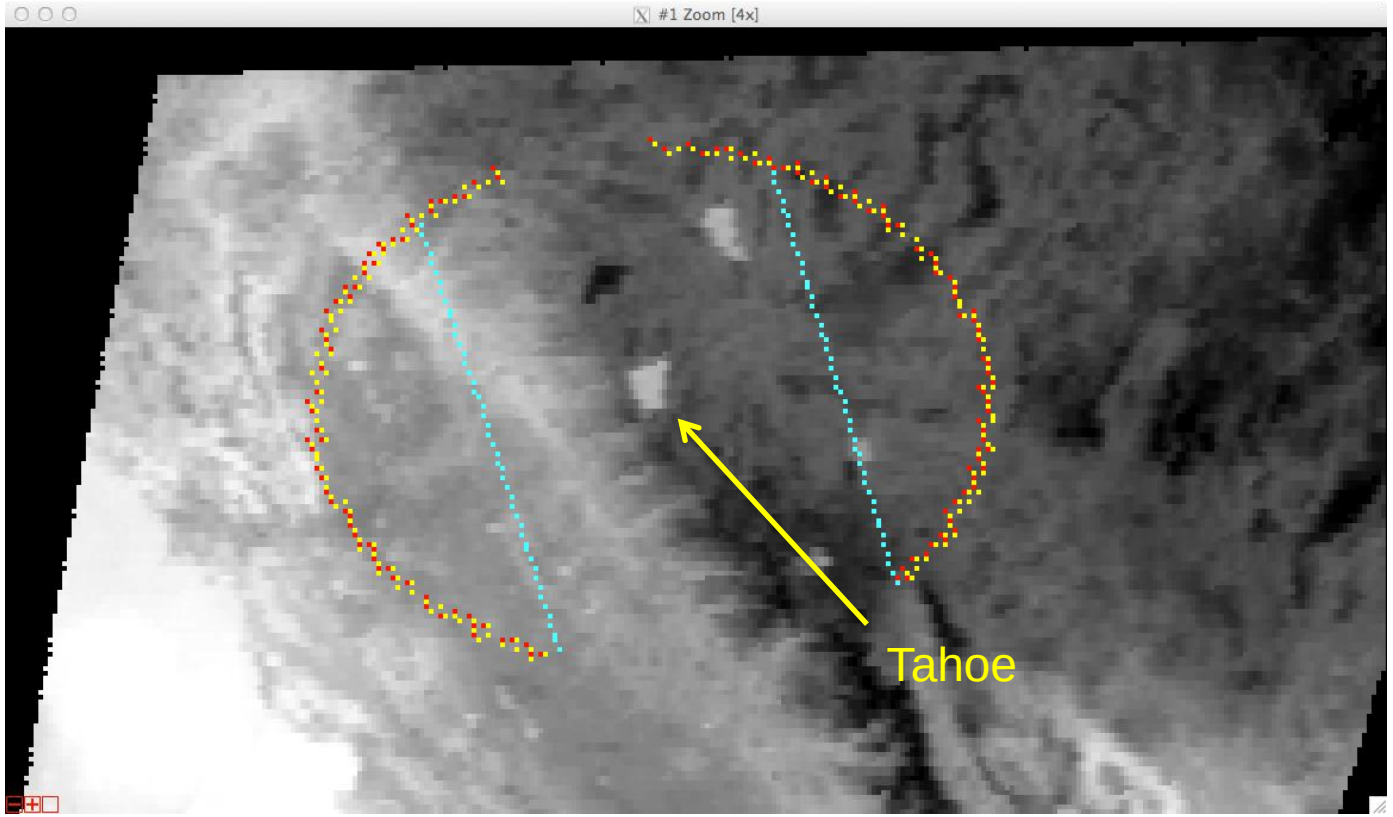
SCA2
n=6



SCA3
n=5

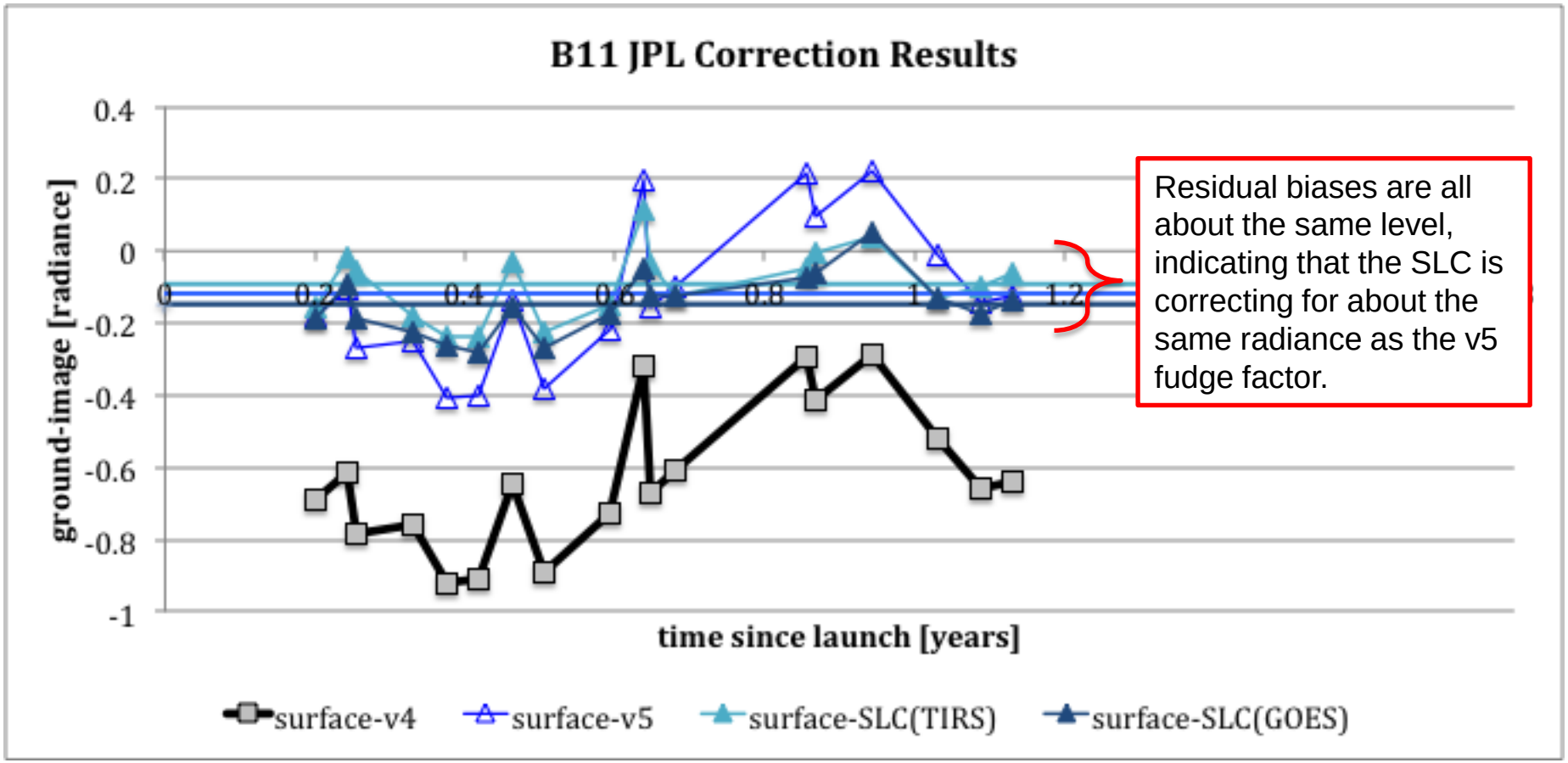
SCA3
N=5

Visualizing correction source
(LC81392112013356LGN00)



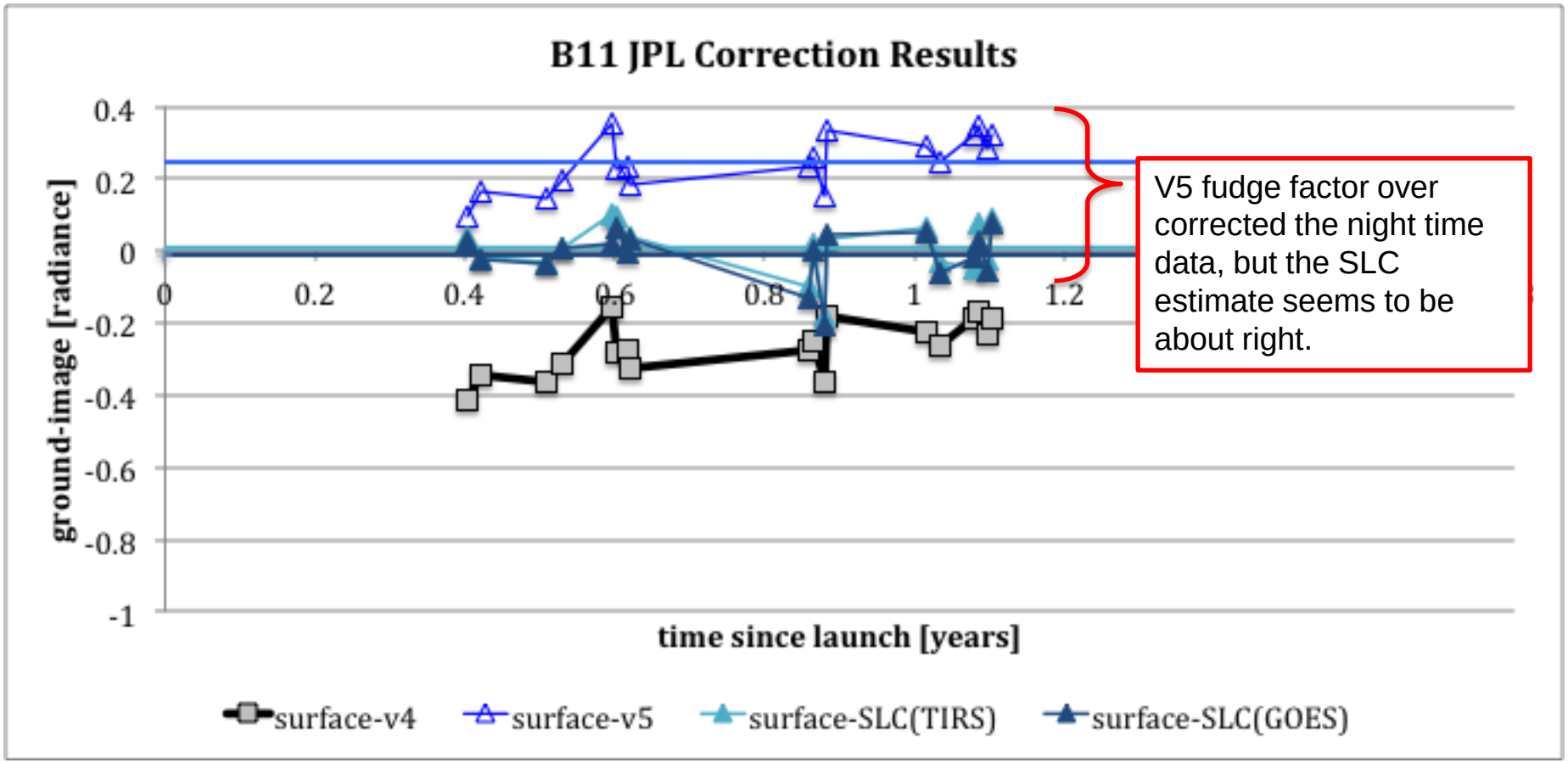
ROI: red = source pixels
yellow= remapped GOES source pixels
cyan = remapped TIRS source pixels

Residual Error: Band 11, JPL DAY

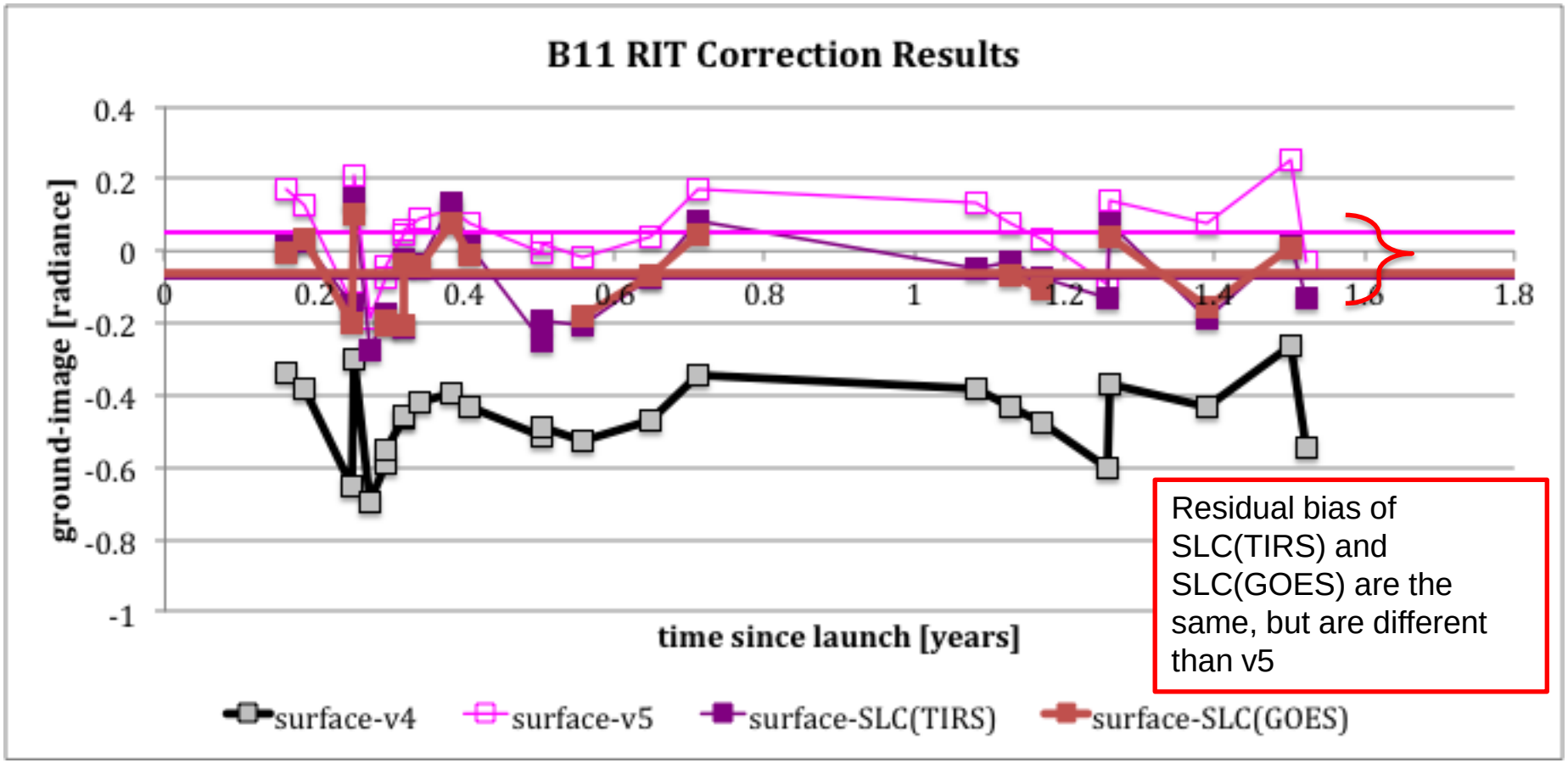


Residual biases are all about the same level, indicating that the SLC is correcting for about the same radiance as the v5 fudge factor.

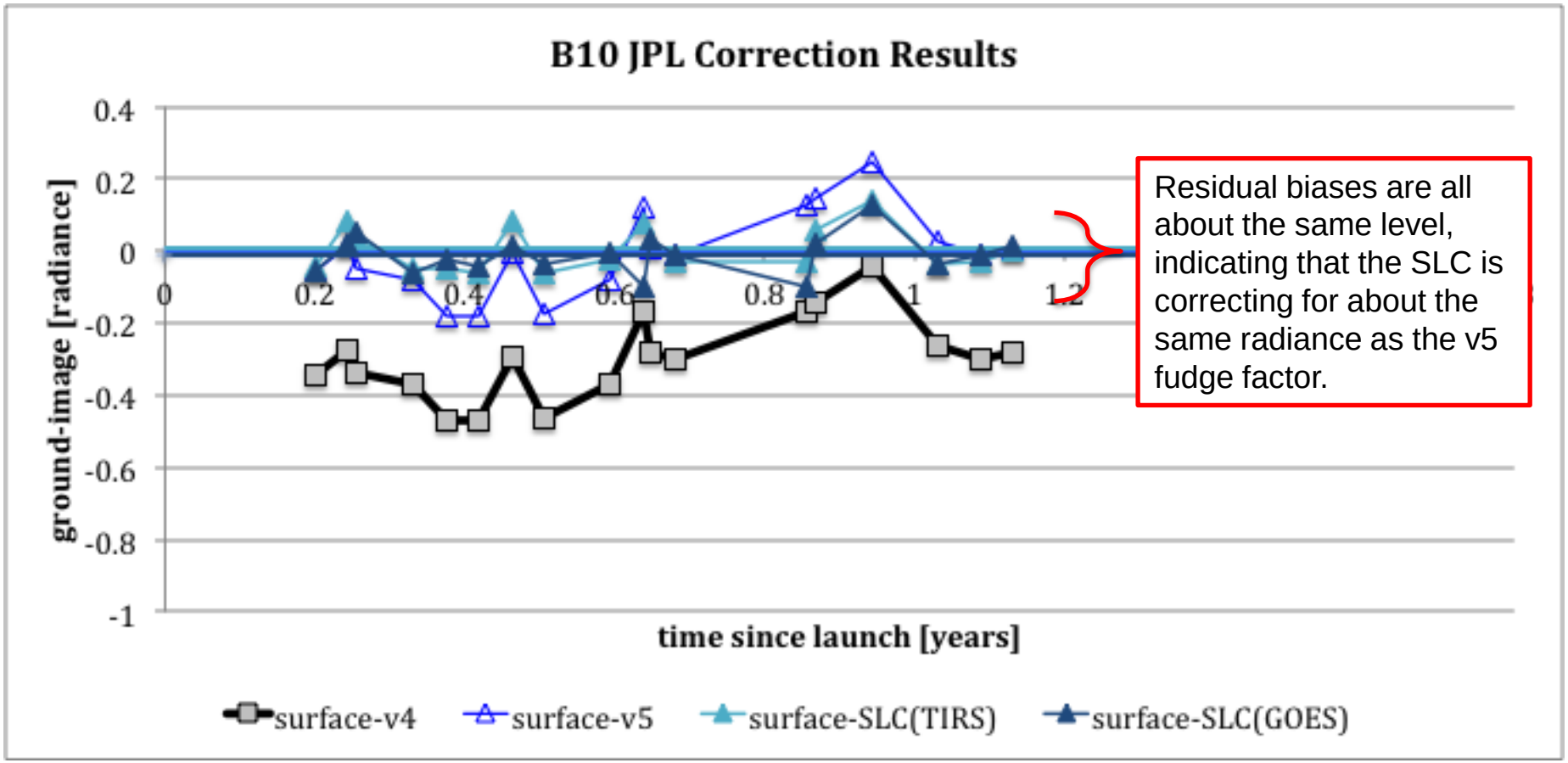
Residual Error: Band 11, JPL NIGHT



Residual Error: Band 11, RIT DAY



Residual Error: Band 10, JPL DAY



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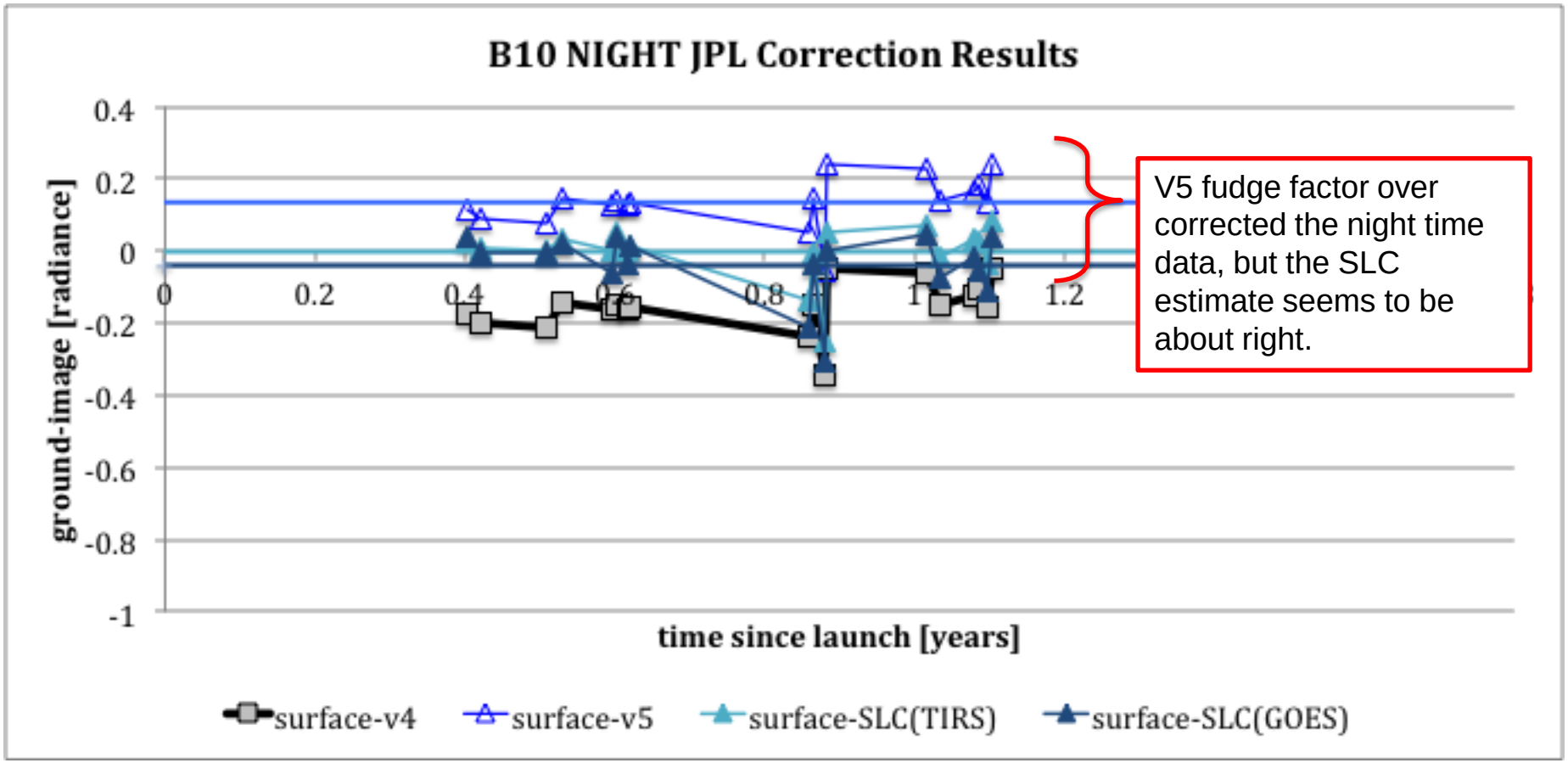
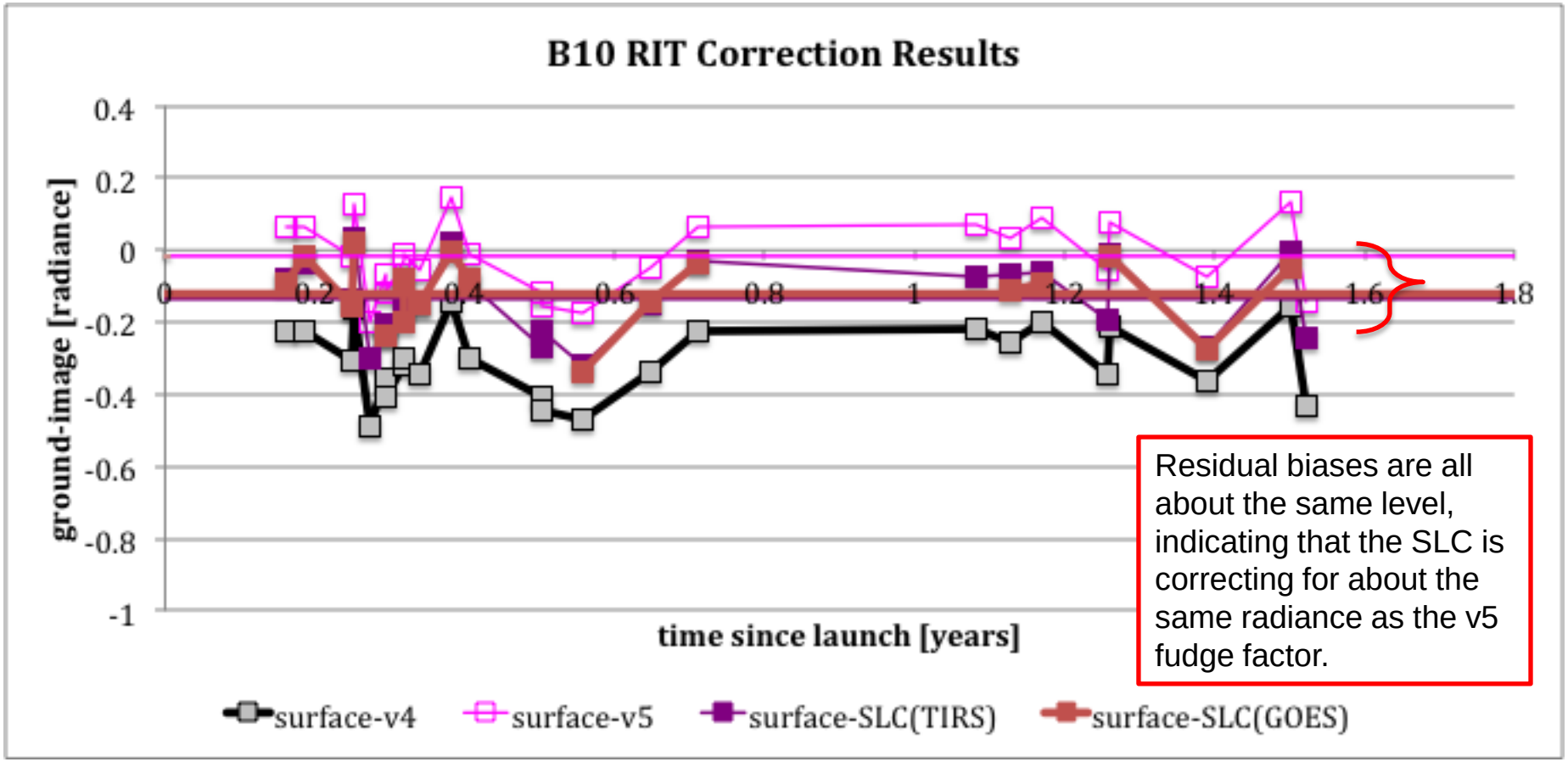
Residual Error: Band 10, JPL NIGHT



Residual Error: Band 10, RIT DAY



Residual biases are all about the same level, indicating that the SLC is correcting for about the same radiance as the v5 fudge factor.

Correction results

- **Removed residual bias from differences to highlight variability**

team		Band	N	RMS [K] V5 Calibration	RMS [K] IAS SLC(TIRS)	RMS [K] IAS SLC(GOES)
JPL	DAY	10	18	0.19	0.10	0.09
JPL	DAY	11	18	0.32	0.16	0.14
JPL	NIGHT	10	18	0.11	0.13	0.15
JPL	NIGHT	11	18	0.12	0.12	0.11
RIT	DAY	10	25*	0.14	0.14	0.18
RIT	DAY	11	25*	0.15	0.16	0.16

* N=19 for SLC(GOES)

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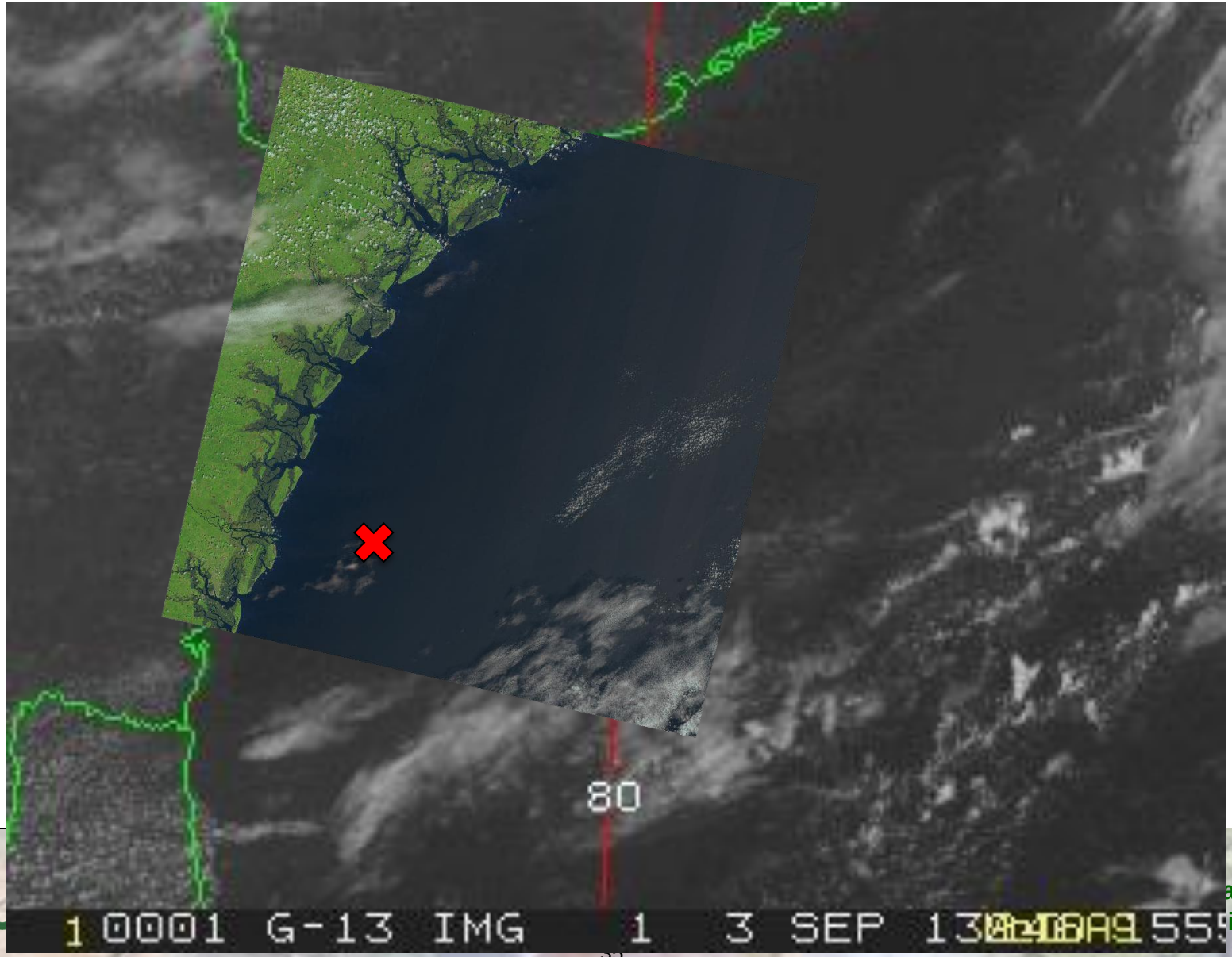

Current Status of Stray Light Correction

- **USGS EROS currently has the algorithm implemented in the Image Assessment System test environment**
  - Implementation flexible, so both the 'TIRS only' and the 'External sensor' methods can be used for testing
- **Rigorous testing underway to characterize correction results**
  - Ensure corrections improve TIRS products
  - Determine accuracy of both methods
    - Differences due to out-of-scene land cover type and clouds
  - Potentially optimize correction parameters to improve results
- **External sensor method not conducive for operational product generation**
  - Automated retrieval of GOES, Meteosat, or other external sensor data would delay processing

Path Forward

- **Quantify residual error of stray light correction**
  - Including any improvments
- **Push stray light correction into production (likely Summer/Fall 2015)**
  - Proposal to use ‘TIRS-only’ method
  - Possibly generate more accurate CONUS scenes using GOES imagery as a Level-2 product days after acquisition
  - Possibly provide off-line tool for ‘External sensor’ method
- **Peer reviewed manuscripts for stray light correction in process**

References

- ***More information for Stray Light & effects in TIRS in:***
  - Montanaro, M.; Gerace, A.; Lunsford, A.; Reuter, D. Stray Light Artifacts in Imagery from the Landsat 8 Thermal Infrared Sensor. Remote Sensing 2014, 6(11), 10435-10456. http://www.mdpi.com/2072-4292/6/11/10435
  - Montanaro, M.; Lunsford, A.; Tesfaye, Z.; Wenny, B.; Reuter, D. Radiometric Calibration Methodology of the Landsat 8 Thermal Infrared Sensor. Remote Sensing 2014, 6(9), 8803-8821. http://www.mdpi.com/2072-4292/6/9/8803
  - Barsi, J.; Schott, J.; Hook, S.; Raqueno, N.; Markham, B. TIRS Vicarious Radiometric Calibration. Remote Sensing 2014, 6(11), 11607-11626. http://www.mdpi.com/2072-4292/6/11/11607.