Landsat Calibration Update

D. Helder, B. Markham, R. Morfitt, Jim Storey,Joel McCorkel

Landsat Science Team Meeting

February 4, 2015

Goddard Space Flight Center

South Dakota State University
Image Processing Lab

The Team

- GSFC
  - Brian Markham
  - Julia Barsi
  - Ed Kaita
  - Lawrence Ong
  - Raviv Levy
  - Joel McCorkel
  - Kurt Thome
- EROS
  - Ron Morfitt
  - Jim Storey
  - Mike Choate
  - Pat Scaramuzza
  - Esad Micijevic
  - Ron Hayes
  - Obaidul Haque
  - Kelley VanDerWerff
  - Mark Lubke
- JPL
  - Simon Hook
- SDSU
  - Dennis Helder
  - Dave Aaron
  - Larry Leigh
  - Nischal Mishra
  - Morakot Kaewmanee
  - \+ students
- RIT
  - John Schott
  - Nina Raqueno
  - Aaron Gerace
  - Matt Montanaro
  - \+ students
- U of A
  - Jeff Czapla-Myers
  - Stu Biggar
  - Nik Andersen

…and the list is not exhaustive!

Outline

- OLI Calibration
  - Relative Gains
  - Stability
  - Absolute Cal
  - Geometry
- PICS
  - OLI performance
  - Dark Targets
  - Cloud Screening
- Cross-cal with Sentinel 2
  - Algodones Dunes Campaign
- Landsat Archive
  - MSS
  - Reflectance Cal

OLI Relative Gain Validation Study

D. Helder, N. Mishra, F. Pesta,
J. Ulmer

Landsat 8 CVT

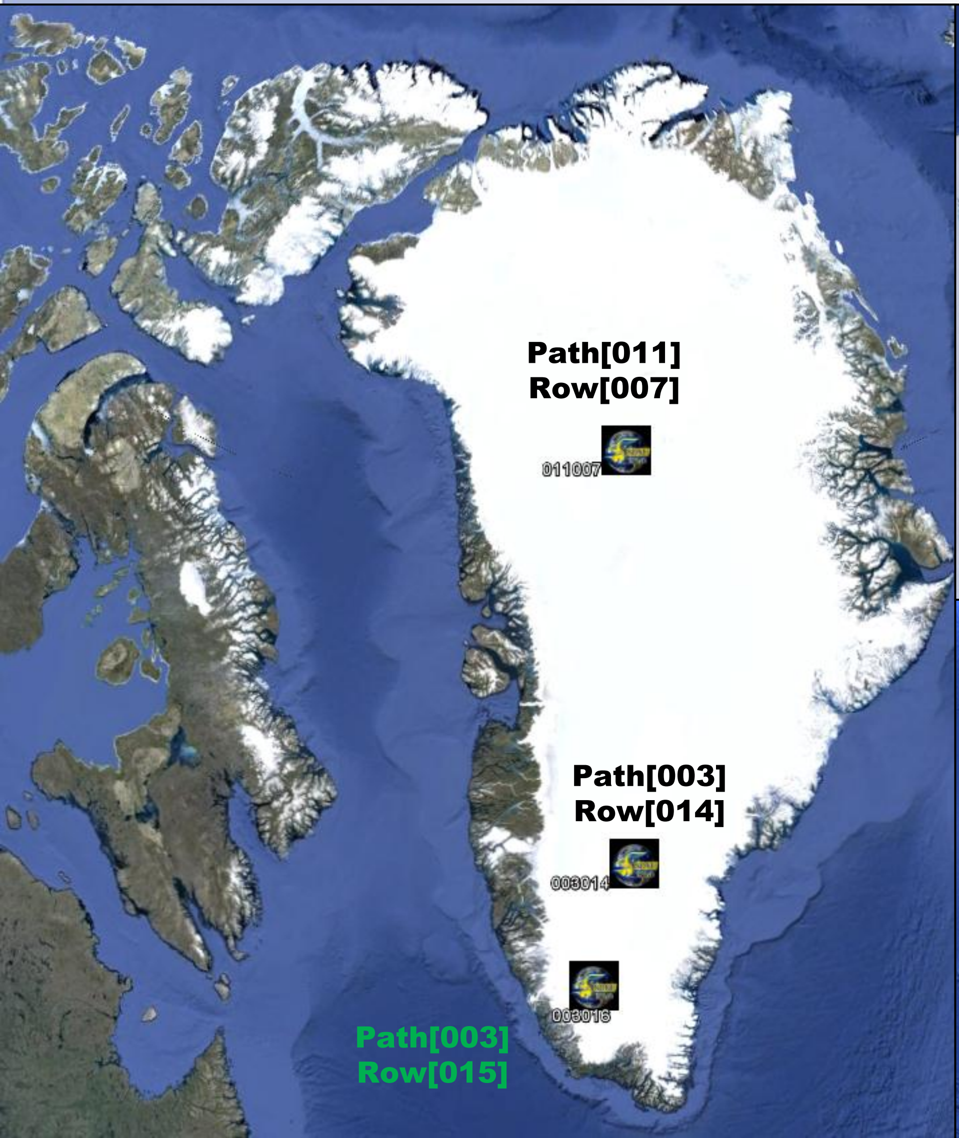
September 16, 2014

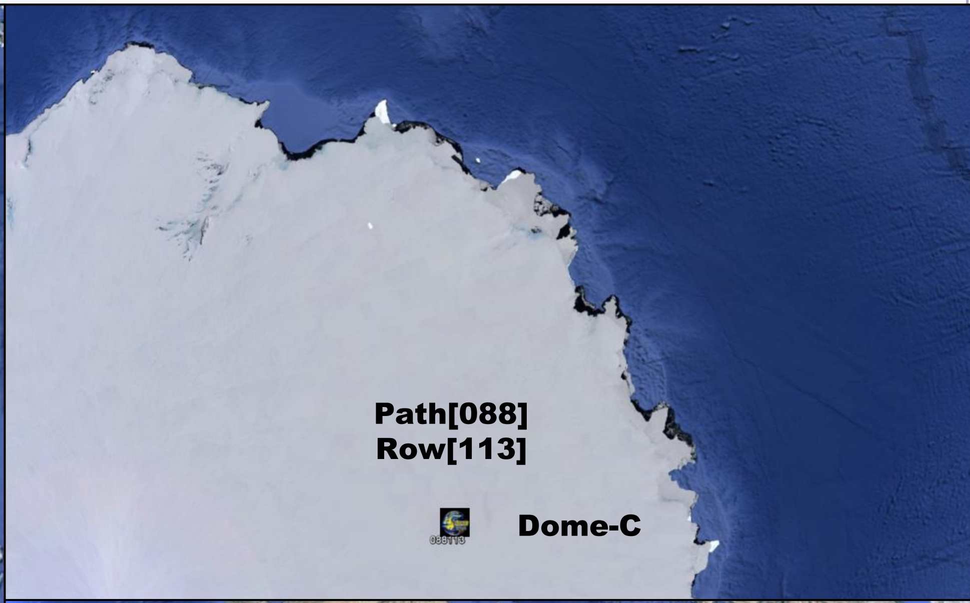
South Dakota State University
Image Processing Lab

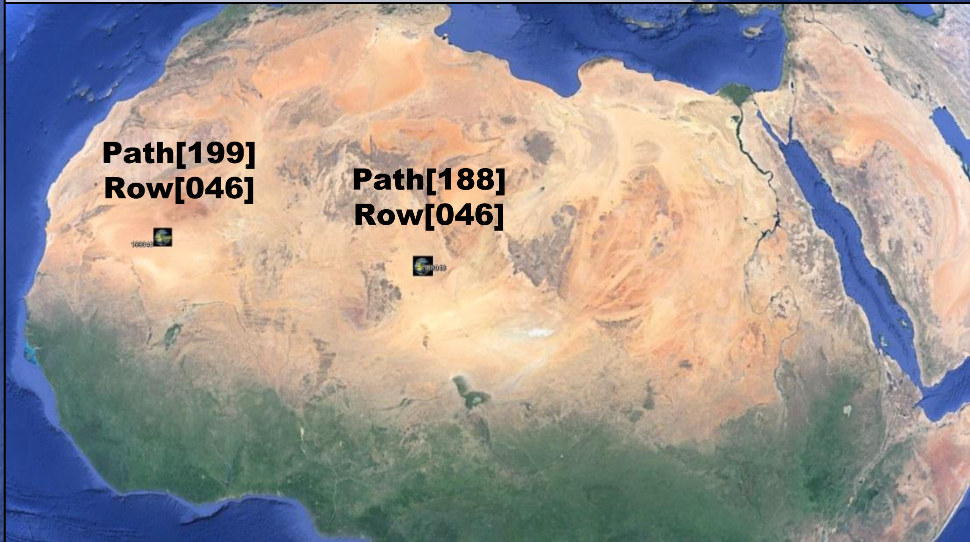
Introduction

- Although within design specs, streaking in certain OLI bands is still discernible in Earth imagery (Blues, SWIRs)
- Three methods of characterizing detector non-uniformity:
  - diffuser (primary)
  - side slither (secondary)
  - lifetime stats (secondary, still developing)
- How well do these work with OLI?

Snow and Desert Test Sites







Description of SS Collects Used

Interval	Date of Collect	Location	Path	Rows
SS2013085	3-26-2013	Niger	189	45-48
SS2013095	4-5-2013	Libya/Niger	187	38-49
SS2013110	4-20-2013	Egypt	177	36-47
SS2013114	4-24-2013	Greenland	4	3-22
SS2013126	5-6-2013	Egypt	177	33-47
SS2013132	5-12-2013	Greenland	2	4-25
SS2013194	7-13-2013	Greenland	4	5-21
SS2013334	11-30-2013	Antarctica	88	103-117
SS2013350	12-16-2013	Antarctica	88	103-117
SS2014001	1-1-2014	Antarctica	88	103-117
SS2014101	4-11-2014	Niger	189	44-51
SS2014197	7-16-2014	Greenland	4	5-21

Test Metrics

- Streaking

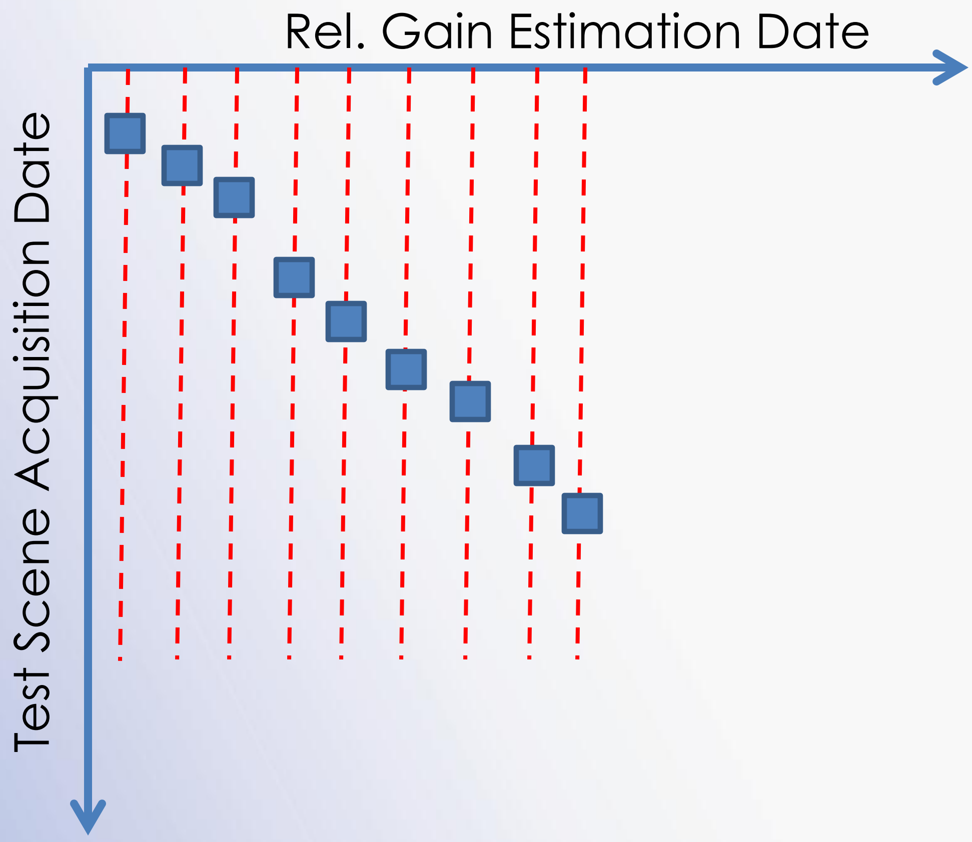
$$S_i = \frac{\left|\bar{L}_i - \frac{1}{2}\left(\bar{L}_{i-1} + \bar{L}_{i+1}\right)\right|}{\bar{L}_i}$$

- Banding

$$B_i = \sqrt{\sum_{i=n}^{n+99} \frac{\left(\bar{L}_i - \bar{L}\right)^2}{99}}$$

Results

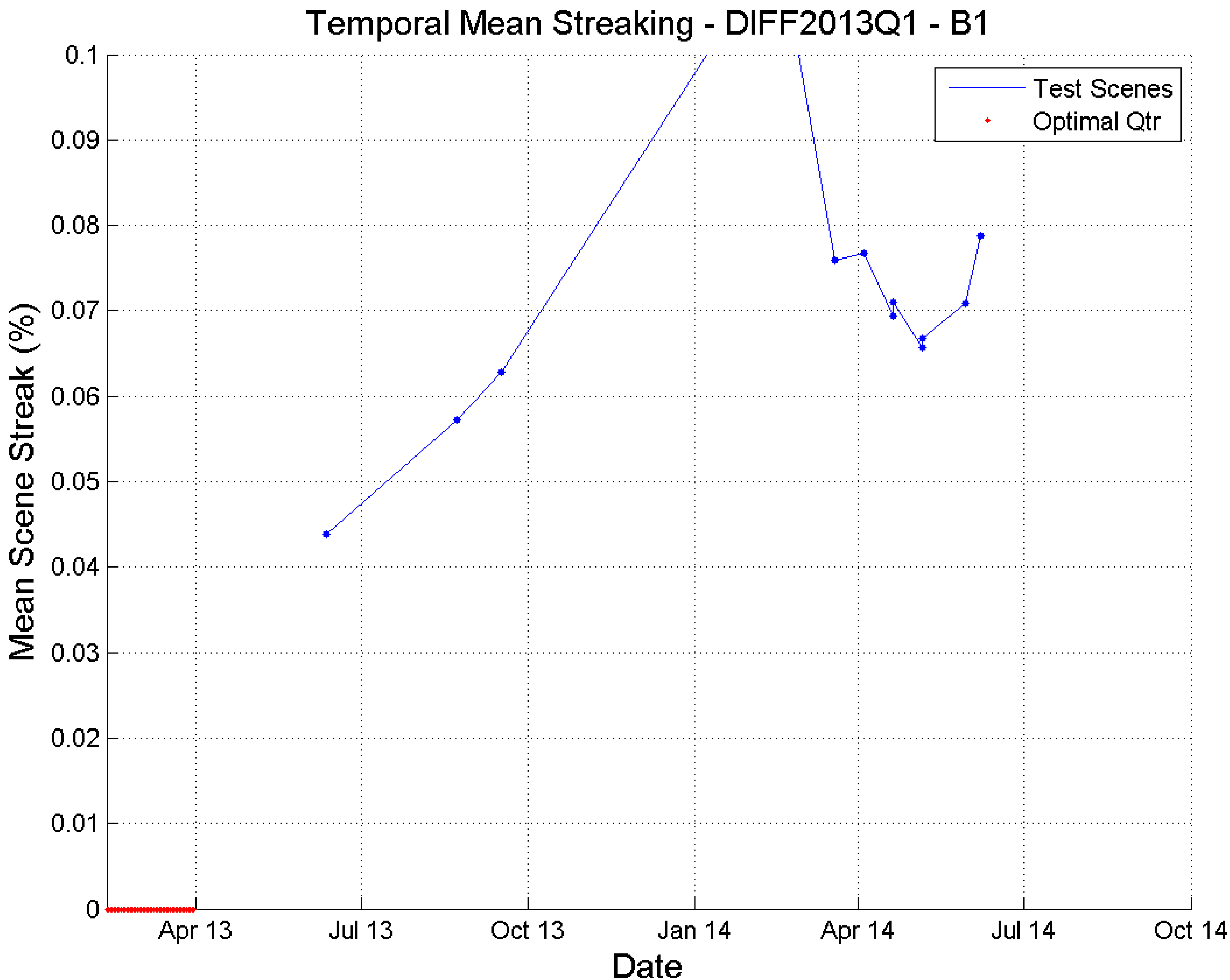
- Visual/Qualitative
- Quantitative



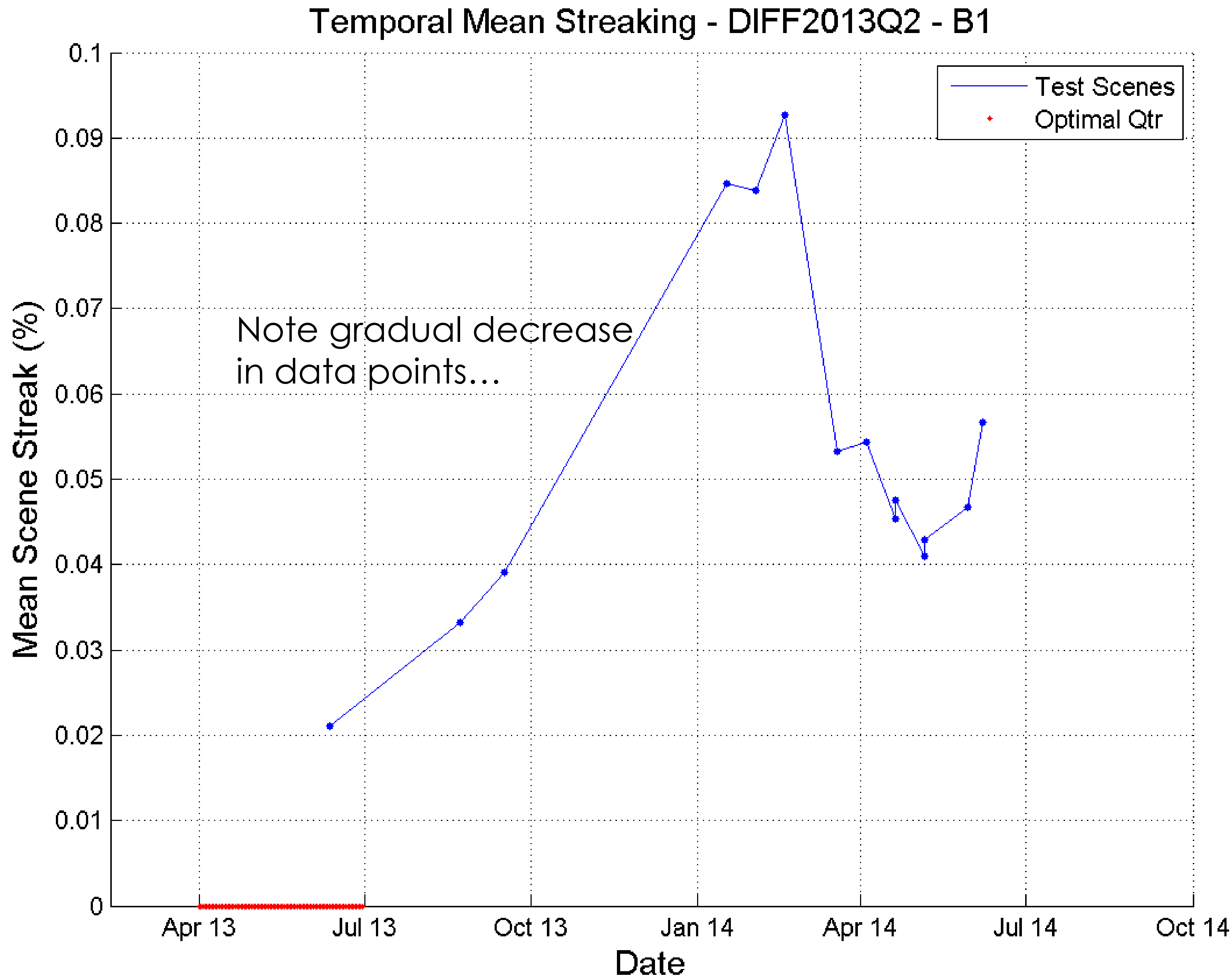
Results

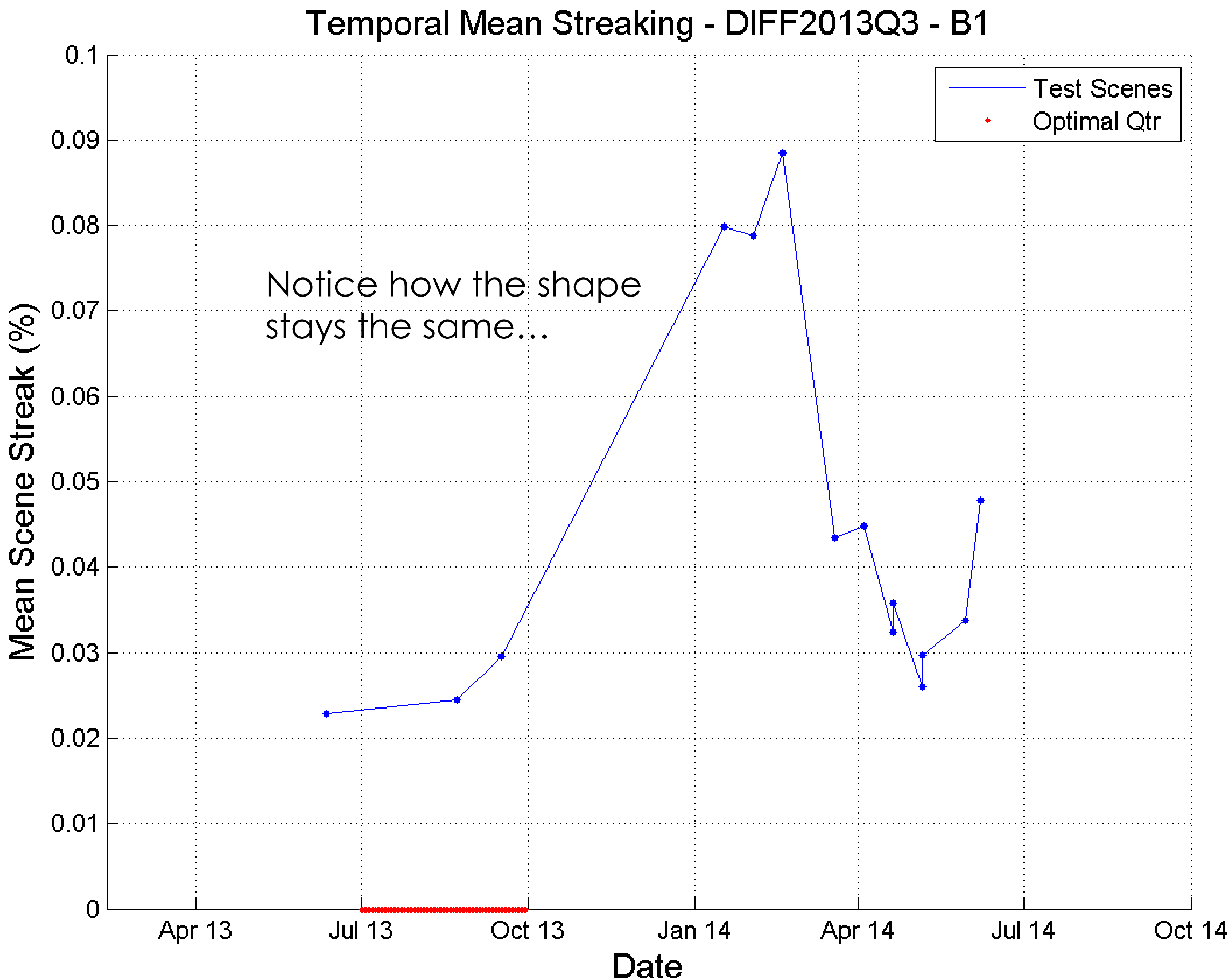
- Visual/Qualitative
- Quantitative*
  - BAND 1 (Coastal Aerosol)

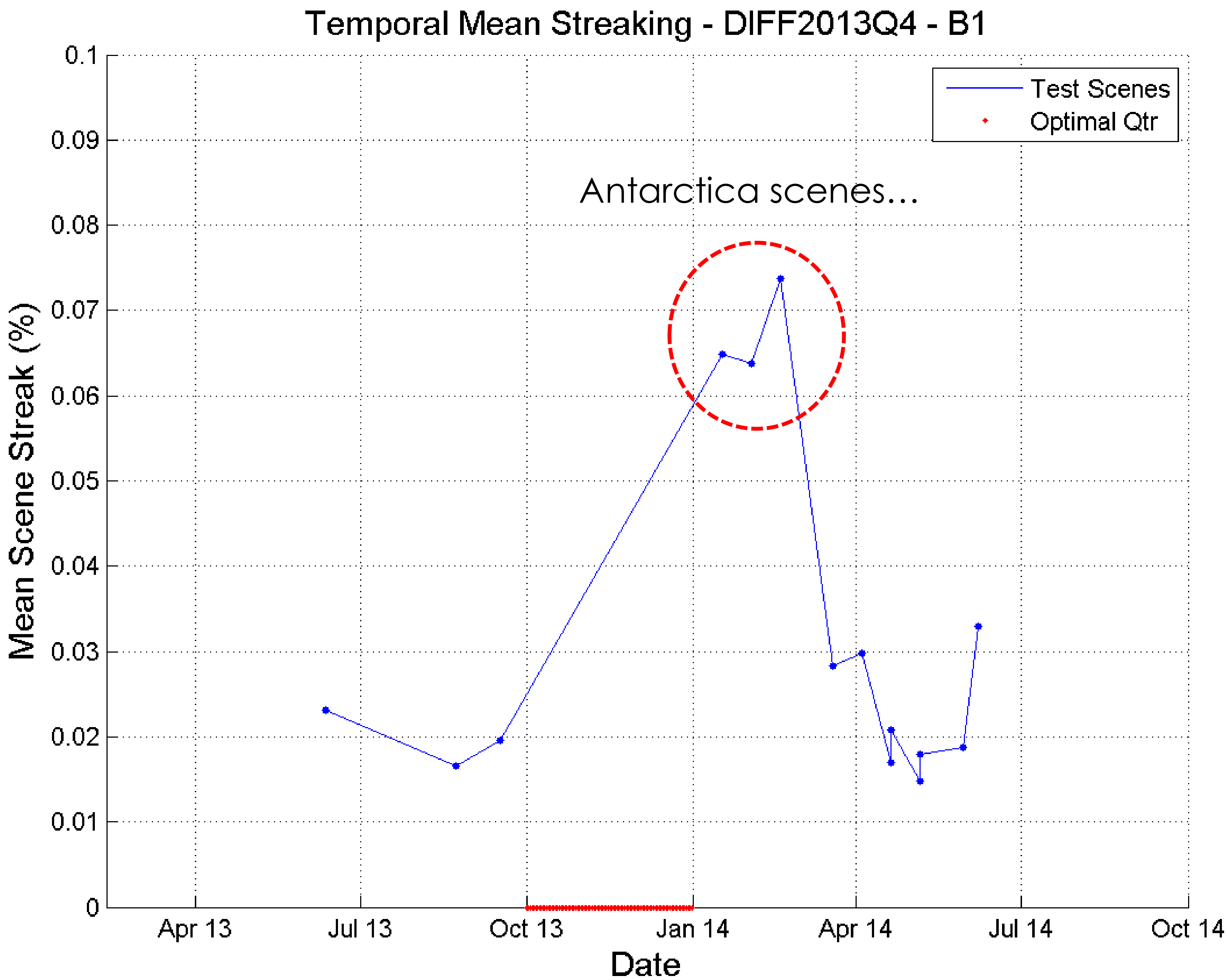
*All plots posted on Frank's website:
https://ldcm-cal.gsfc.nasa.gov/EROS/EROS_web/html/fjpesta/rel_gain_validation/



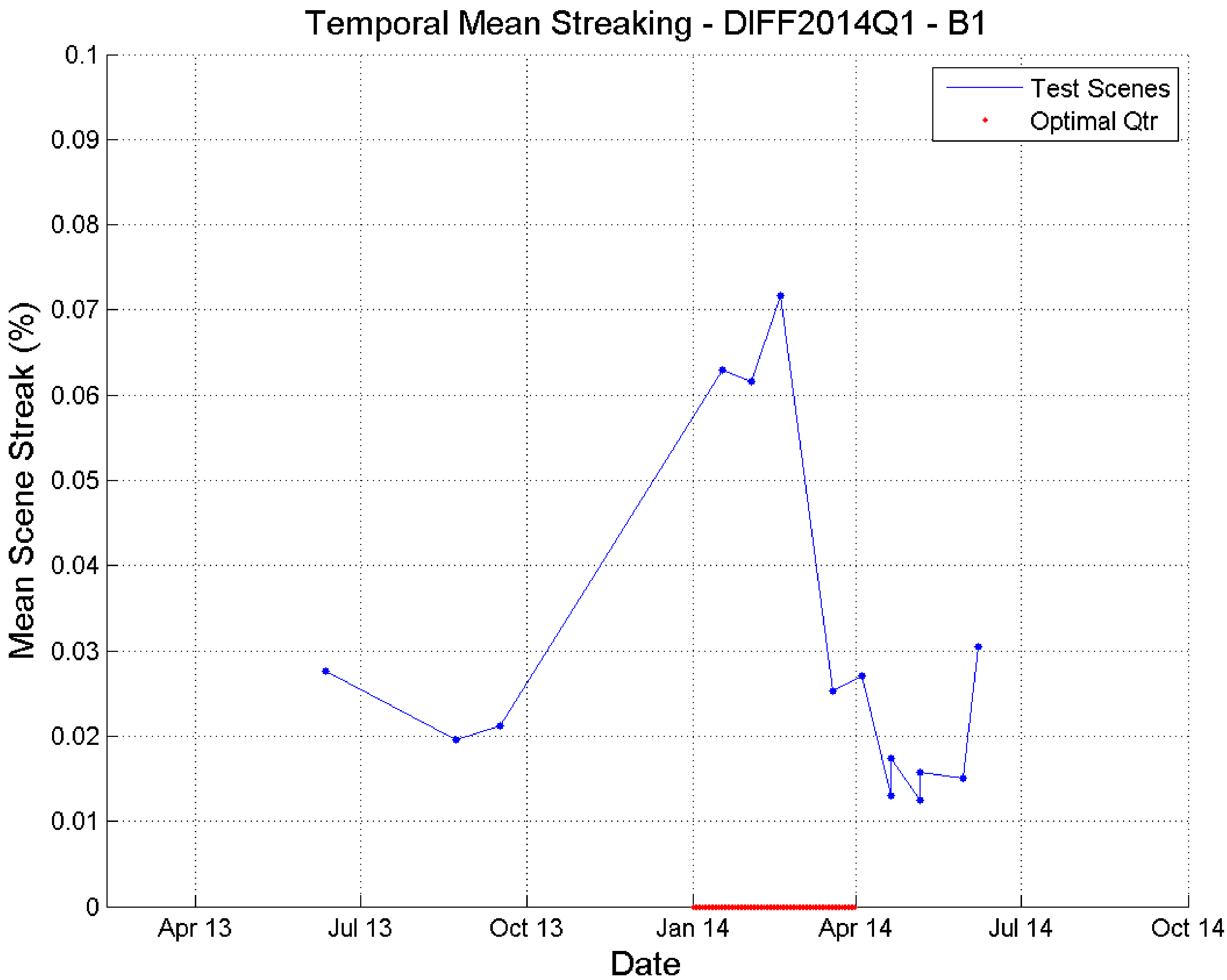
Temporal Mean Streaking - DIFF2013Q1 - B1
Test Scenes
Optimal Qtr
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date

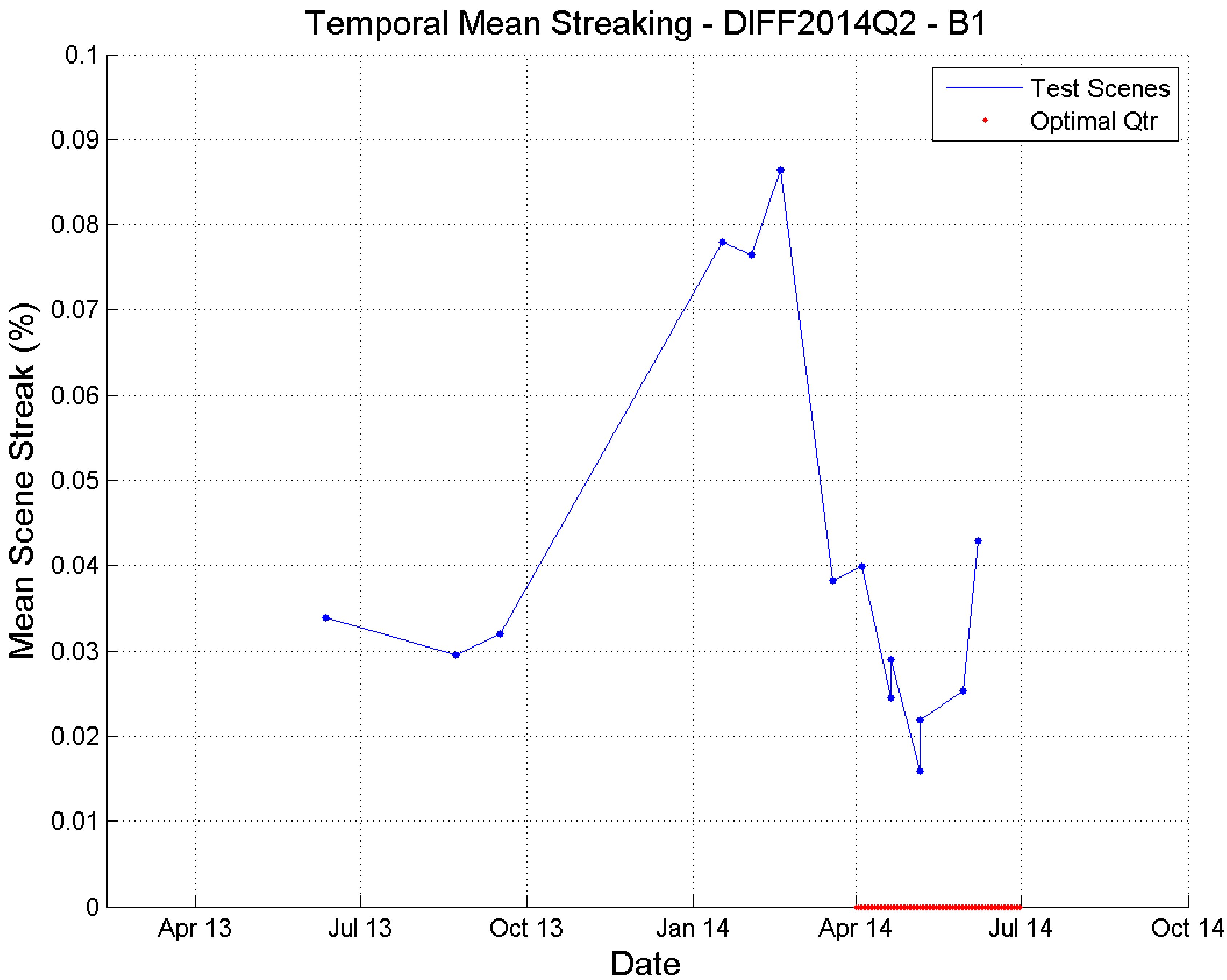

Temporal Mean Streaking - DIFF2013Q2 - B1
Test Scenes
Optimal Qtr
Note gradual decrease
in data points…
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date


Temporal Mean Streaking - DIFF2013Q3 - B1
Test Scenes
Optimal Qtr
Notice how the shape stays the same…
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date

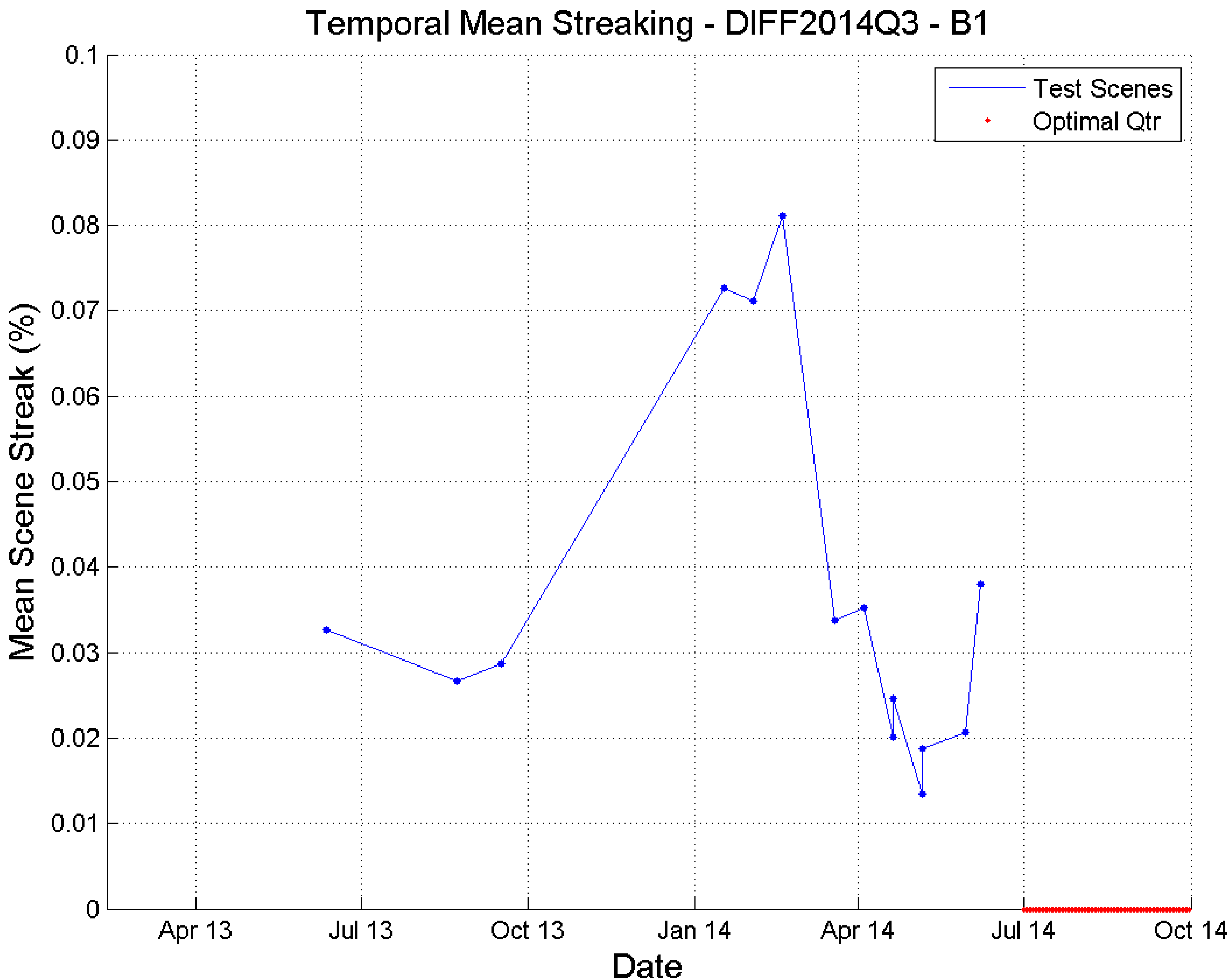


Temporal Mean Streaking - DIFF2013Q4 - B1
Test Scenes
Optimal Qtr
Antarctica scenes...
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date

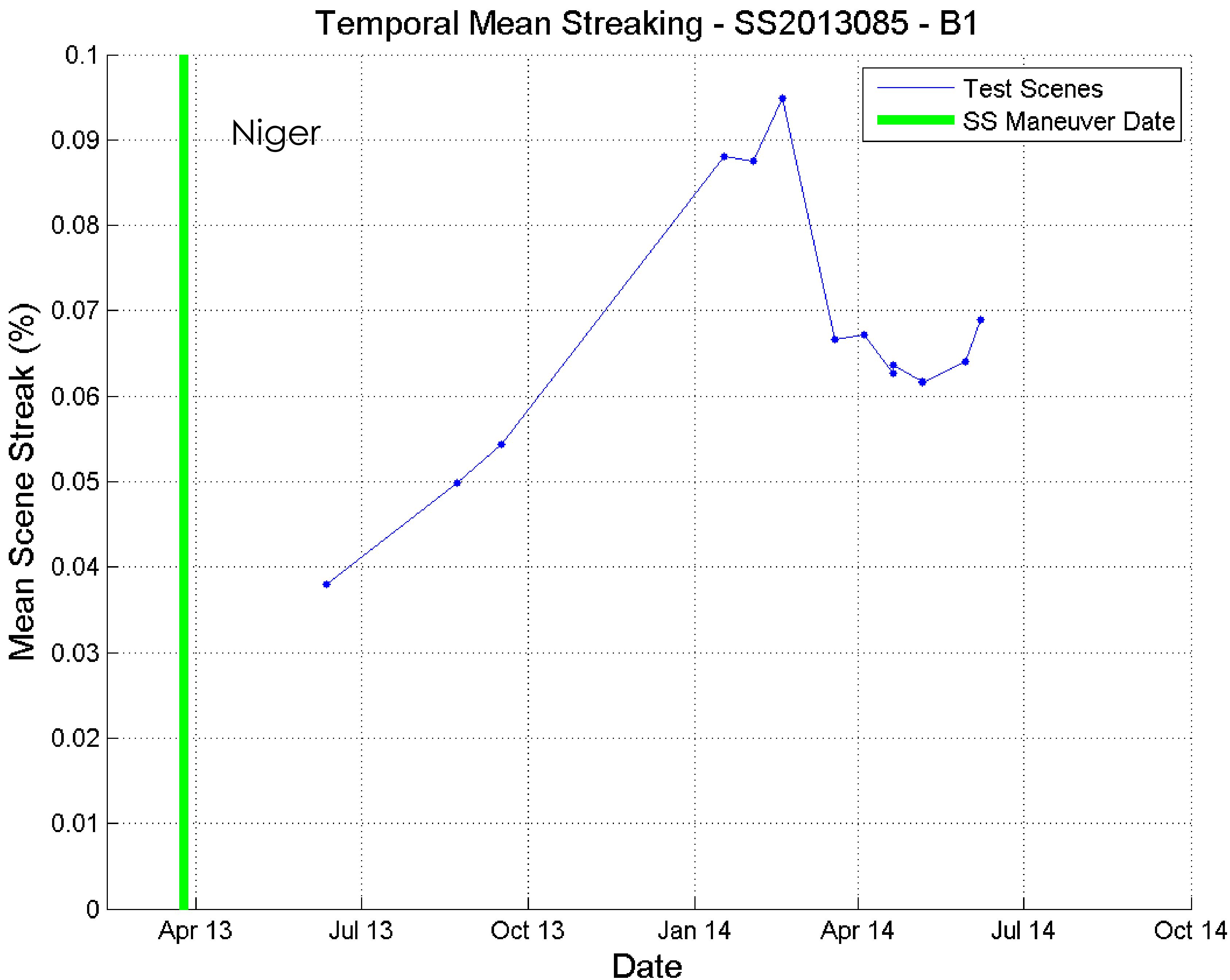

Temporal Mean Streaking - DIFF2014Q1 - B1
Test Scenes
Optimal Qtr
Mean Scene Streak (%)
Date
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14



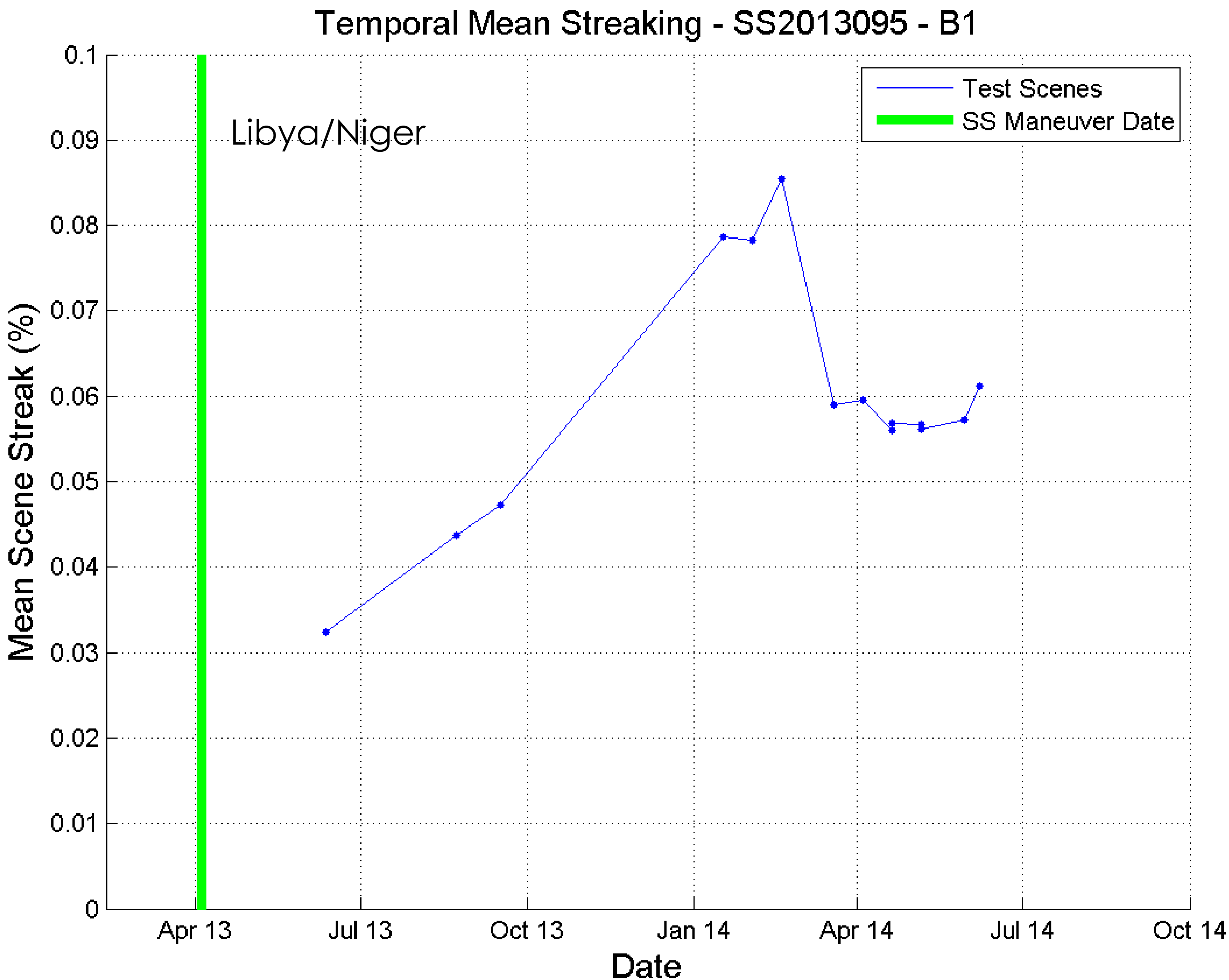
Temporal Mean Streaking - DIFF2014Q2 - B1
Test Scenes
Optimal Qtr
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date



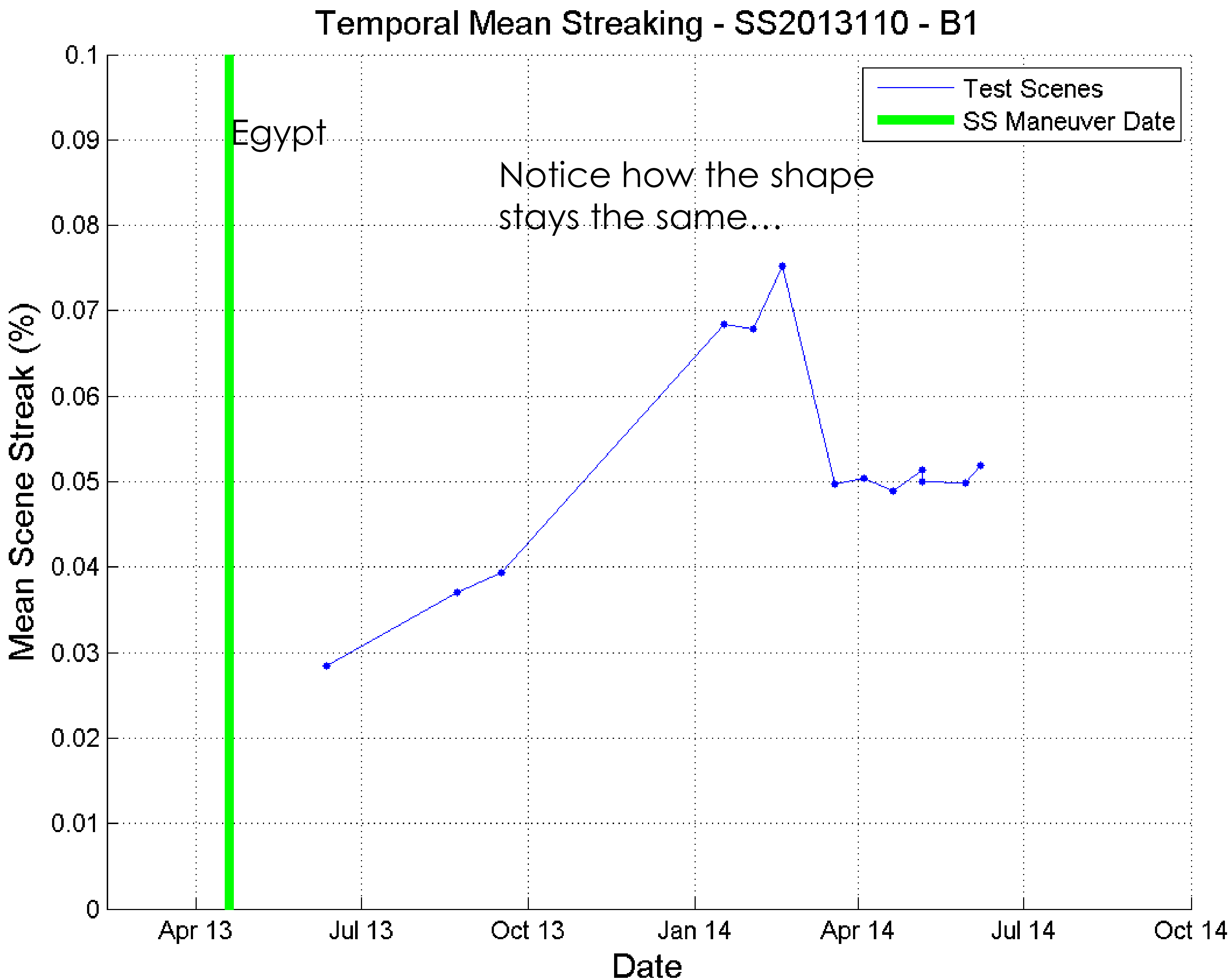
Temporal Mean Streaking - DIFF2014Q3 - B1
Test Scenes
Optimal Qtr
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date



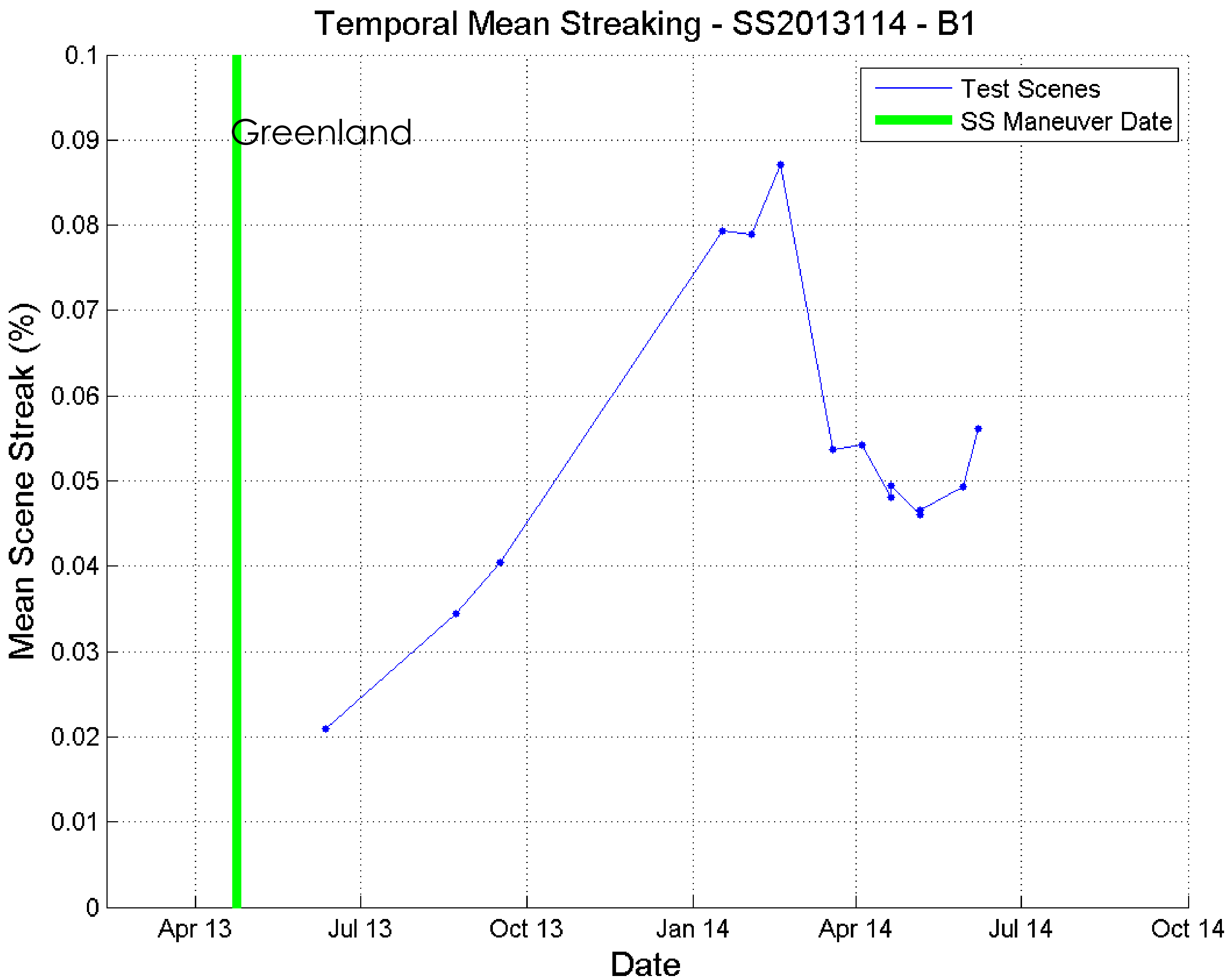
Temporal Mean Streaking - SS2013085 - B1
Niger
Test Scenes
SS Maneuver Date
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date



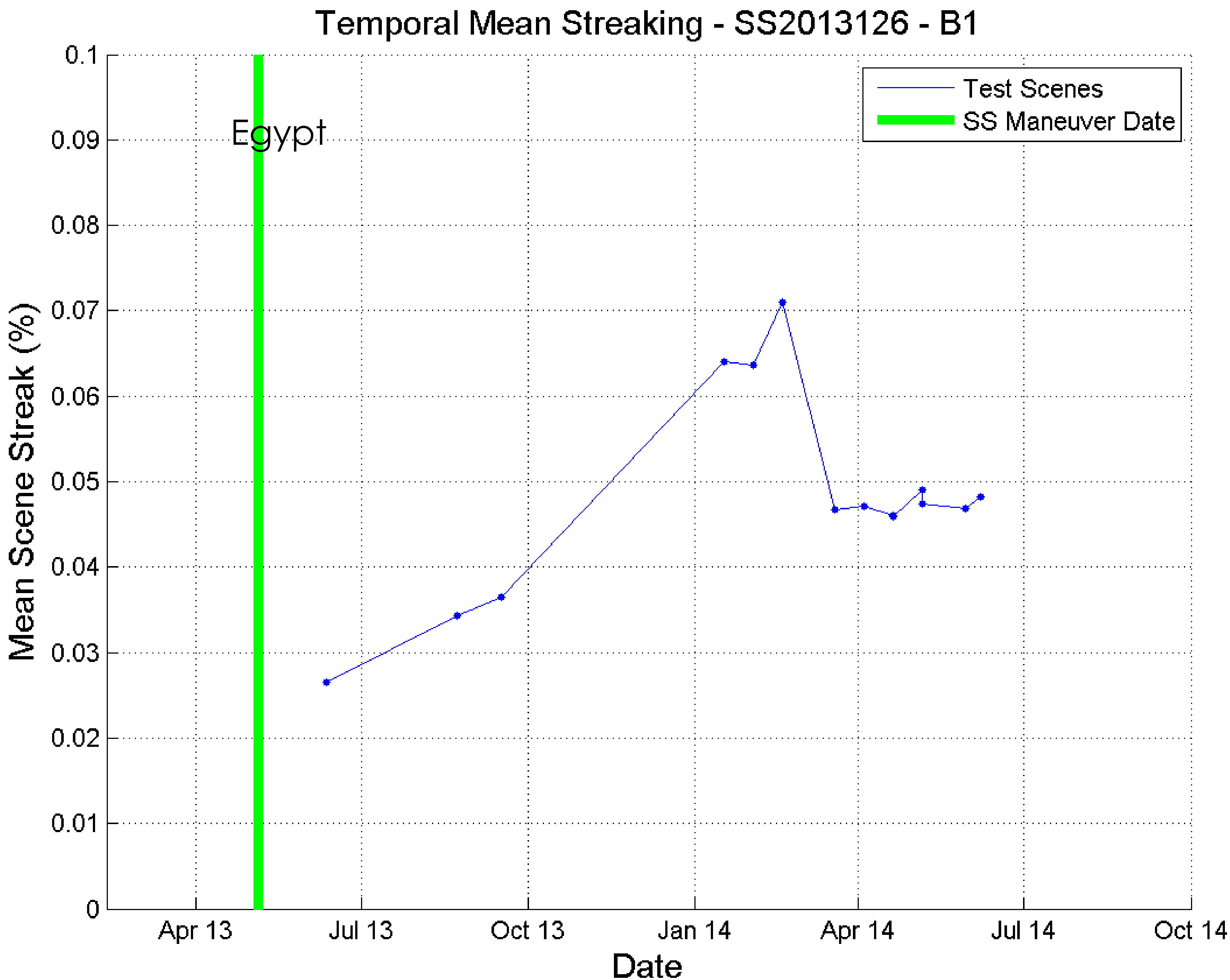
Temporal Mean Streaking - SS2013095 - B1
Test Scenes
SS Maneuver Date
Libya/Niger
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date



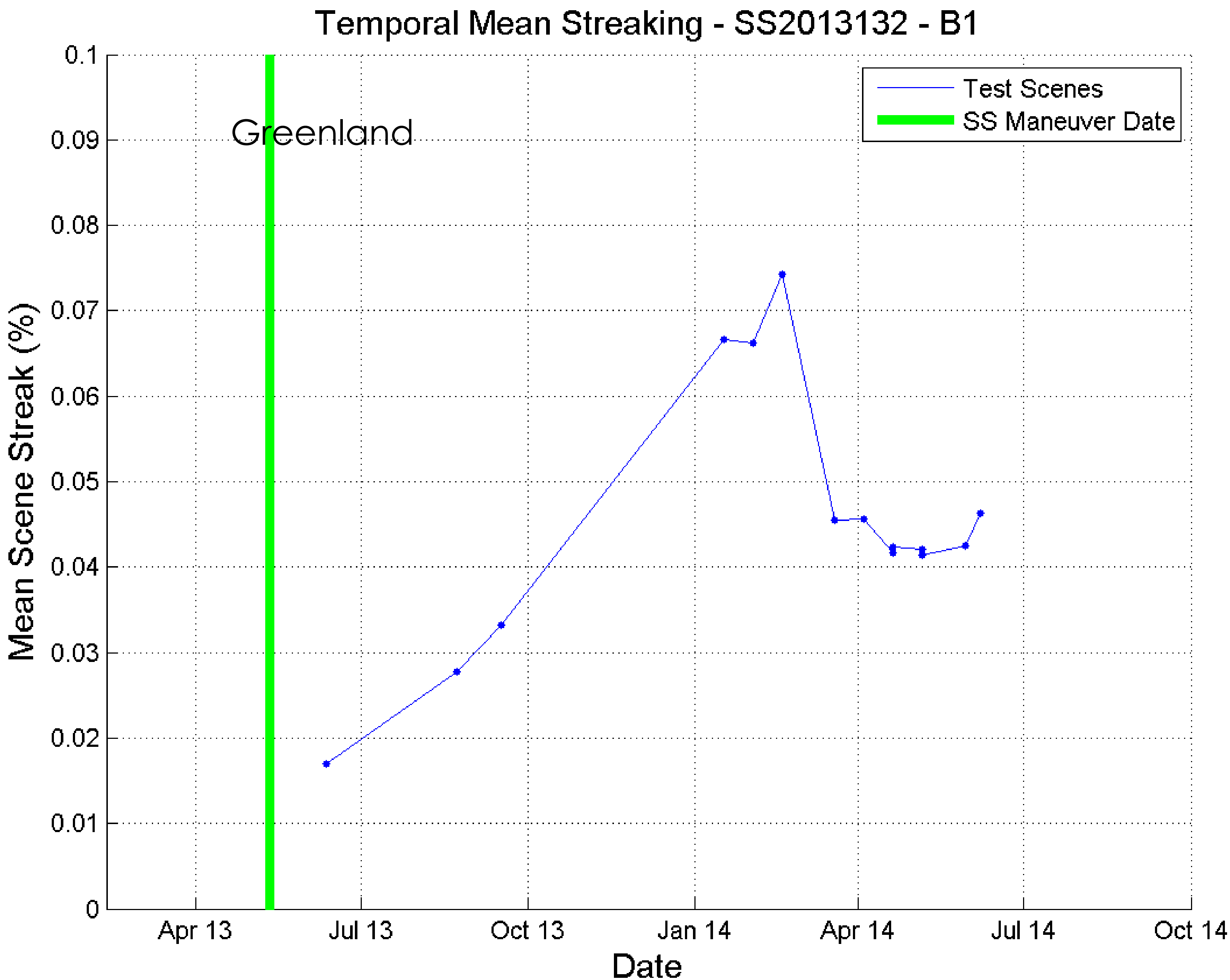
Temporal Mean Streaking - SS2013110 - B1
Test Scenes
SS Maneuver Date
Egypt
Notice how the shape
stays the same...
Mean Scene Streak (%)
Date
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14

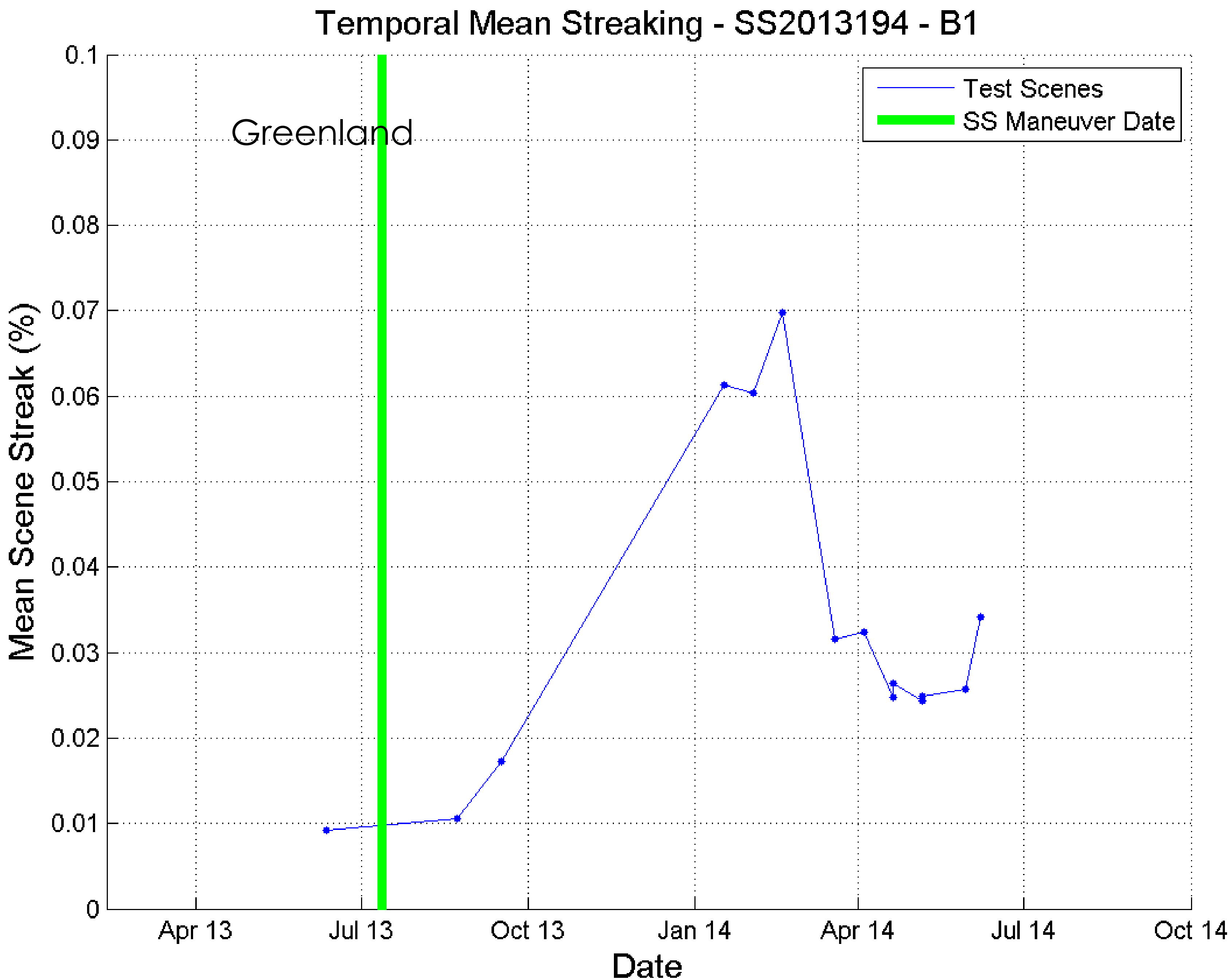


Temporal Mean Streaking - SS2013114 - B1
Greenland
Test Scenes
SS Maneuver Date
Mean Scene Streak (%)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date

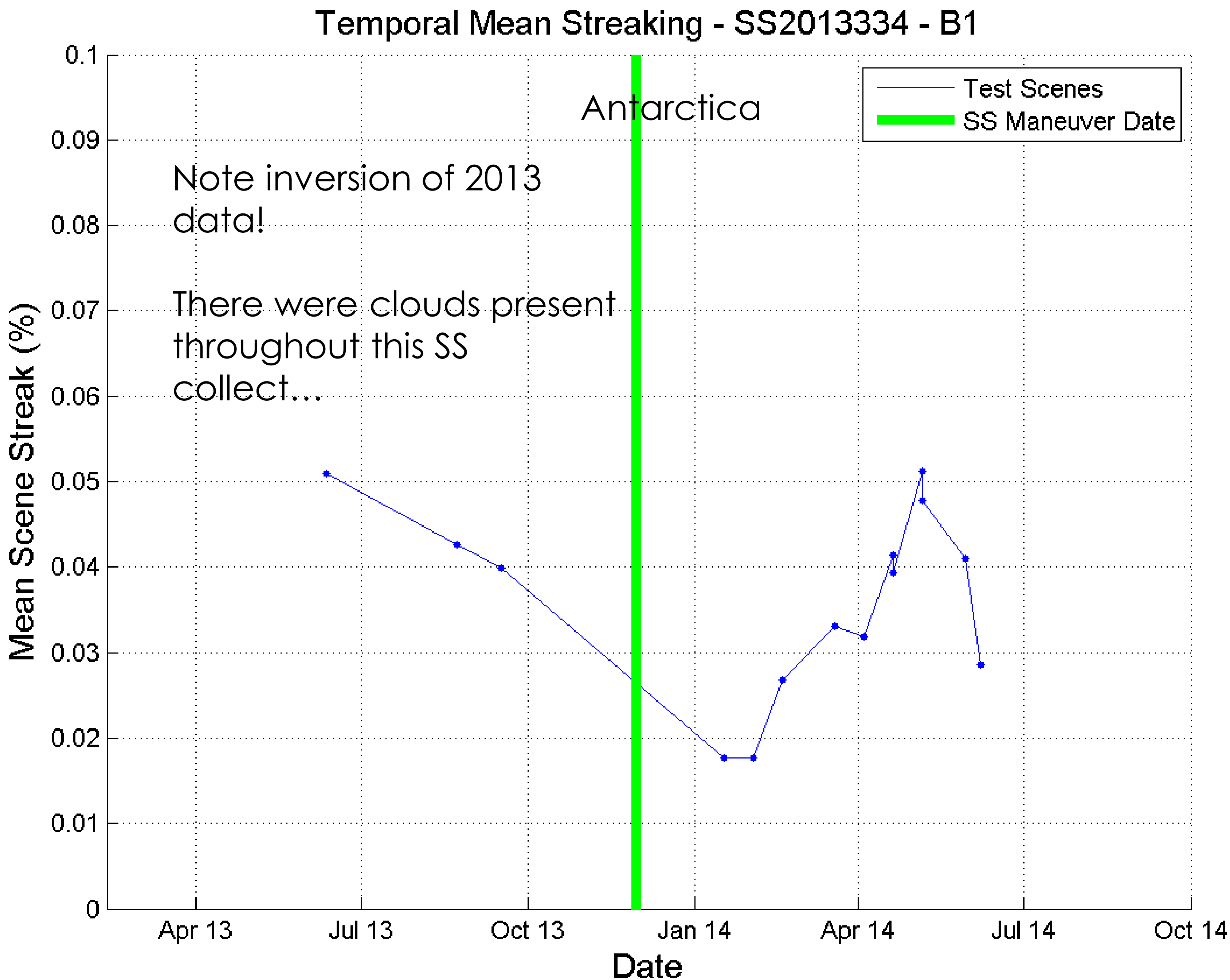


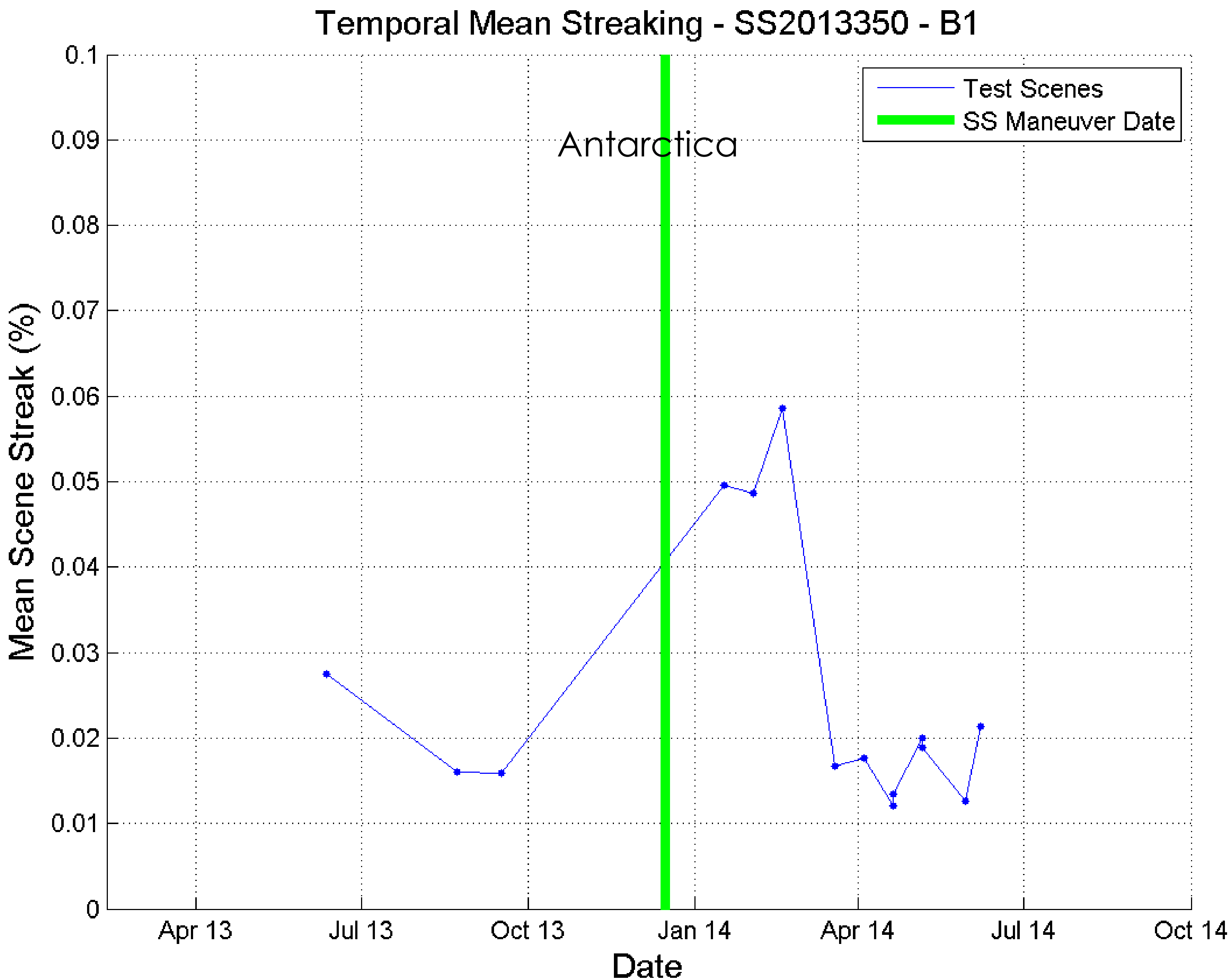
Temporal Mean Streaking - SS2013126 - B1
Test Scenes
SS Maneuver Date
Egypt
Mean Scene Streak (%)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date


Temporal Mean Streaking - SS2013132 - B1
Test Scenes
SS Maneuver Date
Greenland
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date

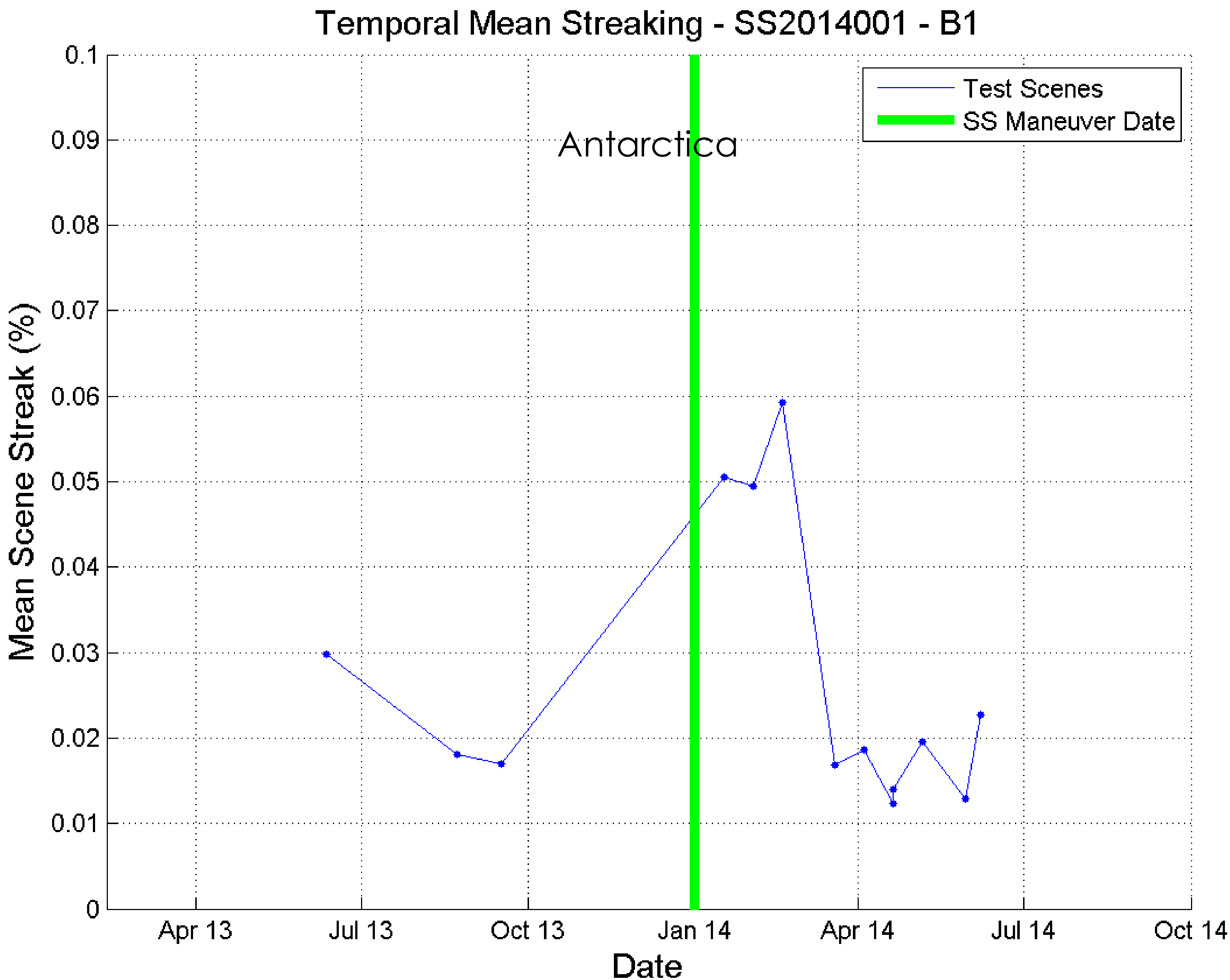


Temporal Mean Streaking - SS2013194 - B1
Greenland
Test Scenes
SS Maneuver Date
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date

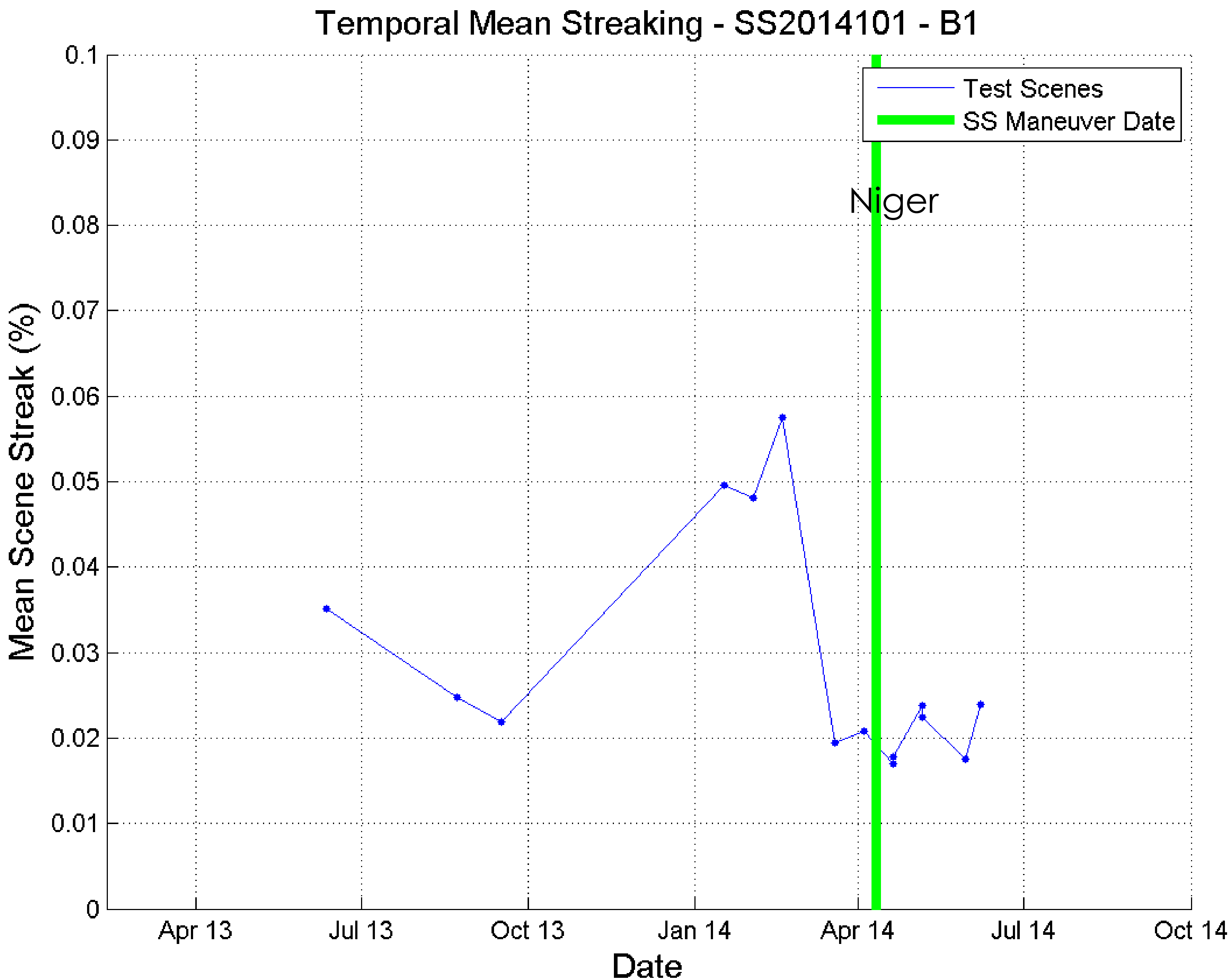

Temporal Mean Streaking - SS2013334 - B1
Test Scenes
SS Maneuver Date
Antarctica
Note inversion of 2013 data!
There were clouds present throughout this SS collect...
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date



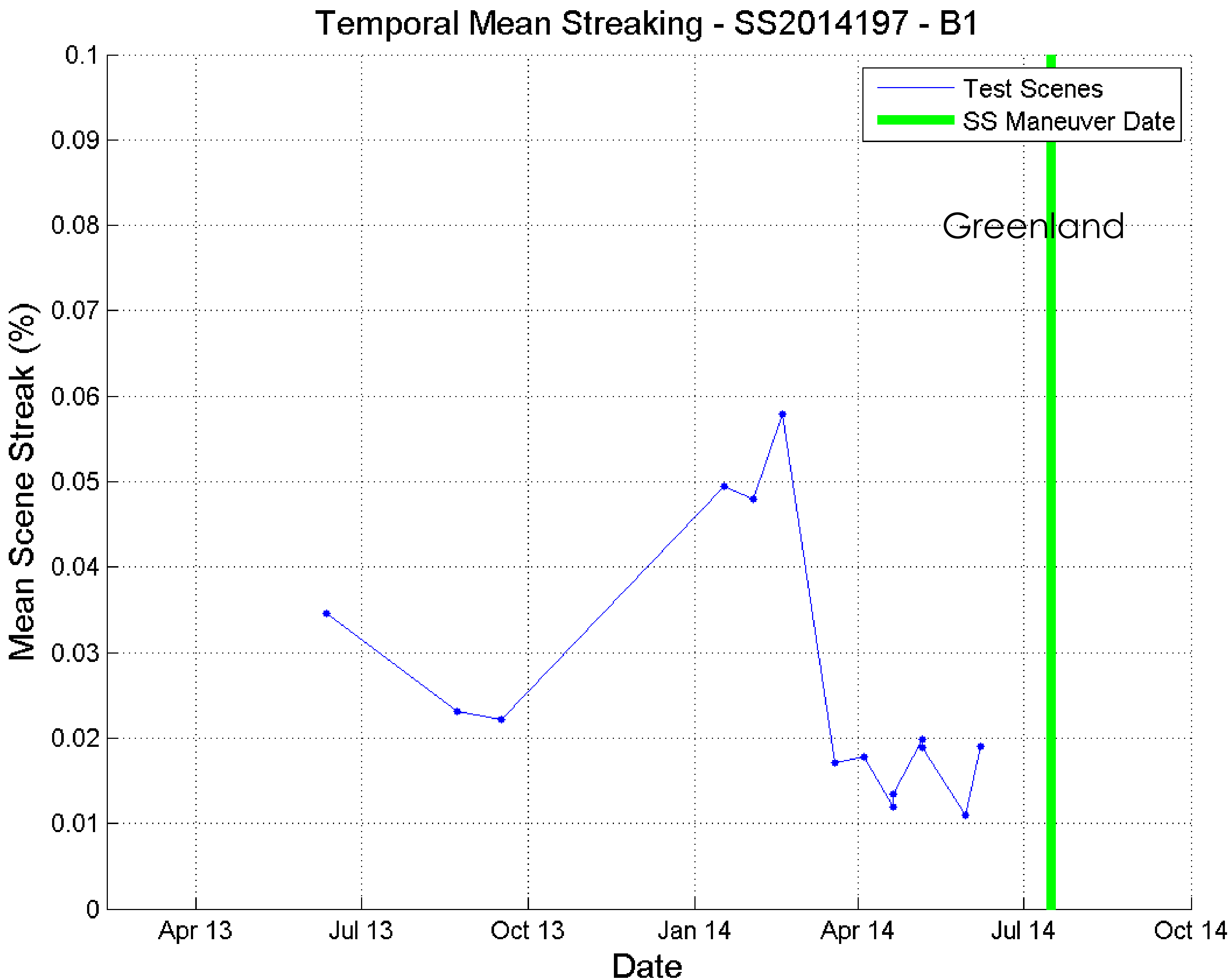
Temporal Mean Streaking - SS2013350 - B1
Test Scenes
SS Maneuver Date
Antarctica
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date



Temporal Mean Streaking - SS2014001 - B1
Test Scenes
SS Maneuver Date
Antarctica
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date



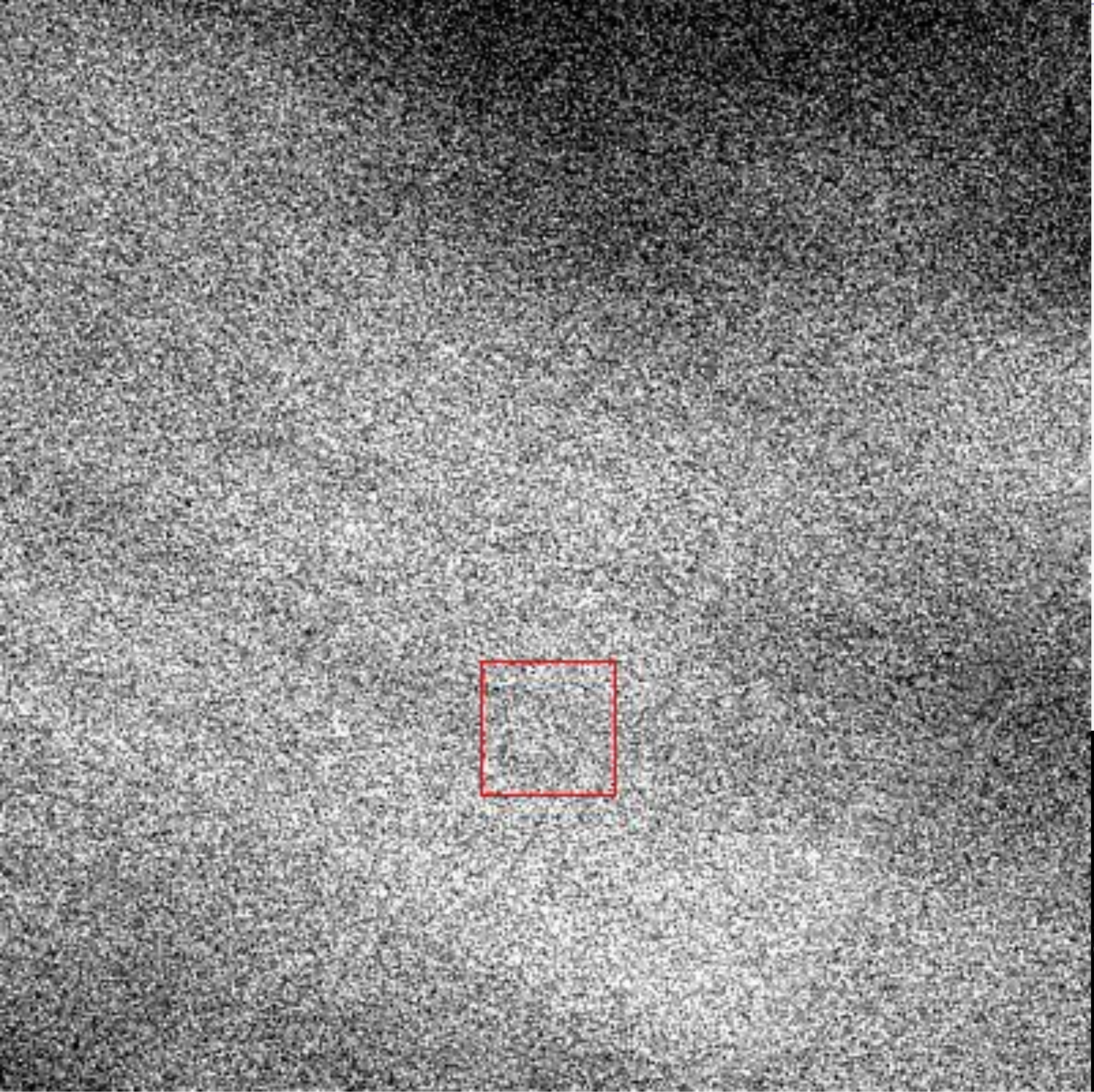
Temporal Mean Streaking - SS2014101 - B1
Test Scenes
SS Maneuver Date
Niger
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date



Temporal Mean Streaking - SS2014197 - B1
Test Scenes
SS Maneuver Date
Greenland
Mean Scene Streak (%)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Apr 13
Jul 13
Oct 13
Jan 14
Apr 14
Jul 14
Oct 14
Date

Visual Example of Top 5 Rankings

- Band 1
- Greenland (p11/r7)
- FPM 10

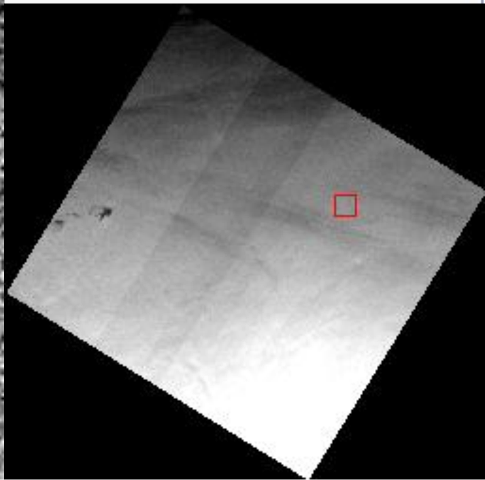


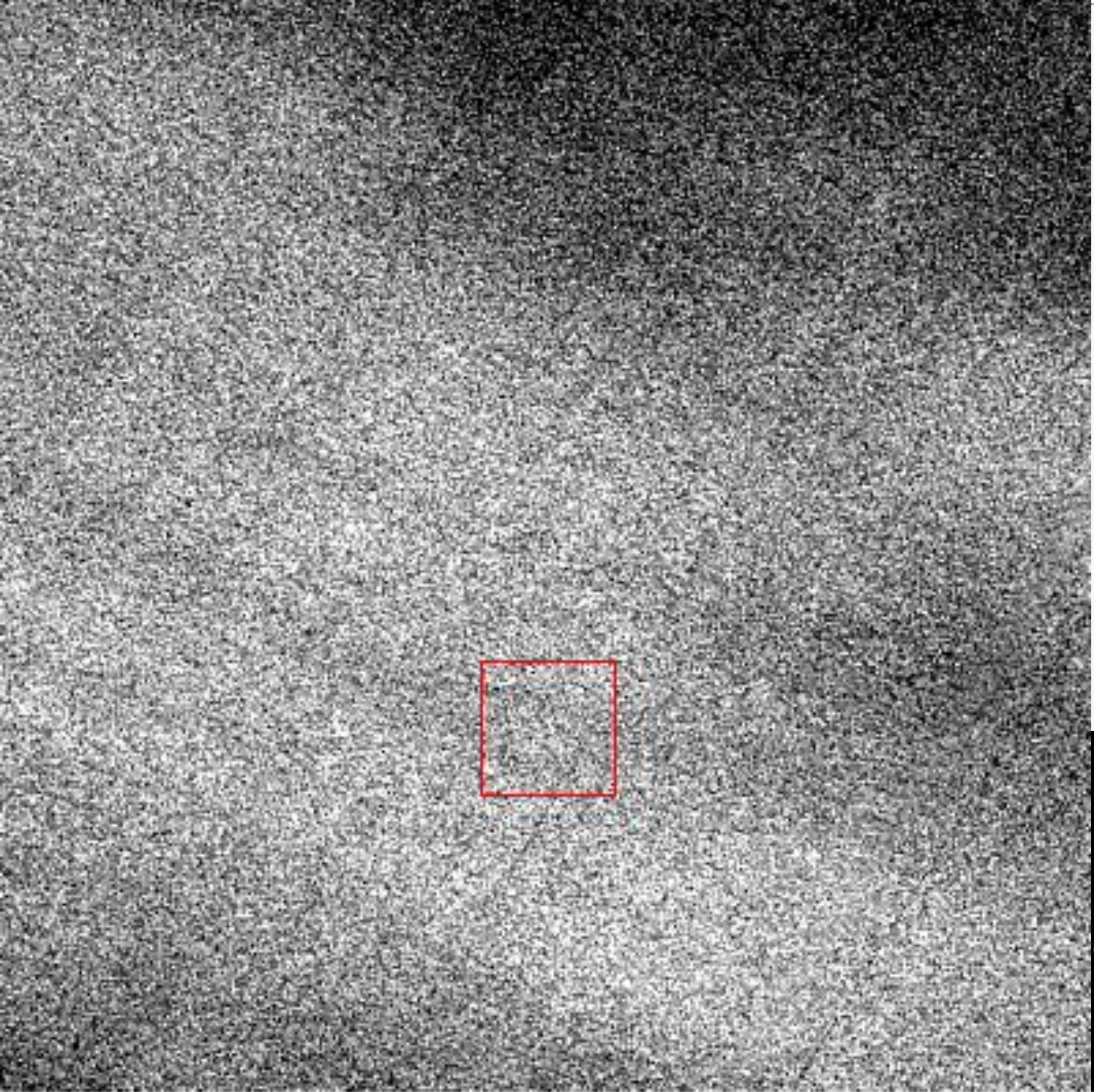
11/7 (GRL)
2013163

Coastal/Aerosol
FPM 10

SS2013194
(GRL)

Ranks:
Strk – 1st
Band – 1st



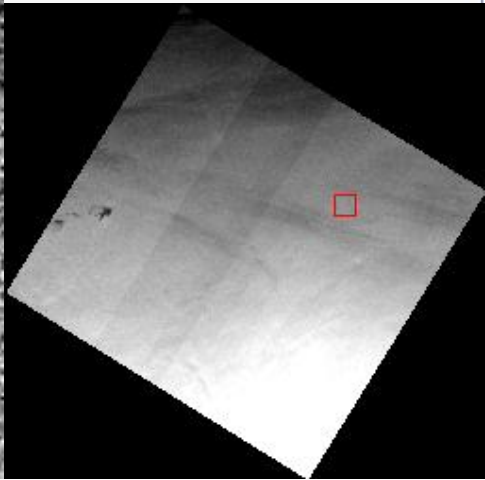


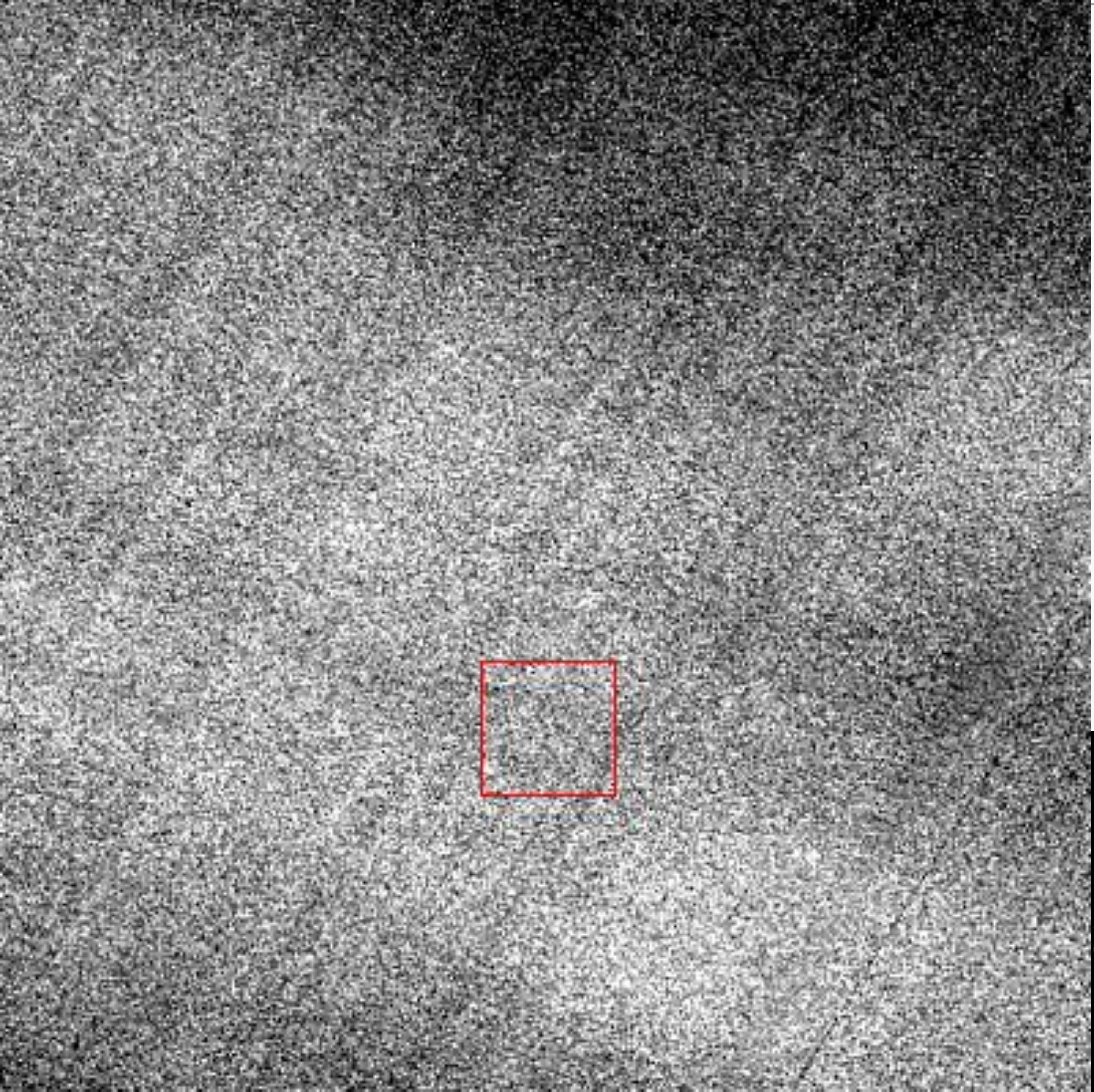
11/7 (GRL)
2013163

Coastal/Aerosol
FPM 10

SS2013132
(GRL)

Ranks:
Strk – 2nd
Band – 2nd



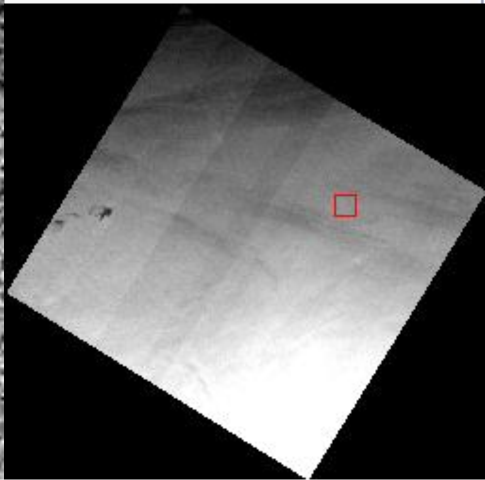


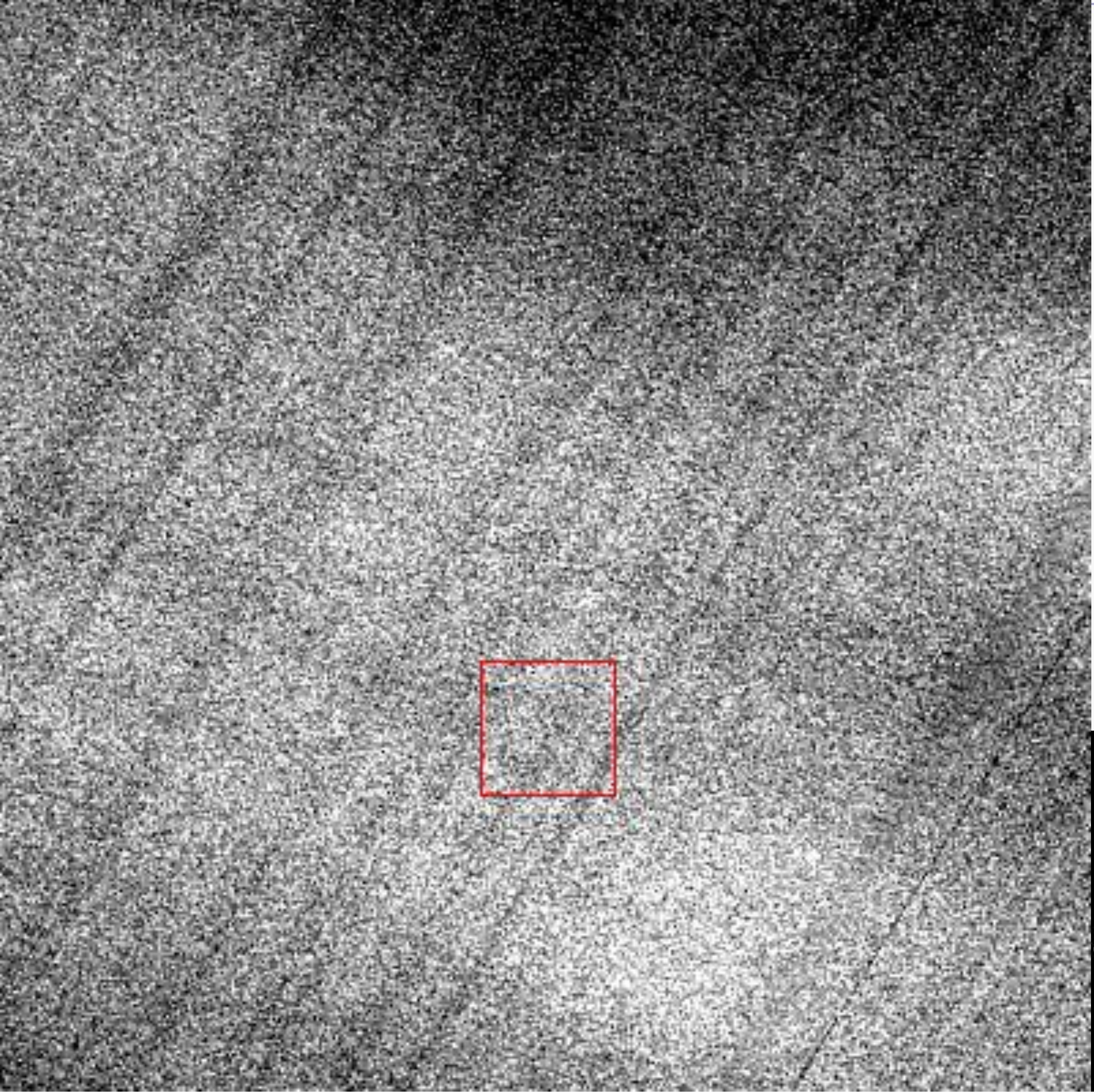
11/7 (GRL)
2013163

Coastal/Aerosol
FPM 10

SS2013114
(GRL)

Ranks:
Strk – 3rd
Band – 4th



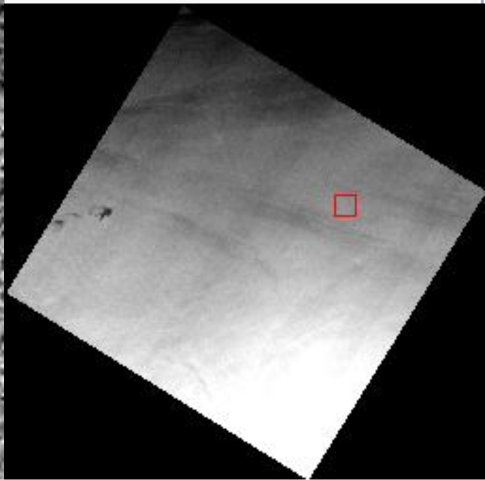


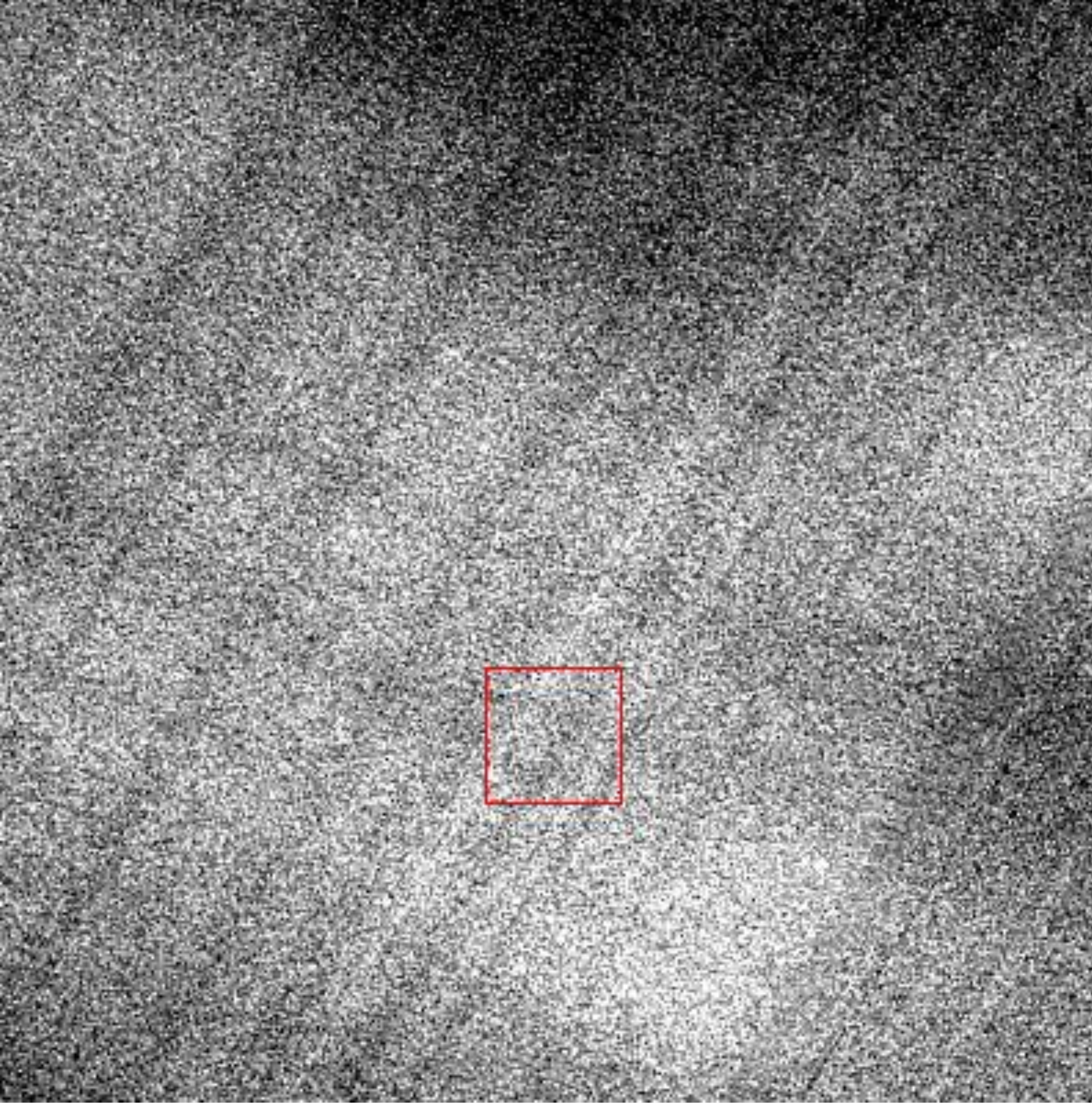
11/7 (GRL)
2013163

Coastal/Aerosol
FPM 9

Diffuser-Based
2013Q2

Ranks:
Strk – 4^{th}
Band – Not Top 5



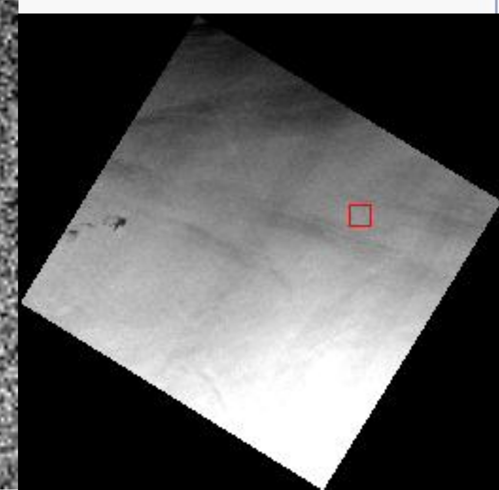


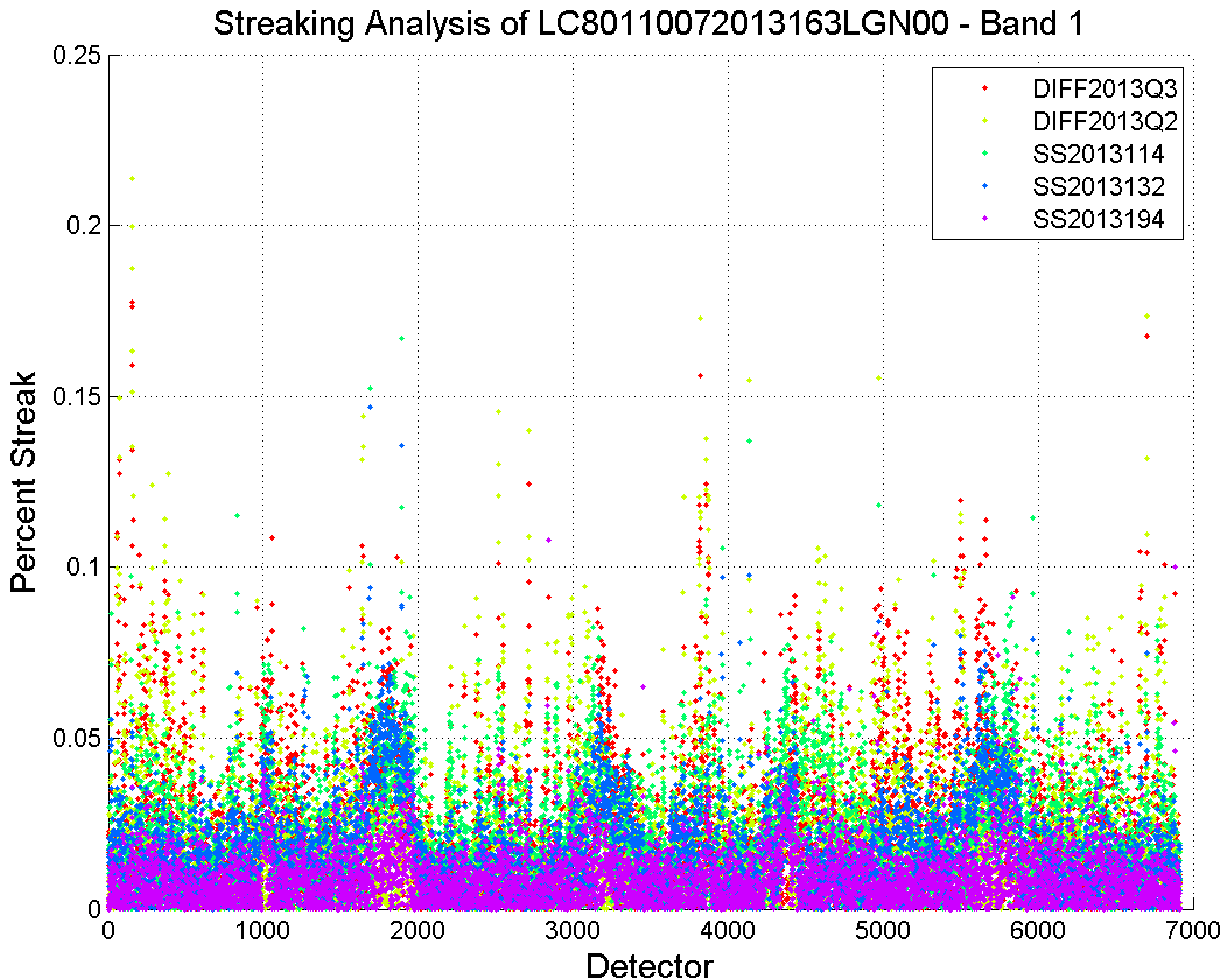
11/7 (GRL)
2013163

Coastal/Aerosol
FPM 9

Diffuser-Based
2013Q3

Ranks:
Strk – 5th
Band – Not Top 5





Streaking Analysis of LC80110072013163LGN00 - Band 1
DIFF2013Q3
DIFF2013Q2
SS2013114
SS2013132
SS2013194
Percent Streak
0.25
0.2
0.15
0.1
0.05
0
0
1000
2000
3000
4000
5000
6000
7000
Detector

Best Method for Mean Banding Reduction in each Band

Band	Method	Score
Coastal/Aerosol	**Side Slither**	**13/14**
Blue	**Side Slither**	**14/14**
Green	**Side Slither**	**14/14**
Red	**Side Slither**	**13/14**
NIR	**Side Slither**	**12/14**
SWIR 1	**Diffuser**	**20/25**
SWIR 2	**Diffuser**	**19/25**
Panchromatic	**Side Slither**	**14/14**

Score = Number of 1^{st} places out of total number of scenes

Solar Relative Gains

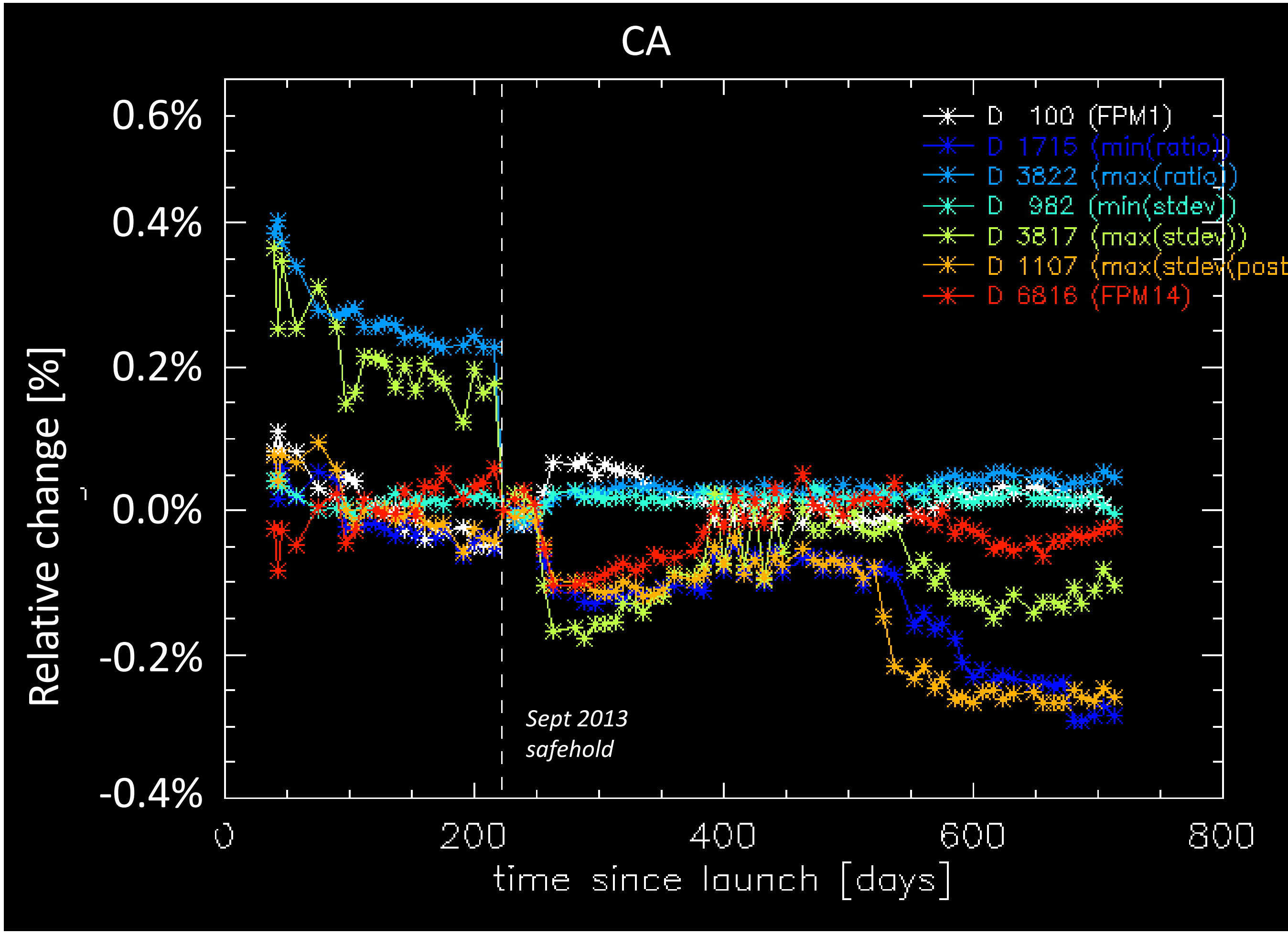
- Relative gains are monitored weekly with the solar diffuser acquisitions
  - Very uniform target with regular observations
- To monitor change, calculate the per-detector ratio of each acquisition to a standard acquisition
  - Currently the standard is the first solar diffuser acquisition after the Sept 2013 safehold
- Generally:
  - CA and Blue have less stable relative gains than the other VNIR bands (0.4% changes)
  - Green, Red, NIR are more stable (0.1% changes)
  - SWIR bands have detectors that “jump” – sudden changes in relative gain of as much as 1.5%

Slide courtesy of Julia Barsi

Relgain Change Over Time Sample Detectors

Relative gain change over time for 7 sample detectors -- some bad, some good.

CA and Blue: exhibit some instabilities since the safehold

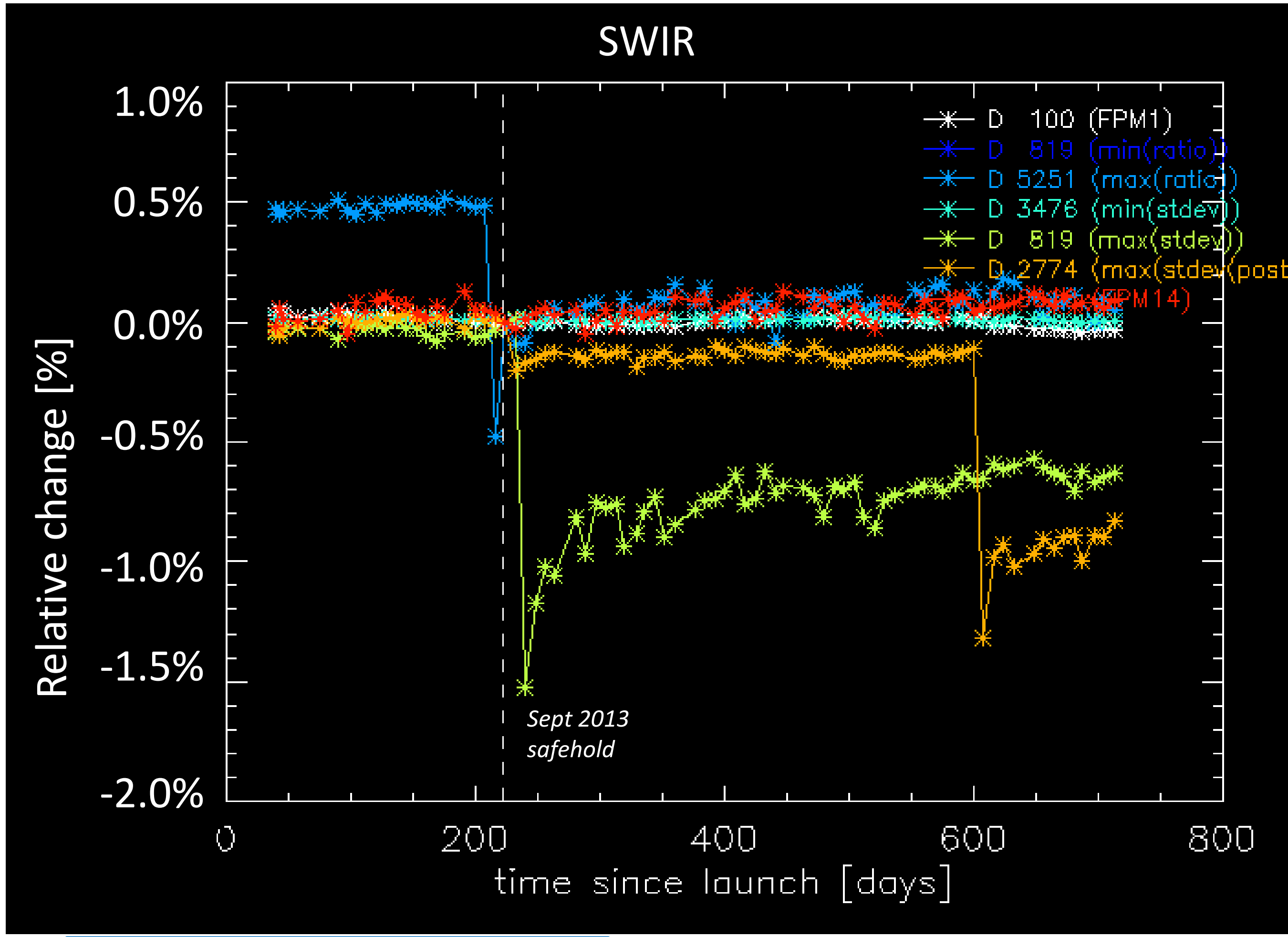


Slide courtesy of Julia Barsi

Relgain Change Over Time Sample Detectors

Relative gain change over time for 7 sample detectors -- some bad, some good.

SWIR1, SWIR2, Cirrus: single detectors jump and drift back to a new “stable” level. Other detectors are better behaved.



Slide courtesy of Julia Barsi

Relative Gain Updates

- The relative gains in the CPF are updated every quarter with the average relgain from the solar collects from the prior quarter
  - That means 2014Q1 solar collects are used to populate the 2014Q2 CPF.
  - So there is a one quarter lag on anything that changes
- The relative gains that are drifting will get worse throughout the quarter, but will be corrected at the beginning of each quarter.
- Note that this level of change in relative gains is difficult to see in “normal” earth data
  - Please don’t look at ice sheets.
- Before the next reprocessing effort, all CPF relgains will be updated with the relative gains derived from each quarter.

Slide courtesy of Julia Barsi

Summary & Conclusions

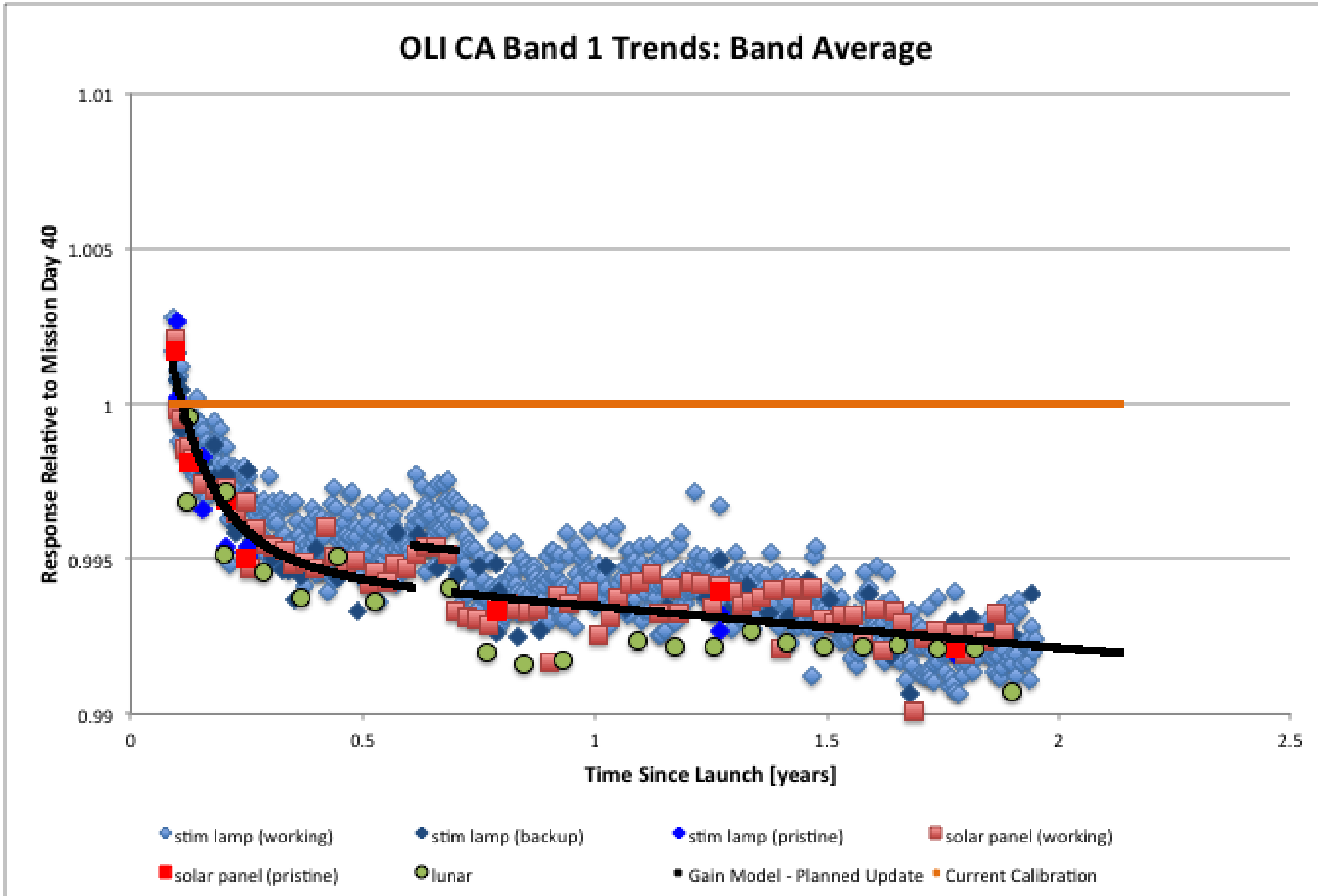
1. Striping due to relative gain differences are largely not noticeable
    1. Most apparent in blue bands and SWIR
2. Vicarious methods of relative gain estimation perform similarly to onboard methods
3. Relative gains are changing slightly
    1. Trackable with both diffuser and vicarious methods
    2. Updated quarterly to minimize any impact.

Landsat-8 OLI Stability and Absolute Calibration

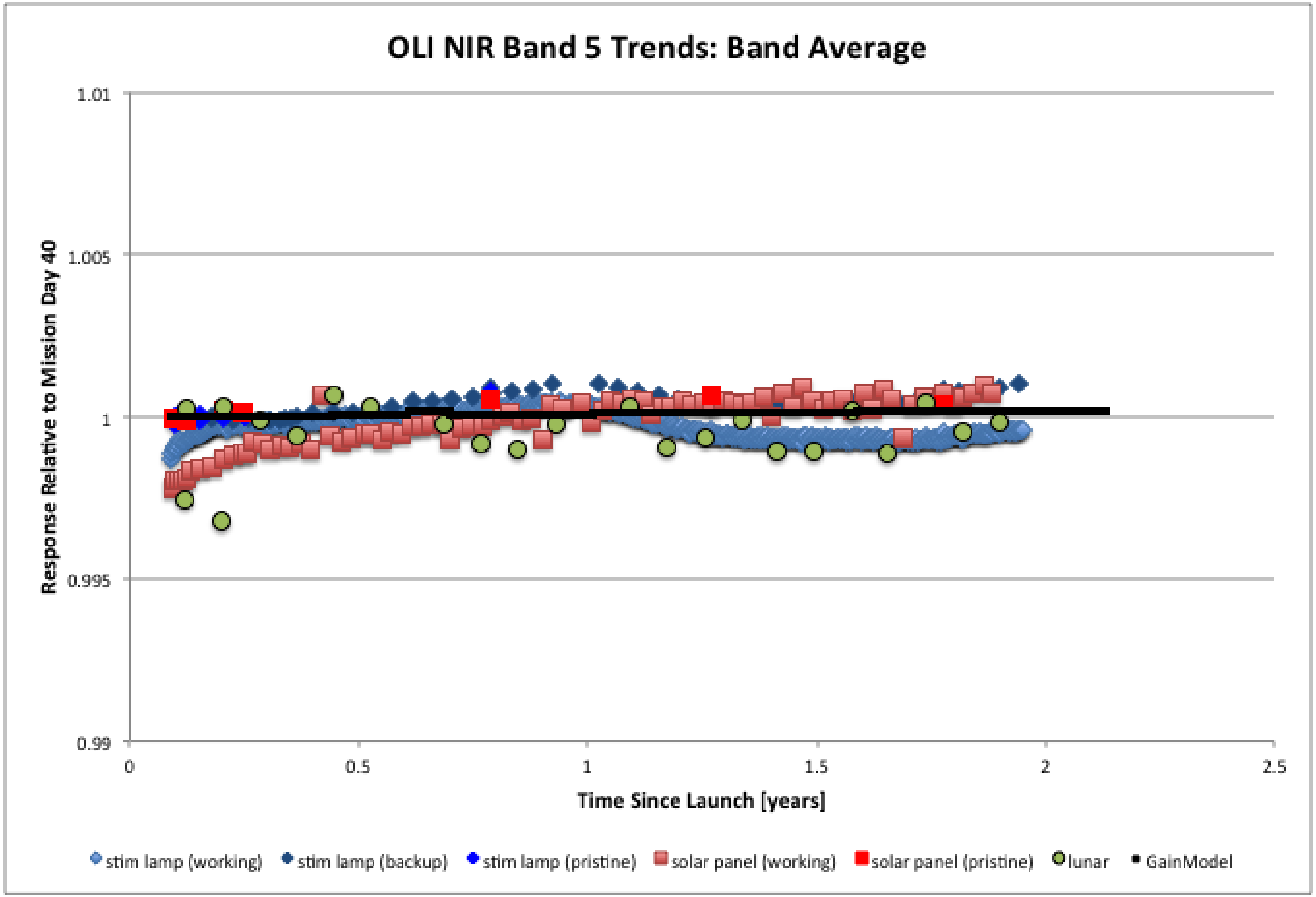
Brian Markham
and
GSFC Crew

OLI Radiometric Stability Summary

- OLI instrument extremely stable
  - Worst band is CA (Band 1) - 1% degradation over 2 years
  - Most bands stable within ~0.3% over 2 years
- OLI radiometric calibration devices and methods well behaved
  - 3 lamps; 2 diffusers, moon show same trends over 2 years to within ~0.3%



Update planned for next reprocessing – quarterly average gains



No change planned in gains

Trending Goals/Refinements

- Reducing scatter in lunar data
- Longer sample of lamp data to reduce scatter
  - About 1/3 reduction in scatter in CA band
- Curve fitting and averaging across calibrators

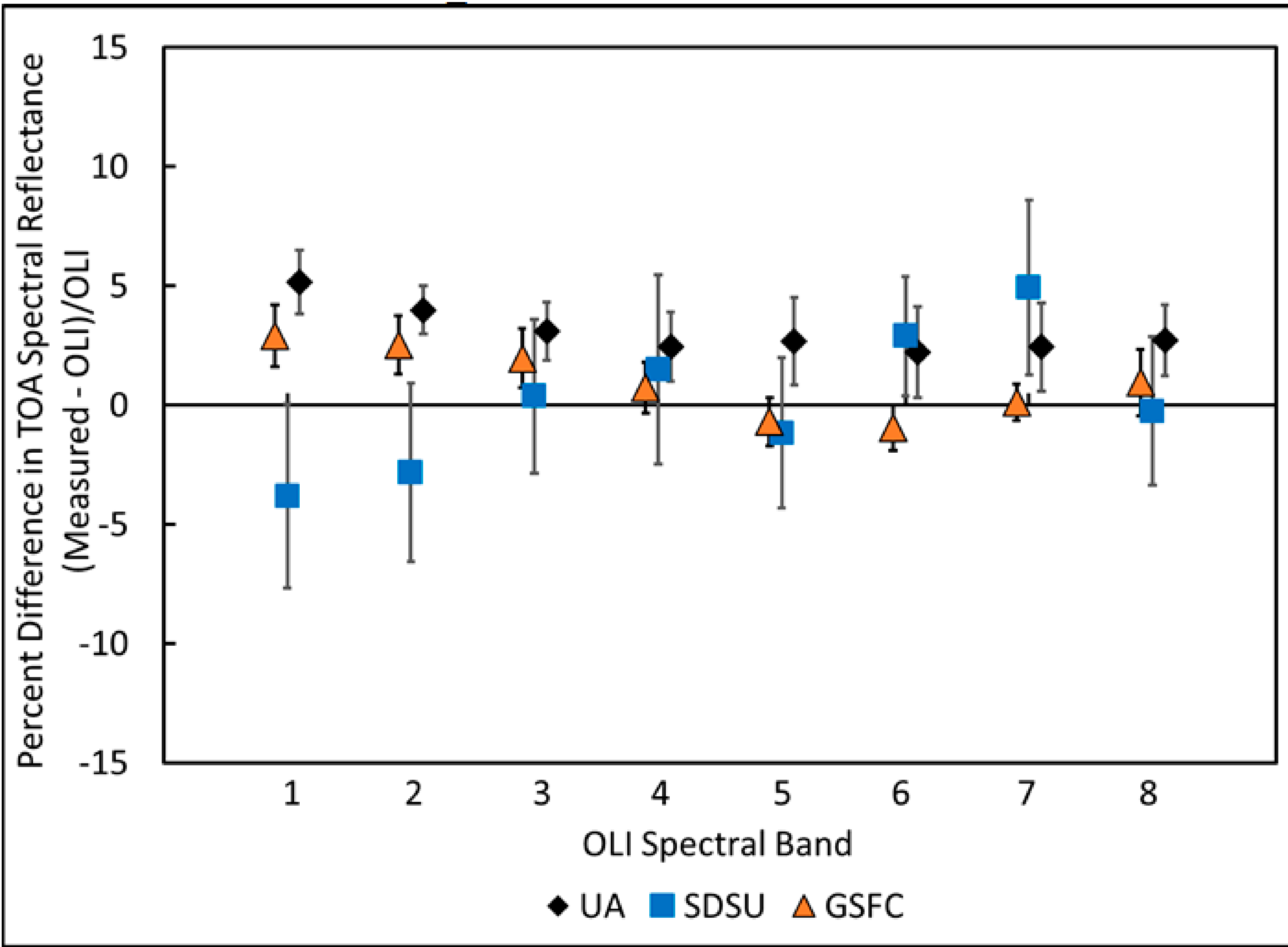
Radiometric Calibration Updates planned

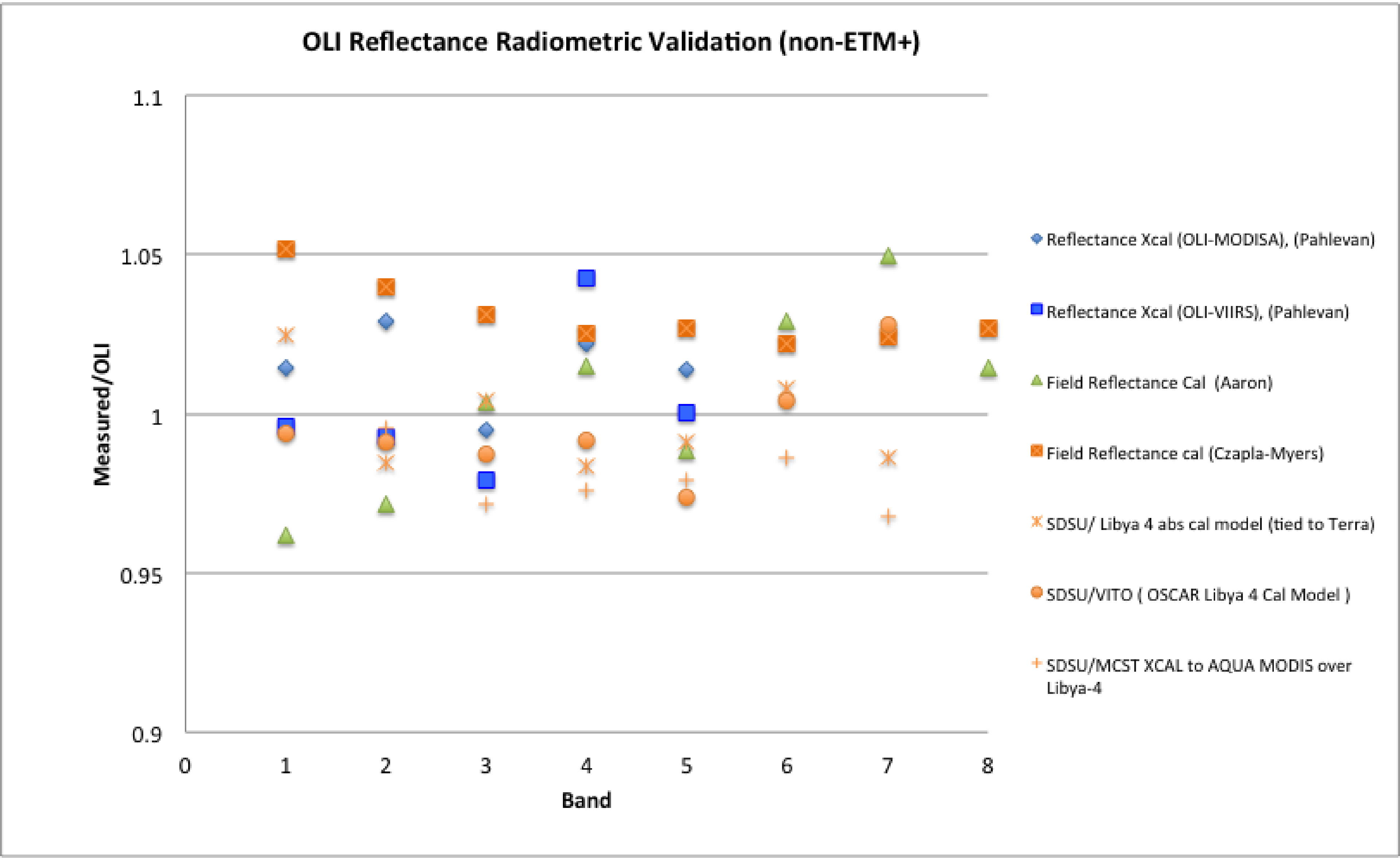
- Update CA band calibration trend for exponential like degradation (~1%)
  - Weighted average of methods
  - Other bands update (if any) TBD
- Include ~0.2% short term increase in responsivity of VNIR bands after safehold

OLI Radiometric Calibration

- Independent Reflectance and Radiance Calibrations provided with data product
  - reflectance calibration should have lower uncertainty (~2% versus ~3% for radiance)
  - Reflectance calibration obviates need for solar spectrum and additional uncertainty introduced
  - Ground (vicarious) and cross calibrations with MODIS generally consistent with OLI operational reflectance calibration (within uncertainties), though issues with shortest wavelength bands.
- Recommendation is to use OLI reflectance calibration; intention is to propagate this calibration back to earlier Landsat sensors.

OLI Vicarious Calibration Results (Czapla-Myers et al, 2015)




OLI Reflectance Radiometric Validation (non-ETM+)
Measured/OLI
1.1
1.05
1
0.95
0.9
0
1
2
3
4
5
6
7
8
Band
Reflectance Xcal (OLI-MODISA), (Pahlevan)
Reflectance Xcal (OLI-VIIRS), (Pahlevan)
Field Reflectance Cal (Aaron)
Field Reflectance cal (Czapla-Myers)
SDSU/ Libya 4 abs cal model (tied to Terra)
SDSU/VITO (OSCAR Libya 4 Cal Model)
SDSU/MCST XCAL to AQUA MODIS over Libya-4

Jim Storey

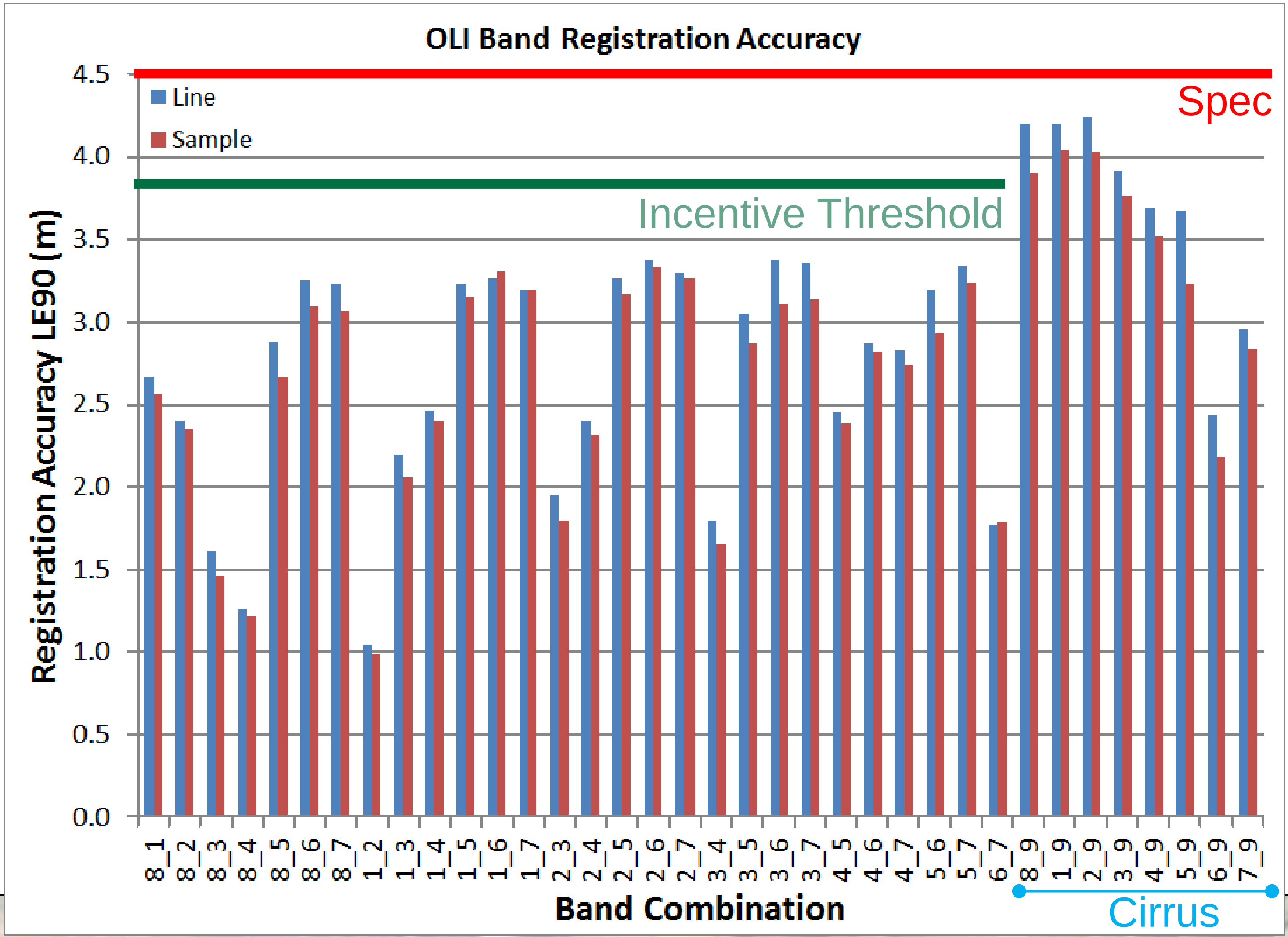
OLI GEOMETRIC CALIBRATION

Geometric Calibration Updates

- **Initial on-orbit geometric calibration was performed during commissioning and several additional on-orbit calibration updates were issued in the first year of operations**
  - All were minor and none involved internal image geometry
- **No further calibration updates have been required**

Calibration Parameter	Date of Update	Effective Date	Magnitude	Reason for Update
OLI-to-S/C Alignment	07/01/2013	Launch	17 μrad (pitch)	Analysis of additional data from WRS-2 orbit
Ground Control Thresholds	08/21/2013	Launch	100 m -> 200 m	Allow scenes with GLS control errors > 100m to process to L1T
TIRS-to-OLI Alignment	09/27/2013	09/21/2013 – 09/30/2013	25 μrad (pitch)	Step change following late-September spacecraft anomaly
TIRS-to-OLI Alignment	11/27/2013	10/01/2013 -	10 μrad (pitch)	Account for recovery of TIRS alignment following anomaly
TIRS-to-OLI Alignment	11/27/2013	04/01/2013 - 09/20/2013	12 μrad (pitch)	Improve accuracy for period from arrival in WRS-2 orbit to spacecraft anomaly
OLI-to-S/C Alignment	02/03/2013	10/01/2013 -	13 μrad (roll)	Account for seasonal drift in alignment of both instruments to the spacecraft

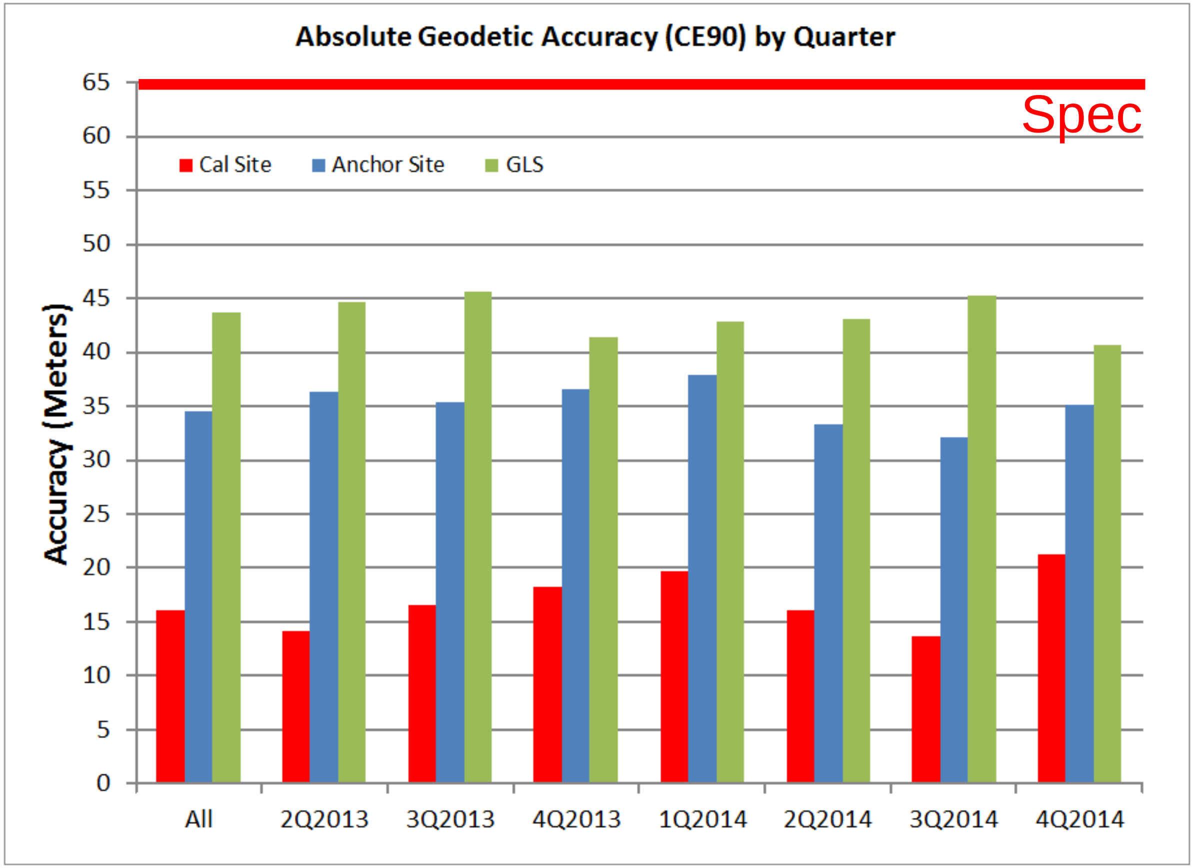
OLI Band Registration by Band Pair



Landsat Science Team – Greenbelt, MD

Geodetic Accuracy by Quarter

- The measured L8 geodetic accuracy results depend upon the type of control points used
- GCP accuracy is a significant contributor to overall measured geodetic accuracy



L8 System Geolocation Accuracy

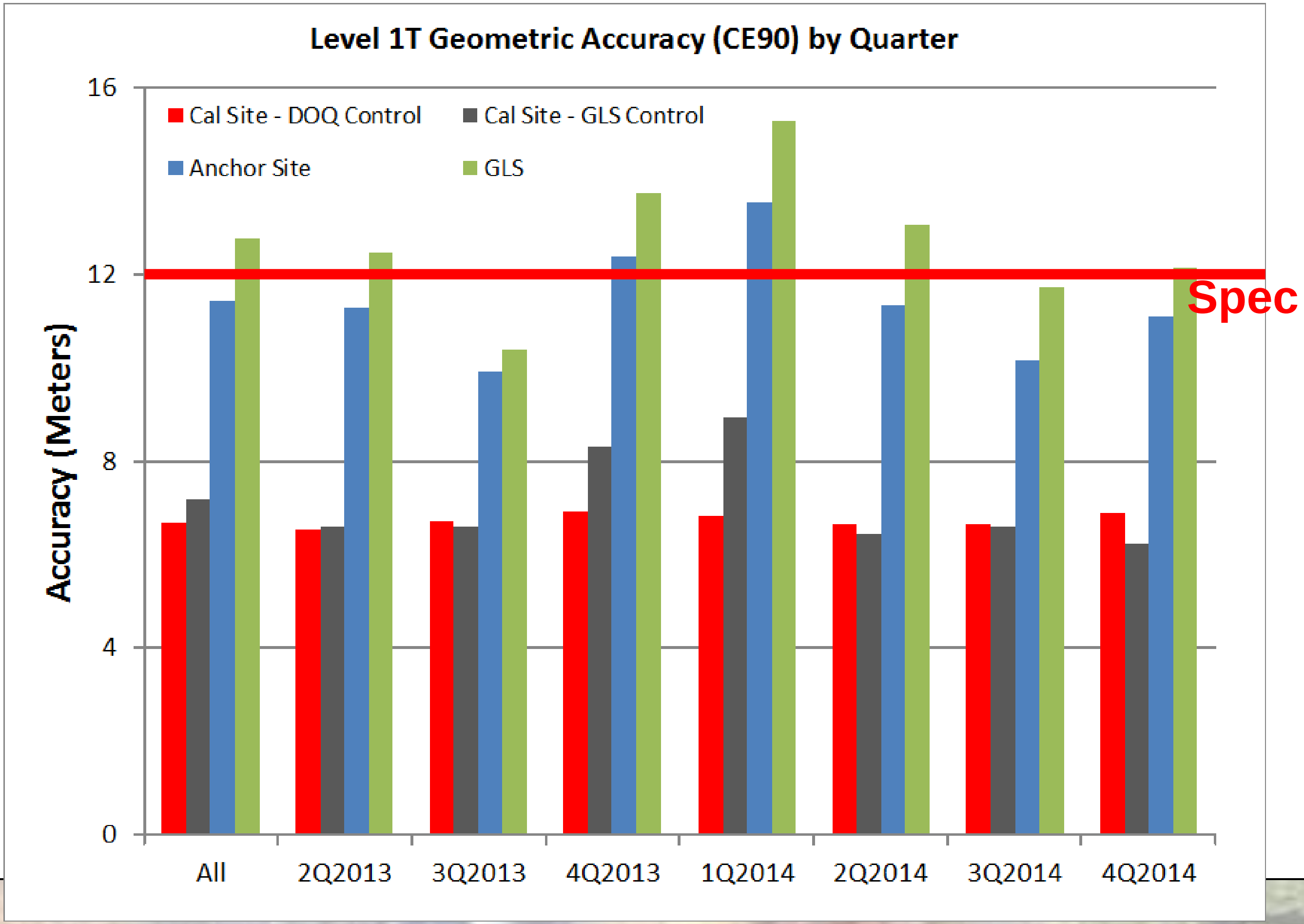
- **An analysis of L8 system geolocation accuracy is presented in the L8 special issue paper on OLI geometric performance**
- **Measured geodetic accuracy contains four elements:**

$$\sigma_{Net}^2 = \sigma_{CalBias}^2 + \sigma_{DynCal}^2 + \sigma_{Pointing}^2 + \sigma_{GCP}^2$$

  - Static calibration error – estimated as residual bias
  - Dynamic calibration error – estimated as within-orbit trend
  - Random pointing error – estimated as date-to-date repeatability
  - Control point error – solve for this from measured cal site/DOQ and GLS geodetic accuracy results
- **Performing this calculation:**
  - Implied GLS control accuracy: 29.2 meters CE90
  - Implied DOQ control accuracy: 2.3 meters CE90
  - Implied L8 geolocation accuracy: 18.1 meters CE90

Geometric Accuracy by Quarter

- Geometric accuracy results depend upon the accuracy of the control used for assessment



L8 Geometric Performance Summary

- **Landsat 8 on-orbit geometric performance is excellent and meets all requirements**

Requirement	Measured Value	Required Value	Units	Margin
OLI Swath	190.2	>185	kilometers	2.8%
OLI MS Ground Sample Distance	29.934	<30	meters	0.2%
OLI Pan Ground Sample Distance	14.932	<15	meters	0.5%
OLI Band Registration Accuracy (all bands)	4.24	<4.5	meters (LE90)	5.8%
OLI Band Registration Accuracy (no cirrus)	3.38	<4.5	meters (LE90)	24.9%
Absolute Geodetic Accuracy	34.4	<65	meters (CE90)	47.1%
Relative Geodetic Accuracy	20.0	<25	meters (CE90)	20.0%
Geometric (L1T) Accuracy	11.4	<12	meters (CE90)	5.0%
OLI Edge Slope	0.02964	>0.027	1/meters	9.8%
TIRS Swath	186.2	>185	kilometers	0.6%
TIRS Ground Sample Distance	103.424	<120	Meters	13.8%
TIRS Band Registration Accuracy	9.9	<18	meters (LE90)	45.0%
TIRS-to-OLI Registration Accuracy	20.7	<30	meters (LE90)	31.0%

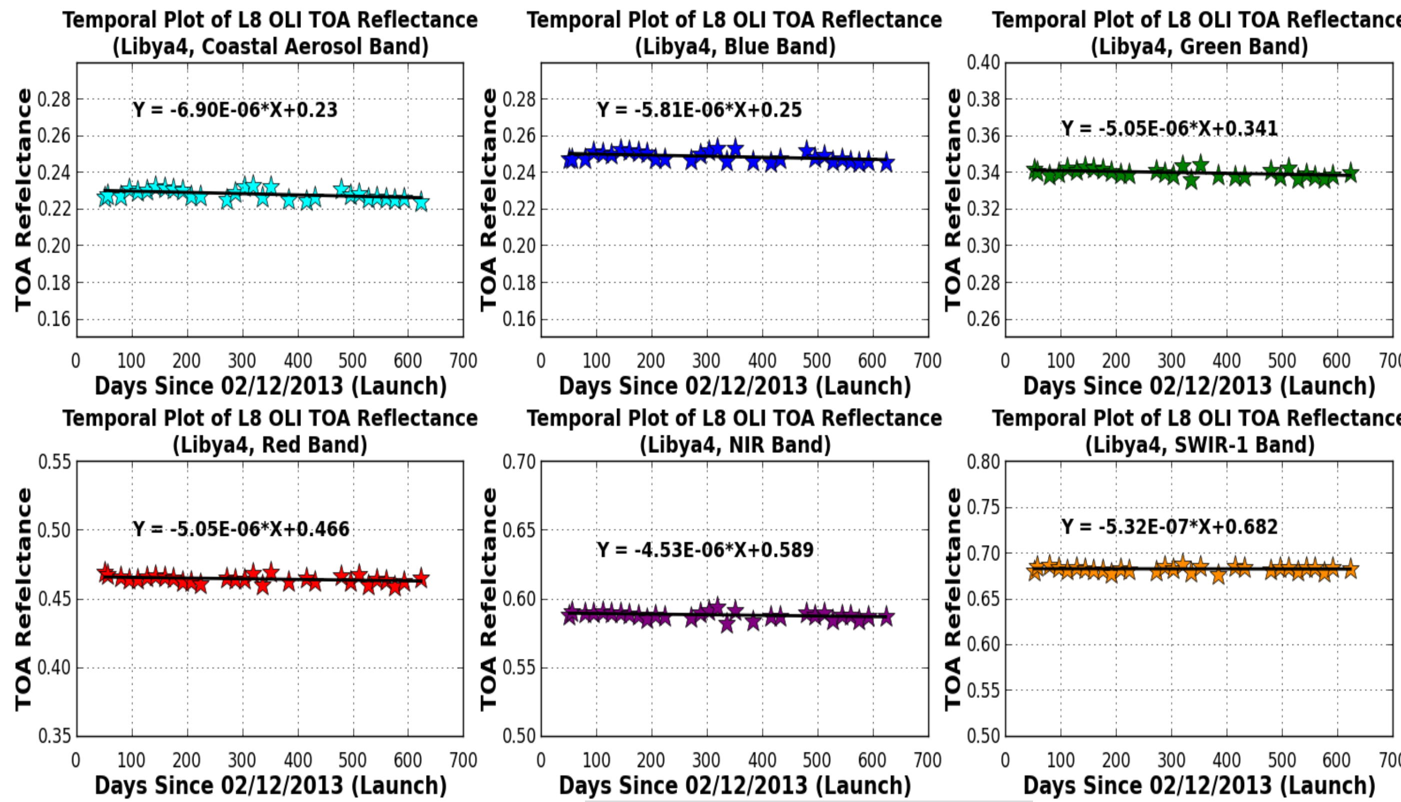
Update on PICS driven calibration of Landsat Instruments

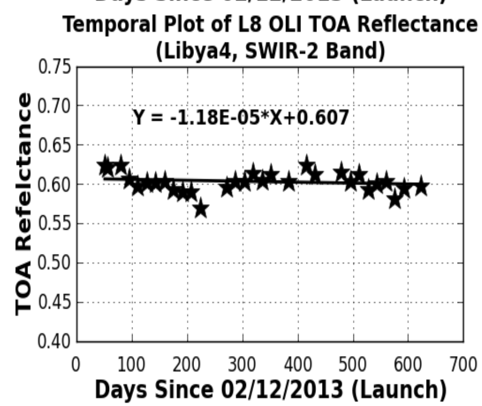
Landsat Science Team Meeting
Feb 4, 2015
NASA Goddard Space Flight Center
Greenbelt, MD

Dennis Helder
Nischal Mishra
SDSU Image Processing Lab

Temporal Trend of Landsat 8 OLI , Libya 4

- Data correction with linear model to account for the solar zenith angle effects.
- Except for SWIR-2, uncertainties about 1% or better
- Green, Red, NIR and SWIR-1 exhibit uncertainties approaching 0.5% or better.

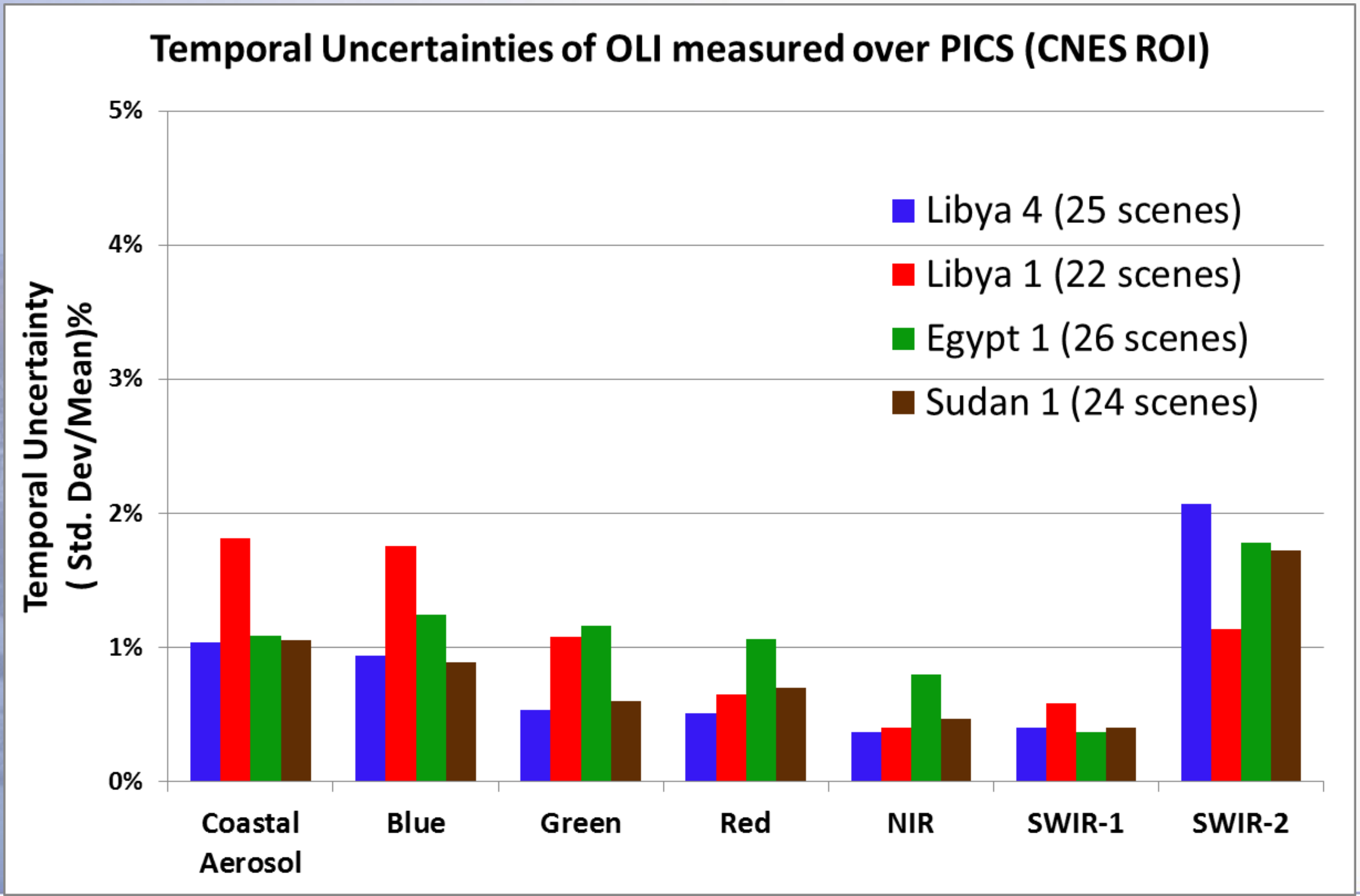




Landsat 8 Bands	Temp. Uncertainty (1-sigma/Mean)
Coastal Aerosol	1.04%
Blue	0.94%
Green	0.53%
Red	0.51%
NIR	0.37%
SWIR-1	0.40%
SWIR-2	2.07%

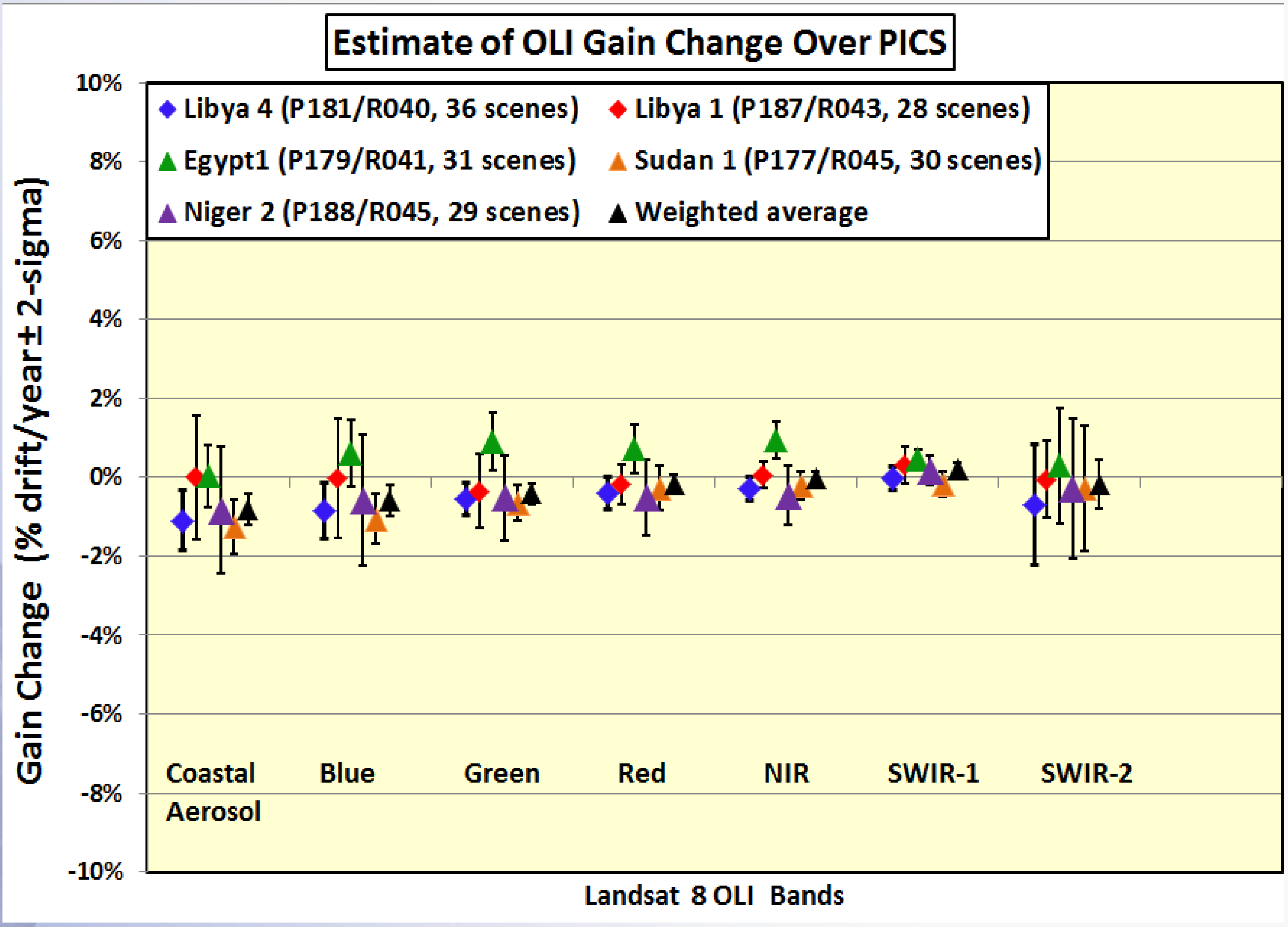
Comparison of OLI Temporal Uncertainties

The temporal stability is ~1 % for all thee bands except for SWIR-2 which is ~2% Cleaner spectral bands such as Red, NIR and SWIR-1 generally exhibit uncertainties of ~0.5% or better.



Drift estimates across PICS

- Drift generally within 0.5% per year When the drifts were weighted by the uncertainties for different sites.
- Weighted average show the drifts to be less than 0.5% per year & 2-sigma values indicate that the drifts are not statistically significant in most of the cases.
- As more OLI data become available, more confidence can be established on the observed drifts as well as the associated uncertainties.

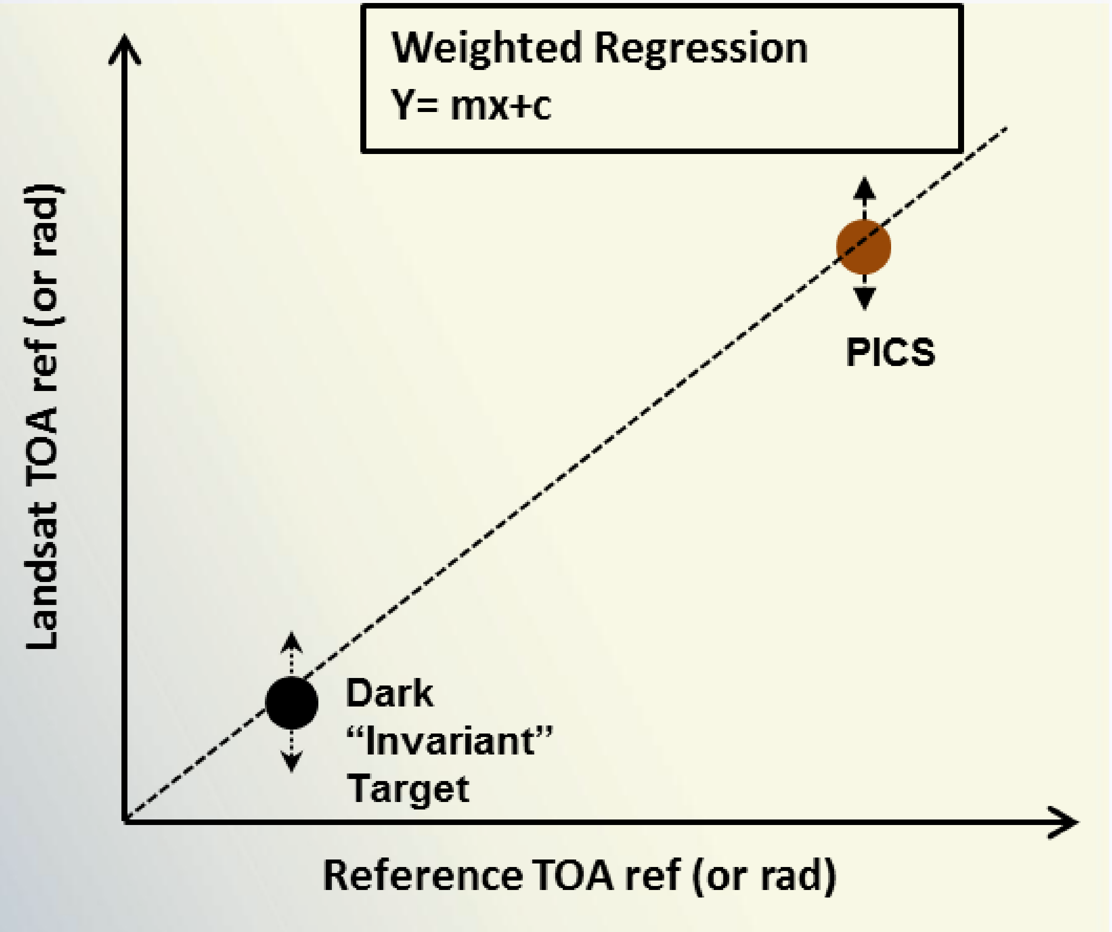


Summary on OLI stability

- Analysis of PICS data indicate that sub 1% stability across all the bands except SWIR-2 with “cleaner” spectral bands exhibiting stability better than 0.5%.
- Statistical analysis using linear degradation model indicate that on average the drift is generally within 0.5% per year and not statistically significant across the bands.
- As more PICS data become available, credible conclusions can be established on the observed drift and better precision can be achieved.

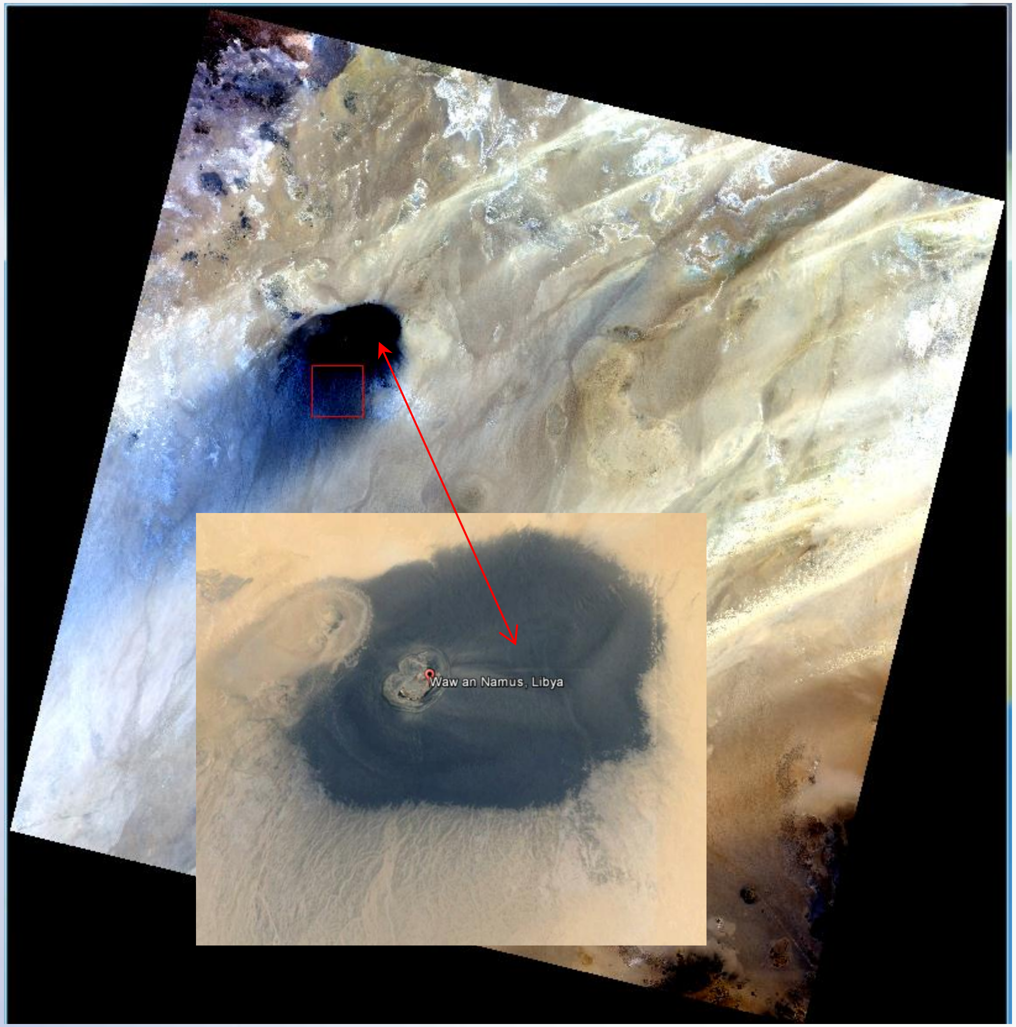
Dark Invariant Target

- The idea behind developing a dark invariant target is to provide two point calibration to complement PICS to cover the dynamic range of the instrument.
  - ❑ Discrepancies have been noticed on MSS calibration over dark target (will be presented later)
  - ❑ As a preliminary analysis volcanic field in Libya was trended with different instruments to study their temporal stability



Volcanic Field in Libya

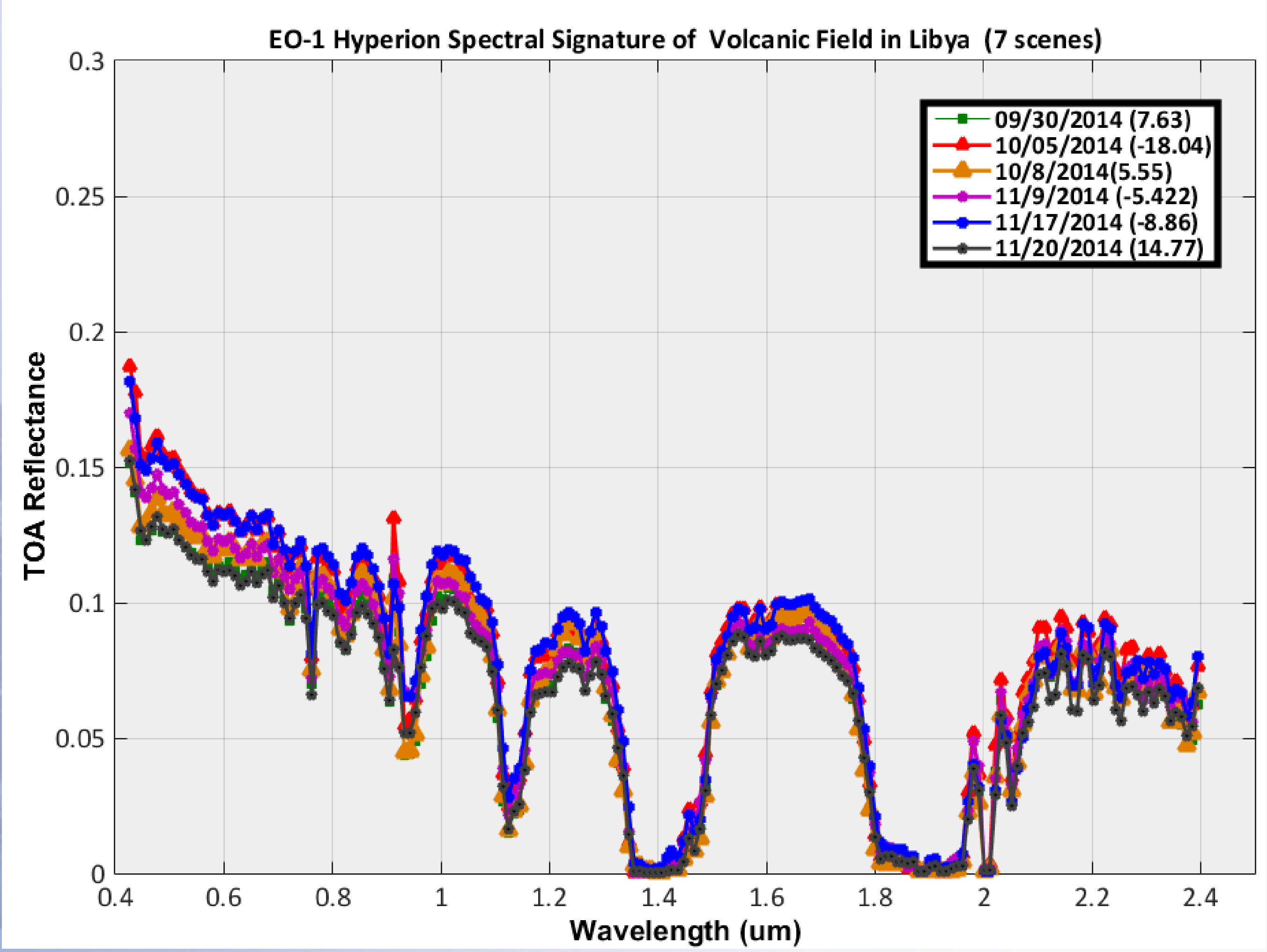
- Waw an Namus located near geographic center of the Sahara Desert in WRS-2 184/043
- Extends up to 10-20 km. Small water body around(oasis), so small test ROI of about 2.5 km * 2.5 km was chosen for analysis.
- Hyperion was scheduled over the target to understand the spectral behavior of the field.
- Long term stability was studied with ETM+ and Aqua MODIS datasets.



Spectral signature of the volcanic field

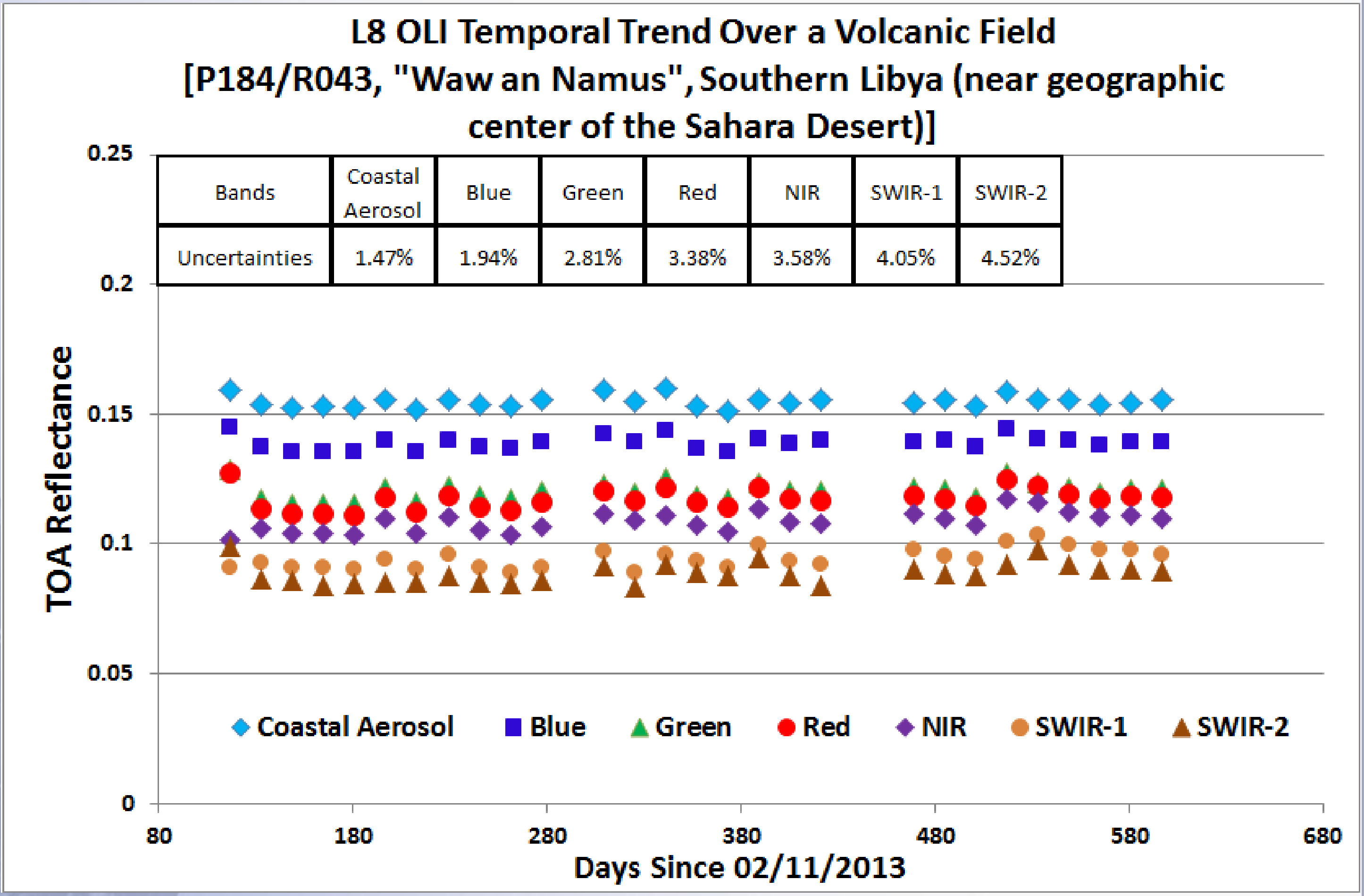
Observations

- Brighter in the VIS bands, TOA ref. decreases gradually across the NIR and SWIR bands
- Spectrally “flat” within the Landsat 7 & 8 spectral bandpasses.
- More Hyperion acquisitions, especially ones close to nadir, will improve the understanding of the spectral behavior of the target.



Landsat 8 OLI Trend

- Even better stability has been observed with OLI data where at the CA, Blue and Green , the site stability is within 3% and for the Red, NIR and SWIRs stability is 3-5%.
- Aqua MODIS data has been requested which will provide further insights into the stability of the site.



Summary

- With 10+ years of nadir looking data from Aqua MODIS, some of the temporally most stable PICS were identified.
- Landsat 7 ETM+ instruments continues to be stable with weighted drifts not exceeding 0.06% per year
- Landsat 8 OLI is being monitored regularly with PICS, as more data become available, better precision can be established on the observed drifts.
- SDSU has started working on identifying some of the dark invariant targets, in order to provided two point calibration to supplement PICS.

Development of Automatic Cloud Mask for Pseudo-Invariant Calibration Site (PICS) to Support Landsat Calibration

- The objective is to develop the cloud mask specifically over PICS to improve uncertainties in PICS driven calibration of Landsat sensors (TM, ETM+ & OLI).
- The algorithm is based on understanding of the spectral signature of cloud Vs. clear desert site and brighter temperature thresholds of cold clouds and hot desert.
- The plan is to include this algorithm in the Landsat PICS database.
- Other flavors of global cloud masks such as Fmask or ACCA doesn’t adequately identify cloud and shadows over PICS.

Cloud and Cloud Shadow Detection Tests

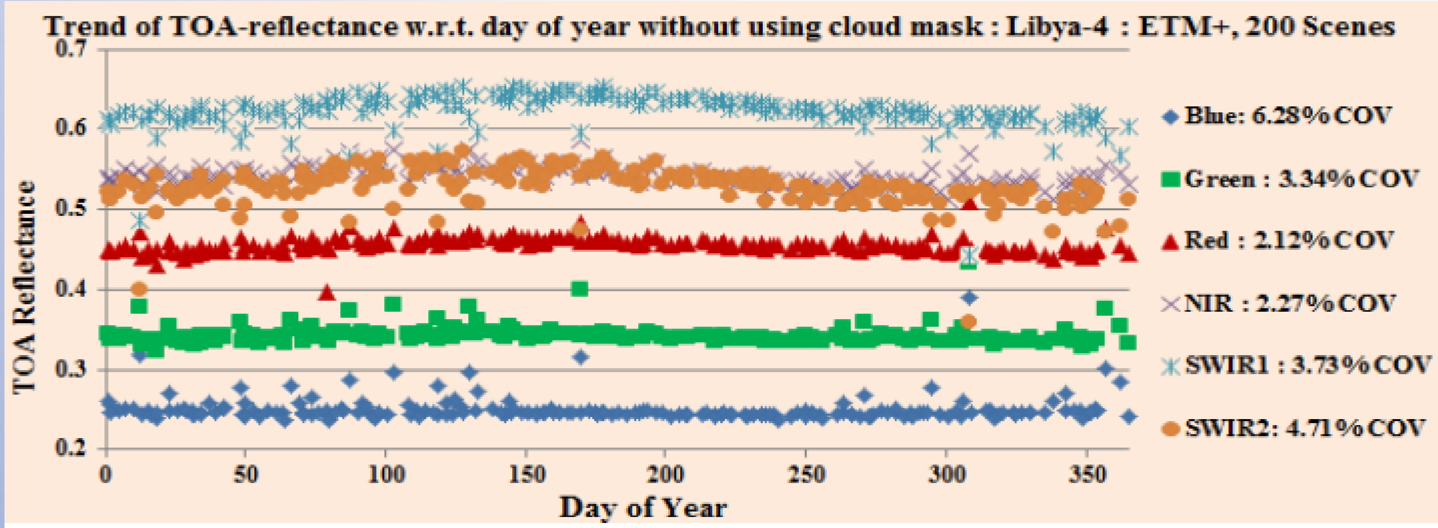
1. **Test_1 = Temperature Test**
   – Is a deterministic and definitive test.
   – detects 85% to 95% clouds and cloud shadows from a cloudy scene.
   – Distinguishes the clear scenes from cloudy scenes.

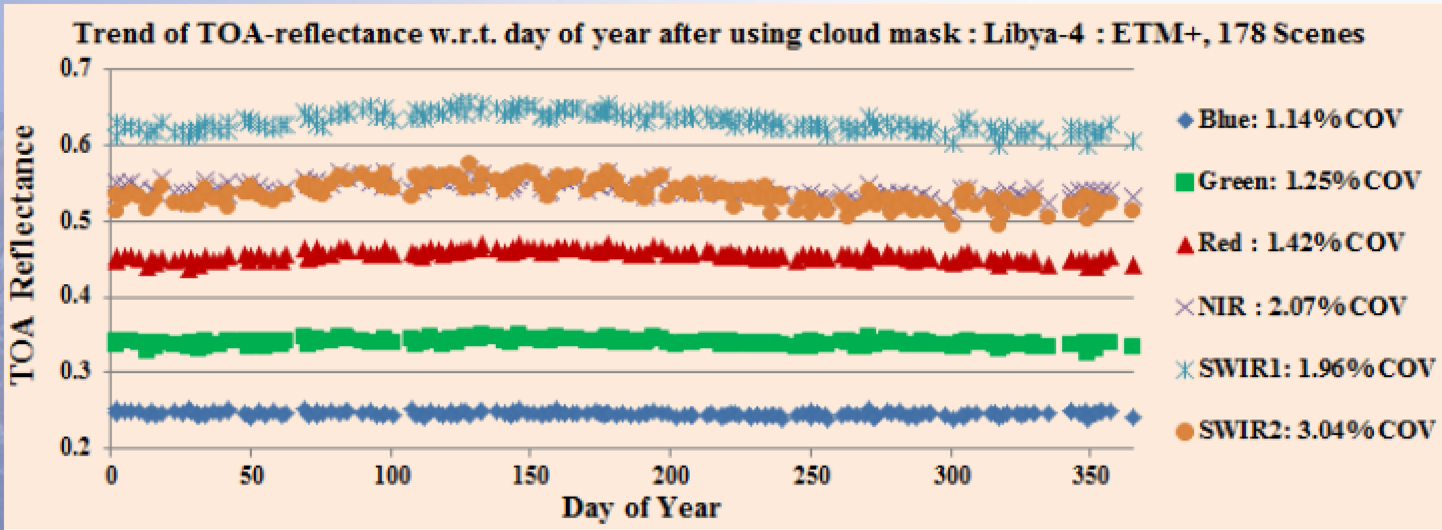
2. **Test_2 =** $\frac{TOA\_Reflectance(Red_{band} * Green_{band})}{TOA\_Reflectance(SWIR1_{band} * SWIR2_{band})}$
   – Similar to NDVI, NDSI, Whiteness tests etc.
      - $NDVI = \frac{Refl_{NIR} - Ref_{RED}}{Refl_{NIR} + Refl_{RED}}$
      - $NDSI = \frac{Refl_{GREEN} - Ref_{SWIR1}}{Refl_{GREEN} + Refl_{SWIR2}}$

3. **Test_3 =** $\frac{TOA\_Reflectance(NIR_{band})}{TOA\_Reflectance(SWIR1_{band})}$
   – Adds information from NIR channel and detects cloudy pixels.

4. **Test_4 (Shadow Test) =** $TOA\_Reflectance\ (SWIR1_{band} * SWIR2_{band})$
   – SWIR bands give lower reflectance from shadow of clouds than from clear desert pixels.

TOA-Reflectance Trend : Libya-4, 200 Scenes: ETM+





- Uncertainties are largely reduced to less than **3%** in all spectral bands.
- Scenes having more than **60%** clouds or having some **artifacts** are considered as outlier scenes and removed manually.

SDSU Sentinel Cross-Cal Activities

Algodones Dunes
Absolute Calibration With PICS

Campaign Dates: March 9—13, 2015

Larry Leigh

South Dakota State University
Image Processing Lab

Goals of the Campaign

- The two main goals of the campaign are.
  - Transform Algodones Dunes from a “relative” PICS Site to an absolute calibration site
    - Key to this effort is a BRDF model of the dunes
  - Develop an understanding / procedure to allow the transformation of other PICS sites into absolute calibration sites.

Goals of the Campaign

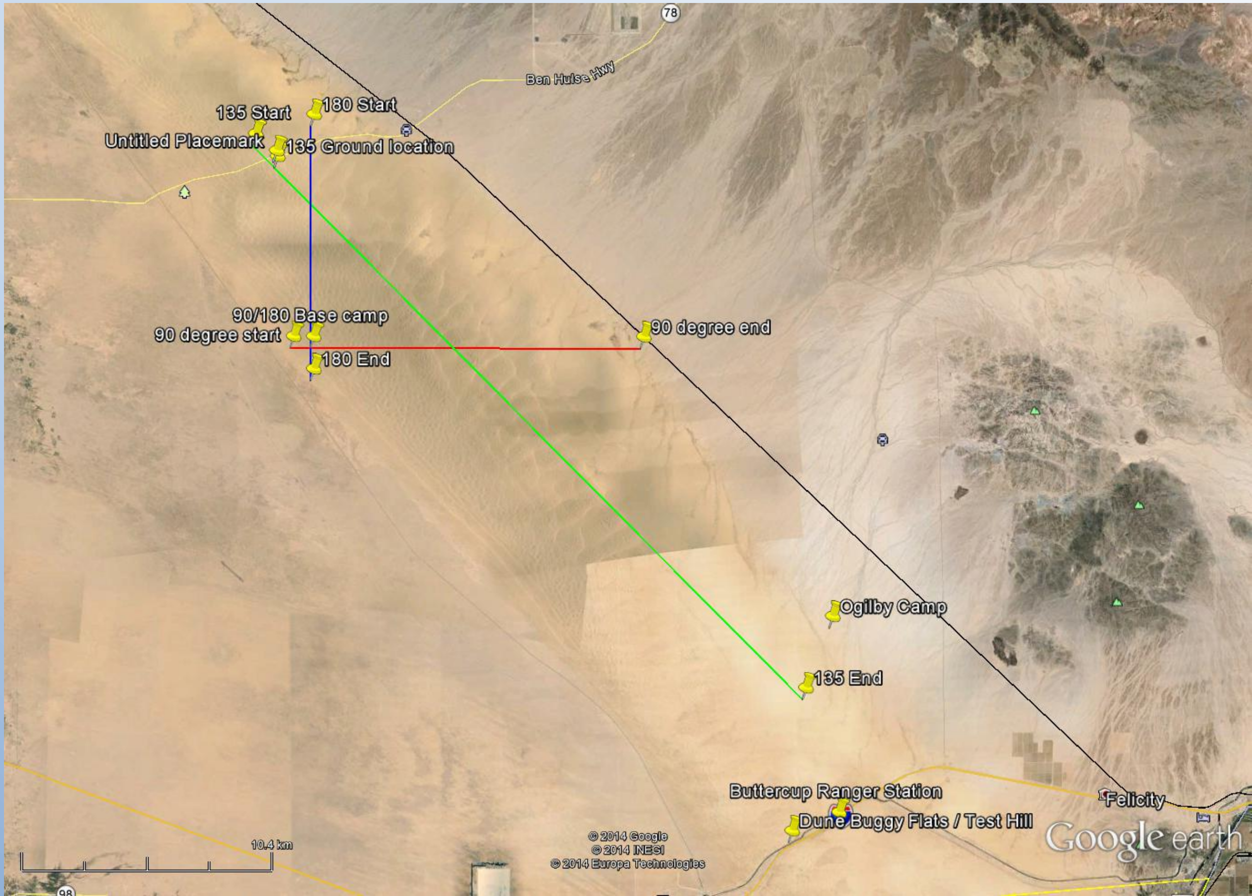
- Campaign will accomplish the goals by answering five basic questions:
  - What is the “point-specific” BRDF of site?
  - Are the Dunes spectrally homogenous?
  - Is the BRDF spatially homogenous across the dunes?
  - Can the point-specific BRDF be scaled to the Dune ROI?
  - What BRDF model best replicates the resulting data?

Measurement Plan

- To answer the questions an extensive data collection campaign will take place, these measurements include:

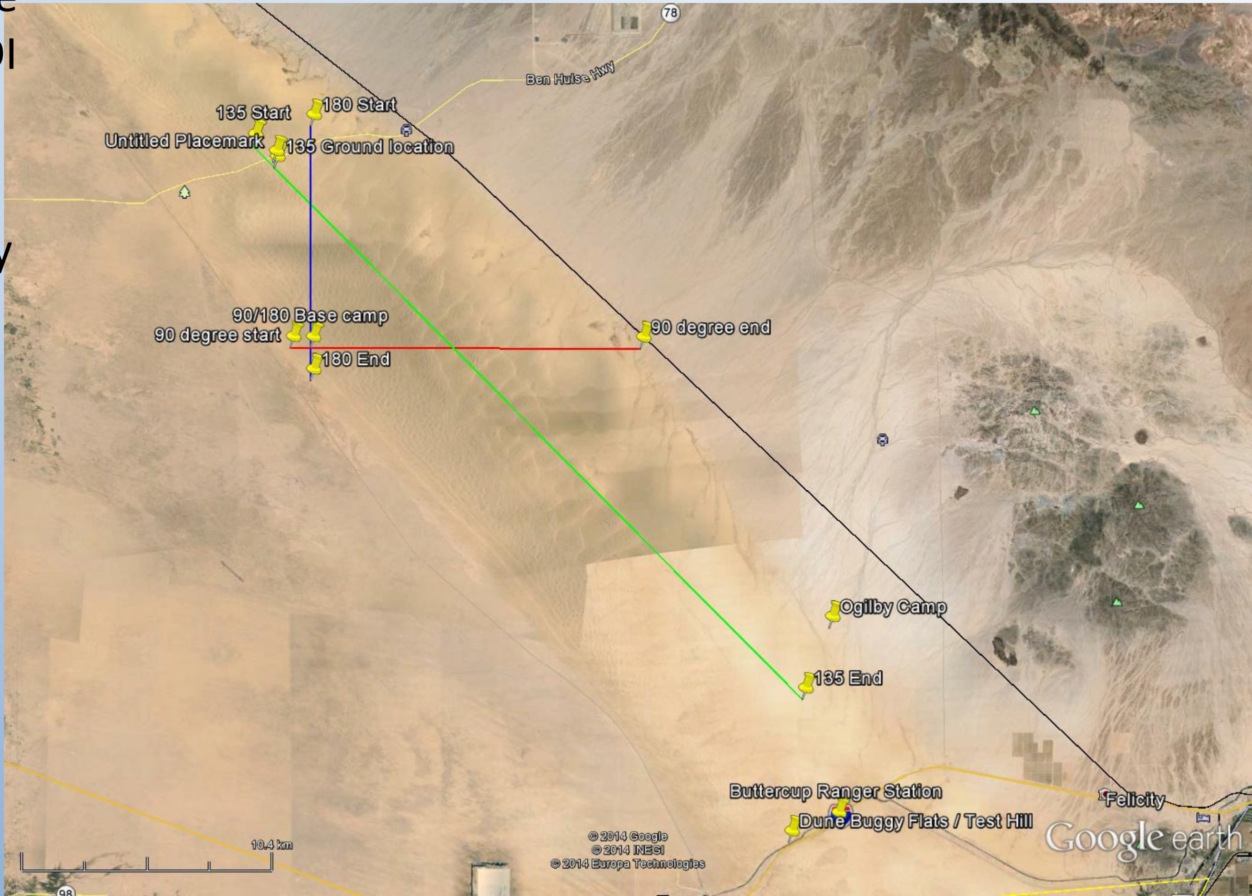
– Ground level in-situ BRDF measurements
  - Per location measurements to include:
    - – Sand Valley
    - – Sand Dune Peak
    - – Windward Slope
    - – Leeward Slope
  - Locations including:
    - – Observation tower
    - – Base Came

– Sand collection for lab measured BRDF of the following locations:
  - – Observation tower
  - – "Base camp "
  - – East end of 90 degree path
  - – Ogilby Camp Site
  - – Dune Buggy Flats Camp Site / Buttercup Ranger Station



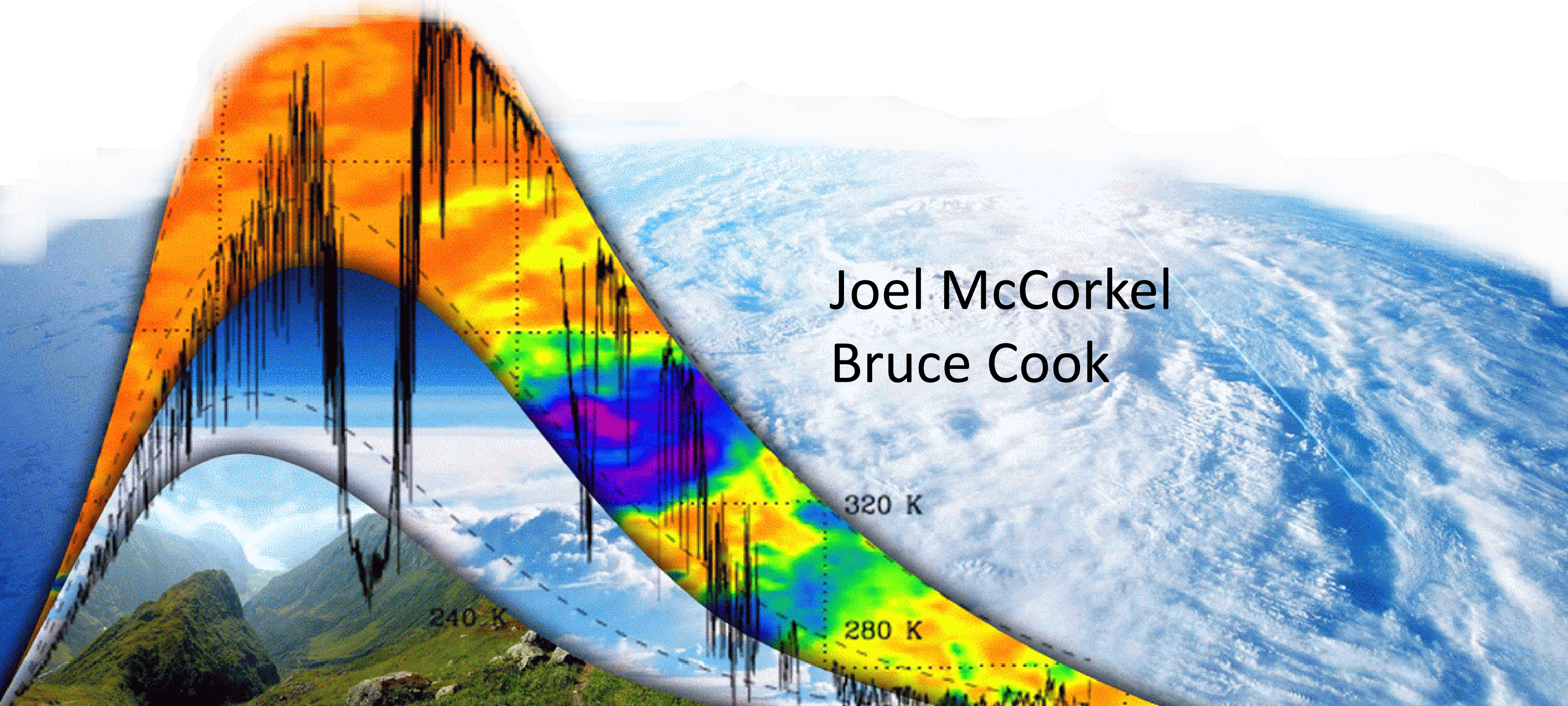
Measurement Plan

- Aircraft based BRDF measurements will be used to get more extended data, including:
  - Hyperspectral reflectance of the majority of the ROI
  - Hyperspectral BRDF of specified ground tracks
  - DEM map of the majority of the ROI



National Aeronautics and Space Administration
Goddard Space Flight Center

Characterization of Algodones Dunes with airborne measurements for satellite cross-calibration



Joel McCorkel
Bruce Cook

Satellite sensor overpasses during campaign: Landsat 7 and 8

Landsat 7 (18:15 UTC)
Tuesday 10 March 2015

Landsat 8 (18:10 UTC)
Wednesday 11 March 2015

CLARREO objectives for the Algodones 2015 flight campaign

- Obtain measurements to populate model of test site that can be used for improved satellite sensor intercalibration
  - 3D model of site (lidar)
  - BRDF point cloud (closely spaced flight lines)
  - High-resolution map of site (free with first item)

- Link SI-traceability among ground, airborne, and satellite measurements
  - **Ground**: **SE-4500** and **SuitcaseSOLARIS** measurements of tarp and small sand site
  - **Airborne**: **G-LiHT** will have flight lines that are coincident with ground-based tarp and sand measurements
  - **Satellite**: **G-LiHT** will have flight lines that are coincident with **Landsat 8** and **Landsat 7**

Airborne measurement approach

G-LiHT can not obtain large-area BRDF measurements, but we can get a good of the site with two discrete measurement plans:

40 km

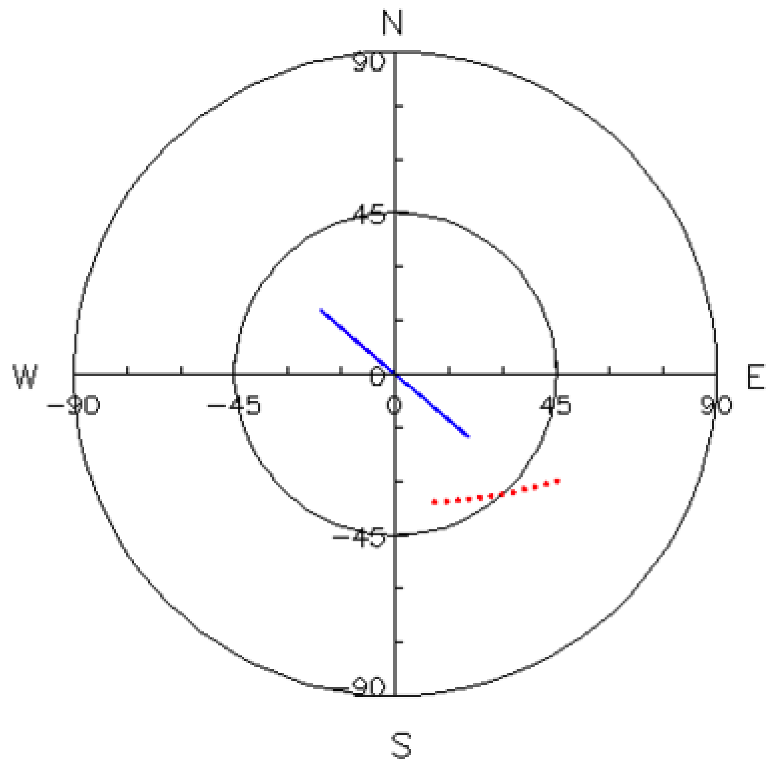
= 40,000 hectares

10 km

- Large area
  - 3D model
  - Spatial variability
  - Less concerned about optimizing geometries
- Small area
  - BRDF point cloud
  - Coincident with ground-based measurements

Example BRDF flight lines: March 11 - AM

Landsat 8 overpass ~18:10 UTC



Start_Lon	Start_Lat	End_Lon	End_Lat	Time line (min)	Time turn (min)	Total time (min)	Total time (hrs)	Time start	Sol zen	Sol azi
-115.11690	32.99874	-115.15726	32.96917	1.67	10.00	11.67	0.2	17:00:00	54.5	123.6
-115.11616	32.99803	-115.15652	32.96845	1.67	10.00	23.33	0.4	17:11:40	52.5	126.2
-115.11542	32.99731	-115.15578	32.96773	1.67	10.00	35.00	0.6	17:23:20	50.6	129.0
-115.11467	32.99659	-115.15504	32.96701	1.67	10.00	46.67	0.8	17:35:00	48.7	131.9
-115.11393	32.99586	-115.15430	32.96629	1.67	10.00	58.33	1.0	17:46:39	46.9	135.0
-115.11319	32.99515	-115.15356	32.96557	1.67	10.00	70.00	1.2	17:58:20	45.2	138.3
-115.11244	32.99443	-115.15282	32.96485	1.67	10.00	81.67	1.4	18:09:59	43.7	141.8
-115.11170	32.99371	-115.15207	32.96413	1.67	10.00	93.33	1.6	18:21:39	42.2	145.5
-115.11096	32.99299	-115.15133	32.96341	1.67	10.00	105.00	1.7	18:33:19	40.9	149.4
-115.11021	32.99227	-115.15059	32.96269	1.67	10.00	116.67	1.9	18:44:59	39.7	153.6
-115.10947	32.99155	-115.14984	32.96197	1.67	10.00	128.33	2.1	18:56:39	38.7	157.9
-115.10873	32.99083	-115.14910	32.96125	1.67	0.00	130.00	2.2	19:08:19	37.9	162.4

Team Members and Equipment

- **<u>U of A</u>**
- Jeff Czapla-Myers (Ground vic, continuous hyper, BRDF, weather station)
- Nik Anderson?

- **<u>SDSU</u>**
- Dave Aaron (BRDF, sunphotometer)
- Larry Leigh (Ground vic)
- Dennis Helder
- Cibele Pinto
- Morakot Kaewmanee

- **<u>Goddard</u>**
- Joel McCorkel (ground vic)
- Amit Angal
- Bruce Cook (Aircraft - G-LIHT)
- Kurt Thome(?)

- **<u>RIT</u>**
- Chip Bachmann (BRDF, sand properties)
- +many students

- **<u>U of Lethbridge</u>**
- Craig Coburn (BRDF)
- +student

A VALIDATION AND UPDATE OF LANDSAT DATA ARCHIVE USING PSEUDO-INVARIENT SITES AND DARK TARGETS

Ashish Shrestha
Larry Leigh
Dennis Helder

10 December, 2014

South Dakota State University
Image Processing Lab

Background

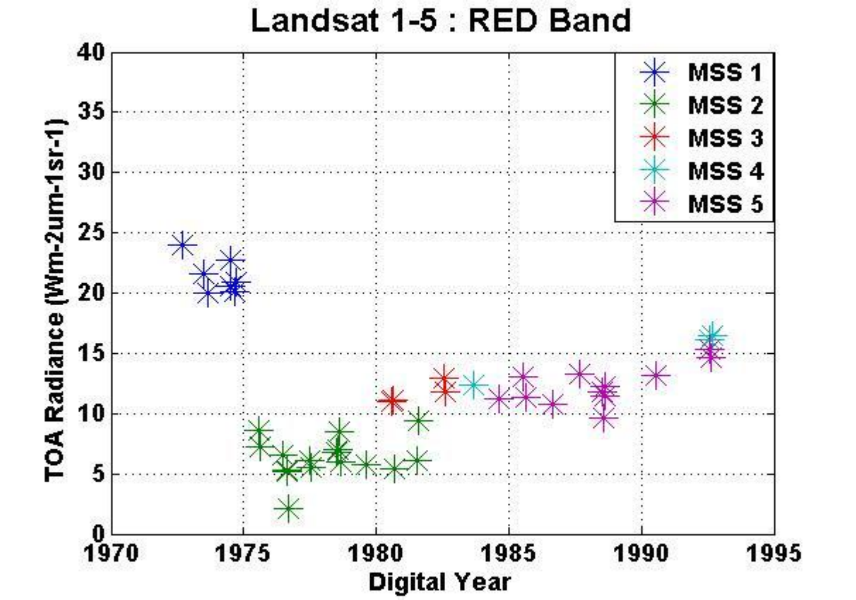
- Sensors on Landsat have been collecting images of the Earth’s surface for more than 40 years.

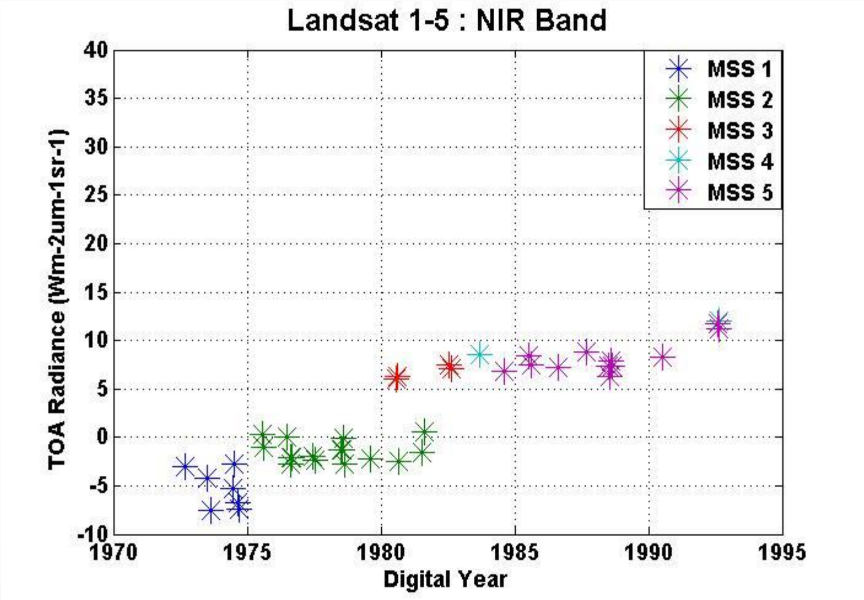
- MSS series of sensors were cross-calibrated and tied to Landsat 5 TM back in 2011.

- SDSU performed validation of this calibration by trending the satellite data for these sensors including Landsat 7 ETM+ and Landsat 8 OLI.

- Then we got a phone call from Warren Cohen…

Current Status: Dark Target





- From the plot of red band, Landsat 1 shows higher values and Landsat 2 shows lower values compared to other Landsat for the dark target (Crater lake).
- From the plot of NIR band, Landsat 1 and 2 shows negative radiance values for the dark target (Crater lake).
- This led us to consider re-calibration of Landsat archive…

Methods

- Selection of Scene pairs
  - Near coincidence scenes for PICS and Dark sites
  - Near simultaneous scenes for vegetative sites
- Selection of ROI
  - Invariant ROI within the imagery.
- Conversion into Radiance (TOA)

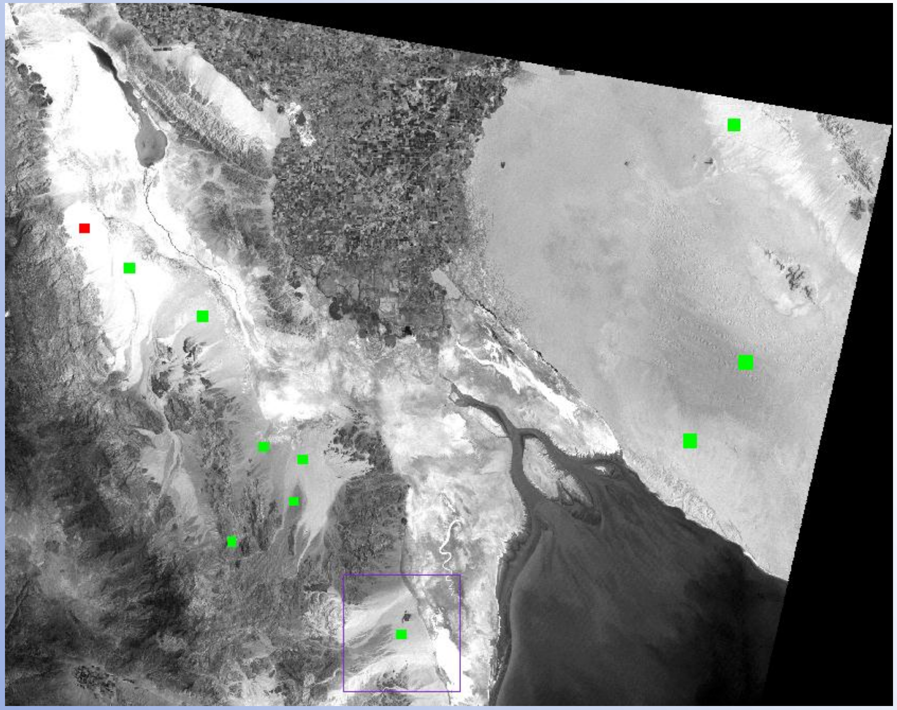
$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{CALMAX}}\right) Q_{CAL} + LMIN_\lambda$$

$$\boxed{L_{TOA} = \frac{L_\lambda \times d^2}{\cos\theta}}$$

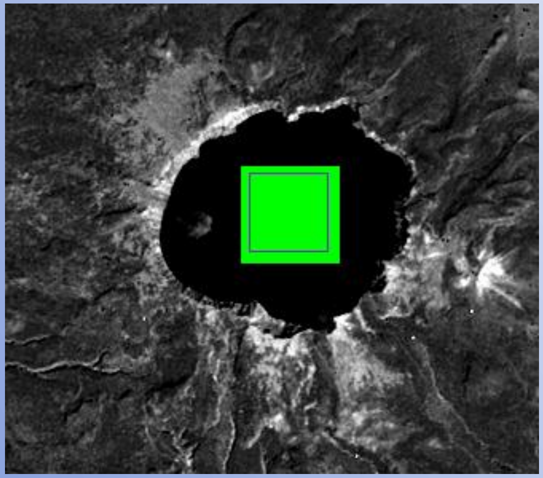
where, L_{TOA}=TOA radiance value *(units: W/m² sr µm)*
-- d = Earth-Sun distance in astronomical units *(AU)*
-- θ = solar zenith angle *(units: degrees)*
$LMIN_\lambda$ and $LMAX_\lambda$ are known as post-calibration dynamic ranges and their values are given for all five MSS sensors

- Find the Regression Coefficients (Bias and Gain)
- Perform Statistical test to validate the significance of gain and bias.
- Validate the calculated gain and bias.

Cross-calibration of Landsat 1 to 2 MSS

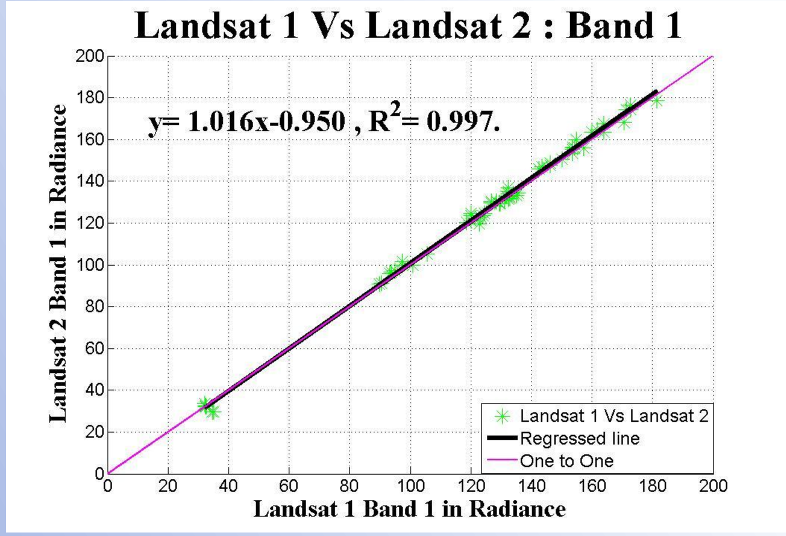


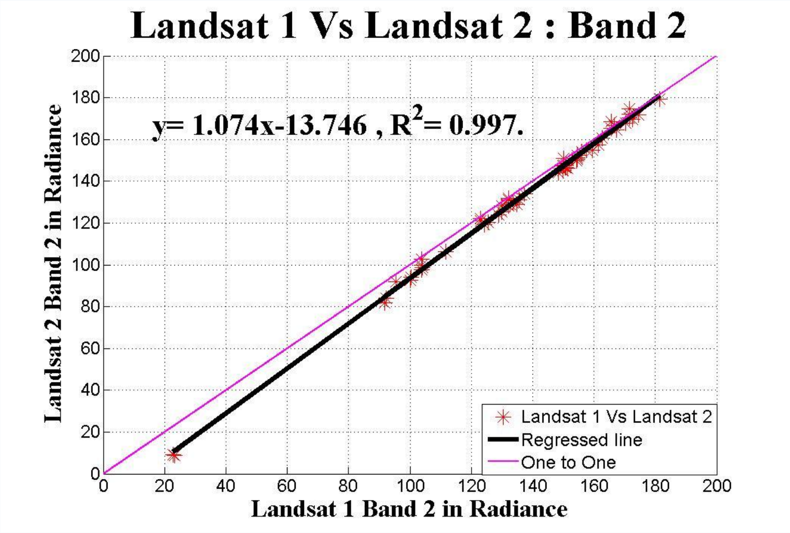
Scene Pair used 5	Total 14 ROIs
Scene Pair-1	LM10410381975150AAA04
	LM20410381975159AAA05
Scene Pair-2	LM10410381976073AAA02
	LM20410381976082AAA01
Scene Pair-3	LM10410381976109AAA02
	LM20410381976100AAA01
Scene Pair-4	LM10410381976289AAA04
	LM20410381976280AAA03
Scene Pair-5	LM10410381976109AAA02
	LM20410381976118AAA01
Scene Pair-6	LM10490301975212GDS03
	LM20490301975203AAA05
Scene Pair-7	LM10480301975247AAA04
	LM20490301975221GDS03



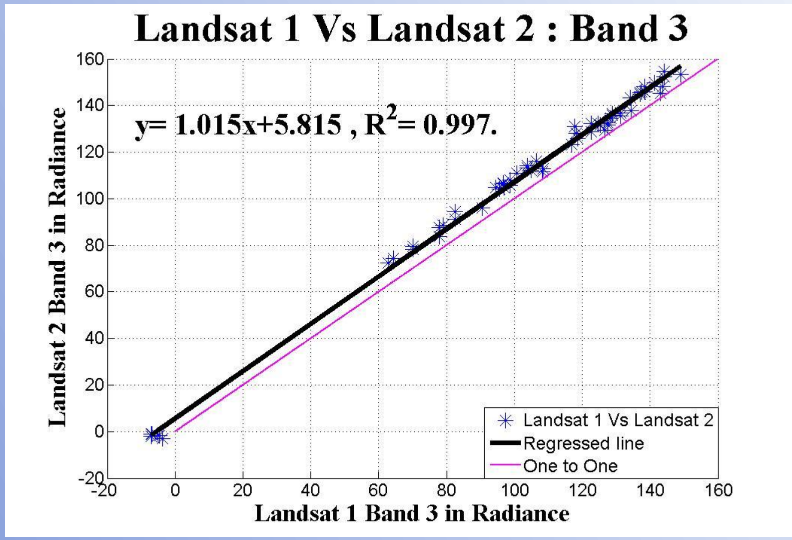
- Five pairs of near-coincident scenes from the Sonora Desert and two from Crater Lake are selected.
- Two dark targets were added to calibrate Landsat 1 to Landsat 2.

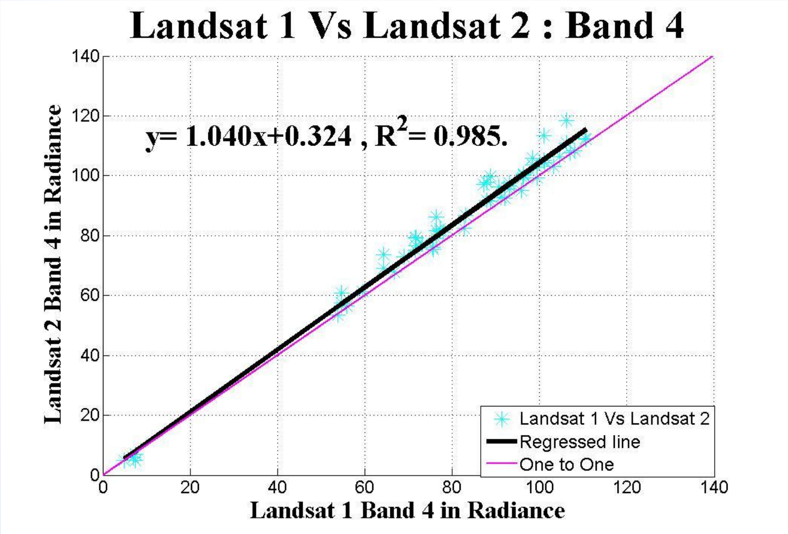
Landsat 1 to 2 Cross-calibration Results





- For band 1, cross calibration shows almost no deviation between regressed and one to one line.
- For band 2, cross calibration shows considerable deviation between regressed and one to one line.





- For band 3, cross calibration shows considerable deviation between regressed and one to one line.
- For band 3, there exist negative radiance values.
- For band 4, cross calibration shows almost no deviation between regressed and one to one line.

Statistical Test For Landsat 1 to Landsat 2 cross calibration

Null Hypothesis: Bias=0
Null Hypothesis: Slope=1

With the 0.01 level of significance to be consistent with previous work

Estimates of Band 1					Estimates of Band 2				
	Estimate	Std.Error	t value	Pr(>|t|)		Estimate	Std.Error	t value	Pr(>|t|)
(Intercept)	-0.950	0.990	-0.961	0.3407	(Intercept)	-13.746	1.234	-11.143	1.67E-15
Slope	1.016	0.008	2.069	0.0431	Slope	1.074	0.009	8.455	2.11E-11

Estimates of Band 3					Estimates of Band 4				
	Estimate	Std.Error	t value	Pr(>|t|)		Estimate	Std.Error	t value	Pr(>|t|)
(Intercept)	5.815	0.784	7.416	5.34E-10	(Intercept)	0.324	1.474	0.251	0.8030
Slope	1.015	0.007	2.001	0.0500	Slope	1.040	0.018	2.252	0.0283

• Statistical tests support that the bias term in the cross-calibration of Landsat 1 and 2 is not zero for Band 2 and Band 3

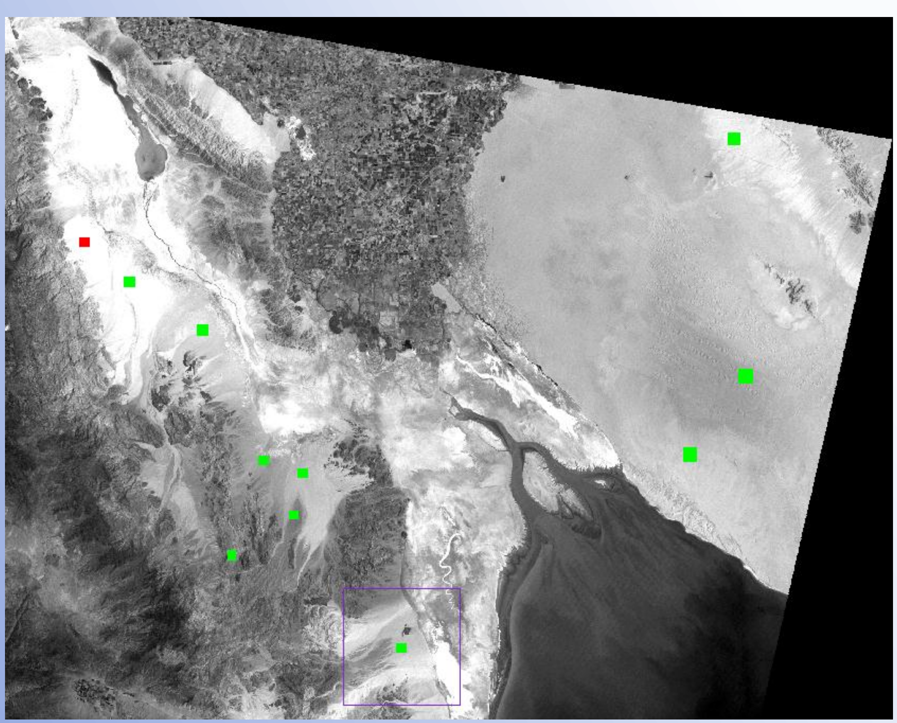
•Similarly statistical tests support that the gain term in the cross-calibration of Landsat 1 and 2 is not one for Band 2.

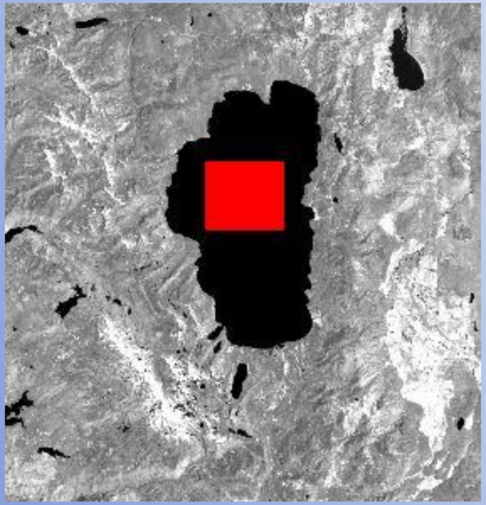
Cross-calibration Summary

Cross Calibration Gains and Biases between the Landsat MSS Sensors					
Landsat-1 to Landsat-2			Landsat-2 to Landsat-3		
	Gain	Bias		Gain	Bias
Band 1	1	0	Band 1	1	0
Band 2	1.0740	-13.7461	Band 2	0.94436	6.1446
Band 3	1	5.8148	Band 3	0.94666	8.7551
Band 4	1	0	Band 4	1	0
Landsat-3 to Landsat-4			Landsat-4 to Landsat-5		
	Gain	Bias		Gain	Bias
Band 1	1	0	Band 1	1	0
Band 2	1	0	Band 2	1	0
Band 3	1	0	Band 3	1	0
Band 4	1	0	Band 4	1	0

- Two bias and gain terms for Band 2
- Similarly two bias and gain term for Band 3.

Cross-calibration of Landsat 5 MSS to Landsat 5 TM

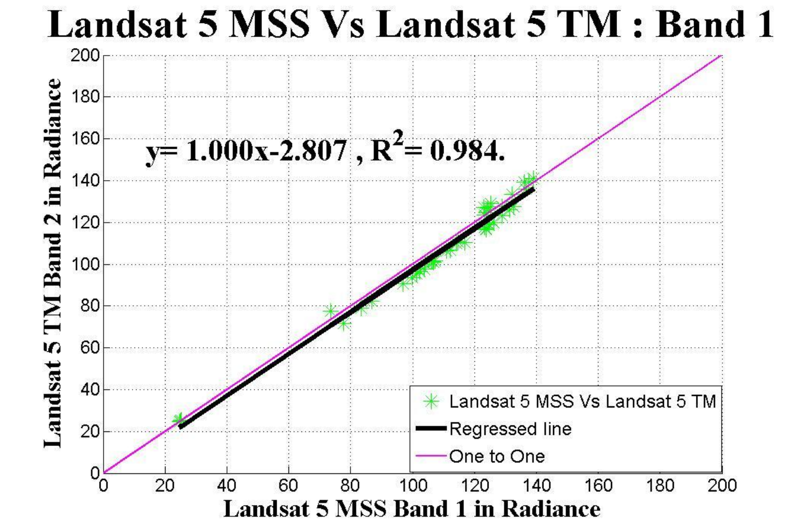




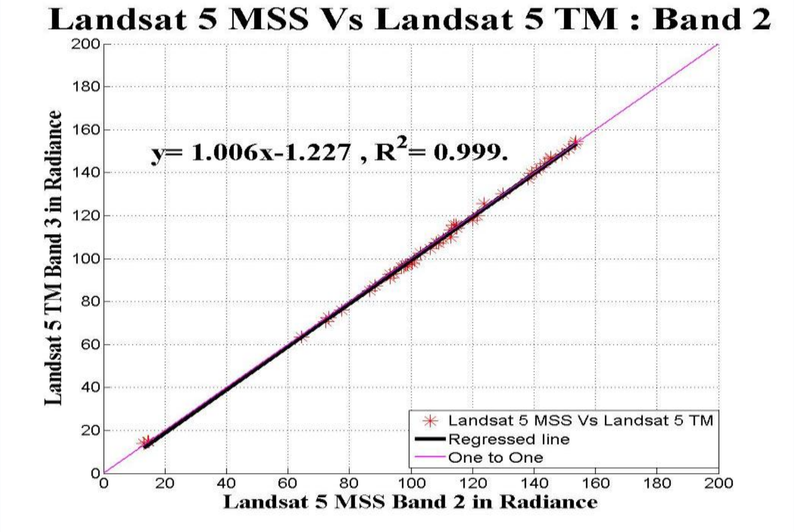
Scene Pair used 5	Total 11 ROIs	
Scene Pair-1	LM50430331984180AAA03	1 sec apart
	LT50430331984180XXX16	
Scene Pair-2	LM50430331985214AAA03	1 sec apart
	LT50430331985214XXX05	
Scene Pair-3	LM50430331987188AAA03	1 sec apart
	LT50430331987188XXX02	
Scene Pair-4	LM50380381985275AAA03	1 sec apart
	LT50380381985275XXX04	
Scene Pair-5	LM50380381986326AAA03	1 sec apart
	LT50380381986326XXX04	
Scene Pair-6	LM50380381987281AAA03	1 sec apart
	LT50380381987281XXX03	
Scene Pair-7	LM50380381988204AAA03	1 sec apart
	LT50380381988204XXX03	

- Four pairs of near-coincident scenes from the Sonora Desert and three from lake Tahoe are selected.
- 10 ROI for each pair of Sonora desert and 1 ROI for Lake Tahoe is used

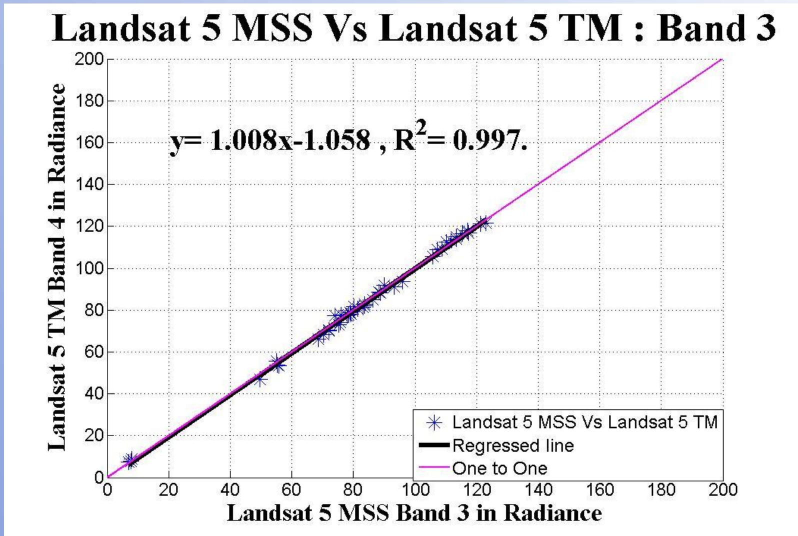
Landsat 5 MSS to TM Cross-Calibration



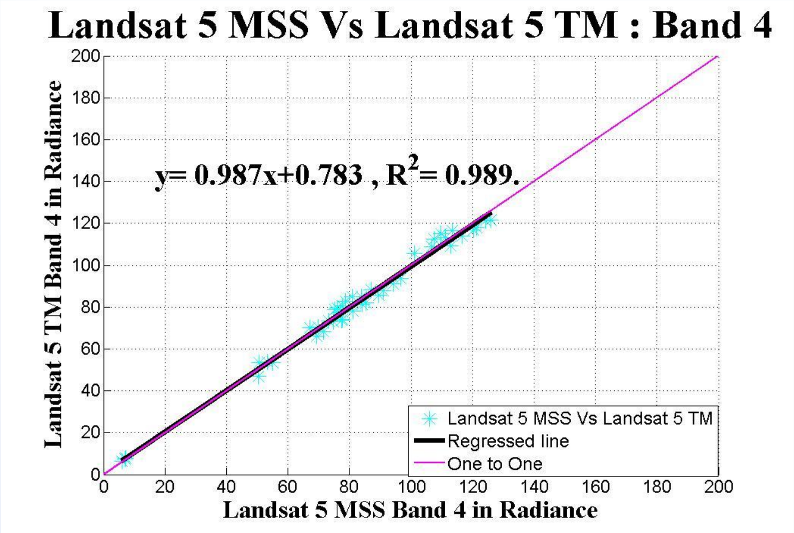
- For band 1, cross calibration shows almost no deviation between regressed and one to one line.



- For band 2, cross calibration shows almost no deviation between regressed and one to one line.

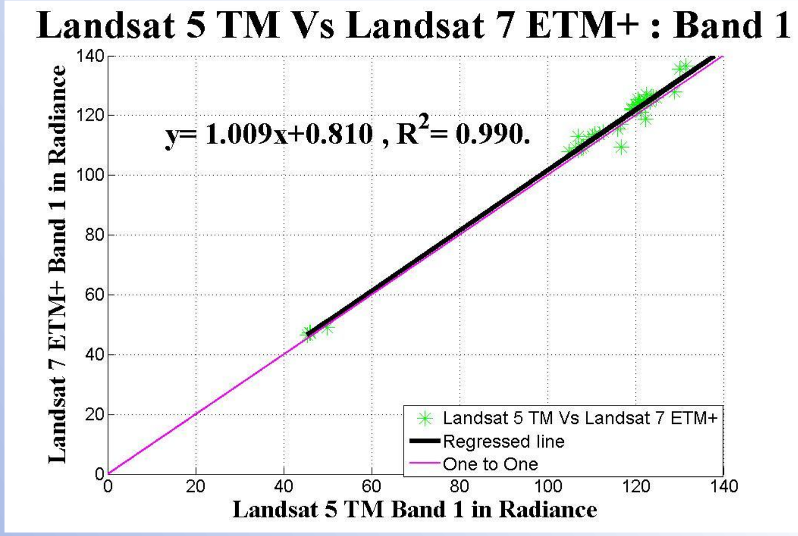


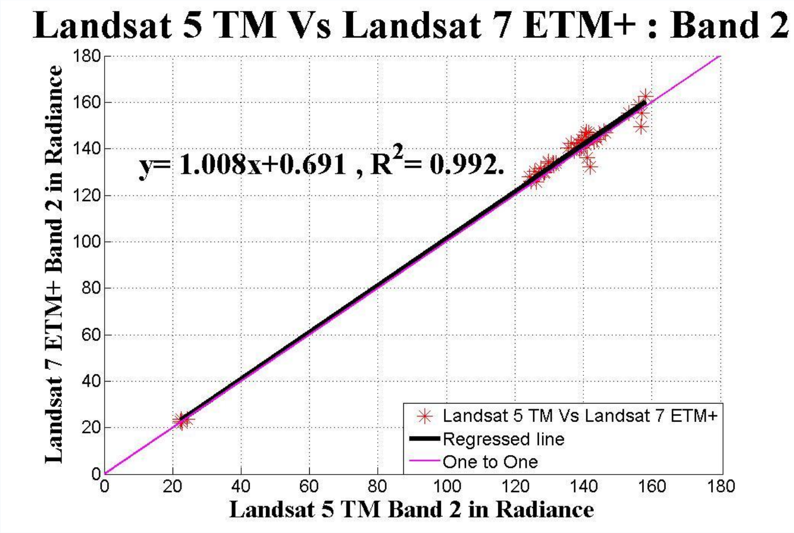
- For band 3, cross calibration shows almost no deviation between regressed and one to one line.



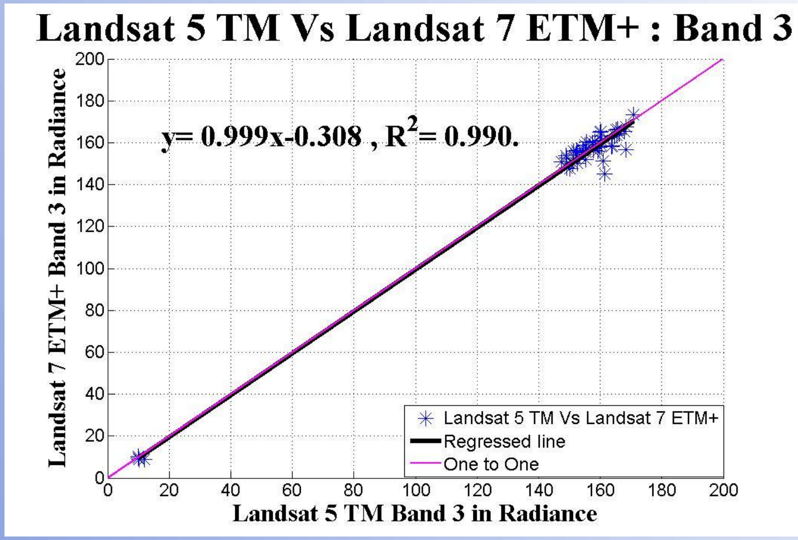
- For band 4, cross calibration shows almost no deviation between regressed and one to one line.

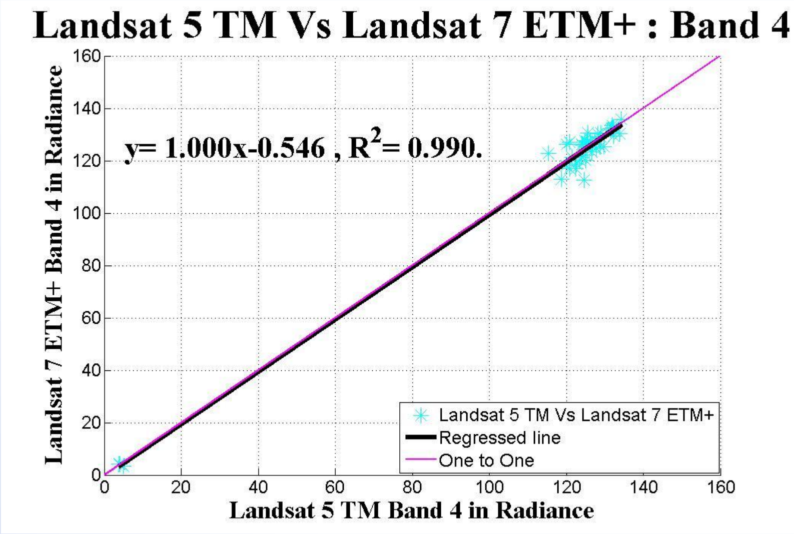
Landsat 5 TM to Landsat 7 ETM+ Cross-Calibration





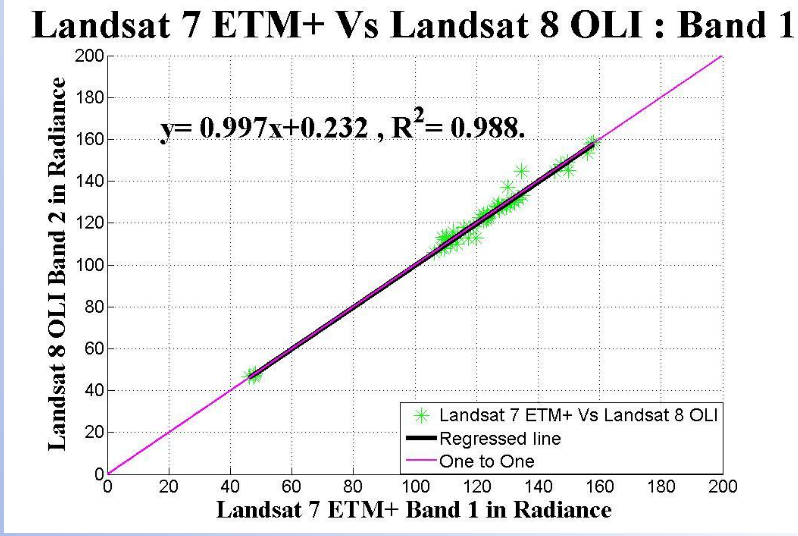
- For band 1, cross calibration shows almost no deviation between regressed and one to one line.
- For band 2, cross calibration shows almost no deviation between regressed and one to one line.



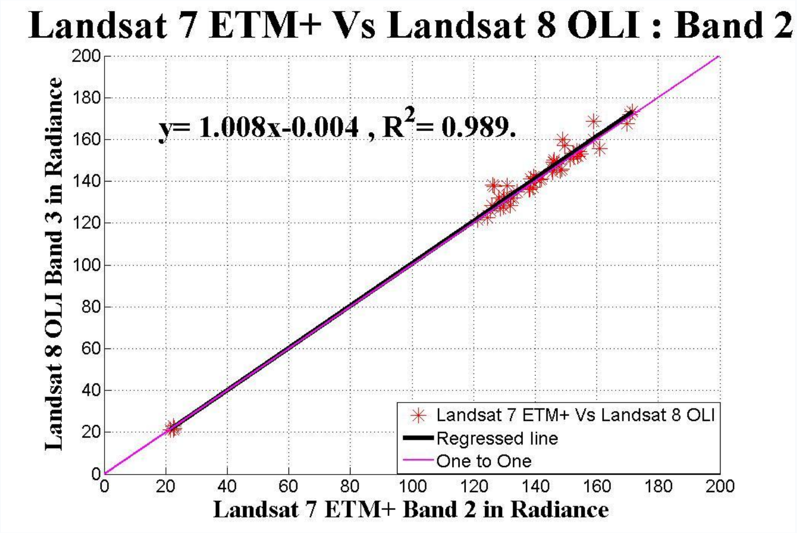


- For band 3, cross calibration shows almost no deviation between regressed and one to one line.
- For band 4, cross calibration shows almost no deviation between regressed and one to one line.

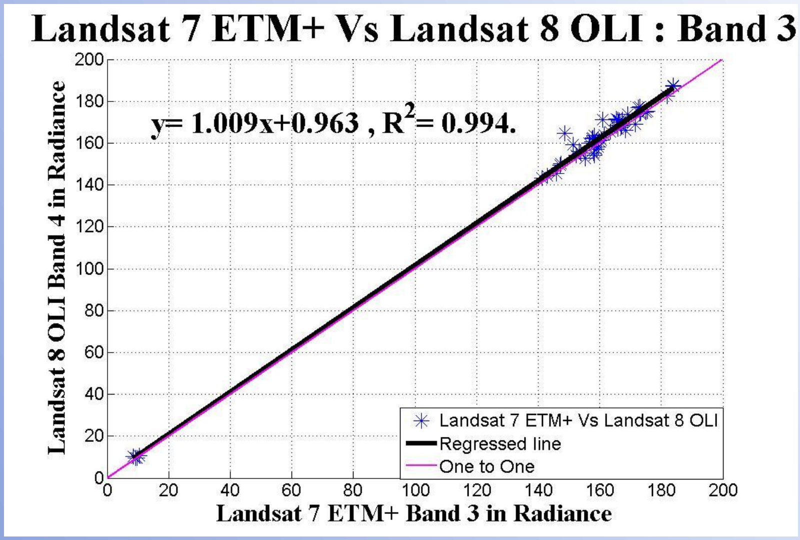
Landsat 7 ETM+ to Landsat 8 OLI Cross-Calibration



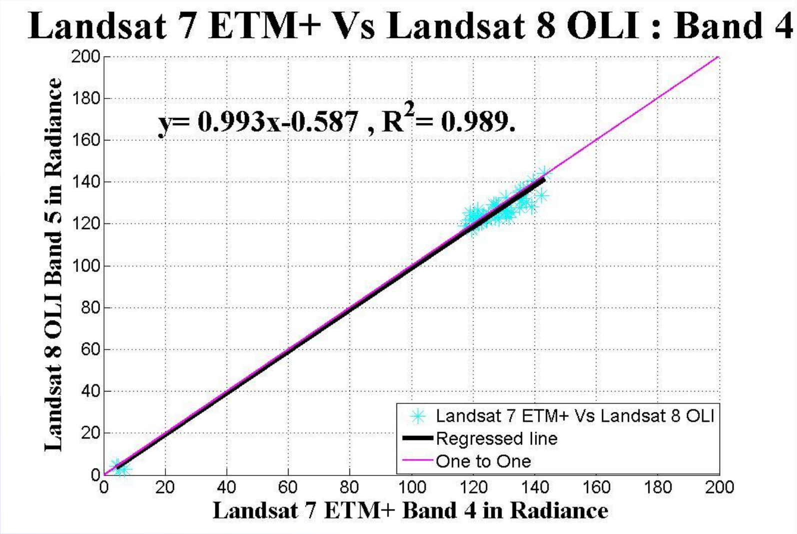
- For band 1, cross calibration shows almost no deviation between regressed and one to one line.



- For band 2, cross calibration shows almost no deviation between regressed and one to one line.

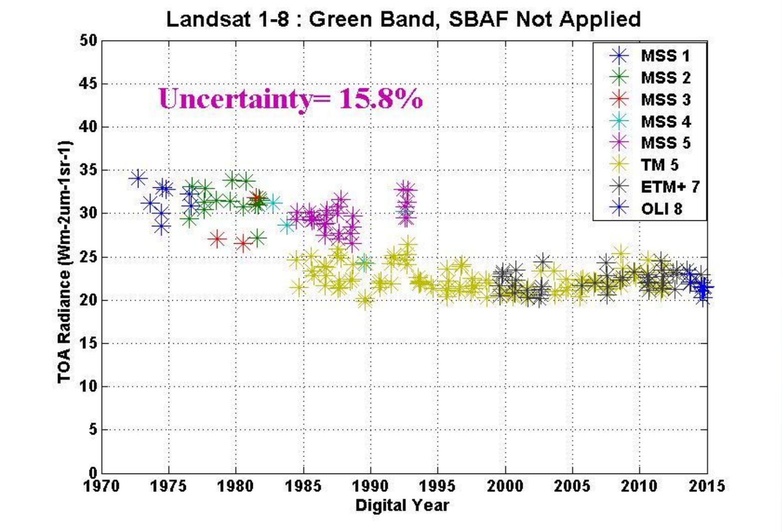


- For band 3, cross calibration shows almost no deviation between regressed and one to one line.

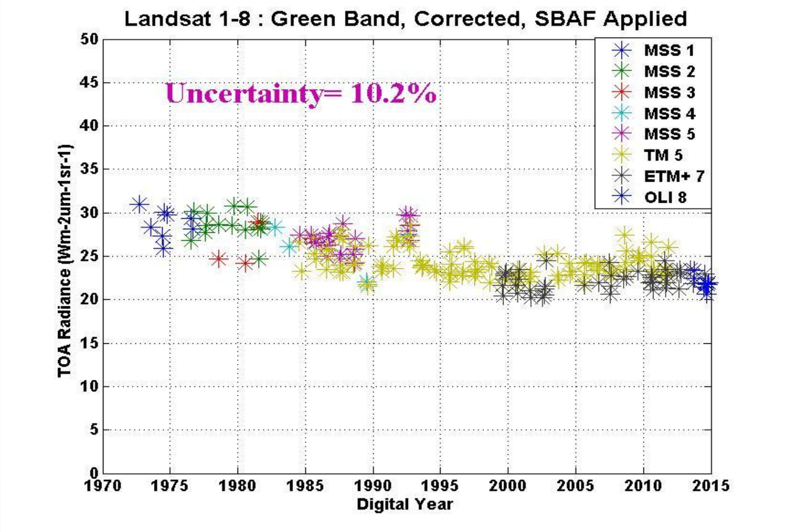


- For band 4, cross calibration shows almost no deviation between regressed and one to one line.

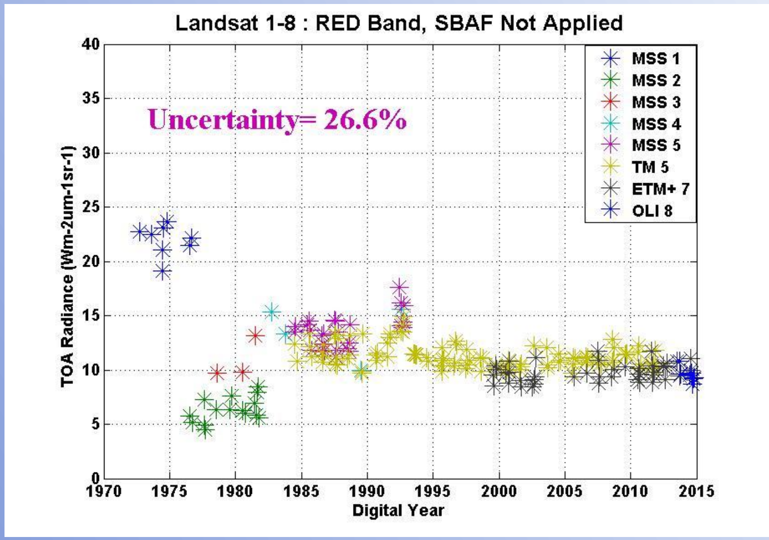
Validation: Lake Tahoe, Dark Target



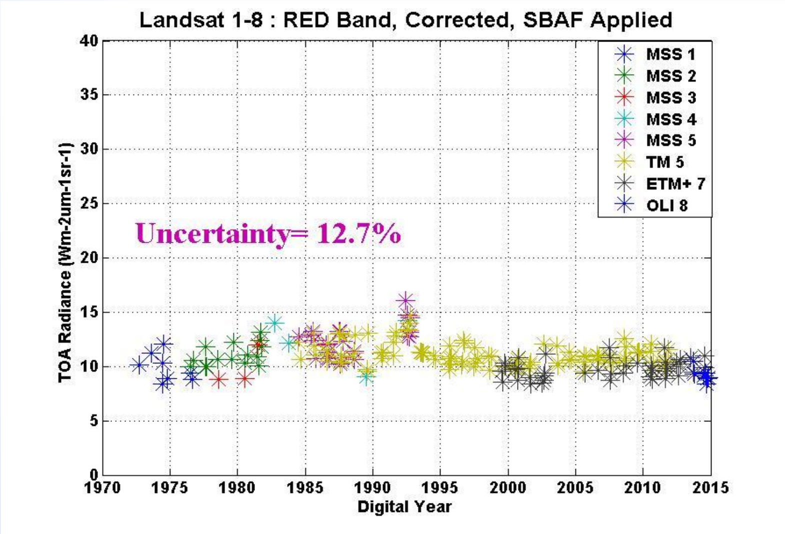
- Plot shows the true TOA radiance values, no any correction is done.
- Uncertainty was found to be 15.8 %



- Plot shows the TOA radiance values after correction and SBAF is applied.
- Uncertainty was reduced to 10.2 %

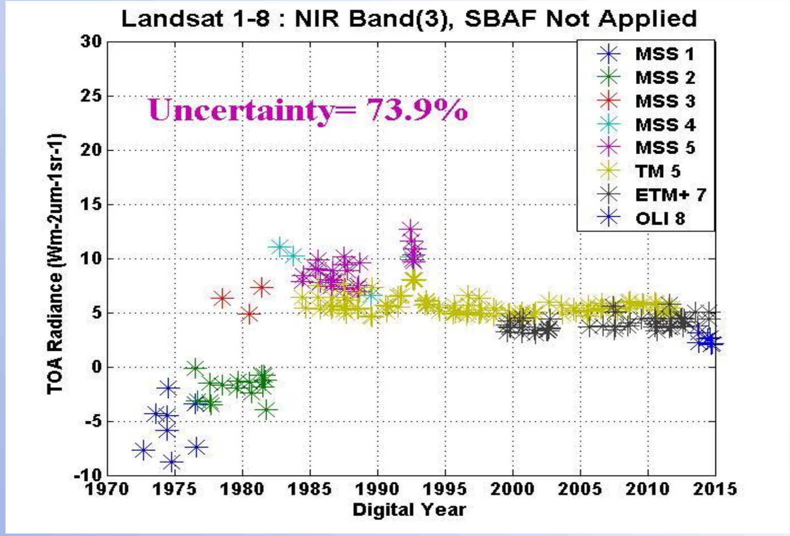


- Plot shows the true TOA radiance values, no any correction is done.
- Uncertainty was found to be 26.6 %

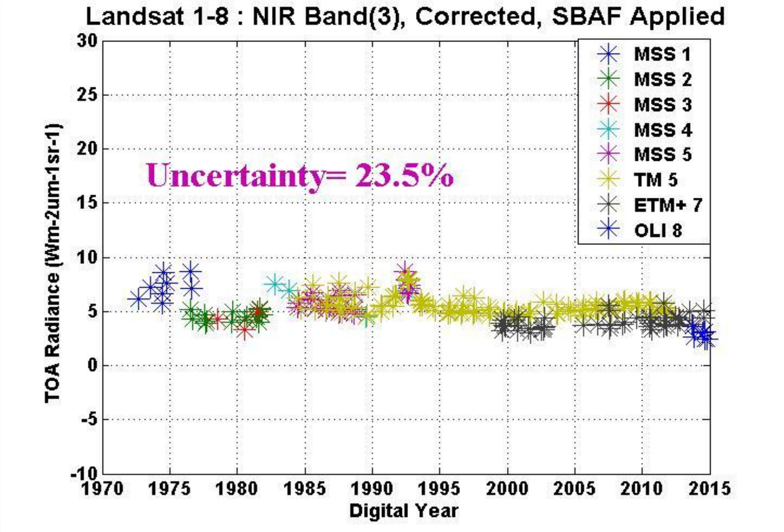


- Plot shows the TOA radiance values after correction and SBAF is applied.
- Uncertainty was reduced to 12.7 %

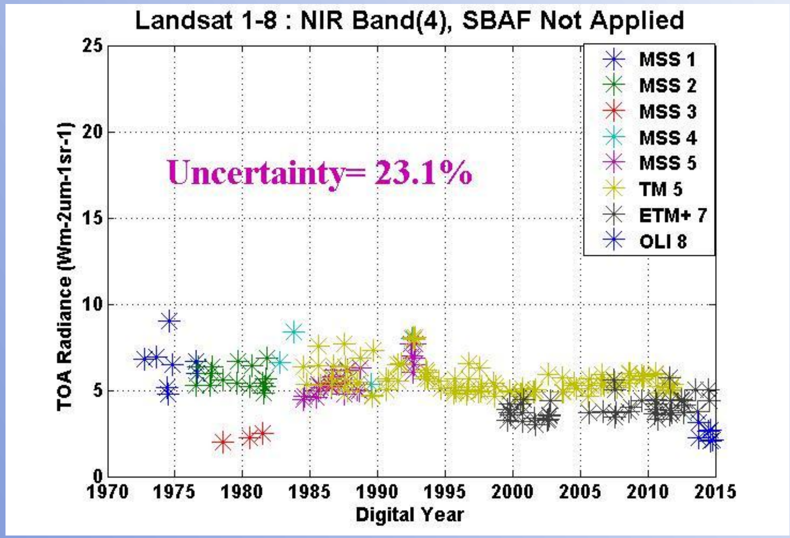
Validation: Lake Tahoe , Dark Target



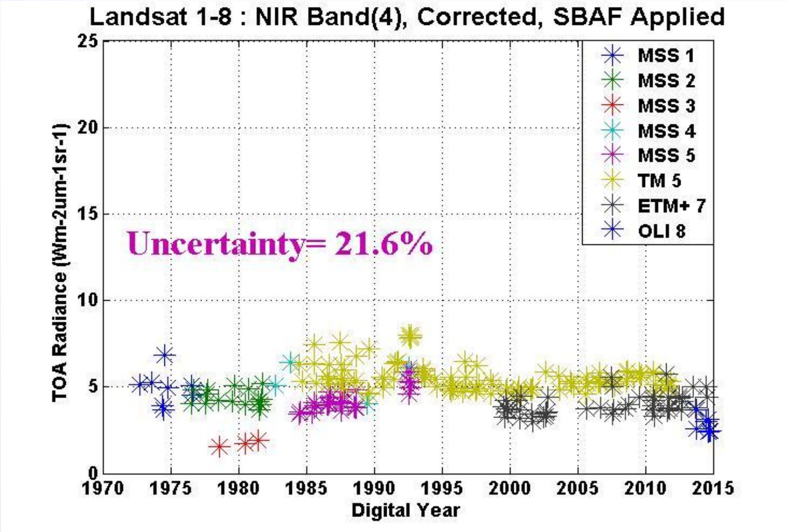
- Plot shows the true TOA radiance values, no any correction is done.
- Uncertainty was found to be 73.9 %



- Plot shows the TOA radiance values after correction and SBAF is applied.
- Uncertainty was reduced to 23.5 %

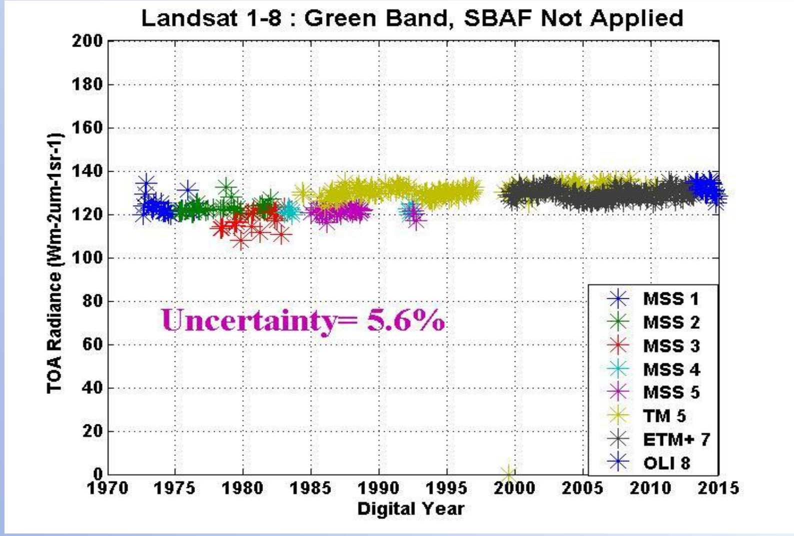


- Plot shows the true TOA radiance values, no any correction is done.
- Uncertainty was found to be 23.1 %

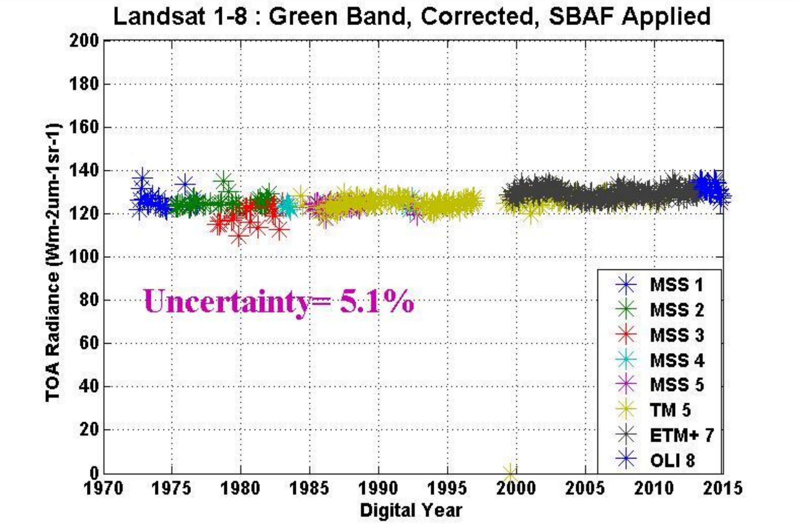


- Plot shows the TOA radiance values after correction and SBAF is applied.
- Uncertainty was reduced to 21.6 %

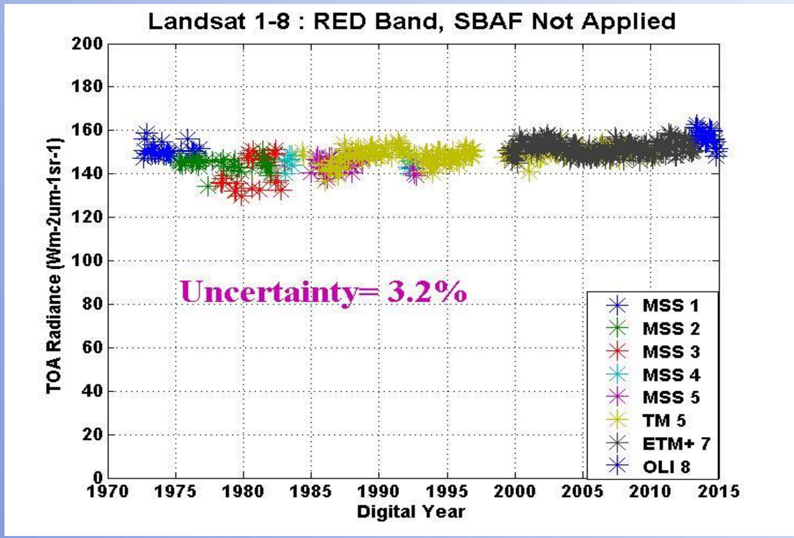
Validation: Sonora Desert , Bright Target



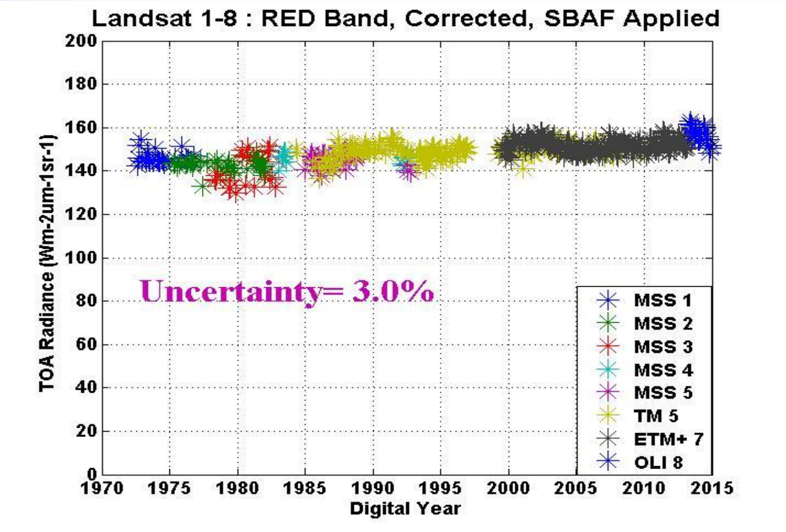
- Plot shows the true TOA radiance values, no any correction is done.
- Uncertainty was found to be 5.6 %



- Plot shows the TOA radiance values after correction and SBAF is applied.
- Uncertainty was reduced to 5.1 %

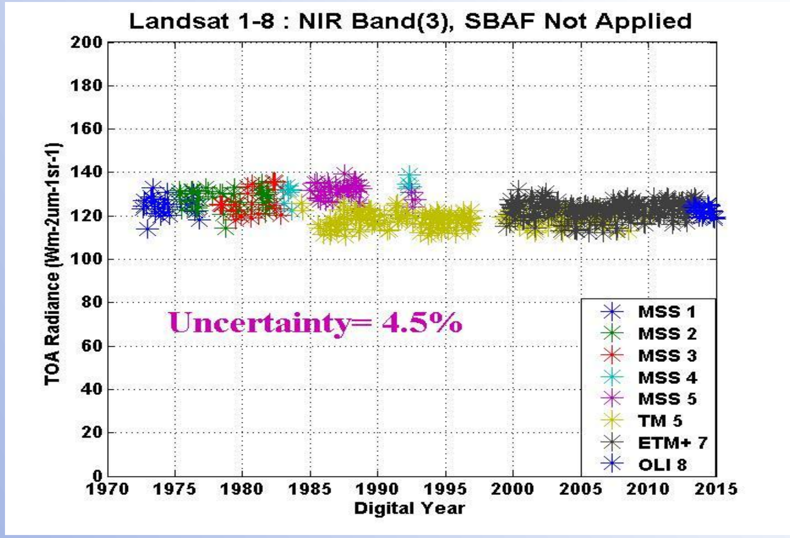


- Plot shows the true TOA radiance values, no any correction is done.
- Uncertainty was found to be 3.2 %

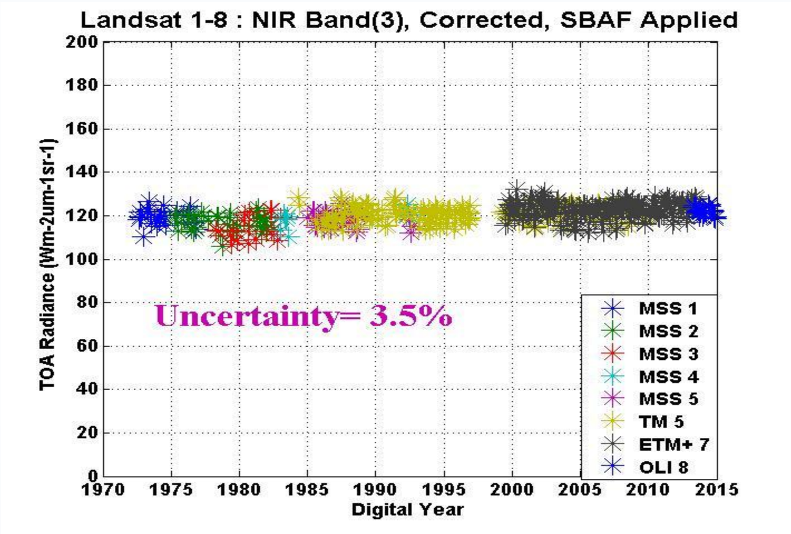


- Plot shows the TOA radiance values after correction and SBAF is applied.
- Uncertainty was reduced to 3.0 %

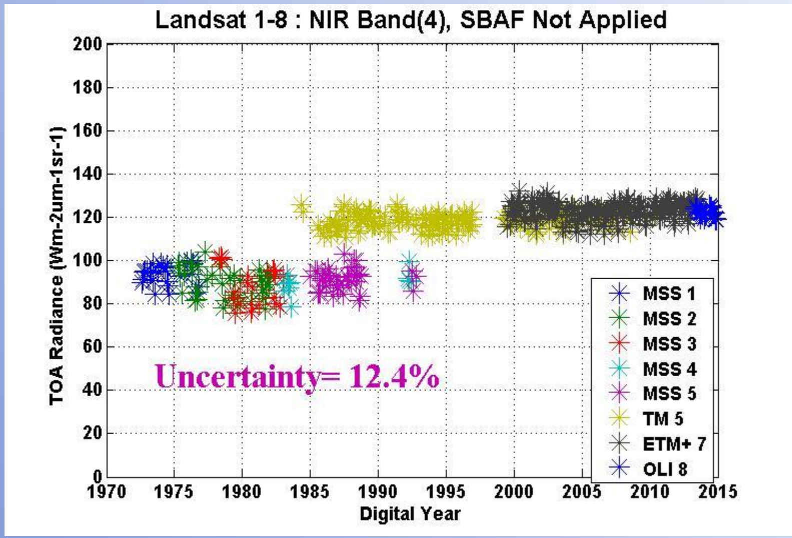
Validation: Sonora Desert, Bright Target



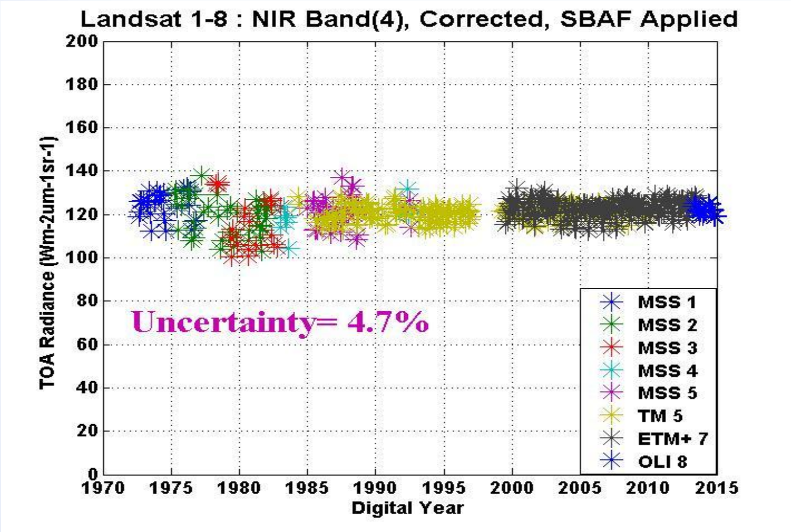
- Plot shows the true TOA radiance values, no correction is done.
- Uncertainty was found to be 4.5 %



- Plot shows the TOA radiance values after correction and SBAF is applied.
- Uncertainty was reduced to 3.5 %

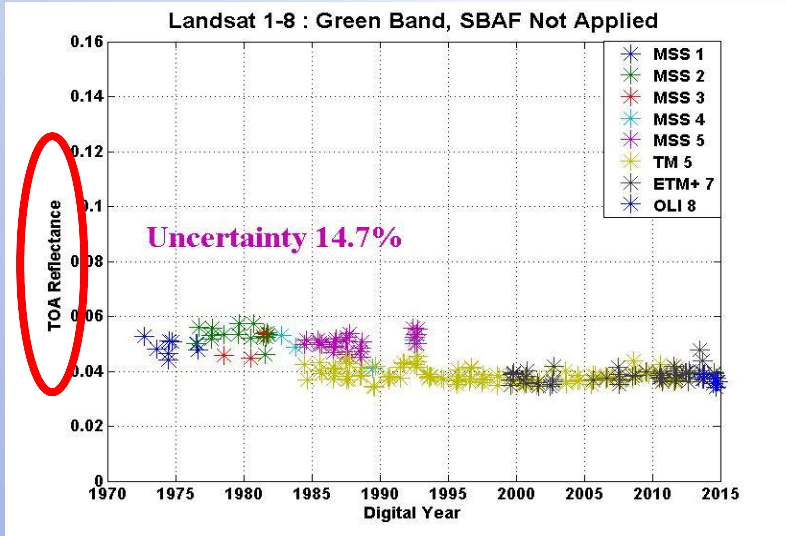


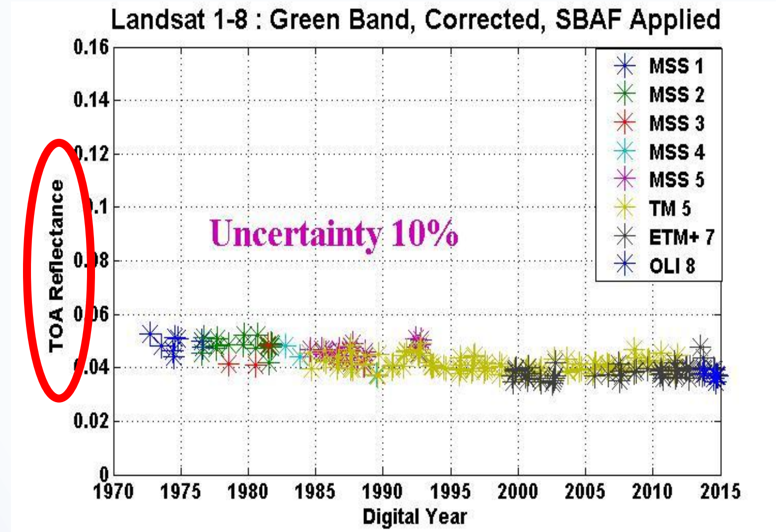
- Plot shows the true TOA radiance values, no correction is done.
- Uncertainty was found to be 12.4 %



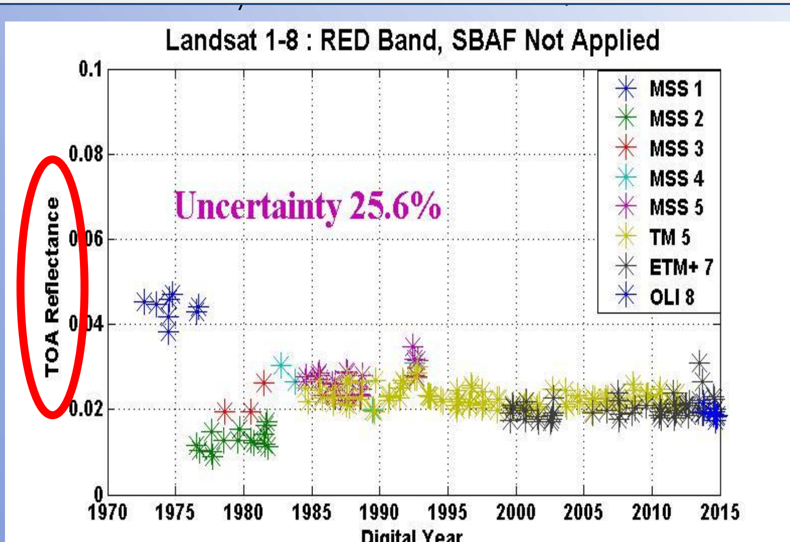
- Plot shows the TOA radiance values after correction and SBAF is applied.
- Uncertainty was reduced to 4.7 %

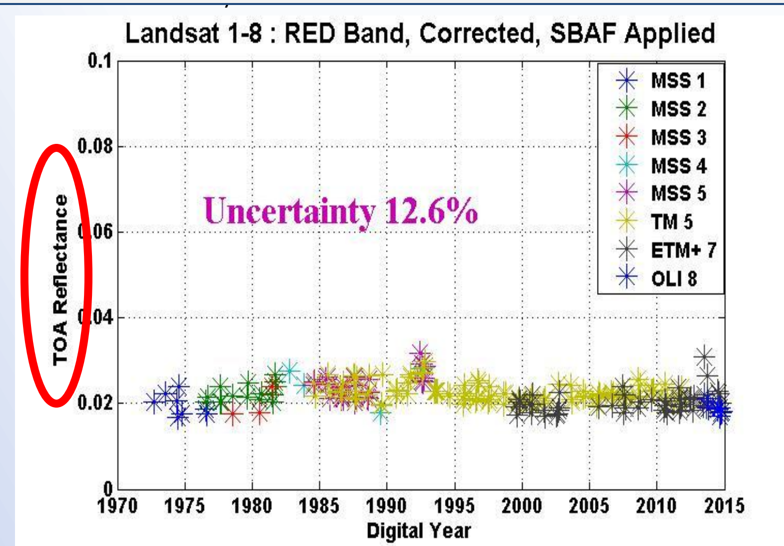
Validation: Lake Tahoe, Dark Target





Validation done in both radiance and reflectance space





- Plot shows the true TOA reflectance values, no any correction is done.
- Uncertainty was found to be 25.6 %

- Plot shows the TOA reflectance values after correction and SBAF is applied.
- Uncertainty was reduced to 12.6 %

Conclusions

- Inconsistencies seen in Landsat 1 and Landsat 2 for band 2 and band 3 were corrected.
- The lifetime radiometric stability of all Landsat sensors was validated.
- Recommend an update to the calibration of the archive.
- Reflectance-based calibration can be propagated back to Landsat 1.

Reflectance-based Calibration Initiative

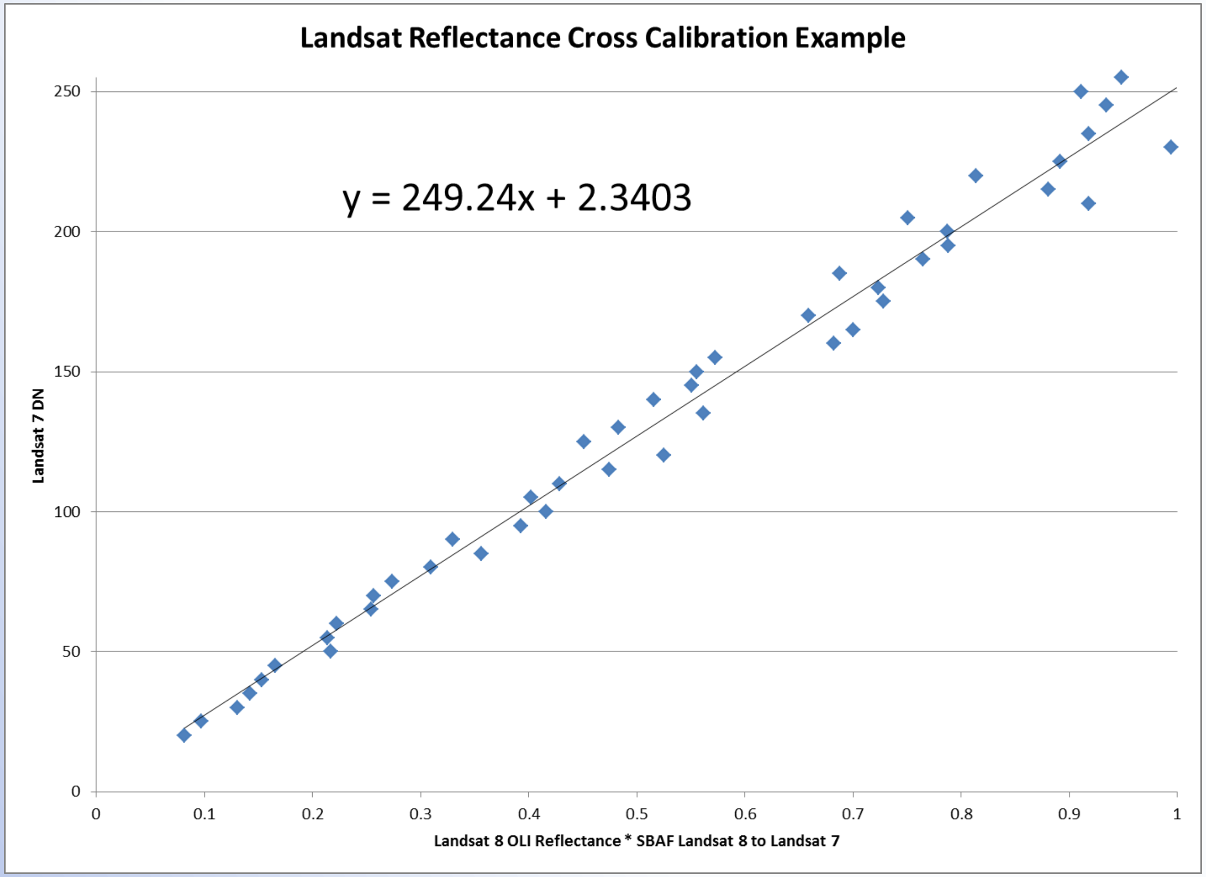
- Currently
  - Landsat 8 OLI calibrated in radiance and reflectance space
  - Landsat 1-7 calibrated in radiance space
  - Landsat 8 OLI calibration considered more accurate than other Landsat instruments. Reflectance calibration more accurate than radiance calibration
- Proposed
  - Declare current radiance calibration as final, no longer update it
  - Propagate Landsat 8 OLI reflectance calibration to all other Landsat instruments
  - Maintain and update Landsat reflectance calibration

Reflectance-based Calibration Initiative

- Advantages
  - Landsat calibration based on most accurate instrument
  - Landsat calibration based on most accurate methodology
  - Users prefer calibrated reflectance product
  - No dependence on Esun
  - Only one calibration chain to maintain
  - Consistency with other sensors (ex. MODIS)

Methodology

- Scales ETM+ DNs to OLI calibrated reflectance scale.
- Use coincident image data over a broad dynamic range.
- Spectral differences between sensors accounted for.
- Result is ETM+ DNs on a reflectance scale.
- Repeat for for Landsat 5 TM to Landsat 7 ETM+.
- Continue…



Methodology

Reflectance-based Landsat Archive Calibration	
OLI	$DN_{8,\lambda} = g_{8,\rho,\lambda} \cdot \rho_{8,\lambda} + b_{8,\rho,\lambda}$
ETM+ to OLI	$DN_{7,\lambda} = g_{7,\rho,\lambda} \cdot (SBAF_{\frac{7}{8},\rho,\lambda,ROI} \cdot \rho_{8,\lambda}) + b_{7,\rho,\lambda}$
TM5 to ETM+	$DN_{5,\lambda} = g_{5,\rho,\lambda} \cdot (SBAF_{\frac{5}{7},\rho,\lambda,ROI} \cdot \rho_{7,\lambda}) + b_{5,\rho,\lambda}$
TM4 to TM5	$DN_{4,\lambda} = g_{4,\rho,\lambda} \cdot (SBAF_{\frac{4}{5},\rho,\lambda,ROI} \cdot \rho_{5,\lambda}) + b_{4,\rho,\lambda}$
MSS5 to TM5	$DN_{5M,\lambda} = g_{5M,\rho,\lambda} \cdot SBAF_{\frac{5M}{5},\rho,\lambda,ROI} \cdot \rho_{5,\lambda} + b_{5M,\rho,\lambda}$
MSS(n) to MSS(n+1)	$DN_{nM,\lambda} = g_{nM,\rho,\lambda} \cdot SBAF_{\frac{nM}{(n+1)M},\rho,\lambda,ROI} \cdot \rho_{(n+1)M,\lambda} + b_{nM,\rho,\lambda}$

Reflectance-based Calibration Initiative

DISCUSSION

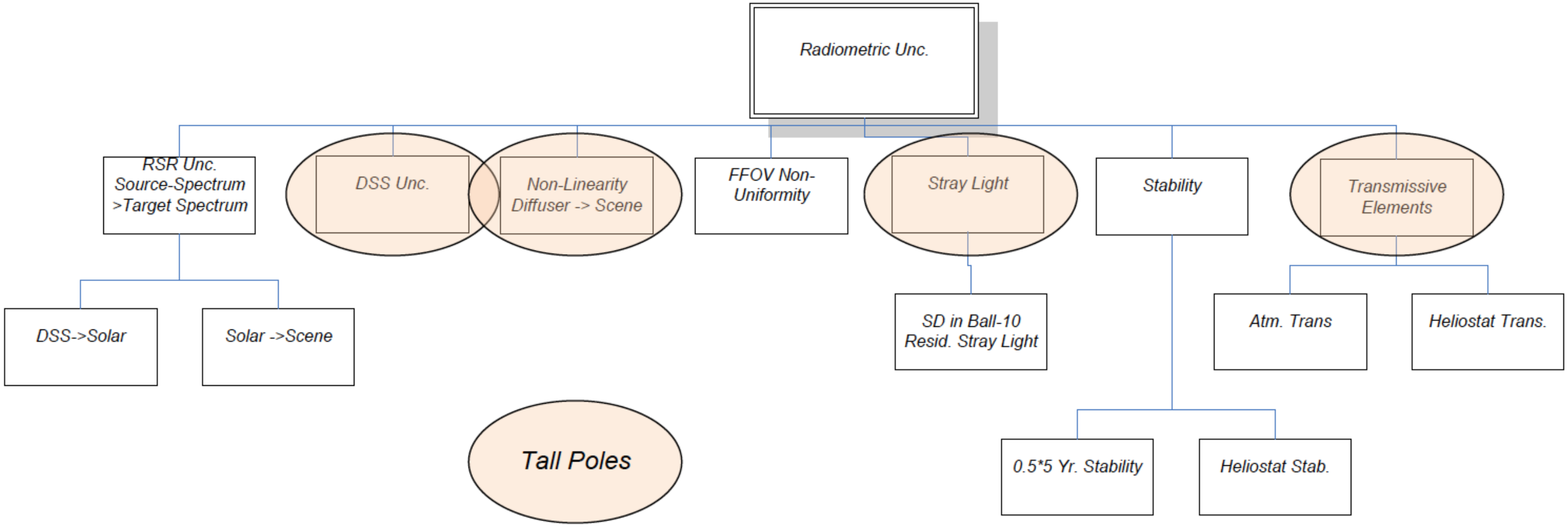
Brian and Ron contribute here!

DISCUSSION BACKUP SLIDES

OLI Radiometric Calibration

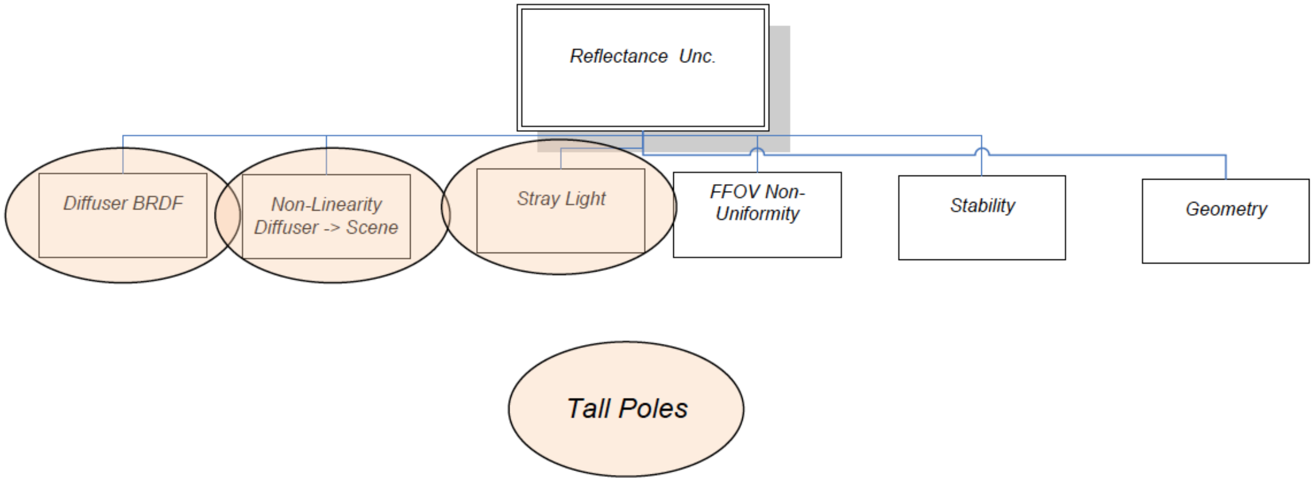
- Independent Reflectance and Radiance Calibrations provided with data product
  - reflectance calibration should have lower uncertainty (~2% versus ~3% for radiance)
  - Reflectance calibration obviates need for solar spectrum and additional uncertainty introduced(1 – 5%); adopted by MODIS, MSI and other sensors
  - Ground (vicarious) and cross calibrations with MODIS generally consistent with OLI operational reflectance calibration (within uncertainties), though issues with shortest wavelength bands.
- Recommendation is to use OLI reflectance calibration; plan is to propagate this calibration back to earlier Landsat sensors.

Radiance Uncertainty



- < 3.5%, 1σ End of Life
- Driving uncertainties:
  - Sphere uncertainty, will be touched on in H. Cutlip's presentation
  - Stray light
  - Heliostat transmission
  - Atmospheric transmission
  - Non-linearity

Reflectance Uncertainty



- < 2.5%, 1σ End of Life
- Driving uncertainties:
  - Diffuser BRDF
  - Stray light
  - Non-linearity

Estimated Uncertainties – Diffuser Measurements

Wavelength	400	650	Cirrus	SWIR 1	SWIR 2
Lamp effects					
Stray light	0.50	0.50	0.50	0.50	0.50
Lamp current uncertainty	0.08	0.05	0.02	0.02	0.02
Lamp current stability	0.10	0.06	0.02	0.02	0.02
Lamp current uncertainty	0.08	0.05	0.02	0.02	0.02
Lamp current stability	0.10	0.06	0.02	0.02	0.02
Alignment	0.40	0.40	0.40	0.40	0.40
Lamp ageing and drift	0.50	0.20	0.10	0.10	0.10
Reference effects					
RF spectral change	0.10	0.10	0.10	0.10	0.90
NIST uncertainty in RF	0.33	0.33	0.31	0.31	0.31
Instrumentation					
Spectral uncertainty	0.50	0.16	0.10	0.10	0.10
HP34970A/lock-In uncertainty	0.03	0.03	1.00	1.00	1.00
Detector/amplifier 'SNR'	0.50	0.30	0.10	0.10	0.10
Detector/amplifier 'SNR'	0.50	0.30	0.10	0.10	0.10
Stability	0.20	0.20	0.20	0.20	0.20
Repeatability	0.50	0.50	0.50	0.50	0.50
Transmittance	0.10	0.10	1.00	0.10	0.10
Total	1.4	1.1	1.7	1.4	1.9

From Stuart Biggar, University of Arizona