# PICS Normalization:

Improved Temporal Trending Using PICS

CalCon
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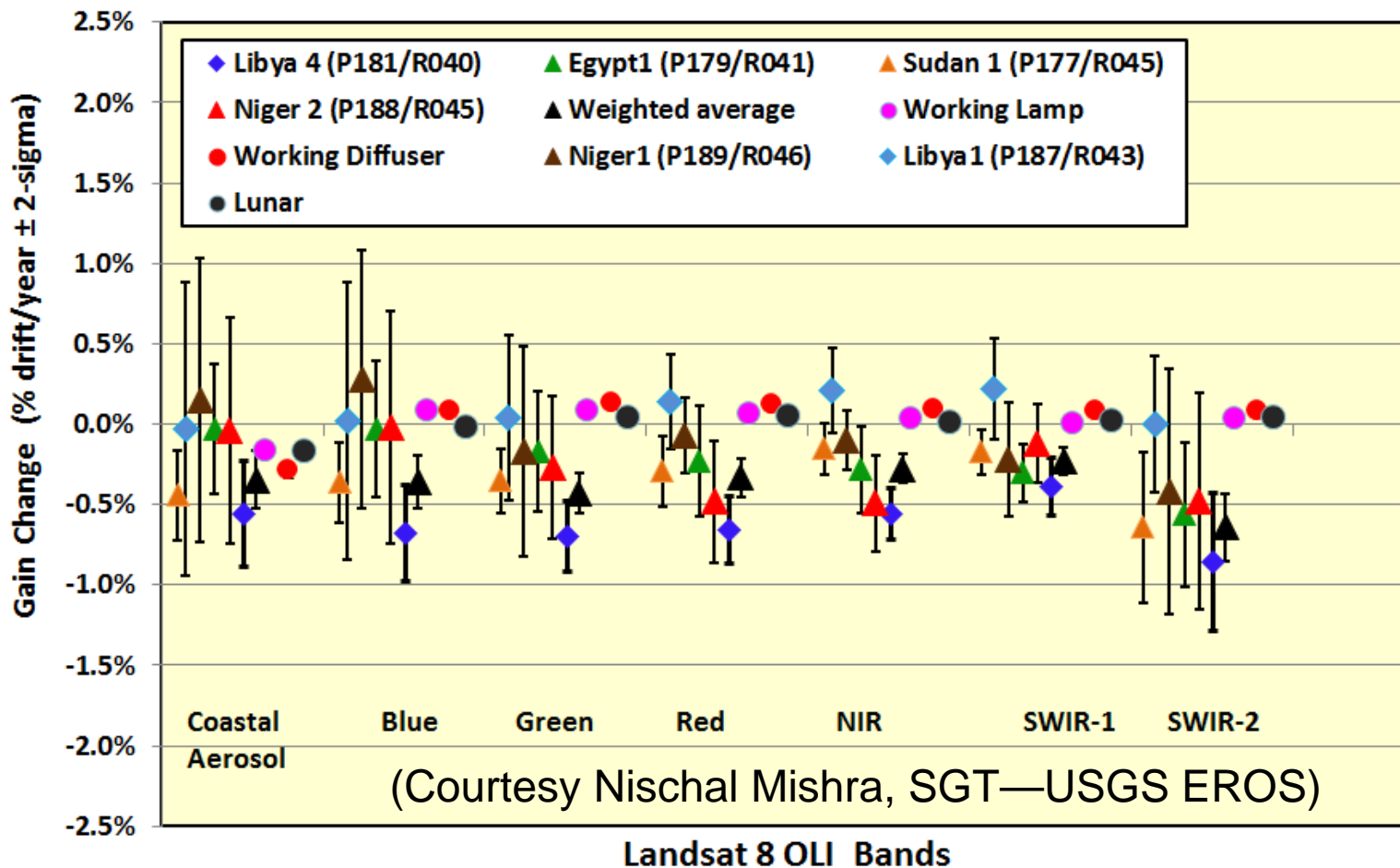Ruchira Tabassum, Morakot Kaewmanee

Background

- PICS (Pseudo Invariant Calibration Site) have been used for on-orbit radiometric trending of optical satellite sensors for many years,

- Highly regarded sites used by the calibration community are located in the Sahara desert, Northern Africa, i.e. well known-Libya4, Libya1, Egypt1, Niger1, Niger2, Sudan1

- If the site is invariant, any change we see from the trending indicates the change in sensor responsivity.

Temporal Plot OLI TOA Reflectance: 181-40
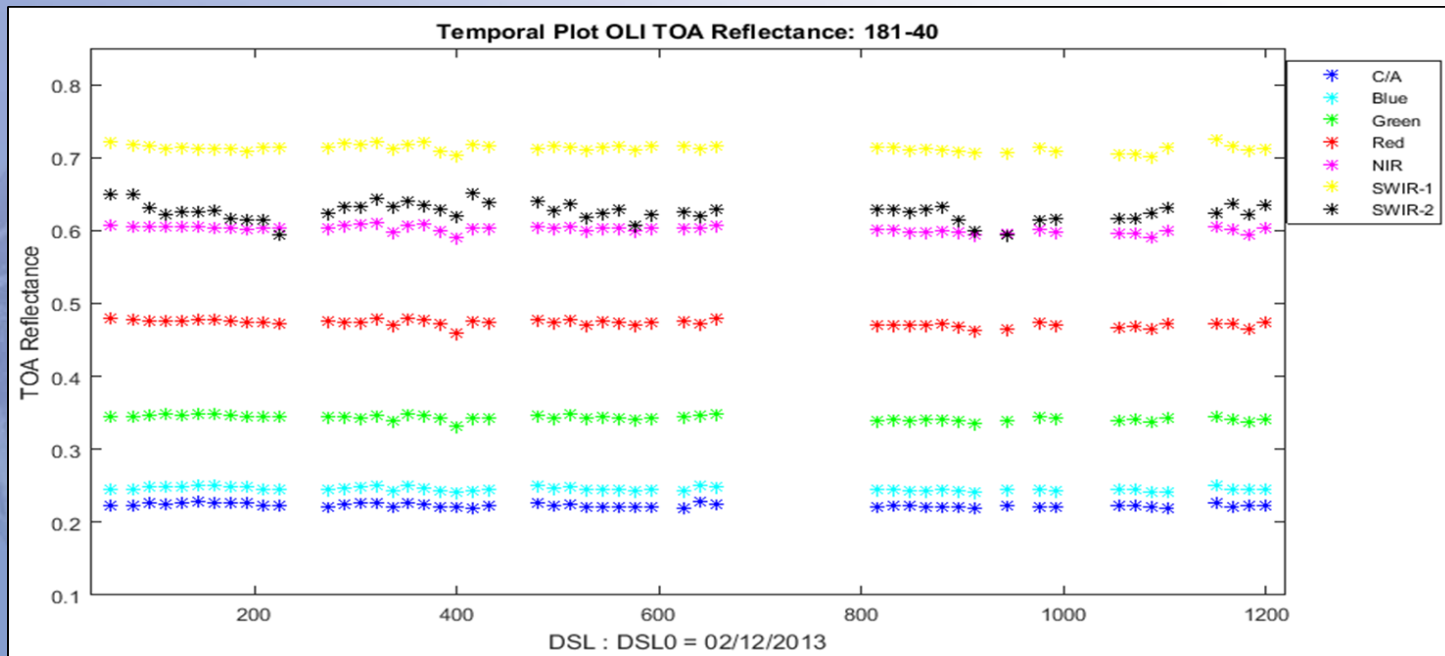
OLI-Bands	Temporal Uncertainty
Coastal	0.96%
Blue	0.92%
Green	0.83%
Red	0.78%
NIR	0.59%
SWIR-1	0.54%
SWIR-2	1.94%

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Drift Estimates – The Problem

Estimate of OLI Gain Change Over PICS and On-board calibrators

Legend:
- ◆ Libya 4 (P181/R040)
- ▲ Niger 2 (P188/R045)
- ● Working Diffuser
- ● Lunar
- ▲ Egypt1 (P179/R041)
- ▲ Weighted average
- ▲ Niger1 (P189/R046)
- ▲ Sudan 1 (P177/R045)
- ● Working Lamp
- ◆ Libya 1 (P187/R043)

Y-axis: Gain Change (% drift/year ± 2-sigma)

X-axis bands: Coastal Aerosol, Blue, Green, Red, NIR, SWIR-1, SWIR-2

Landsat 8 OLI Bands

(Courtesy Nischal Mishra, SGT—USGS EROS)

USGS   NASA

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Stability of ETM+ after 2013

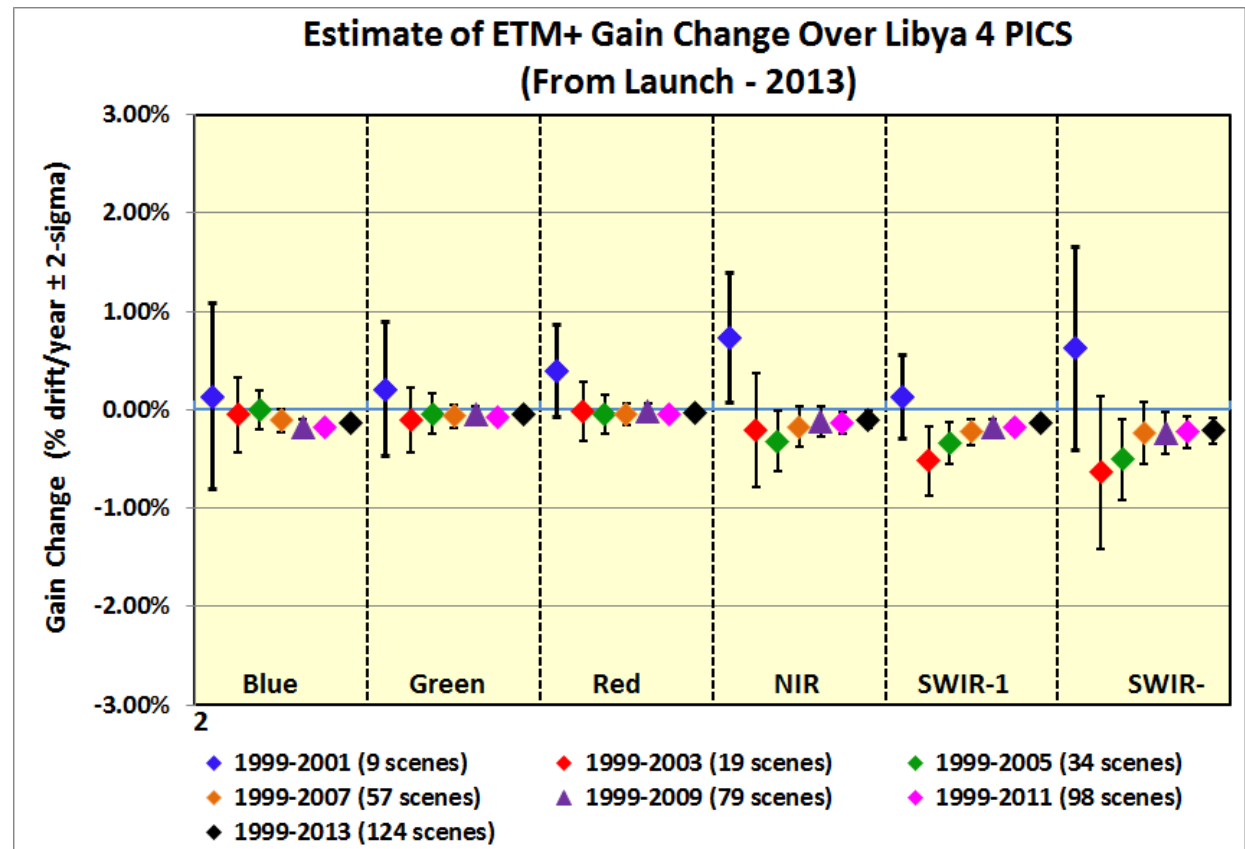- **Since OLI launch, ETM+ is behaving similarly.**
  - ◆ However ETM+ is very stable when the lifetime statistics are calculated.
  - ◆ So the gain changes observed in Libya 4 PICS is possibly because of the change in site rather than the sensor.

Estimate of ETM+ & OLI Gain Change Over Libya 4
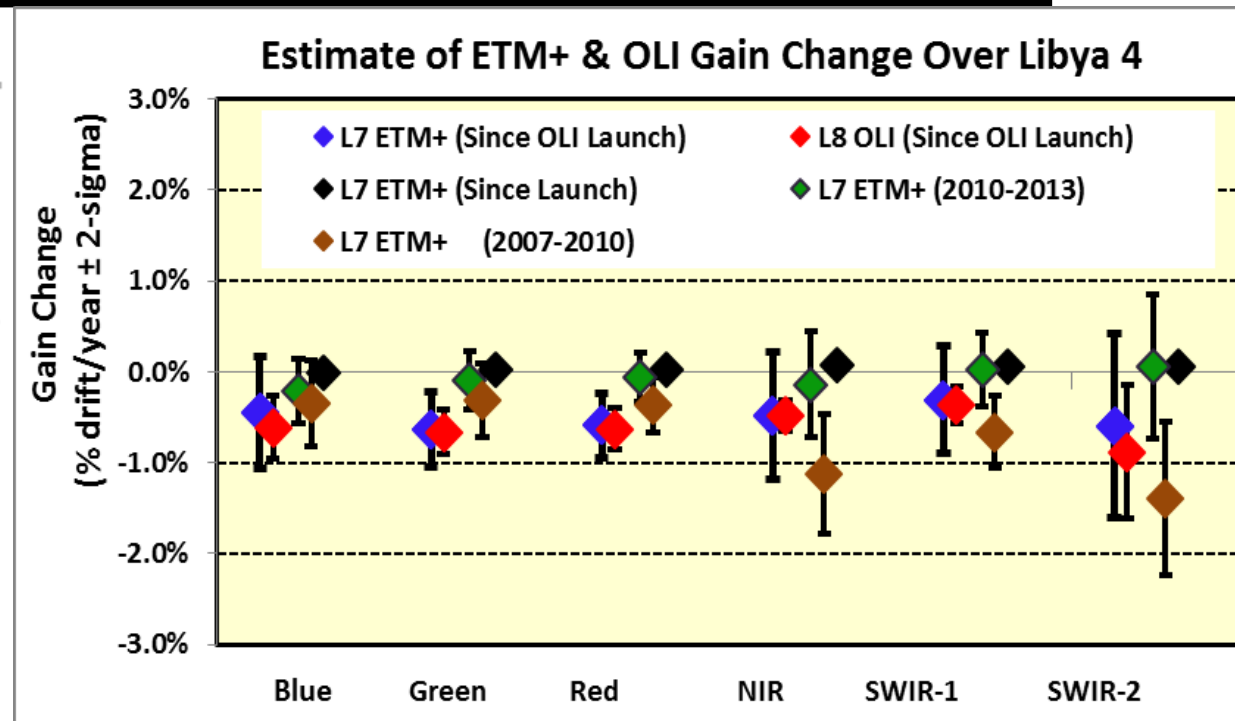
- Stability of ETM+ over different 3 years time period vary compared to lifetime stability
- This would mean that 3 years time may not be adequate to average out the noise inherent with PICS, primarily site variability.

(Courtesy Nischal Mishra, SGT—USGS EROS)

ETM+ gain change at different times

- **ETM+ gain was updated in 2013 with about 14 years of data over PICS.**

- **The uncertainty has $\sqrt{N}$ dependence hence will decrease with time when the number of observations increase.**

Estimate of ETM+ Gain Change Over Libya 4 PICS (From Launch - 2013)

Legend:
- 1999-2001 (9 scenes)
- 1999-2003 (19 scenes)
- 1999-2005 (34 scenes)
- 1999-2007 (57 scenes)
- 1999-2009 (79 scenes)
- 1999-2011 (98 scenes)
- 1999-2013 (124 scenes)

- **The trend indicates that the gain estimate started converging after 6-8 years for most bands**

(Courtesy Nischal Mishra, SGT—USGS EROS)
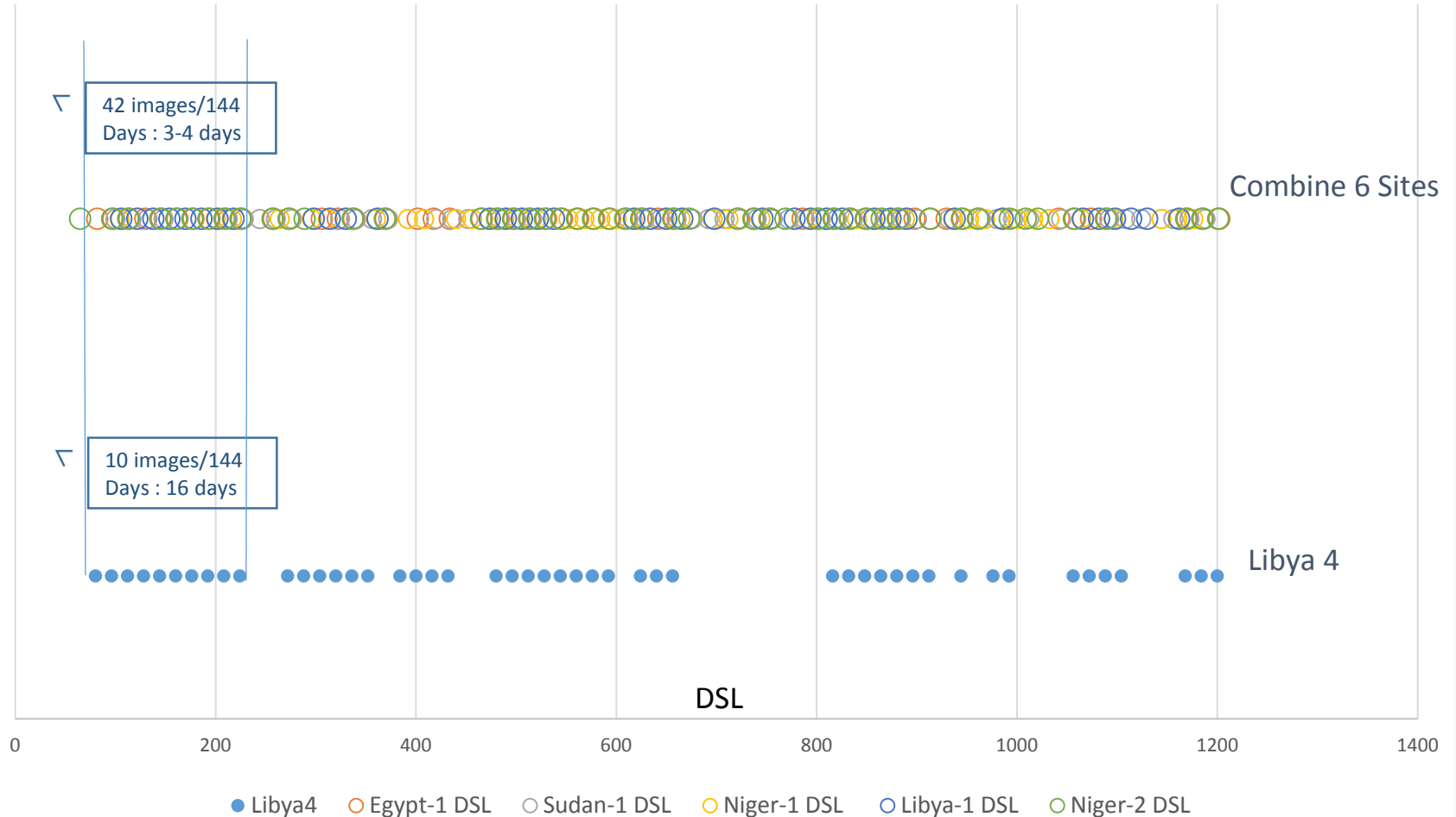
USGS   NASA

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Proposed Solution

- Limitation on data acquisition
  - Every 16 days,
  - Cloudy scenes
- Recent study shows that small number of acquisitions (less than 3 years) not adequate enough to show sensor degradation
- **New Approach – PICS Normalization Process (PNP): use all 6 PICS site to increase number of data acquisitions, and align them with reference to well-known Libya4**
  - Increase temporal resolution of data acquisition
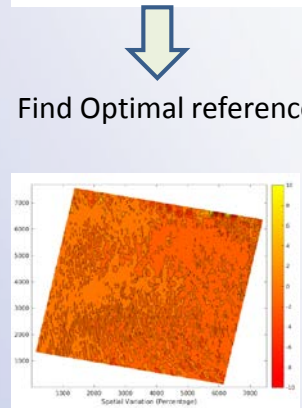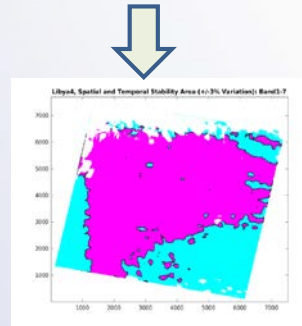 - Normalize each site to Libya4

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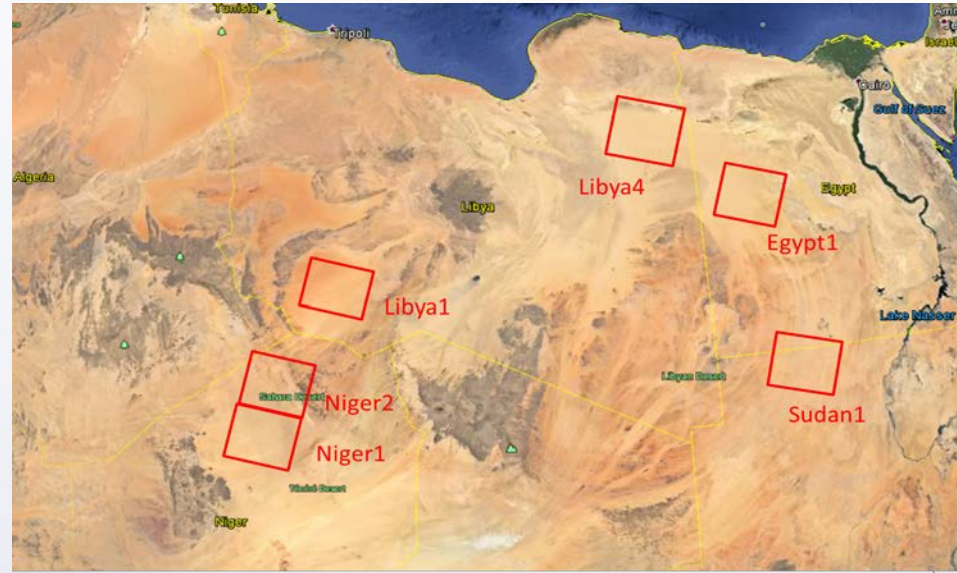
PICS Normalization: Increasing Temporal Resolution

Increase Image Acquisition Temporal Resolution

42 images/144
Days : 3-4 days

Combine 6 Sites

10 images/144
Days : 16 days

Libya 4

DSL

● Libya4   ○ Egypt-1 DSL   ○ Sudan-1 DSL   ○ Niger-1 DSL   ○ Libya-1 DSL   ○ Niger-2 DSL
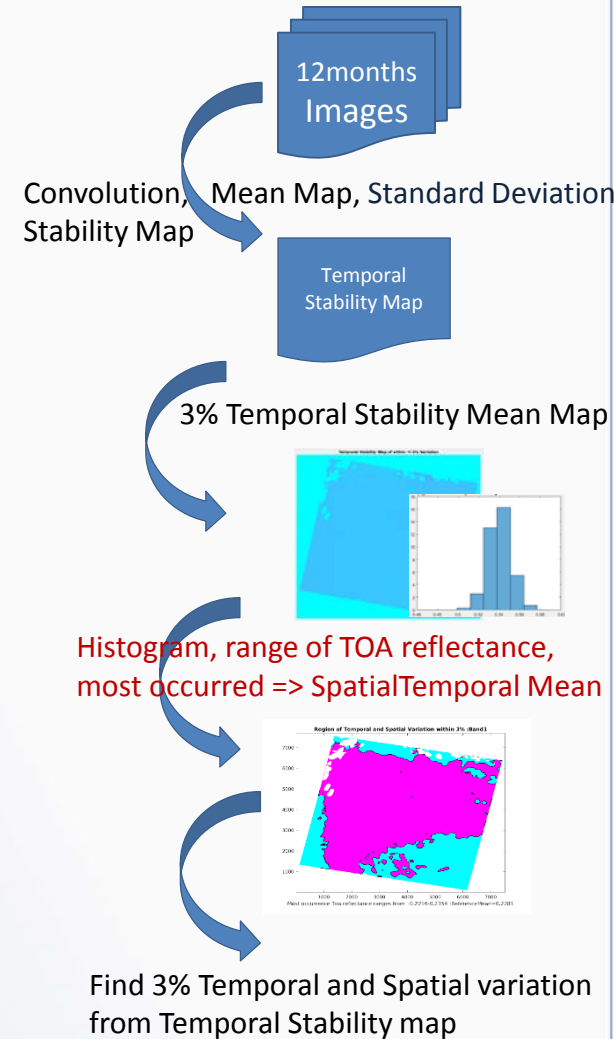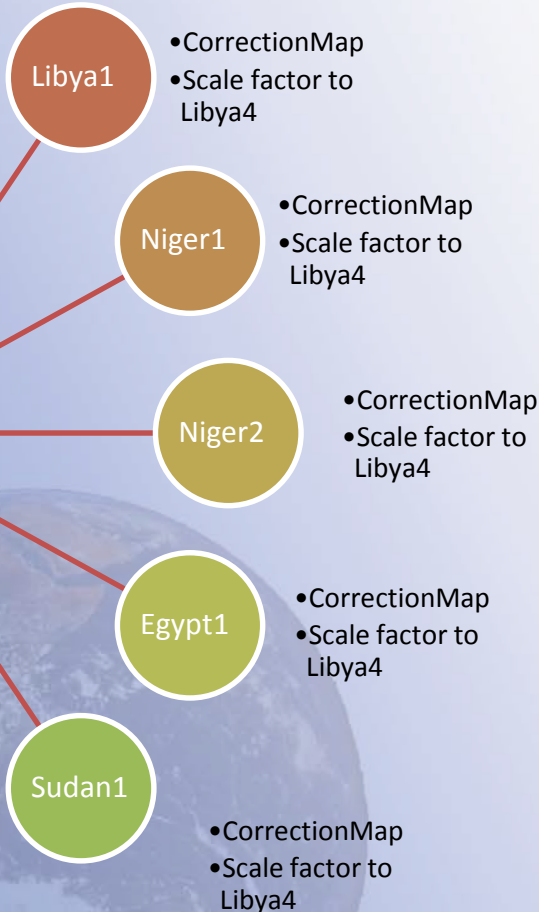
$$\text{Scale factor to Libya4} = \frac{\text{Optimal Reference Libya4}}{\text{Optimal Reference(PICS)}}$$

Find Optimal Stable Region :
3% Temporal and Spatial &Spectral

Libya1
•CorrectionMap
•Scale factor to Libya4

Niger1
•CorrectionMap
•Scale factor to Libya4

Libya4
-CorrectionMap

Niger2
•CorrectionMap
•Scale factor to Libya4

Egypt1
•CorrectionMap
•Scale factor to Libya4

Sudan1
•CorrectionMap
•Scale factor to Libya4

12months Images

Convolution, Mean Map, Standard Deviation
Stability Map

Temporal Stability Map

3% Temporal Stability Mean Map

Histogram, range of TOA reflectance,
most occurred => SpatialTemporal Mean

Find Optimal reference

Find 3% Temporal and Spatial variation
from Temporal Stability map

CorrectionMap : Normalized to Optimal Reference

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PROCEDURE
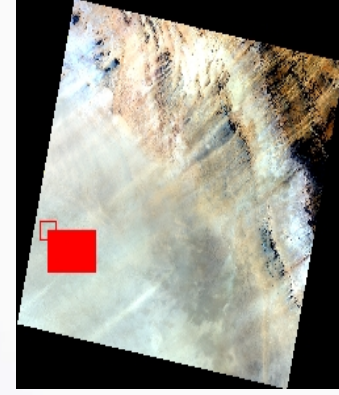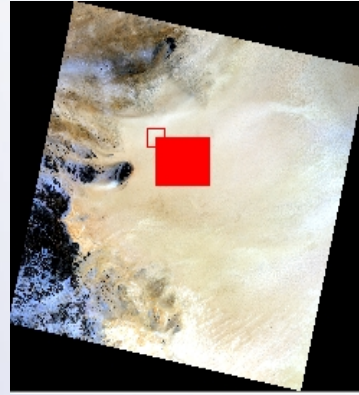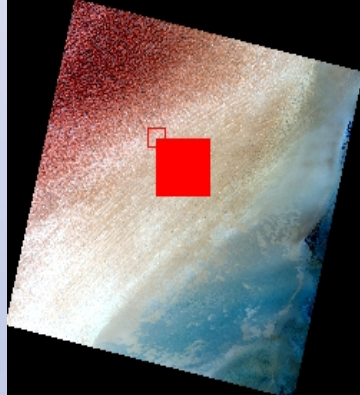# (Normalization within the PICS site)

- Find <u>optimal reference region:</u> a 3% Spatially, Temporally and Spectrally stable region for each PICS site.

  - One year, 12 months Cloud Free images.
  - Perform smoothing filter to the images and stack the 12 smoothed images together.
  - Calculate temporal mean, standard deviation then calculate temporal uncertainties map.
  - Create a temporal stability mean map having 3% temporal uncertainty.
  - Use Histogram to find a range of TOA Reflectance most occurred in the 3% temporal stability mean map.
  - Take a mean of this range, call it '<u>Temporal Spatial Mean</u>', then find pixels having TOA reflectance within 3% from '<u>Temporal Spatial Mean</u>'.
  - Create a 3% Temporal and Spatial Stability Map.
  - Repeat the process for all the bands and combine the results to find a region having 3% spatial, temporal and spectral stability called 'OPTIMAL STABILITY REGION'.
  - Calculate the mean TOA Reflectance => 'Optimal Reflectance' of the PICS site.
  - Calculate correction Map for each image-month: Normalizing the smoothed image to the 'Optimal Reflectance'.

New ROI with SDSU Cloud Mask Filter

54 /70 scenes — Egypt1 179-41

38/49 scenes — Libya1 187-43

41/61 scenes — Niger1 189-46

47/64 scenes — Niger2 188-45

44/62 scenes — Sudan1 177-45

45/67 scenes

Libya4 – CNES ROI
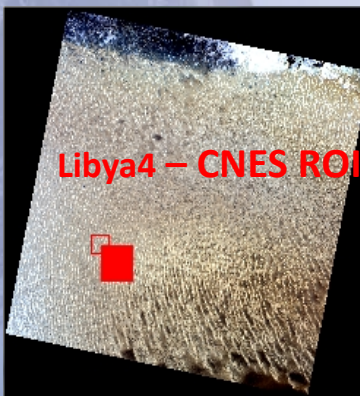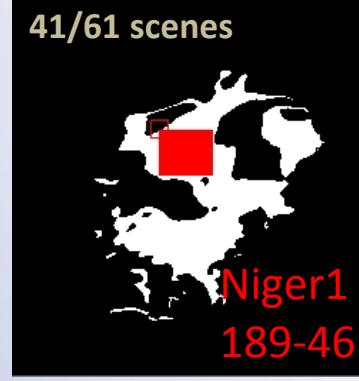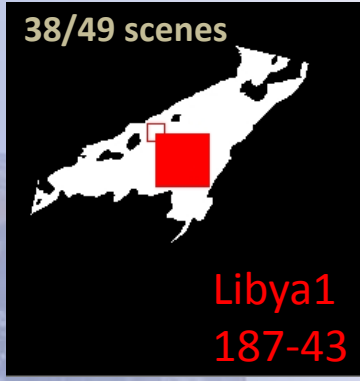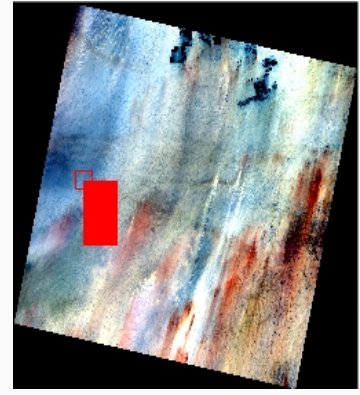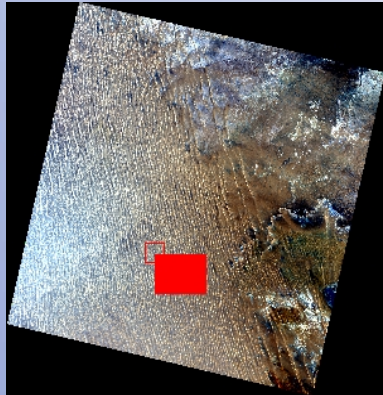
- White region : 3% Temporally, Spatially and Spectrally Stable region
- Red Region : New ROI for each PIC site from optimal stable area.
- SDSU Cloud Mask is used

PICS Normalization : ACROSS Sites

| Smoothed Image (ROI) | ✖ | CorrectionMap (ROI) | ✖ | SF2Libya4 | ➡ | PICS Normalization |

Libya4 vs Sudan1 After Scaling up
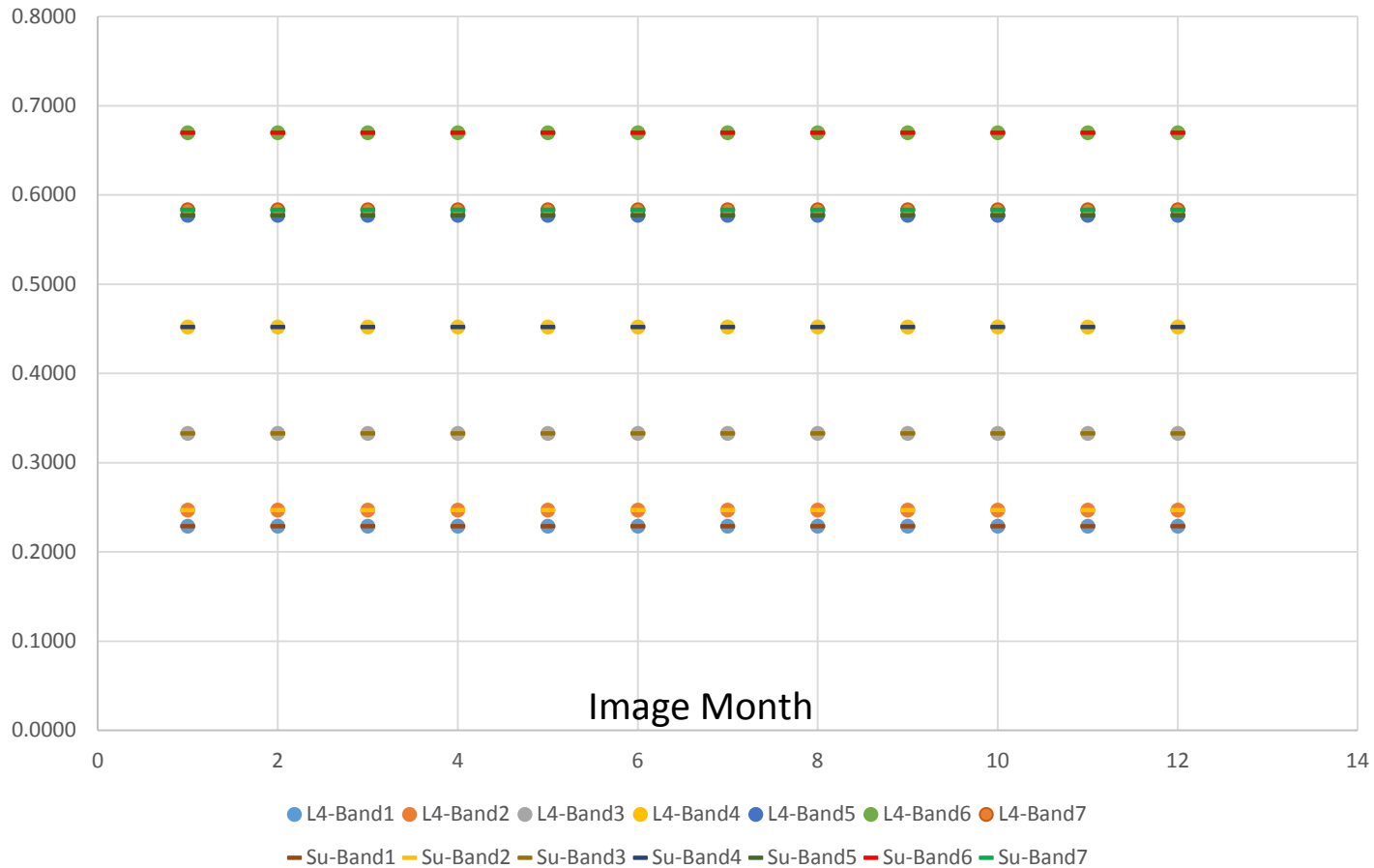
Legend: L4-Band1, L4-Band2, L4-Band3, L4-Band4, L4-Band5, L4-Band6, L4-Band7, Su-Band1, Su-Band2, Su-Band3, Su-Band4, Su-Band5, Su-Band6, Su-Band7

Y-axis: TOA Reflectance

X-axis: Image Month

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PICS Normalization: 6 PICS sites

Mean of Each scene after PICS Normalization : Libya4-PNP 6 Sites

Landsat 8 Bands

Band6
Band5
Band4
Band3
Band2

TOA Reflectance

SWIR 1
NIR
Red
Green
Blue

DSL of Landsat 8
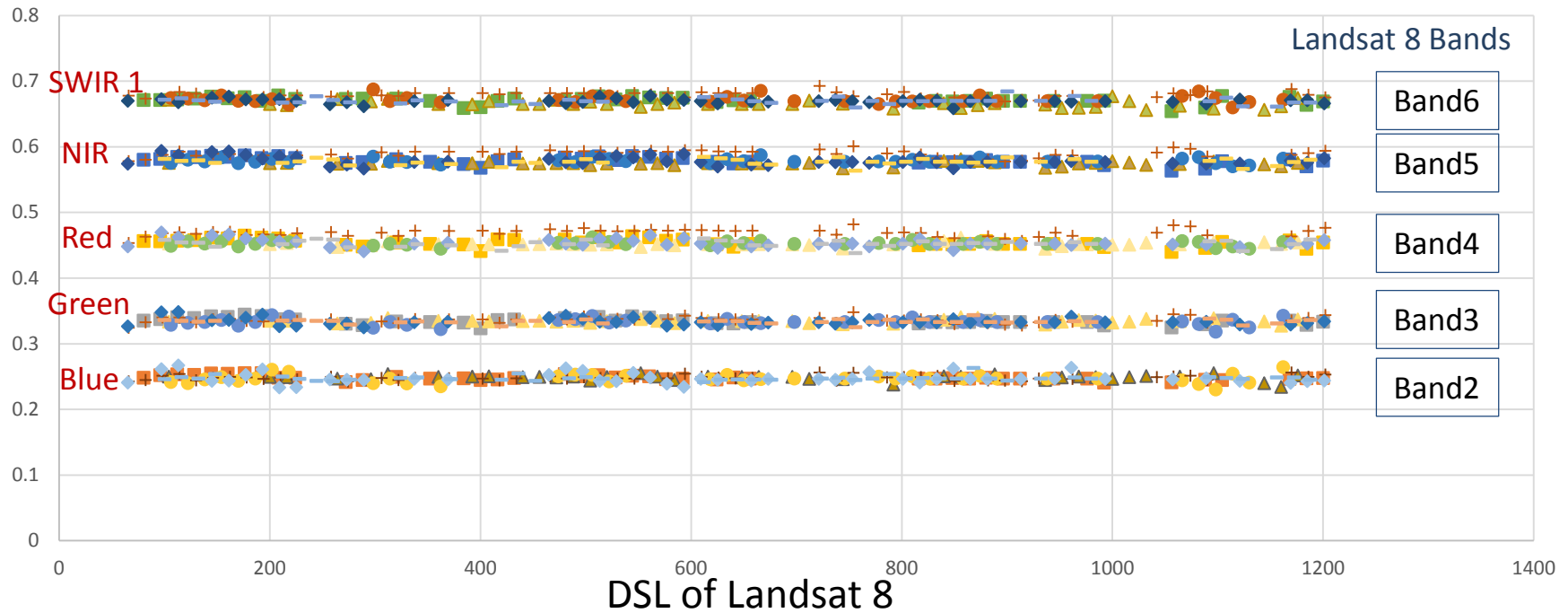
Libya4 ■ L4-B2 ■ L4-B3 ■ L4-B4 ■ L4-B5 ■ L4-B6

Niger1 ▲ N1-B2 ▲ N1-B3 ▲ N1-B4 ▲ N1-B5 ▲ N1-B6

Libya1 ● L1-B2 ● L1-B3 ● L1-B4 ● L1-B5 ● L1-B6

Egypt1 + E1-B2 + E1-B3 + E1-B4 + E1-B5 + E1-B6

Niger2 ◆ N2-B2 ◆ N2-B3 ◆ N2-B4 ◆ N2-B5 ◆ N2-B6

Sudan1 — S1-B2 — S1-B3 — S1-B4 — S1-B5 — S1-B6

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PICS Normalization : 6 PICS sites

Mean of each scene after PICS Normalization : Libya4-PNP- 6 Sites
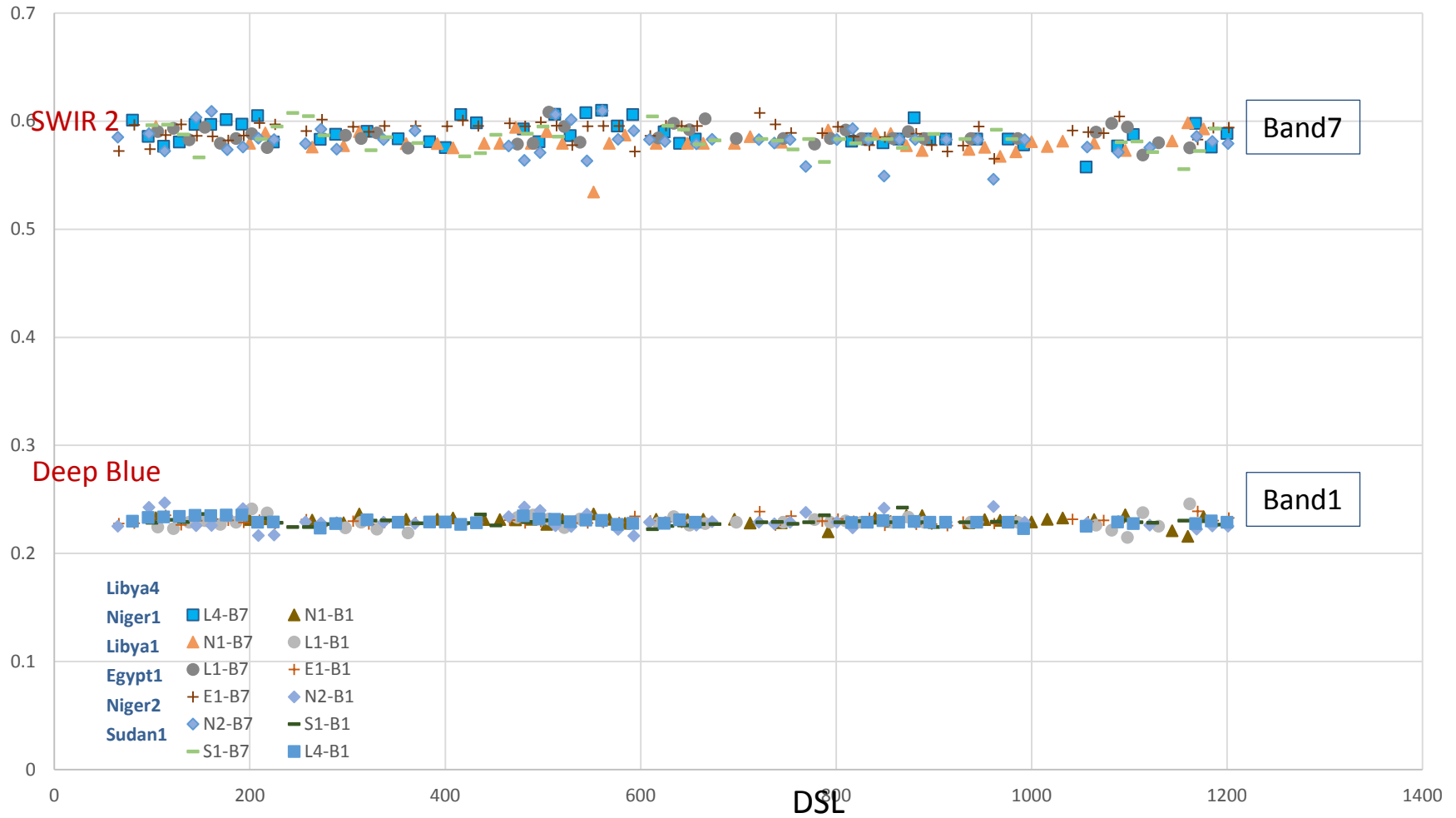
Statistical Z-test : PICS Mean vs Libya4- After Normalization at 95% Confidence Level

	Image Scenes	Band1	Band2	Band3	Band4	Band5	Band6	Band7
Libya4PNP	**45**	**0.2298**	**0.2482**	**0.3346**	**0.4543**	**0.5789**	**0.6709**	**0.5889**
Libya-1	38	Band1	Band2	Band3	Band4	Band5	Band6	Band7
mean		0.2291	0.2469	0.3332	0.4527	0.5786	0.6721	0.5864
Diff(L4 vs L1)		**-0.31%**	**-0.51%**	**-0.42%**	**-0.35%**	**-0.05%**	**0.17%**	**-0.43%**
Null Hypothesis		Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
Sudan-1	44	Band1	Band2	Band3	Band4	Band5	Band6	Band7
mean		0.2291	0.2474	0.3338	0.4523	0.5770	0.6699	0.5838
Diff(L4 vs S1)		**-0.28%**	**-0.31%**	**-0.26%**	**-0.43%**	**-0.33%**	**-0.16%**	**-0.86%**
Null Hypothesis		Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
Egypt-1	54	Band1	Band2	Band3	Band4	Band5	Band6	Band7
mean		0.2297	0.2480	0.3361	0.4690	0.5893	0.6788	0.5901
Diff(L4 vs E1)		**-0.04%**	**-0.07%**	**0.45%**	**3.24%**	**1.79%**	**1.18%**	**0.22%**
Null Hypothesis		Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
Niger-1	41	Band1	Band2	Band3	Band4	Band5	Band6	Band7
mean		0.2306	0.2486	0.3343	0.4517	0.5745	0.6653	0.5805
Diff(L4 vs N1)		**0.36%**	**0.14%**	**-0.09%**	**-0.58%**	**-0.76%**	**-0.84%**	**-1.42%**
Null Hypothesis		Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
Niger-2	47	Band1	Band2	Band3	Band4	Band5	Band6	Band7
mean		0.2297	0.2475	0.3338	0.4539	0.5789	0.6697	0.5815
Diff(L4 vs N2)		**-0.05%**	**-0.26%**	**-0.24%**	**-0.10%**	**-0.01%**	**-0.18%**	**-1.24%**
Null Hypothesis		Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted

Uncertainty Budget Analysis

PICS Uncertainty – OLI Trending

	C/A	Blue	Green	Red	NIR	SWIR-1	SWIR-2
Libya4	0.96	0.92	0.83	0.78	0.59	0.54	1.94
Libya1	2.16	2.19	1.32	0.68	0.45	0.61	1.4
Sudan1	1.23	1.25	0.95	0.97	0.62	0.35	1.71
Egypt1	1.37	1.39	1.21	1.16	0.89	0.55	2.04
Niger1	1.48	1.41	0.85	0.66	0.48	0.6	1.87
Niger2	2.12	2.19	1.22	1.03	0.76	0.42	2.23

Difference between L4Mean and PICS site after PNP

	C/A	Blue	Green	Red	NIR	SWIR-1	SWIR-2
Libya4	0	0	0	0	0	0	0
Libya1	-0.31	-0.51	-0.42	-0.35	-0.05	0.17	-0.43
Sudan1	-0.28	-0.31	-0.26	-0.43	-0.33	-0.16	-0.86
Egypt1	-0.04	-0.07	0.45	3.24	1.79	1.18	0.22
Niger1	0.36	0.14	-0.09	-0.58	-0.76	-0.84	-1.42
Niger2	-0.05	-0.26	-0.24	-0.10	-0.01	-0.18	-1.24

Uncertainty of Libya4

	C/A	Blue	Green	Red	NIR	SWIR-1	SWIR-2
Libya4	0.96	0.92	0.83	0.78	0.59	0.54	1.94
Libya1	0.96	0.92	0.83	0.78	0.59	0.54	1.94
Sudan1	0.96	0.92	0.83	0.78	0.59	0.54	1.94
Egypt1	0.96	0.92	0.83	0.78	0.59	0.54	1.94
Niger1	0.96	0.92	0.83	0.78	0.59	0.54	1.94
Niger2	0.96	0.92	0.83	0.78	0.59	0.54	1.94

Uncertainties Budget

$= \sqrt{PICSUncertainty^2 + DiffMean^2 + L4Uncertainty^2}$

	C/A	Blue	Green	Red	NIR	SWIR-1	SWIR-2
Libya4	1.36	1.30	1.17	1.10	0.83	0.76	2.74
Libya1	2.38	2.43	1.61	1.09	0.74	0.83	2.43
Sudan1	1.59	1.58	1.29	1.32	0.92	0.66	2.73
Egypt1	1.67	1.67	1.54	3.53	2.09	1.41	2.82
Niger1	1.80	1.69	1.19	1.18	1.08	1.16	3.04
Niger2	2.33	2.39	1.49	1.30	0.96	0.71	3.21

Temporal Plot :OLI TOA Reflectance : PNP – 6 PICS Sites

Landsat 8 OLI

Legend:
- C/A
- Blue
- Green
- Red
- NIR
- SWIR-1
- SWIR-2

Y-axis: TOA Reflectance

X-axis: DSL : DSL0 = 02/12/2013
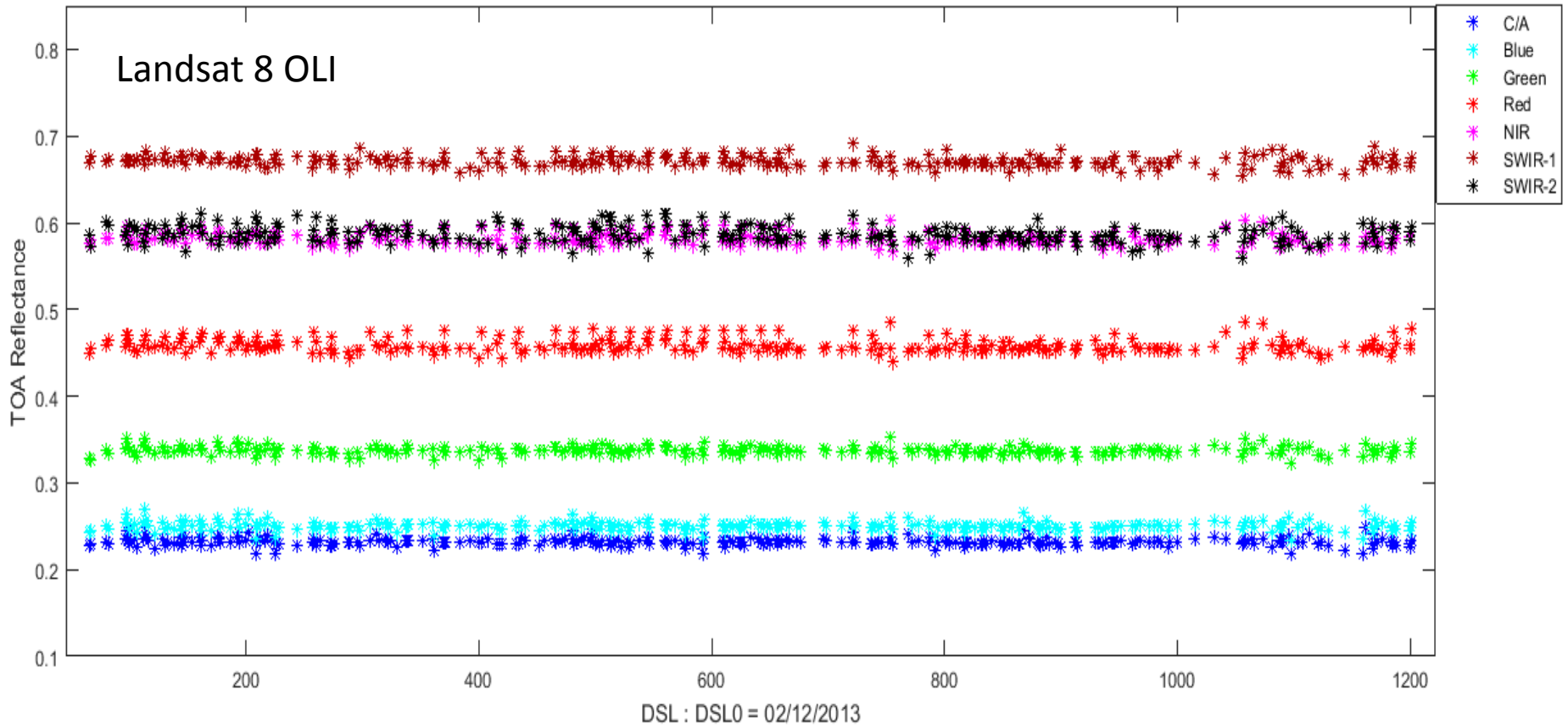
	Coastal	Blue	Green	Red	NIR	SWIR-1	SWIR-2
%Drift/yr ± 2σ	-0.19±0.26	-0.14±0.26	-0.13±0.18	-0.24±0.24	-0.22±0.16	-0.17±0.12	-0.37±0.23
p-Value	0.1406	0.2810	0.1335	0.0525	0.0059	0.0062	0.0011
Null hypothesis (Slope=0)	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Reject	Reject	Reject

Bands	Uncertainty	
	PNP-6Sites (269 scenes CF)	
Band 1	Coastal Aerosol	1.88%
Band 2	Blue	1.92%
Band 3	Green	1.29%
Band 4	Red	1.77%
Band 5	NIR	1.18%
Band 6	SWIR-1	0.92%
Band 7	SWIR-2	1.70%

CONCLUSIONS

- Individual PICS limited to measuring drift ≥ 0.5%/yr for time periods < 3 years postlaunch
  - Libya 4 may be one of the worst offenders!
- PICS Normalization Process (PNP) combines and normalizes multiple PICS to Libya 4.
  - Simple averaging and normalization approach
- Using PNP with 6 PICS reduces uncertainties in drift measurement for time periods of 3 years or less
  - Application to Landsat 8 improved drift measurement accuracy from ~0.5% to nearly 0.2%/year
  - Consistent with onboard systems at shorter wavelengths, still showing drift at longer wavelengths (NIR & SWIR)

Future Work

- Refine the normalization process

- Expand PICS Normalization to longer time periods

- Include Atmospheric Model with PICS Normalization

- Apply PICS Normalization to other sensors to create additional calibration opportunities

THANK YOU

BACK UP SLIDES

Summary : OLI Trending

Landsat Bands	Trending -OLI Temporal Uncertainty since launch with CloudMask					
	Libya4	Libya1	Niger1	Niger2	Sudan1	Egypt1
Coastal Aerosol	0.96%	2.16%	1.48%	2.12%	1.23%	1.37%
Blue	0.92%	2.19%	1.41%	2.19%	1.25%	1.39%
Green	0.83%	1.32%	0.85%	1.22%	0.95%	1.21%
Red	0.78%	0.68%	0.66%	1.03%	0.97%	1.16%
NIR	0.59%	0.45%	0.48%	0.76%	0.62%	0.89%
SWIR-1	0.54%	0.61%	0.60%	0.42%	0.35%	0.55%
SWIR-2	1.94%	1.40%	1.87%	2.23%	1.71%	2.04%



OLI Temporal Uncertainties over 6 PICS Sites

- Temporal uncertainties over Green, Red, NIR and SWIR-1 within 1.5% in general for all 6 Sites
- Higher uncertainties in coastal aerosol, blue and SWIR-2 bands within 2.5 %
- All bands within 2.5% for all 6 PICS sites

- OLI Drift Estimate – There is no statistically significant drift shown over Sudan1, Egypt1 and Niger1
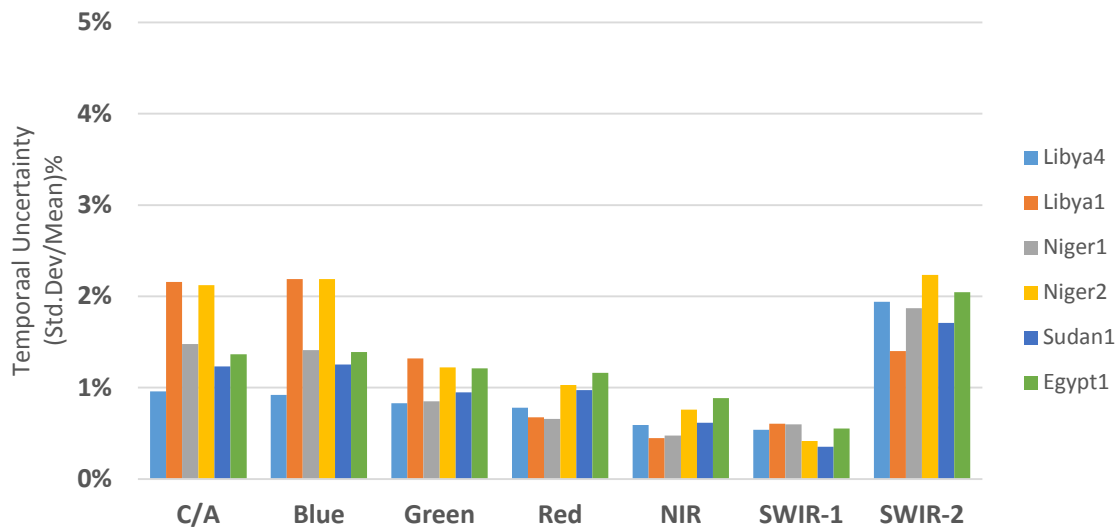
  - ❑ Niger2, depicts statistically drift in only NIR
  - ❑ Libya1, depicts statistically drift in Red, NIR and SWIR2
  - ❑ Lybya4, depicts statistically drift in all Bands except SWIR-2

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Temporal Plot OLI TOA Reflectance: 181-40

Libya4 :45 scenes

DSL : DSL0 = 02/12/2013
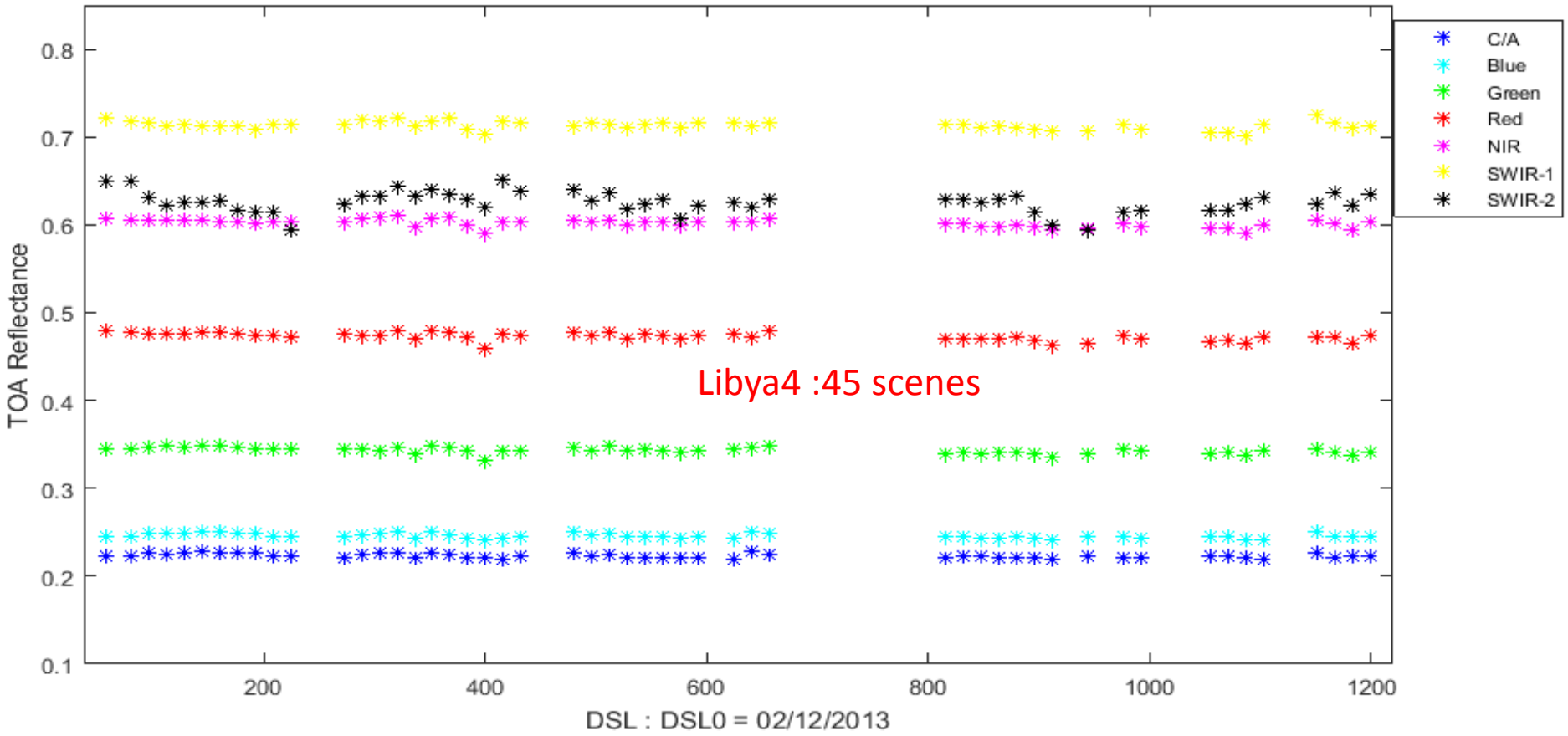
	Coastal	Blue	Green	Red	NIR	SWIR-1	SWIR-2
%Drift/yr ± 2σ	-0.60±0.31	-0.70±0.30	-0.65±0.26	-0.54±0.25	-0.45±0.19	-0.23±0.17	-0.31±0.62
p-Value	0.0003	<0.00001	<0.00001	<0.00001	<0.00001	0.0119	0.3225
Null hypothesis (Slope=0)	Reject	Reject	Reject	Reject	Reject	Reject	Fail to Reject

	Uncertainty	
Bands	Dec'15 (52 scenes)	Now (45 scenes CF)
Band 1	1.38%	0.96%
Band 2	1.25%	0.92%
Band 3	0.95%	0.83%
Band 4	0.81%	0.78%
Band 5	0.61%	0.59%
Band 6	0.65%	0.54%
Band 7	2.13%	1.94%