Improved Temporal Resolution of Pseudo Invariant Calibration Sites (PICS) Through Development of the PICS Normalization Process (PNP)

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By

Morakot Kaewmanee, Harika Vuppula, Dennis Helder

South Dakota State University, Image Processing Lab

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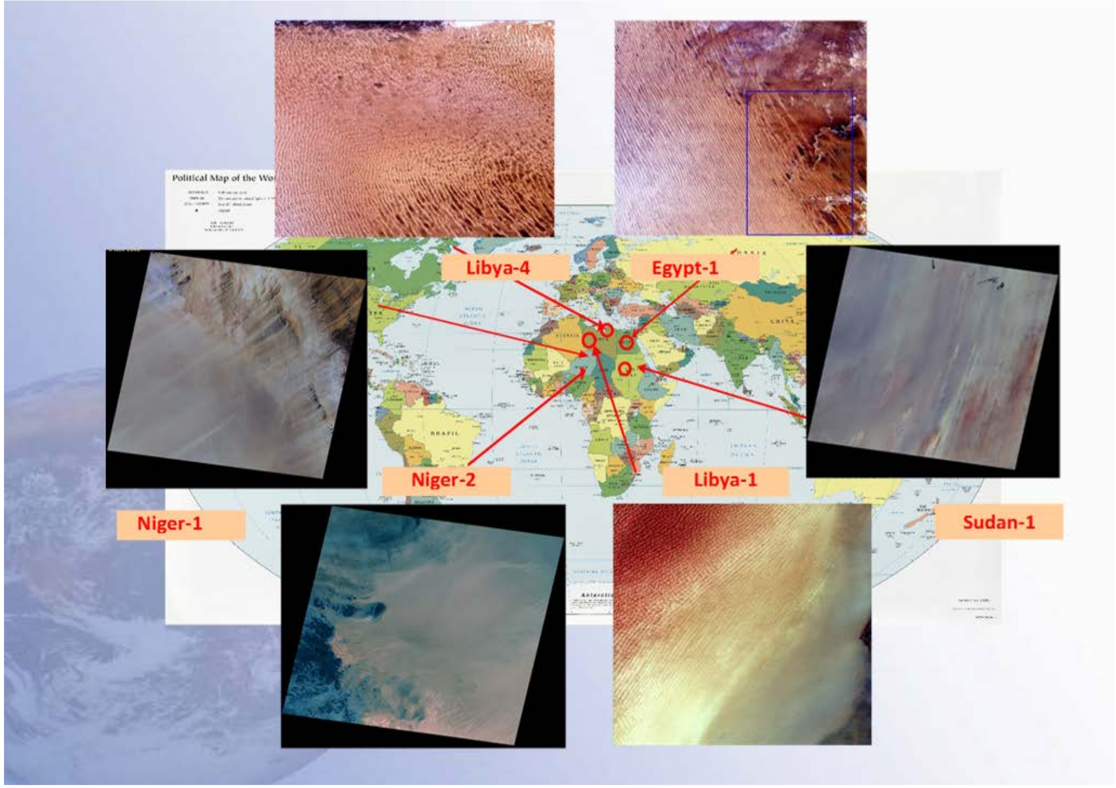
Outline

- PNP Objectives
- Thoughts and Process
- PNP Results
- Refined PNP process (BRDF-PNP) and results
- Comparison of PNP&BRDF-PNP vs On board Calibrator
- Summary

OBJECTIVE

- To combine sensor observations of multiple PICS into a single time series with greater temporal resolution. Normalize each PICS site to the well known Libya-4 PICS which is used as the overall reference calibration site. After combining these 6 PICS into one dataset, a radiometric assessment is performed.—L8 Pre-Collection data



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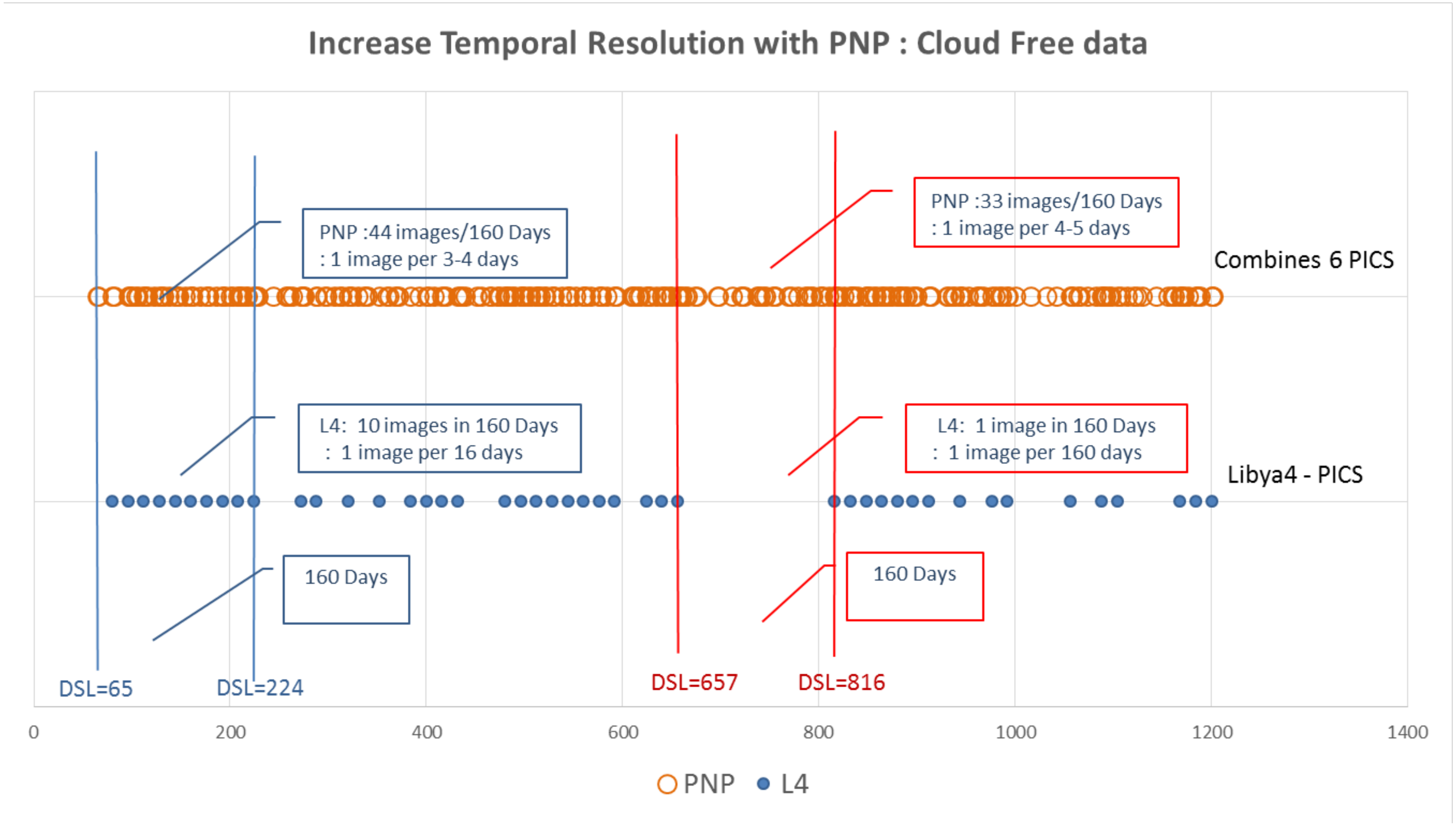
Increase Temporal Resolution using 6 PICS sites



Key problem: From DSL 65 to 224, 6 PICS provide 44 images to PNP within 160 day interval, L4 provides 10 images
and from DSL 657 to 816, Libya4 provides 1 image to PNP in a 160 day interval

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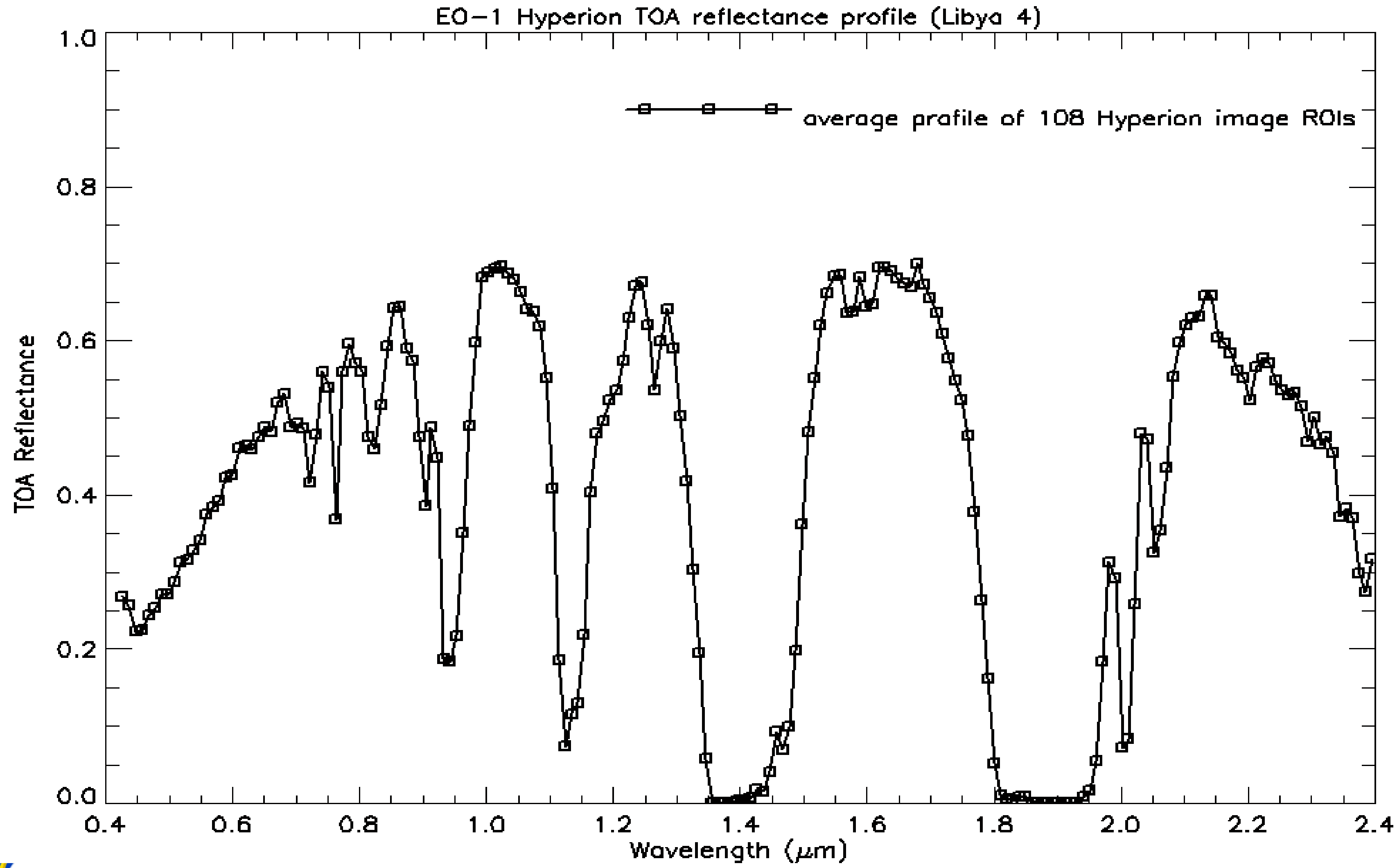
Typical Spectral Signature of a PICS



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Different PICS have different spectral signature

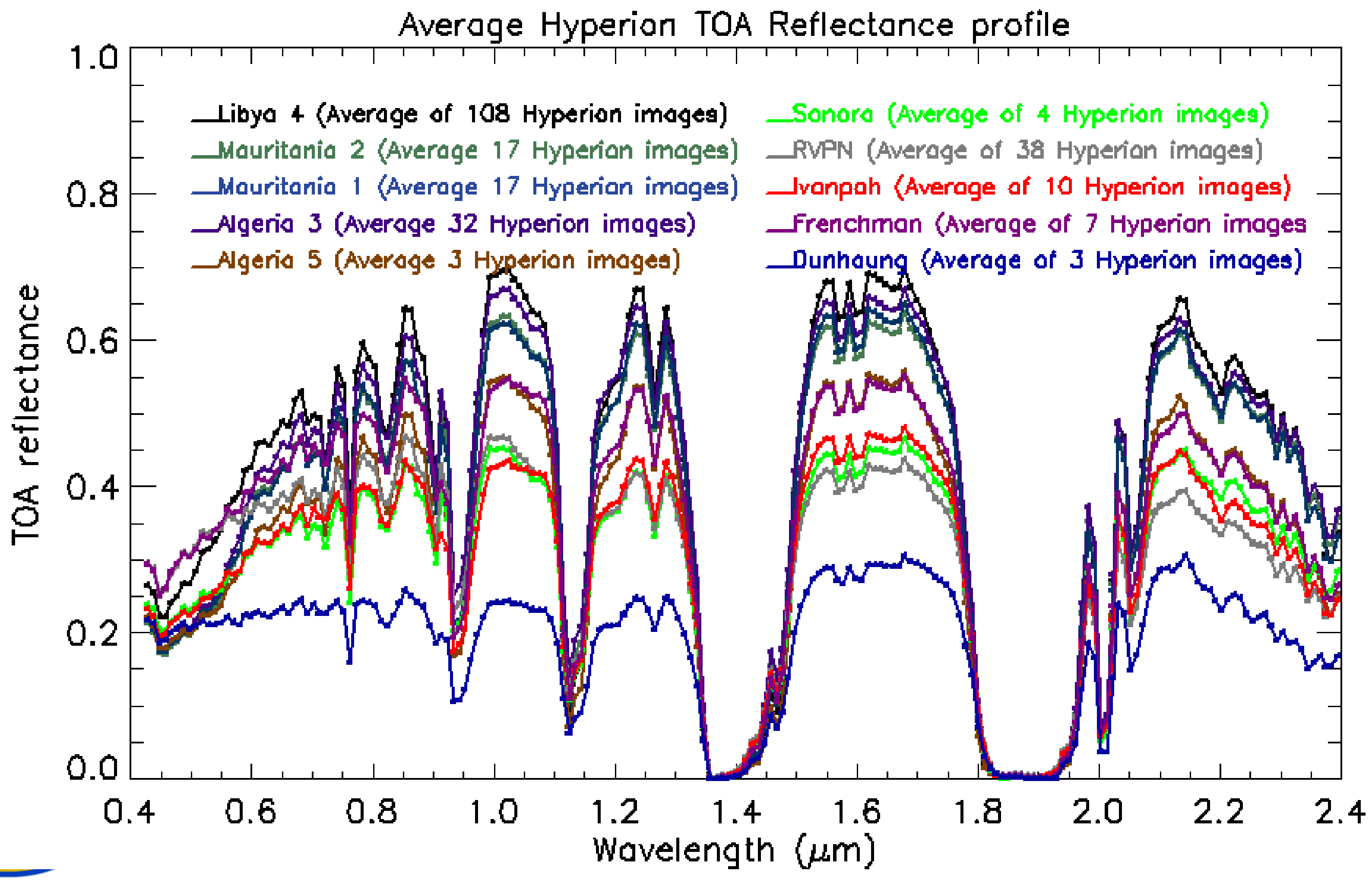

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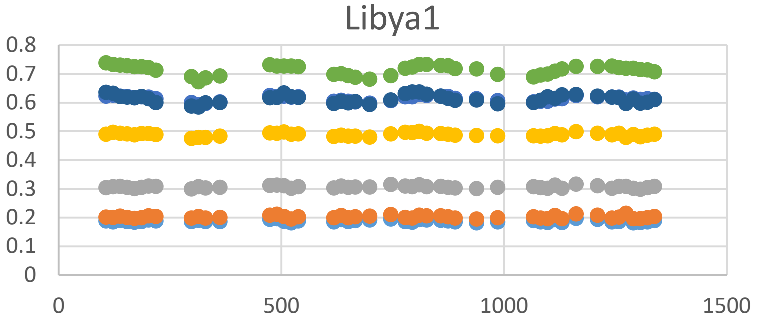
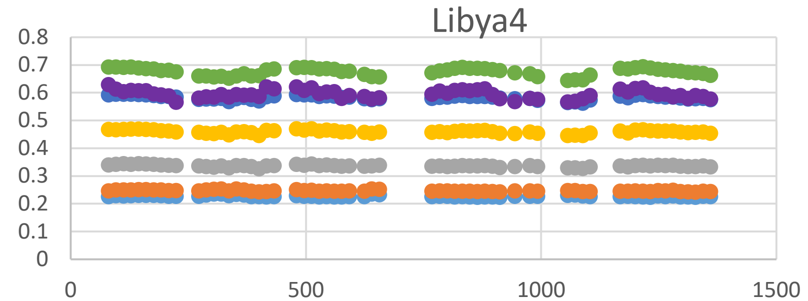
Image -TOA Reflectance of 6 PICS : 2013-2016,

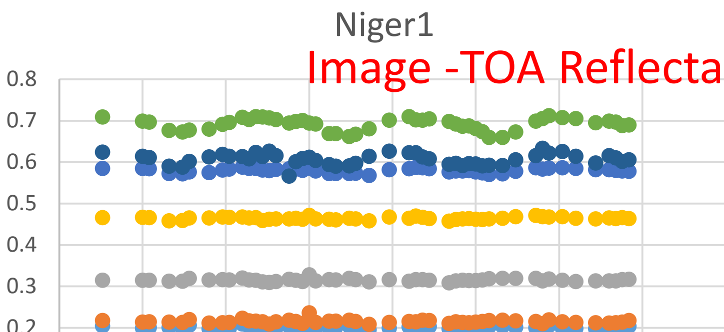
showing Mean TOA reflectance & Temporal Uncertainties



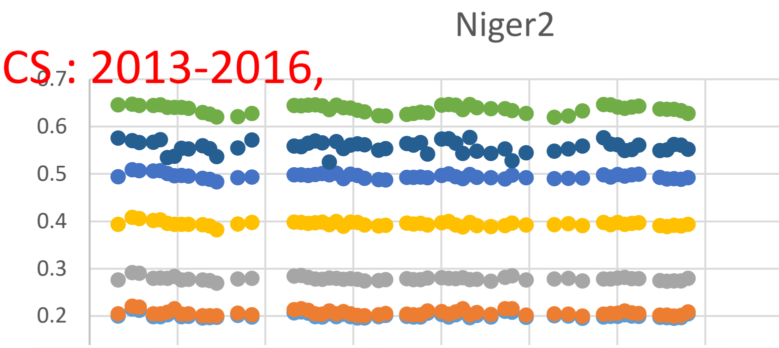
COASTAL	BLUE	GREEN	RED	NIR	SWIR1	SWIR2
0.1885	**0.2027**	**0.3071**	**0.4892**	**0.6145**	**0.7144**	**0.6137**
2.43%	2.41%	1.38%	1.18%	1.46%	2.33%	2.19%



COASTAL	BLUE	GREEN	RED	NIR	SWIR1	SWIR2
0.2271	**0.2466**	**0.3358**	**0.4586**	**0.5818**	**0.6744**	**0.5934**
1.33%	1.13%	1.14%	1.30%	1.31%	2.02%	2.53%

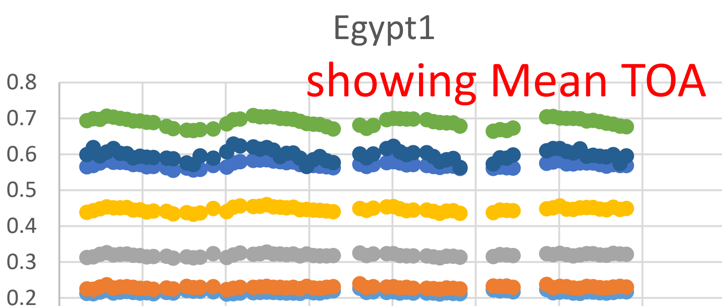


COASTAL	BLUE	GREEN	RED	NIR	SWIR1	SWIR2
0.1968	**0.2107**	**0.3089**	**0.4552**	**0.5684**	**0.6779**	**0.5949**
2.28%	2.04%	1.07%	0.71%	0.91%	2.15%	2.21%



COASTAL	BLUE	GREEN	RED	NIR	SWIR1	SWIR2
0.2008	**0.2063**	**0.2786**	**0.3946**	**0.4951**	**0.6368**	**0.5573**
2.00%	2.22%	1.12%	0.93%	0.86%	1.32%	2.07%

COASTAL BLUE GREEN RED NIR SWIR1 SWIR2



COASTAL	BLUE	GREEN	RED	NIR	SWIR1	SWIR2
0.2159	**0.2296**	**0.3193**	**0.4465**	**0.5706**	**0.6880**	**0.5971**
1.49%	1.29%	1.09%	1.24%	1.14%	1.70%	2.57%

COASTAL BLUE GREEN RED NIR SWIR1 SWIR2

COASTAL	BLUE	GREEN	RED	NIR	SWIR1	SWIR2
0.2089	**0.2174**	**0.2985**	**0.4268**	**0.5384**	**0.6726**	**0.5819**
1.34%	1.53%	1.53%	1.83%	1.69%	1.92%	2.51%

COASTAL BLUE GREEN RED NIR SWIR1 SWIR2

Thoughts

- Each PICS site has its unique TOA Reflectance
- How can we identify the optimal TOA reflectance that represents the site?
    - Find TOA Reflectance Reference that is the mean TOA reflectance derived from the region of TOA reflectance having better than 3% Temporal , Spatial and Spectral Stability within the site

- How can we normalize all 6 PICS sites to Libya 4?

    1. Find optimal region defined as 3% Temporal, Spatial and Spectral stability using 1 year of Landsat 8 data (Jan-Dec Cloud-free images)
    2. Account for seasonal variation by using a month-by-month approach to generate a correction map
    3. Derive Scale Factor to normalize to Libya 4

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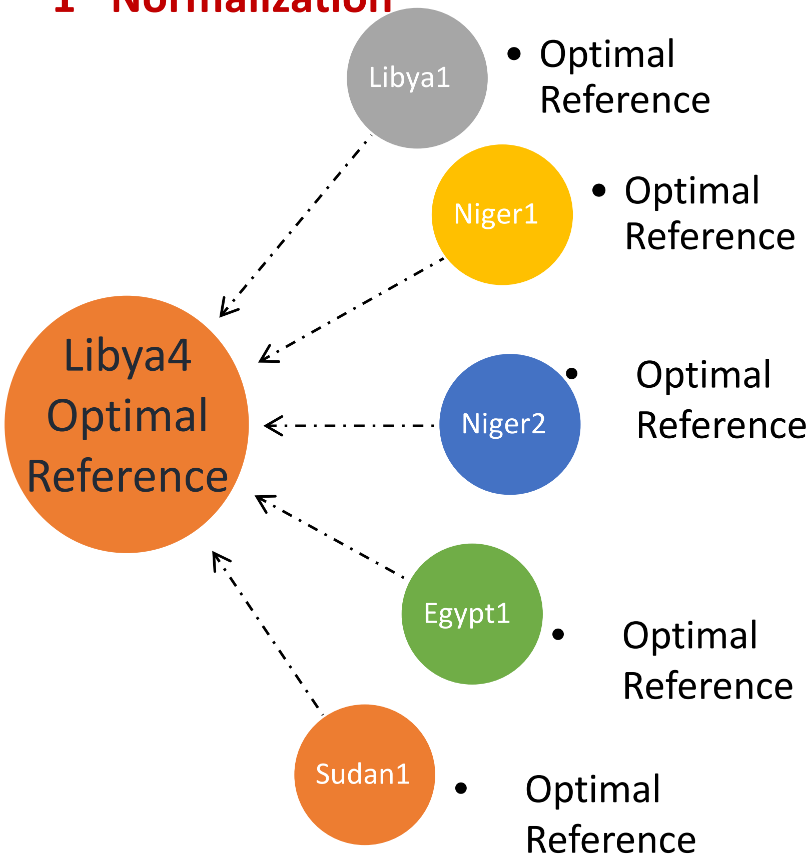
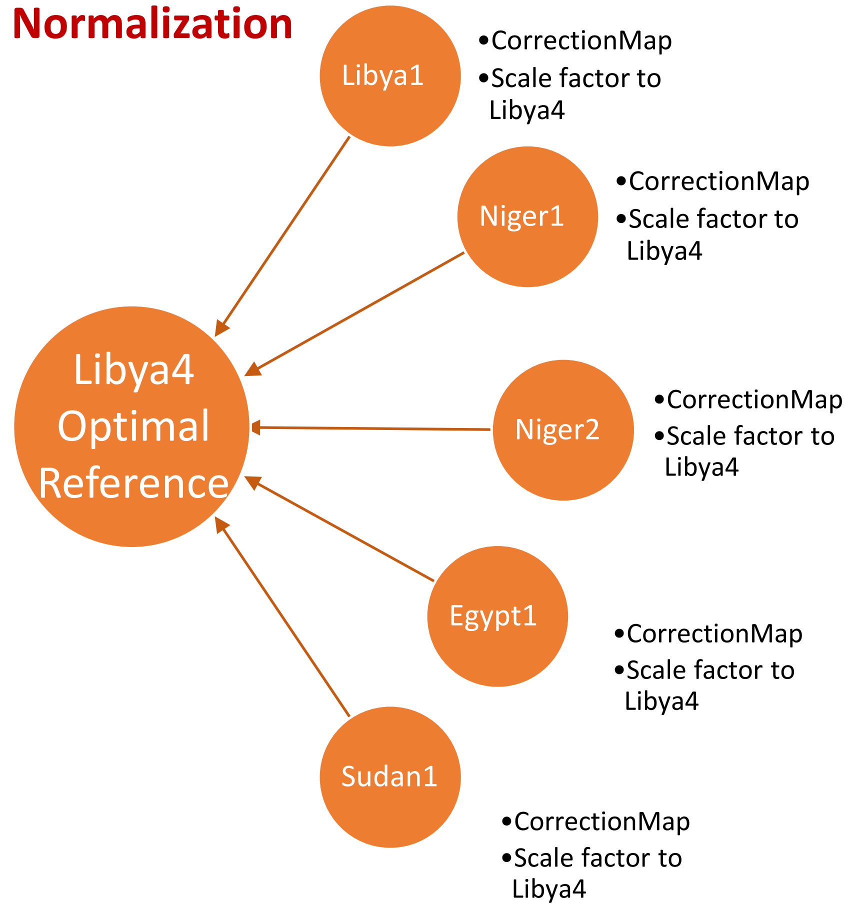
PICS Normalization Process-Concept

1st Normalization



2nd Normalization



$$CorrectionMap(i,j,t)_{(Band)} = \frac{Optimal\ Reference_{(band)}}{Smoothed\ Image\ (I')(i,j,t)_{(band)}}$$

$$\text{Scale factor to Libya4} = \frac{\text{Optimal Reference Libya4}_{(band)}}{\text{Optimal Reference(PICS)}_{(band)}}$$

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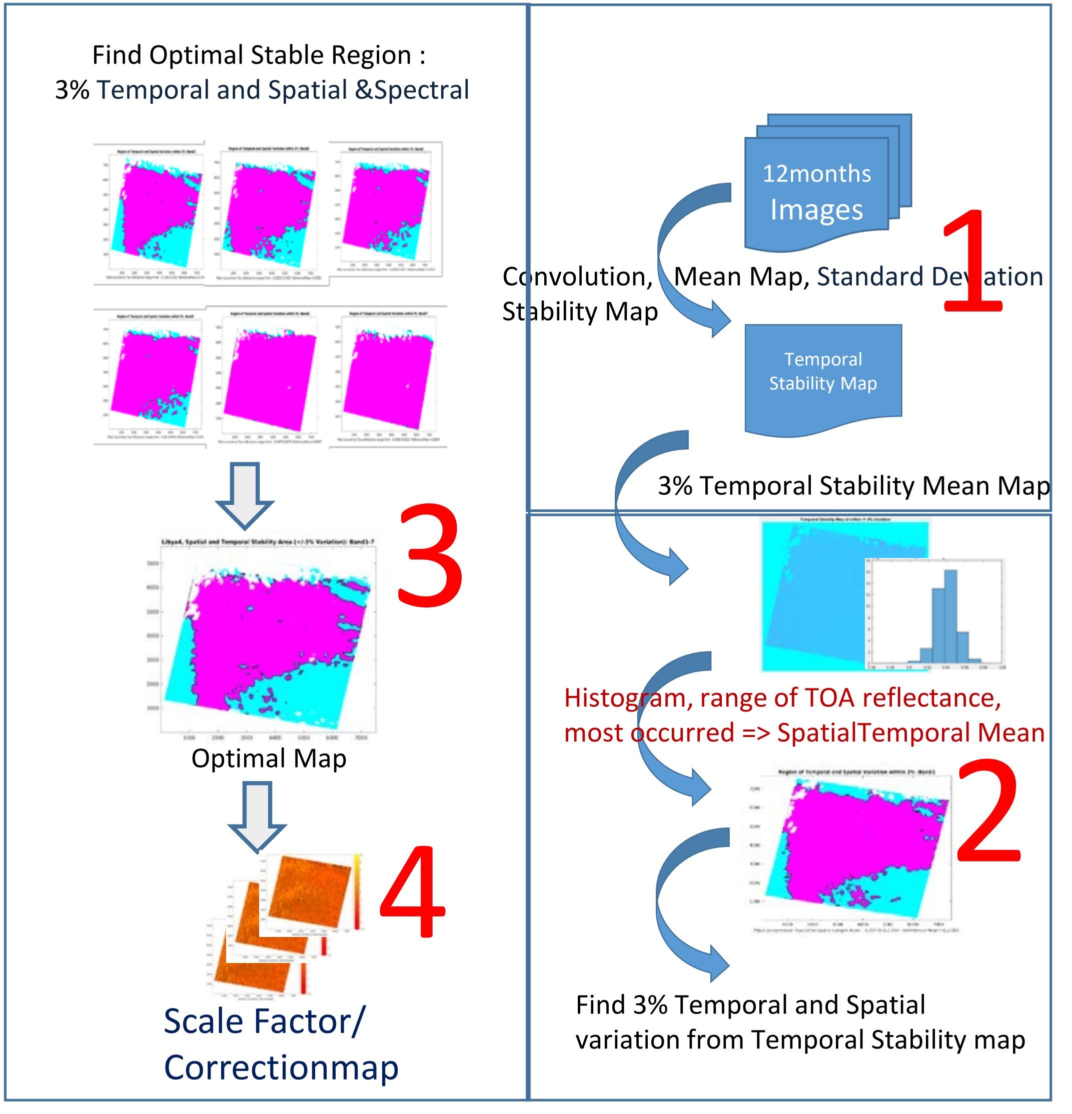
What is the optimal region/reference of a PICS site?

Answer: a TOA Reflectance derived from the Optimal stable region which satisfies 3% Temporal, Spatial and Spectral Stability

Work done in 2016 by : Ruchira, Harika, Leah and Morakot

Flowchart showing how to find Optimal stable region in PICS : 3% Temporal, Spatial and Spectral

Scale Factor, Correction Map



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PROCEDURE (Finding Optimal Stable region within the PICS site, Scale Factor, Correction Maps)

- Find optimal reference and a region which is 3% Spatially, Temporally and Spectrally stable for each PICS site.

1

- One year, 12 months Cloud Free images.
- Apply smoothing filter to the images and stack the 12 smoothed images together.
- Calculate temporal mean and standard deviation, then calculate temporal uncertainties map.
- Create a temporal stability mean map having 3% temporal uncertainty.

2

- From the Histogram, find a range of TOA Reflectance most often occurring in the 3% temporal stability mean map.
- Take a mean of this range, called it 'Temporal Mean', then find pixels with TOA reflectance within 3% of 'Temporal Mean'.
- Create a 3% Temporal and Spatial Stability Map.

3,4

- 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.
- Correction Maps => Optimal Reference-Pics$_{(band)}$/Smoothed image$_{(month,band)}$
- Calculate Scale Factor to bring each PICS to Libya4 => OptimalReference-Libya-4/OptimalReference-PICS

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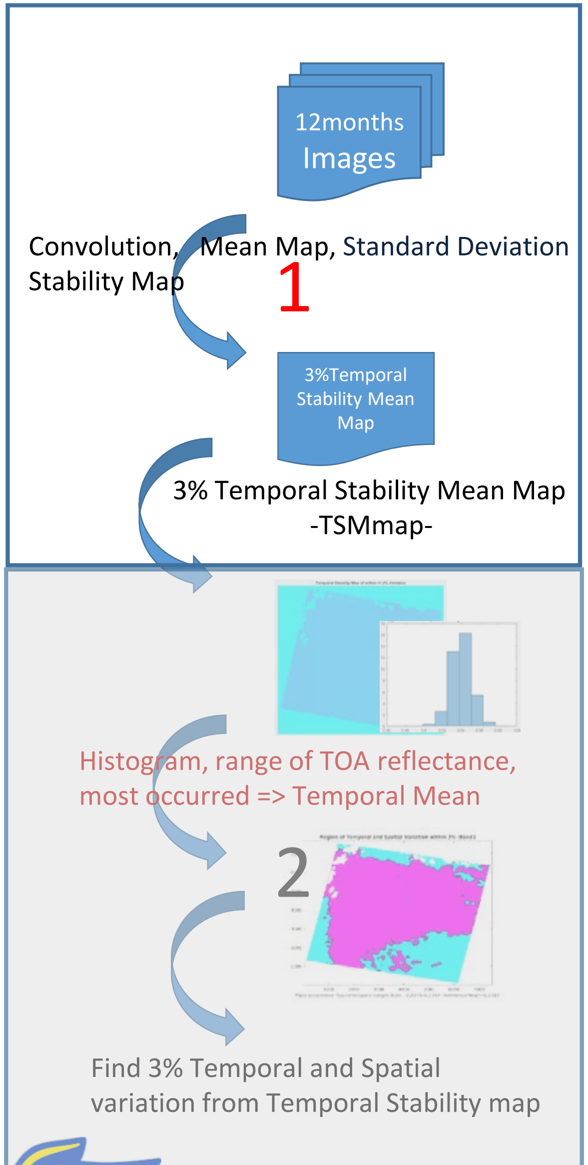


Convolution Equation

Let H : $R_H \rightarrow [0,K-1]$

$$I'_{t,band}(u,v) = \left[\sum_{(i,j)\in R_H} I_{(t,band)}(u+i, v+j) \bullet H(i,j) \right]_{t=1,band=1}^{12,band7}$$

Also denoted: $I' = I * H$; $R_H = (165x165)$ (5kmx5km)

I' = smoothed images,

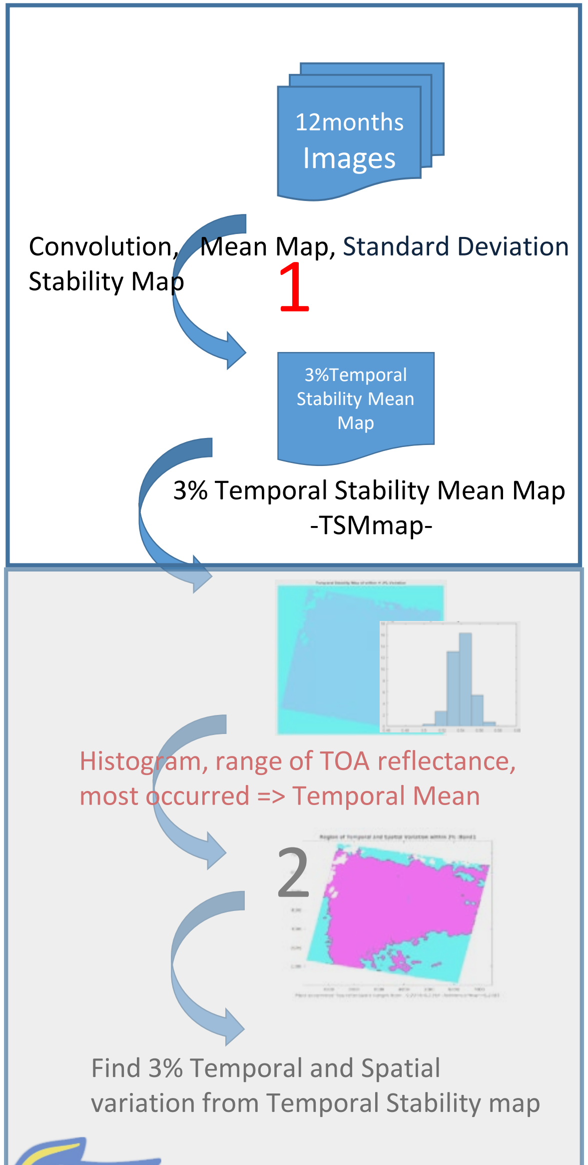
Each image is convolved, then stack them together temporally:-

(1) Scene Temporal mean

$$\mu_{band}(i,j) = \frac{1}{12}\left[\sum_{t=1}^{12} I'_{band}(i,j,t) \right]_{band=1..,7}$$

(2) Scene Temporal Standard Deviation

$$s_{band}(i,j) = \left| \sqrt{\frac{1}{12-1} \sum_{t=1}^{12} \left| I'_{band}(i,j,t) - \mu_{band}(i,j,t) \right|^2} \right|_{band=1..,7}$$



Calculate 3% Temporal Stability Mean Map

1. Create Uncertainty Map then mask pixel that < 3% Uncertainty

   Temporal Uncertainty Map : $TUM_{(i,j)} = \left[\frac{S_{(band)}(i,j)*100\%}{\mu_{(band)}(i,j)} \right]_{band=1..,7}$

$$\text{If,} \quad TSM_{band}(i,j) = 1, TUM_{band}(i,j) < 3\%]_{band=1..,7}$$

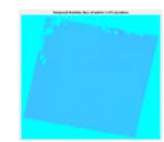
$$\text{else} \quad TSM_{band}(i,j) = 0, TUM_{band}(i,j) > 3\%]_{band=1..,7}$$

TSM_{band} = 3% Temporal Stability Mask (TSM)

2. Create 3% Temporal Stability Mean Map

$$TSMM_{band}(i,j) = [\mu(i,j) * TSM_{band}(i,j)]_{band\,1..,7}$$

$TSMM_{band}(i,j)$ = 3%Temporal Stability Mean Map (TSMM)



Identify TOA Reflectance region having 3% Temporal Uncertainty

What range of TOA Reflectance most often occurs in the region?

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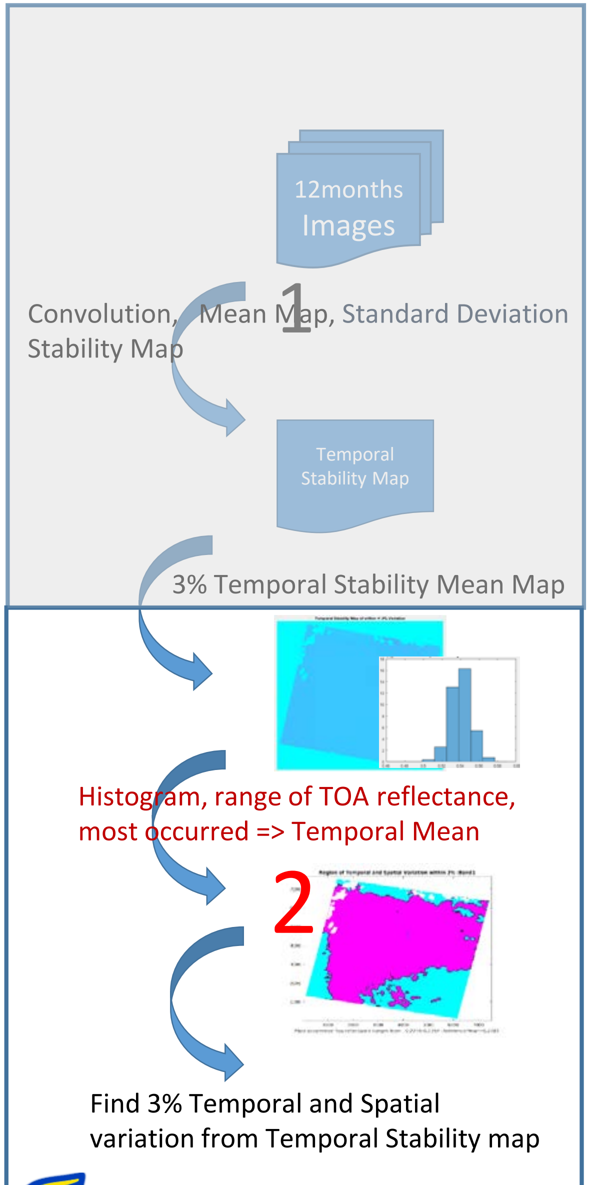
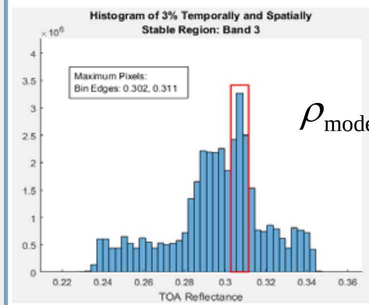
Find range of TOA reflectance, most often occurring and calculate (Temporal Mean)





$$\rho_{\text{mode,(band)}} = \text{mode}(histogram(TSMM, binnum))\Big]_{band=1..,7}$$

N = total no. of bins in the sample,

x_i is the **i**th bin whose elements have a value equal to **i.**

Find a range of TOA reflectance within 3% of the max bin

$$\rho_{max,band} = (1+0.15)\ \rho_{mode,band}$$
$$\rho_{min,band} = (1-0.15)\ \rho_{mode,band}$$

$$\textit{If,}\quad TempMap_{band}(i,j) = TSMM_{band}(i,j), \forall[\rho_{\min,band} \le TSMM_{band} \le \rho_{\max,band}\ \Big]_{band=1..,7}$$
$$\textit{else}\quad TempMap_{band}(i,j) = 0,$$

Tempmap is a Region that contains Toa Reflectance within (ρ_{min} ,ρ_{max})

$$TemporalMean_{band} = \frac{1}{N}\sum_{i=1}^{N} Tempmap_{i,band}$$

N = No. of pixels satisfying, $\rho_{min} < \rho < \rho_{max}$

We now have the highest occurring Temporal TOA reflectance mean (mode) of each band.

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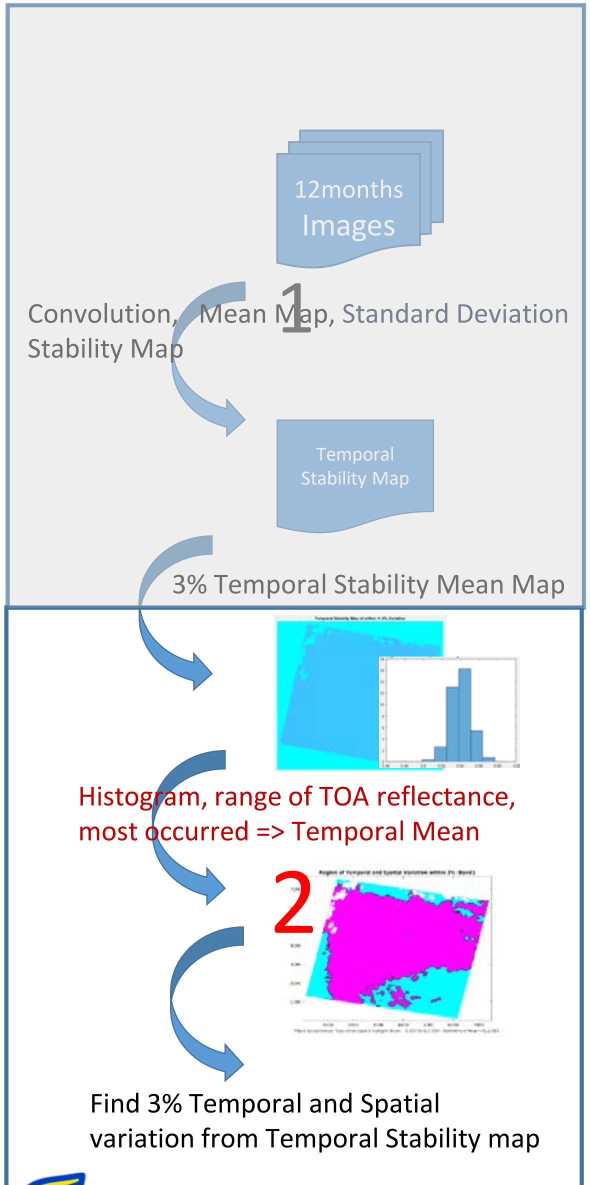
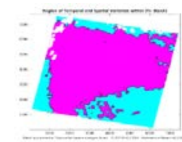


A spatial variation map is next created showing spatial variation from the Temporal_Mean => Spatial Temporal Map (STmap) or STM

$$SpatialTemporalMap\ (STM)(i,j) = abs\left|\frac{(TSMM(i,j) - TemporalMean)}{TemporalMean}\right| * 100\%$$

$$SPTM_{band}(i,j) = 1, If\ [STM_{band}(i,j) < 3\%]_{band1..7}$$
$$else\ \ SPTM_{band}(i,j) = 0,$$



The resulting map was restricted to 3% variation and named the SPatial_TemporalMask (SPTM)

We repeat the process for all 7 bands, then find the optimal region that contains 3%, Temporal, Spatial and Spectral stability.

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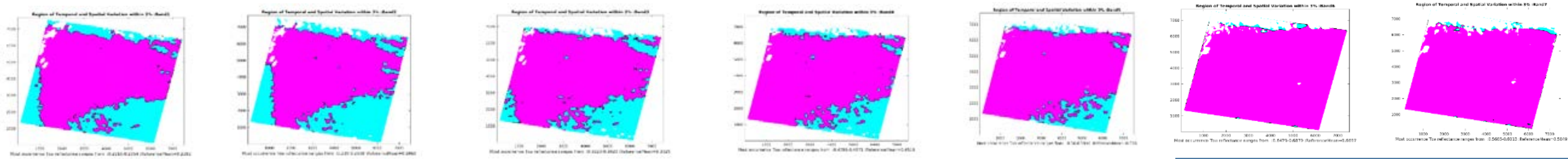
Find Optimal Stable Region : 3% Temporal, Spatial and Spectral

Band1:SPTM Band2:SPTM Band3:SPTM … Band7:SPTM

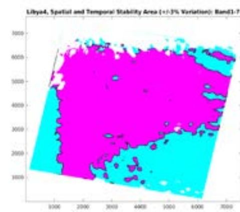


$$OAM((i,j) = 1, If\ \frac{1}{7}\left[\sum_{i=1}^{band} SPTM_{band}(i,j,band)\right]_{band=1}^{band7} = 1$$

Else

$$OAM((i,j) = 0$$

The Optimal Area mask (OAM) contains the area with less than 3% Temporal, Spatial and Spectral variation



Optimal Map

$$OptMap_{(band)} = OAM(i,j)\ .*TSMM_{band}(i,j)$$

$$OptimalReference_{band} = \frac{1}{N}\sum_{i=1}^{N} OptMap_{band}(i,j)$$

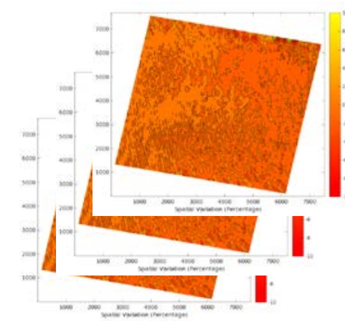
N = No. of pixels of TOA reflectance in OptMap

Replicate over entire PICS site for all 12 months

3,4

$$CorrectionMap(i,j,t)_{(Band)} = \frac{Optimal\ Reference_{(band)}}{Smoothed\ Image\ (I')(i,j,t)_{(band)}}$$

Correction map will provide a correction ratio to bring each image back to Optimal Reference for each Pics and each band



Correctionmap

$$ScaleFactor2Libya4_{(PICS,Band)} = \frac{Optimal\ Reference_{(Libya4,Band)}}{Optimal\ Reference_{(PICS,Band,)}}$$

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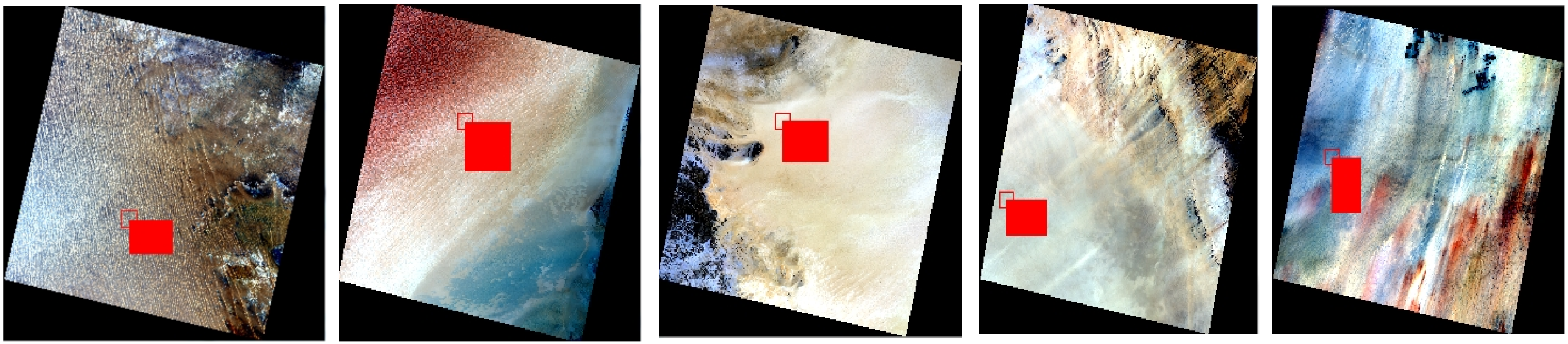
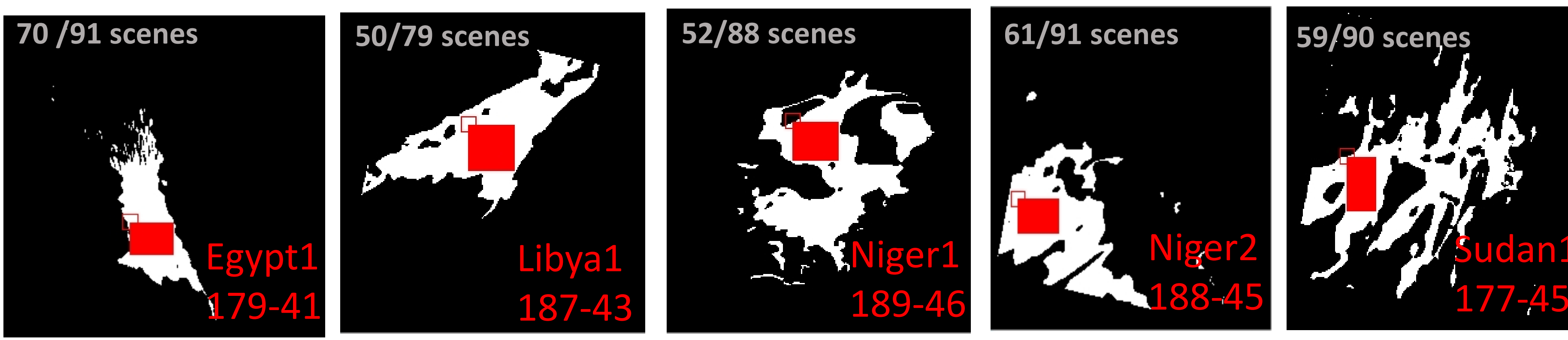
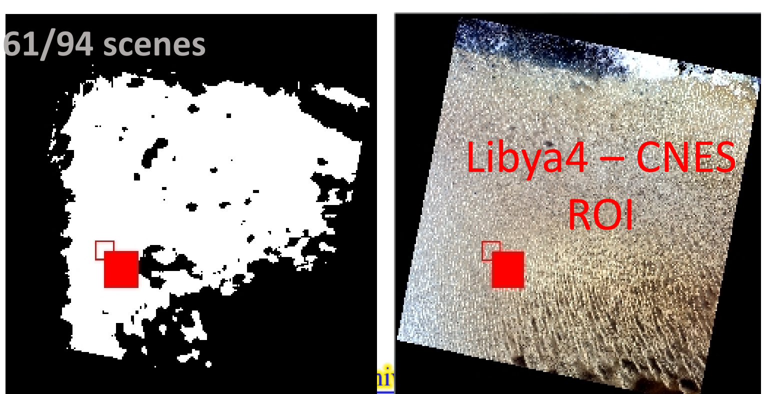
ScaleFactor will bring each PICS to match Libya4

353 OLI data : High Stability ROI with SDSU Cloud Mask







as of May 2017- Landsat8 Pre-collection data			
Sites	**Total scenes in Archive**	**Cloud Free-scenes**	**% Success Rate**
Libya4	94	61	65%
Libya1	79	50	63%
Niger1	88	52	59%
Niger2	91	61	67%
Sudan1	90	59	66%
Egypt1	91	70	77%

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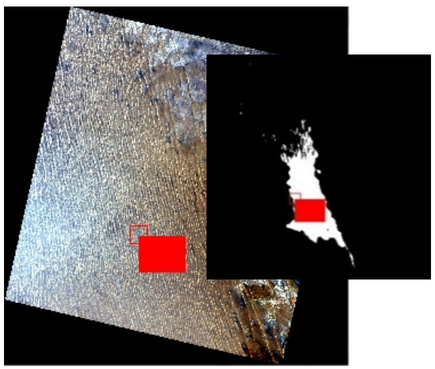
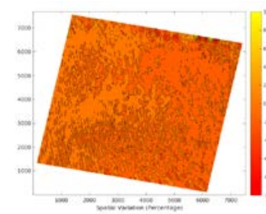
PICS Normalization Process

Cloud Free Images



×

CorrectionMap By month, band



Bring the images equal to Optimal reference

×

Scale Factor, band

SF2 Libya4

Bring the images equal to Libya4_Optimal reference

=

PNP to Libya4

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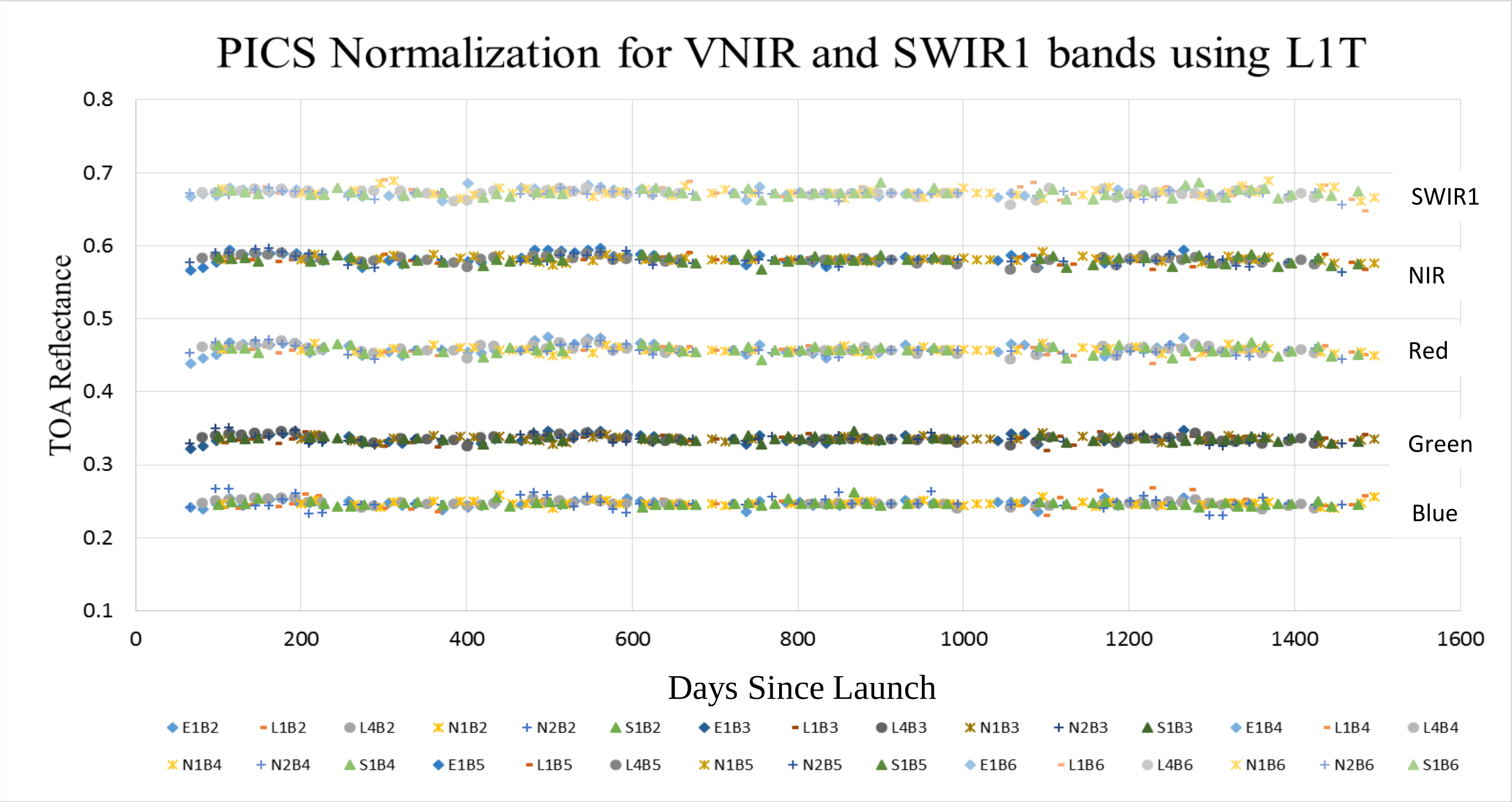
PNP Super PICS Trending: 6 PICS sites: 353 Scenes



Temp Uncertainty	C/A	Blue	Green	Red	NIR	SWIR1	SWIR2
Egypt1	1.77%	1.84%	1.76%	1.70%	1.23%	0.75%	2.12%
Libya1	2.99%	2.92%	1.49%	1.08%	0.84%	1.03%	1.76%
Libya4	1.33%	1.45%	1.32%	1.14%	0.83%	0.69%	1.73%
Niger1	1.49%	1.47%	1.02%	0.88%	0.62%	0.88%	1.94%
Niger2	3.13%	3.23%	1.57%	1.34%	1.18%	0.61%	2.20%
Sudan1	1.47%	1.36%	0.93%	1.16%	0.85%	0.76%	1.93%

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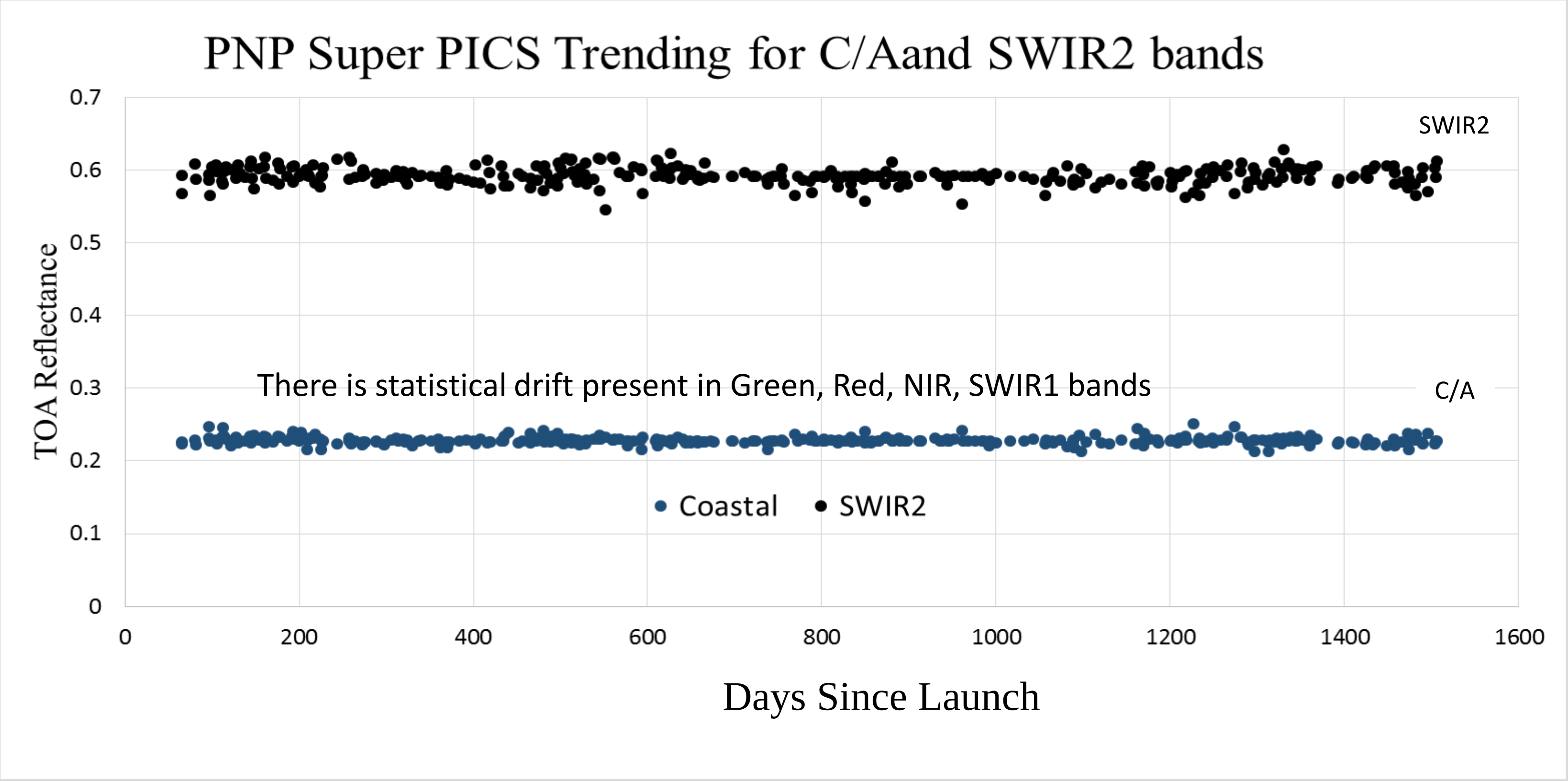
PNP Super PICS Trending: 6 PICS sites: 353 Scenes



Statistics	C/A	Blue	Green	Red	NIR	SWIR1	SWIR2
%Drift/year	-0.16	-0.13	-0.13	-0.18	-0.20	-0.09	-0.16
2Sigma	0.19	0.20	0.13	0.12	0.09	0.07	0.18
P value slope=0	0.101	0.178	0.045	0.002	0.000	0.012	0.072
SuperPICS Temp Uncertainty	2.14%	2.16%	1.40%	1.28%	0.97%	0.79%	1.99%

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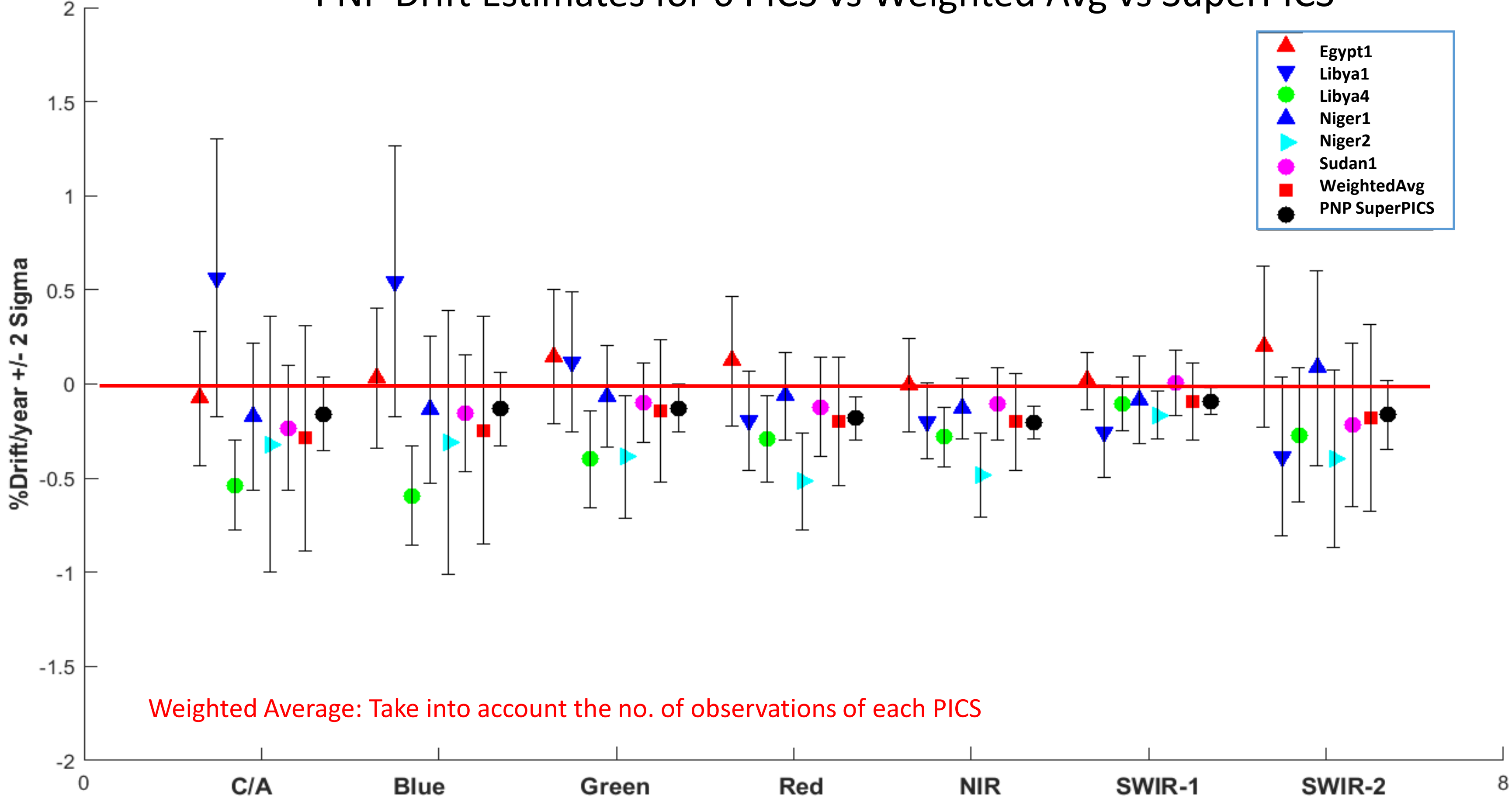
PNP Drift Estimates for 6 PICS vs Weighted Avg vs SuperPICS



Drift	Egypt1	Libya1	Libya4	Niger1	Niger2	Sudan1	W.avg	SuperPICS
CA	-0.08	0.57	-0.54	-0.18	-0.32	-0.23	-0.29	**-0.16**
Blue	0.03	0.55	-0.59	-0.14	-0.31	-0.15	-0.25	**-0.13**
Green	0.15	0.12	-0.40	-0.07	-0.39	-0.10	-0.14	**-0.13**
Red	0.12	-0.19	-0.29	-0.06	-0.52	-0.12	-0.20	**-0.18**
NIR	-0.01	-0.20	-0.28	-0.13	-0.48	-0.10	-0.20	**-0.20**
SWIR1	0.02	-0.25	-0.11	-0.08	-0.17	0.00	-0.09	**-0.09**
SWIR2	0.20	-0.38	-0.27	0.09	-0.40	-0.22	-0.18	**-0.16**

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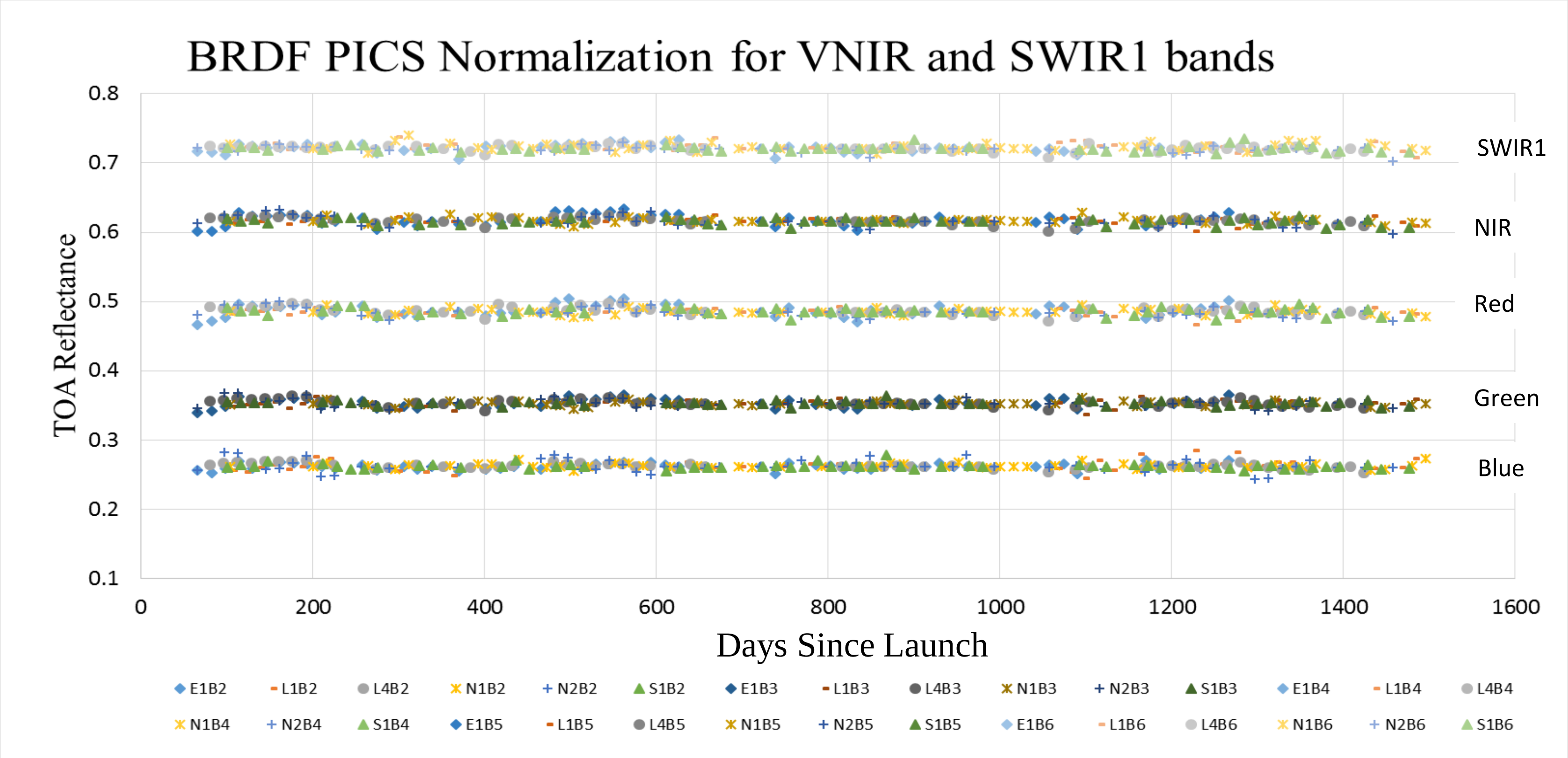
Refined PNP technique

- Introduce BRDF-SZA correction, create PNP basemap with BRDF-SZA Correction – BRDF PNP Basemap
- Construct a BRDF correction model from stable region: BRDF quadratic model
- Apply BRDF quadratic model to selected 12 month images, stack them, create temporal BRDF mean map for each band
- Mask image with identified stable ROI-PNP, then calculate TOA reflectance mean : BRDF optimal Mean_{band}
- Create Correctionmap : $\dfrac{\text{BRDF optimal Mean}_{band}}{\text{BRDF-Image}_{12month}}$
- Calculate Scale Factor : $\dfrac{\text{BRDF Optimal Mean Libya4}_{band}}{\text{BRDF Optimal Mean (PICS)}_{band}}$
- Perform BRDF PNP, test results

BRDF-PNP Super PICS Trending: 6 PICS sites: 353 Scenes



BRDF Temp Uncertainty	C/A	Blue	Green	Red	NIR	SWIR1	SWIR2
Egypt1	1.64%	1.78%	1.80%	1.76%	1.29%	0.76%	2.27%
Libya1	3.01%	2.93%	1.48%	1.01%	0.70%	0.77%	1.60%
Libya4	1.25%	1.40%	1.30%	1.14%	0.81%	0.59%	1.79%
Niger1	1.39%	1.37%	0.96%	0.89%	0.66%	0.77%	1.95%
Niger2	3.07%	3.14%	1.53%	1.34%	1.19%	0.65%	2.24%
Sudan1	1.48%	1.39%	0.92%	1.09%	0.75%	0.60%	1.82%

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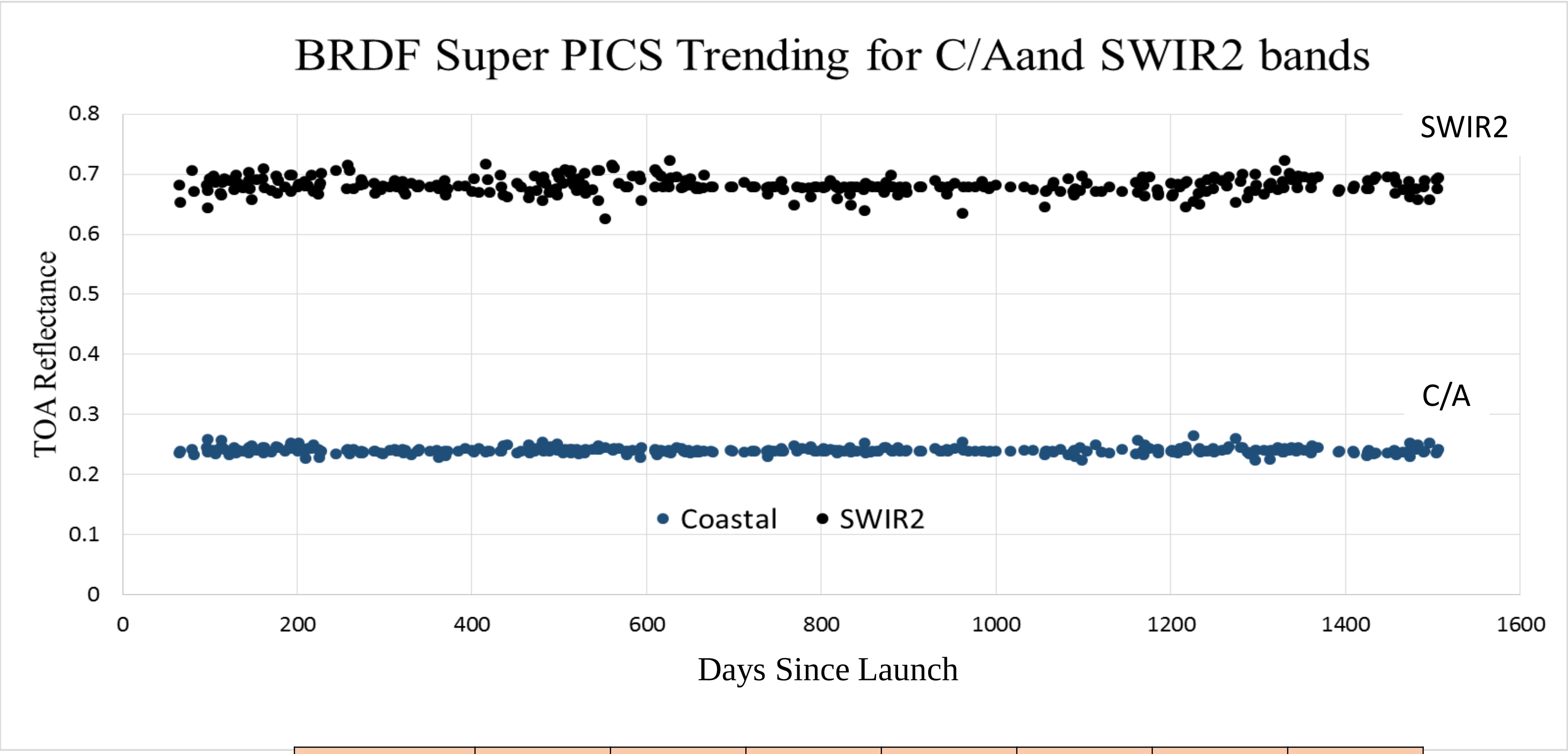
BRDF-PNP Super PICS Results: CA and SWIR1 Bands

Libya4, Libya1, Niger1,Niger2, Egypt1 and Sudan1 : 353 Images, 4 years

Test if slope is equal to 0 , if p-value < 0.05, there is a significant trend for that band



SuperPICS	CA	Blue	Green	Red	NIR	SWIR1	SWIR2
%Drift/year	-0.13	-0.11	-0.13	-0.19	-0.21	-0.10	-0.16
2Sigma	0.19	0.19	0.13	0.12	0.09	0.06	0.18
Uncertainty	2.09%	2.11%	1.38%	1.28%	0.96%	0.71%	2.00%
p-value	0.180	0.239	0.038	0.001	0.000	0.002	0.081

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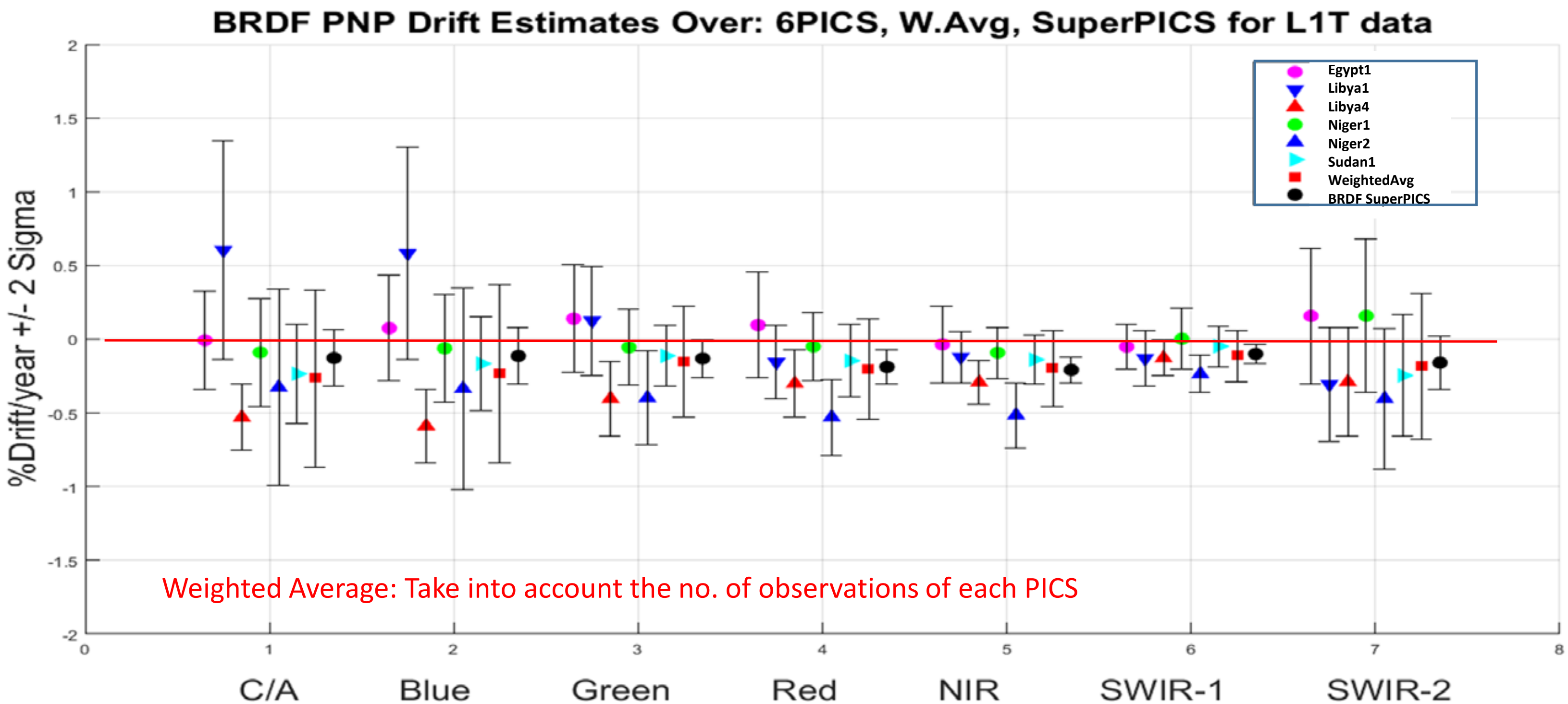
Drift Estimates Comparison : BRDF SUPERPICS vs BRDF Individual PICS Trending



Drift	Egypt1	Libya1	Libya4	Niger1	Niger2	Sudan1	Wavg	SuperPICS
CA	-0.01	0.60	-0.53	-0.09	-0.33	-0.23	-0.26	**-0.13**
Blue	0.07	0.58	-0.59	-0.06	-0.34	-0.17	-0.24	**-0.11**
Green	0.14	0.13	-0.40	-0.06	-0.40	-0.11	-0.15	**-0.13**
Red	0.10	-0.16	-0.30	-0.05	-0.53	-0.15	-0.20	**-0.19**
NIR	-0.04	-0.12	-0.29	-0.09	-0.51	-0.14	-0.20	**-0.21**
SWIR1	-0.05	-0.13	-0.13	0.00	-0.24	-0.05	-0.11	**-0.10**
SWIR2	0.16	-0.31	-0.29	0.16	-0.40	-0.25	-0.19	**-0.16**

PNP provides similar drift estimates as onboard calibration, i.e. <0.1% per year

: Mishra N, Helder D, Barsi J, Markham B, Continuous calibration improvement in solar reflective bands : Landsat 5 through landsat8, Remote Sensing of Environment , 2016,7-15,

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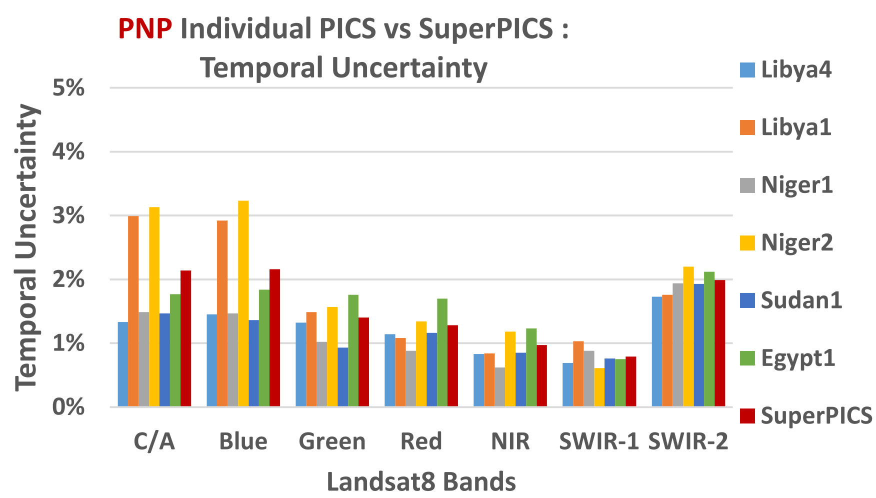
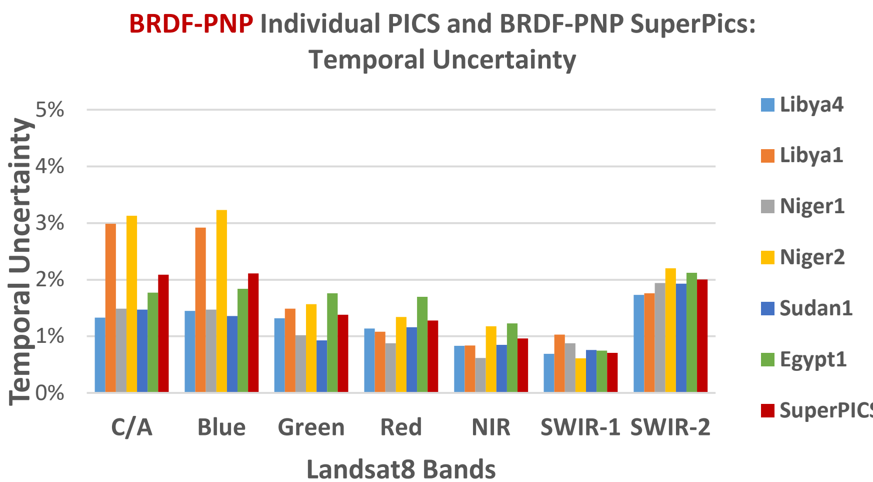
Initial PNP vs BRDF PNP : Temporal Uncertainty

Landsat8	PNP Temporal Uncertainty, data since launch						
Bands	Libya4	Libya1	Niger1	Niger2	Sudan1	Egypt1	SuperPICS
C/A	1.33%	2.99%	1.49%	3.13%	1.47%	1.77%	**2.14%**
Blue	1.45%	2.92%	1.47%	3.23%	1.36%	1.84%	**2.16%**
Green	1.32%	1.49%	1.02%	1.57%	0.93%	1.76%	**1.40%**
Red	1.14%	1.08%	0.88%	1.34%	1.16%	1.70%	**1.28%**
NIR	0.83%	0.84%	0.62%	1.18%	0.85%	1.23%	**0.97%**
SWIR-1	0.69%	1.03%	0.88%	0.61%	0.76%	0.75%	**0.79%**
SWIR-2	1.73%	1.76%	1.94%	2.20%	1.93%	2.12%	**1.99%**



Landsat8 Bands	BRDF PNP Temporal Uncertainty, data since launch						
	Egypt1	Libya1	Libya4	Niger1	Niger2	Sudan1	SuperPics
C/A	1.64%	3.01%	1.25%	1.39%	3.07%	1.48%	**2.09%**
Blue	1.78%	2.93%	1.40%	1.37%	3.14%	1.39%	**2.11%**
Green	1.80%	1.48%	1.30%	0.96%	1.53%	0.92%	**1.38%**
Red	1.76%	1.01%	1.14%	0.89%	1.34%	1.09%	**1.28%**
NIR	1.29%	0.70%	0.81%	0.66%	1.19%	0.75%	**0.96%**
SWIR-1	0.76%	0.77%	0.59%	0.77%	0.65%	0.60%	**0.71%**
SWIR-2	2.27%	1.60%	1.79%	1.95%	2.24%	1.82%	**2.00%**



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%Drift Estimates PNP vs BRDF PNP

% Drift Estimates/year : PNP

Drift	Egypt1	Libya1	Libya4	Niger1	Niger2	Sudan1	W.avg	SuperPICS
CA	-0.08	0.57	-0.54	-0.18	-0.32	-0.23	-0.29	**-0.16**
Blue	0.03	0.55	-0.59	-0.14	-0.31	-0.15	-0.25	**-0.13**
Green	0.15	0.12	-0.40	-0.07	-0.39	-0.10	-0.14	**-0.13**
Red	0.12	-0.19	-0.29	-0.06	-0.52	-0.12	-0.20	**-0.18**
NIR	-0.01	-0.20	-0.28	-0.13	-0.48	-0.10	-0.20	**-0.20**
SWIR1	0.02	-0.25	-0.11	-0.08	-0.17	0.00	-0.09	**-0.09**
SWIR2	0.20	-0.38	-0.27	0.09	-0.40	-0.22	-0.18	**-0.16**

% Drift Estimates/year : BRDF PNP

Drift	Egypt1	Libya1	Libya4	Niger1	Niger2	Sudan1	Wavg	SuperPICS
CA	-0.01	0.60	-0.53	-0.09	-0.33	-0.23	-0.26	**-0.13**
Blue	0.07	0.58	-0.59	-0.06	-0.34	-0.17	-0.24	**-0.11**
Green	0.14	0.13	-0.40	-0.06	-0.40	-0.11	-0.15	**-0.13**
Red	0.10	-0.16	-0.30	-0.05	-0.53	-0.15	-0.20	**-0.19**
NIR	-0.04	-0.12	-0.29	-0.09	-0.51	-0.14	-0.20	**-0.21**
SWIR1	-0.05	-0.13	-0.13	0.00	-0.24	-0.05	-0.11	**-0.10**
SWIR2	0.16	-0.31	-0.29	0.16	-0.40	-0.25	-0.19	**-0.16**

Both PNP techniques give % Drift Estimates within -0.2% for all Bands

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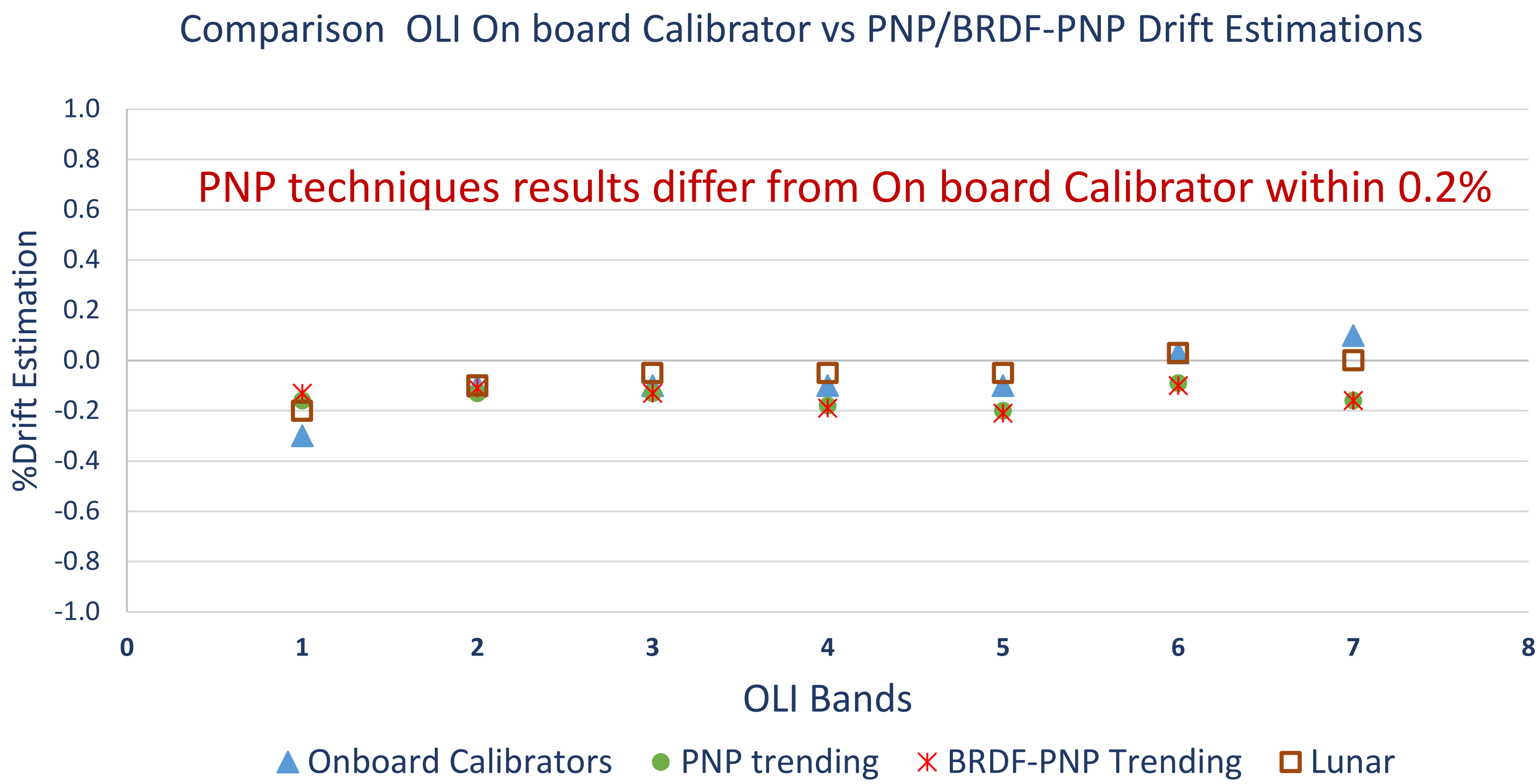
PNP/BRDF-PNP Drift Estimates vs On-board Calibrators



http://www.sciencedirect.com/science/article/pii/S0034425716302899

Nischal Mishra, Dennis Helder, Julia Barsi, Brian Markham, Continuous calibration improvement in solar reflective bands: Landsat 5 through Landsat 8, Remote Sensing of Environment Volume 185, November 2016, Pages 7–15

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BRDF PICS Normalization Process : Uncertainty Analysis

Uncertainty Sources	CA	Blue	Green	Red	NIR	SWIR1	SWIR2
BRDF Super PICS Temporal Uncertainty	2.05%	2.07%	1.38%	1.26%	0.91%	0.66%	1.93%
Bin Analysis (spatial)	0.66%	0.72%	0.73%	0.84%	0.54%	0.52%	0.61%
Temporal Uncertainty across PICS (Images)	1.65%	1.65%	1.13%	0.95%	0.69%	0.54%	1.81%
Total PNP Uncertainty	**2.74%**	**2.77%**	**1.93%**	**1.80%**	**1.30%**	**1.03%**	**2.77%**

Summary

- PNP approach increase data acquisition rate up to 3-4 times for Landsat 8 (every 3-4 days)
- PICS Normalization Process for both methods, the drift estimates for all spectral bands in the order of - 0.2% per year which provides very comparable results to On-board Calibrators.
- Temporal Uncertainty of the SuperPICS after PNP and BRDF PNP was well within 2% for all bands.
- BRDF PNP Uncertainty Analysis: PNP-SuperPICS Uncertainty, Optimal Reference Uncertainty, Temporal Uncertainty of PICS
  - ❖ The overall Uncertainty of the PNP technique is within 3% for all OLI bands
- If there is no on-board calibrator, PNP technique a viable alternative technique to perform radiometric assessment of satellites especially the older ones.

Moving Forward

- Libya-4 has shown more variability recently, there is new study, Worldwide Exhaustive PICS Search (WEPS), using Google Earth Engine that has located stable regions with better than 2% temporal uncertainty for each spectral band.
- Modify PNP technique to incorporate these new results, and with Collection 1 data.

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THANK YOU

Back up Slides

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Average Drift calculation procedure

- For N measurements $x_1, x_{2,} \ldots x_N$ with uncertainties $\sigma_1, \sigma_2, \ldots. \sigma_{N,}$, the weighted average is calculated as

$$Weighted\ Average\ (x_{wavg}) = \frac{\sum_1^N w_i\, x_i}{\sum_i^N w_i}.$$

Xi = %Drift for each site

wi = 2 Sigma for each site

- The weights are
  - $w_i = \frac{1}{{\sigma_i}^2}$
- The uncertainty on weighted average

$$\sigma = \sqrt{\frac{\sum n_i \sigma_i^2 + \sum n_i (\bar{y}_i - \hat{y})^2}{\sum n_i}}$$

for site i, where n is the number of points, σ is the standard deviation, and $\bar{y}$ is the mean, and $\hat{y}$ is the weighted mean.

- Therefore the average value will be weighted towards the data take account of no. of observations for each site.
- The weighted average will have combined uncertainty of all the measurements associated with the average.

Y^= Weighted Average

Y_bar= %Drift for each site

n= no. of observations for each site

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Refined PNP technique: BRDF PNP Basemap

Libya4
•-BRDF CorrectionMap$_{ban}$

Libya1
- BRDF CorrectionMap$_{band,month}$
- Scale factor to Libya4

Niger1
- BRDF CorrectionMap$_{band,month}$
- Scale factor to Libya4

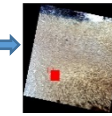
Niger2
- BRDF CorrectionMap$_{band,month}$
- Scale factor to Libya4

Egypt1
- BRDF CorrectionMap$_{band,month}$
- Scale factor to Libya4

Sudan1
- BRDF CorrectionMap$_{band,month}$
- Scale factor to Libya4

$$\text{BRDF Scale factor to Libya4} = \frac{\text{BRDF.Opt Ref. Libya4}_{band}}{\text{BRDF Opt. Ref (PICS)}_{band}}$$

Archived Images



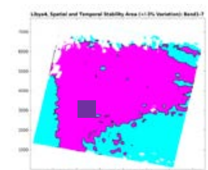
PNP-ROI archived data
BRDF-SZA Corrected, Quadratic model
With Ref SZA = 0 degree,

BRDF-Corr 12months Images

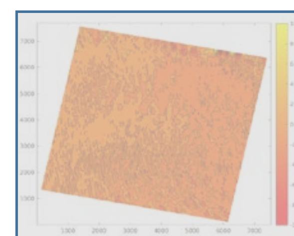
Stack BRDF Corrected images,

Temporal BRDF Map

Temporal BRDF Mean Map



ROI-PNP, 3% Temporal,Spatial, Spectral Stability, Find BRDF Optimal Reference



BRDFCorrectionMap : Normalized to BRDF Optimal Reference

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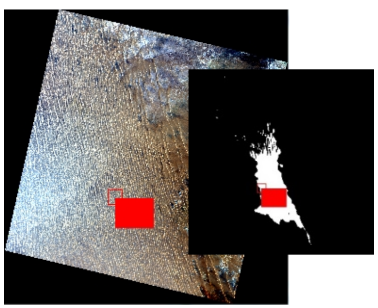
Refined PICS Normalization across multiple PICS

- ❑ Calculate the scale factor for each PICS TOA to bring them to the Libya4 (reference PICS) TOA level

$$\text{Scale factor to Libya4} = \frac{\text{Optimal BRDF Reference Libya4}}{\text{Optimal BRDF Reference(PICS)}}$$

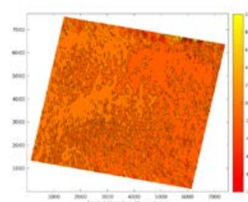
PICS Normalization Process

Cloud Free BRDF corrected L1T images of selected ROI for each PICS



X

BRDF Correction Map
By month,band



Bring the images to equal to Optimal BRDF reference

X

BRDF Scale Factor, per band

SF2 Libya 4

Bring the images to equal to Libya4_Optimal BRDF reference

=

PNP to Libya 4

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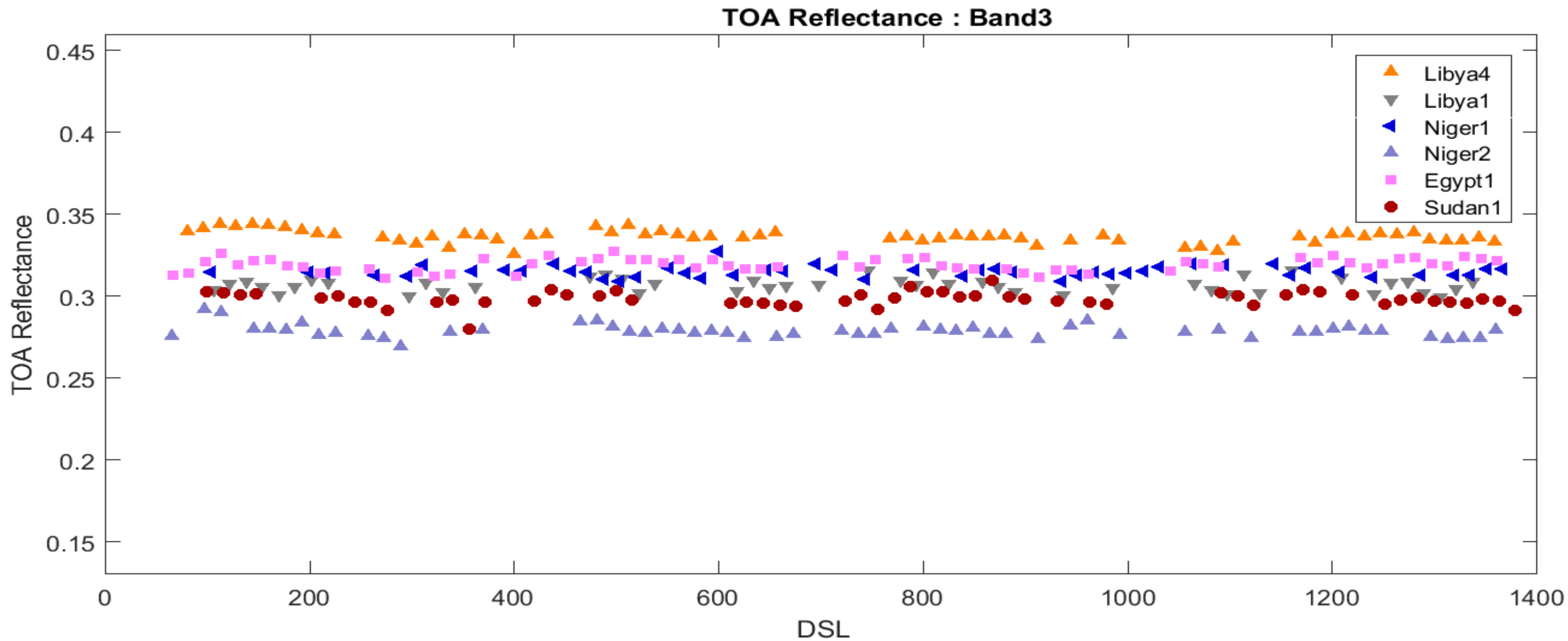
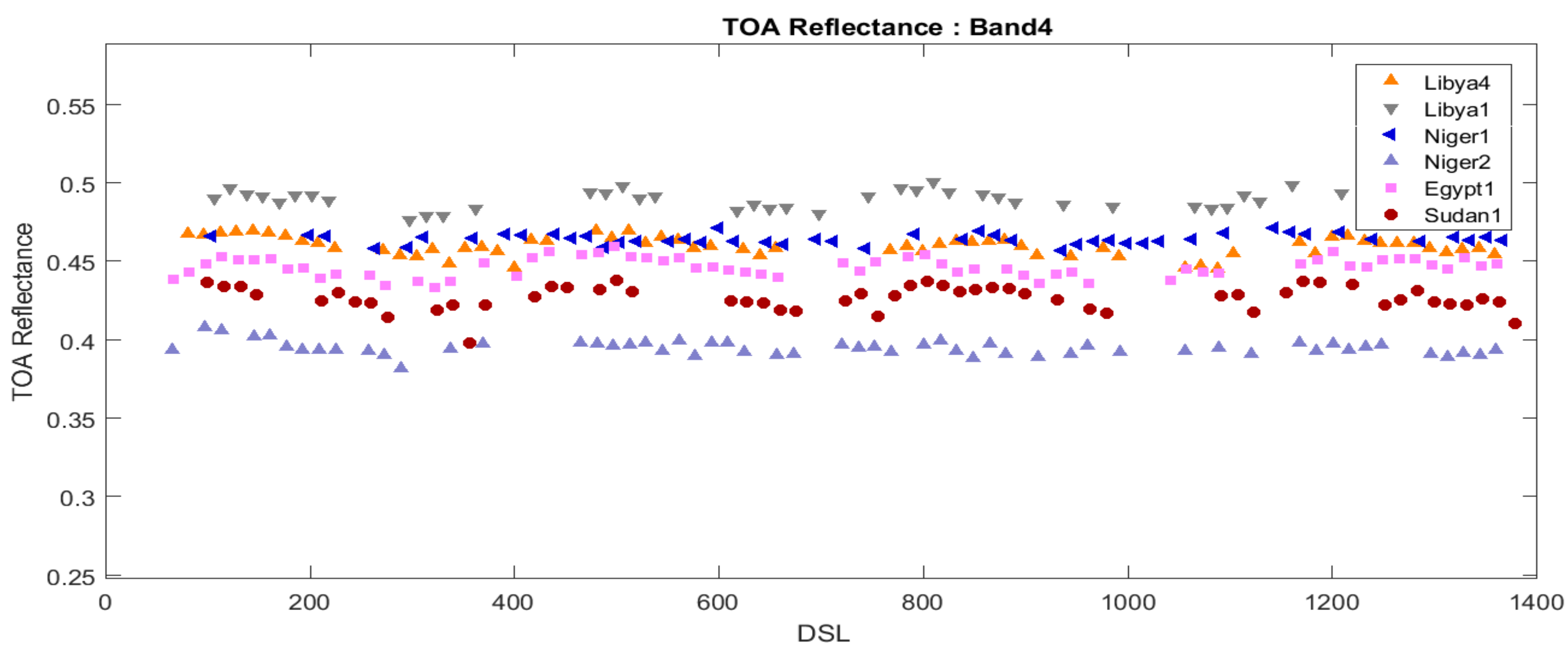
TOA reflectance Band 3,4 for each PICS in the same plot: Shows different Intensity of each PICS





Plot TOA Reflectance with each site scaled to the Libya 4 (no correction map)