Radiometric Calibration and Stability Monitoring of Optical Satellite Sensors using Global Extended Pseudo Invariant Calibration Sites (During Landsat 9 OIV)

December 2022

By

J. Fajardo Rueda, M. Kaewmanee, R. Shah, L. Leigh, C. Teixeira Pinto

South Dakota State University, Image Processing Laboratory

South Dakota State University
Image Processing Lab

Outline

Algorithm Development to identify Stable pixels/regions – Extended PICS (EPICS)

- PICS: *Libya1,Libya4, Niger1, Niger2, Sudan1, Egypt1*
- North African desert sites– EPICS
- Global EPICS

New Techniques development for radiometric calibration

- PICS & EPICS Trending Analysis
- Global EPICS trend to trend Cross Calibration Analysis– Trend to Trend Analysis (T2T)
- Extended PICS Absolute Calibration model – ExPAC Model

Landsat 9 OIV : monitoring the performance summary

- ExPAC Double Ratio: EPICS-NA
- Traditional Xcal – EPICS-NA, EPICS-Global
- T2T : EPICS-NA, EPICS-Global

Conclusion

PICS to EPICS in A Nutshell

Finding Stable pixels: SDSU timeline

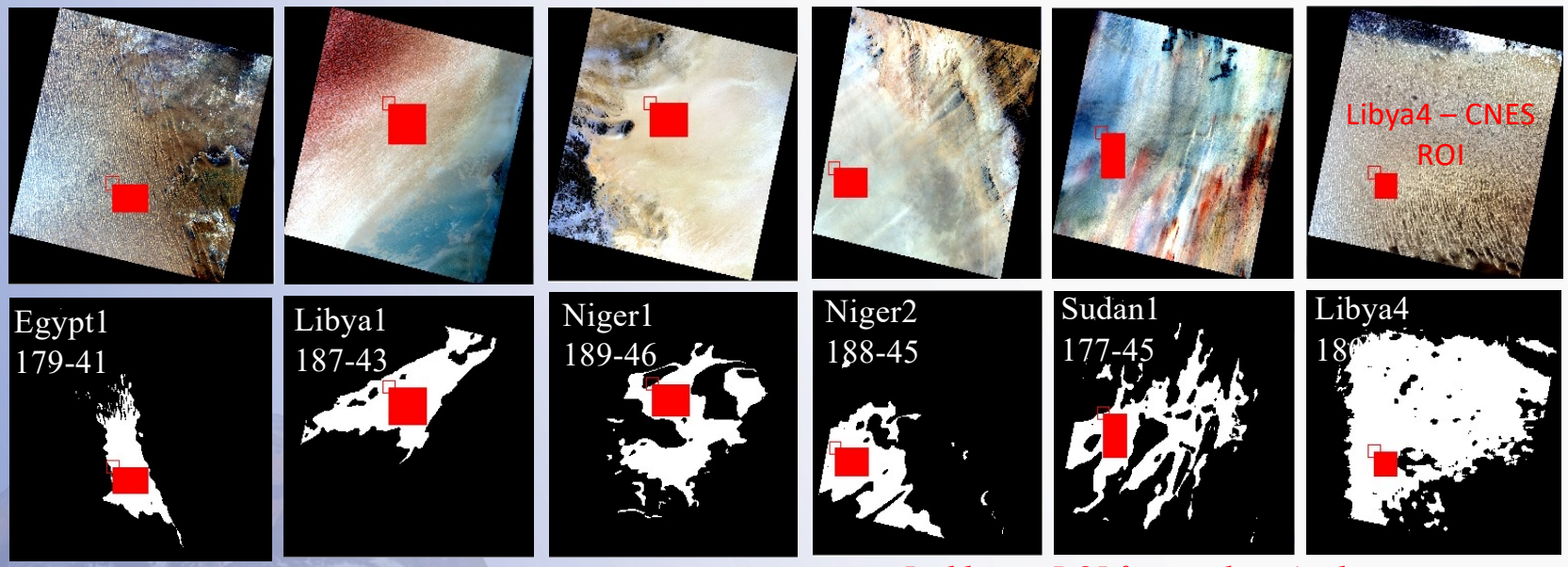
- Based on SDSU IPLab research

1. 2010, Optimized identification of worldwide radiometric pseudo-invariant calibration sites; http://www.tandfonline.com/loi/ujrs20
2. 2014, Absolute Calibration of Optical Satellite Sensors Using Libya 4 Pseudo Invariant Calibration : https://doi.org/10.3390/rs6021327
3. 2016,2017, PICS Normalization Process: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1287&context=calcon
4. 2017, Worldwide Optimal PICS Search, https://openprairie.sdstate.edu/etd/1693/
5. 2019, North African Classification: https://doi.org/10.3390/rs11070875
6. 2021, Global Classification: https://doi.org/10.3390/rs13173350

Work evolve around Landsat Collection data

Topics		...	Years												
			2010		2012		2014		2015		2017		2019		2021
Satellites	L7														
	L8														
	L9														
Data	Pre-Collection														
	Collection-1														
	Collection-2														
PICS	Optimized ROI														
	SDSU PICS selection														
	PICS PNP														
	Worldwide Optimal Search														
	N. African Classification														
	Global Classification														

Limitations of traditional PICS



White area = 3% spatial, temporal and spectral stability

Red box = ROI for trending Analysis

Limitations when using these sites:

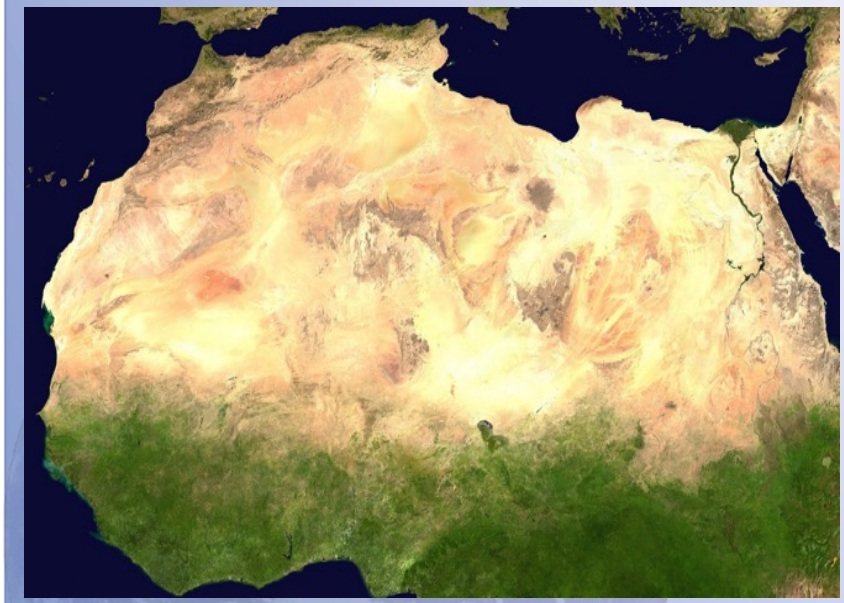
- Satellite revisit cycle and cloud cover over a region of interest can reduce the number of observations.
  - For Landsat 8 ~ 16/collects/year over PICS, 2-3 years to develop enough data to detect drifts.
- Reliability on a single site to be invariant – potential of false drift detection.

1.2014, Absolute Calibration of Optical Satellite Sensors Using Libya 4 Pseudo Invariant Calibration : https://doi.org/10.3390/rs6021327
2.2016,2017, PICS Normalization Process: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1287&context=calcon

Finding Stable pixels: Algorithm Development

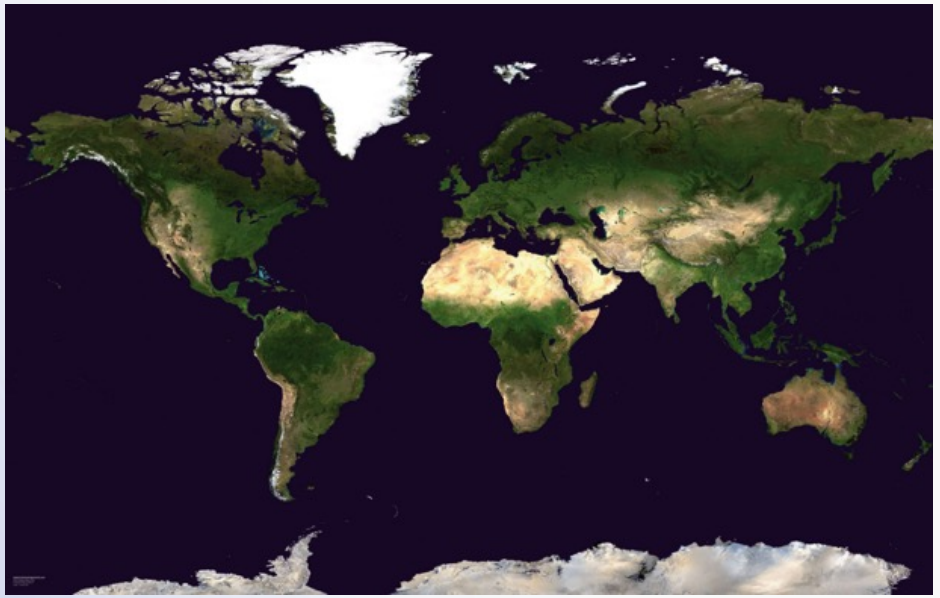
Larger targets can provide a solution to temporal limitation as well as dependency on PICS to be invariant

Continental scale Extended PICS (EPICS)
2019



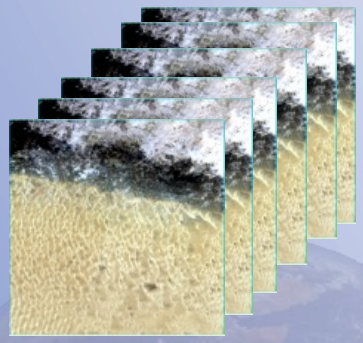
Shrestha, M.; Leigh, L.; Helder, D. Classification of North Africa for Use as an Extended Pseudo Invariant Calibration Sites (EPICS) for Radiometric Calibration and Stability Monitoring of Optical Satellite Sensors. Remote Sens. 2019, 11, 875.

Global scale Extended PICS (EPICS)
2021

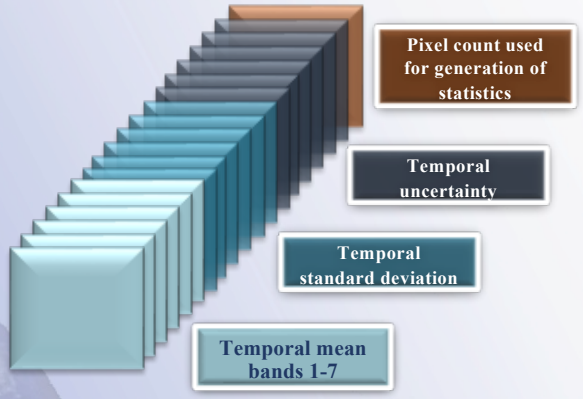


Fajardo Rueda, J.; Leigh, L.; Teixeira Pinto, C.; Kaewmanee, M.; Helder, D. Classification and Evaluation of Extended PICS (EPICS) on a Global Scale for Calibration and Stability Monitoring of Optical Satellite Sensors. Remote Sens. 2021, 13, 3350.

Finding Stable pixels: Algorithm Development



3D array of all Landsat 8 images in Google Earth Engine (GEE)



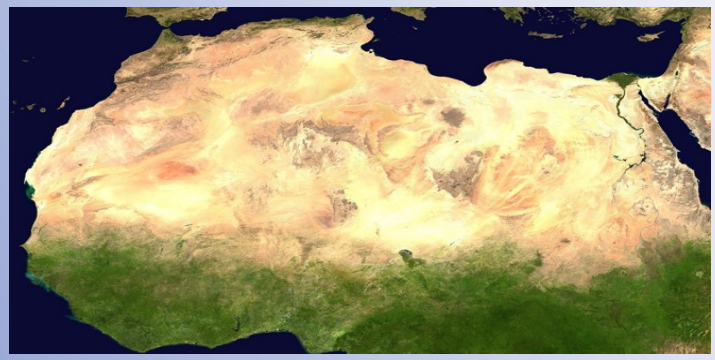
Input data creation, data cube of 1° latitude by 1° longitude

Classification each pixel via a unsupervised K-means algorithm

Landsat 8 bands 1-7 were then used as input to an unsupervised k-means clustering algorithm

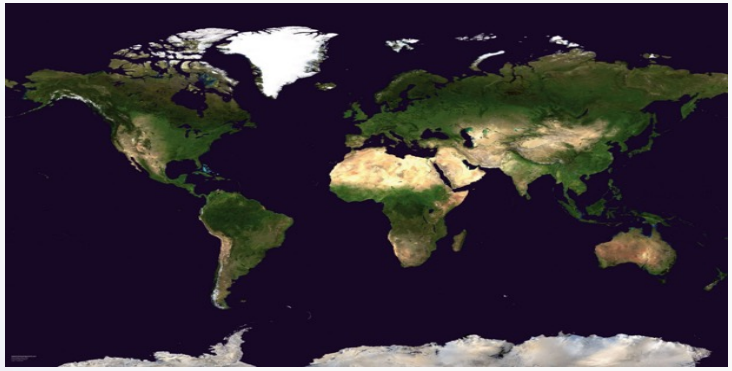
Finding Stable pixels: Algorithm Development

Continental EPICS : North Africa



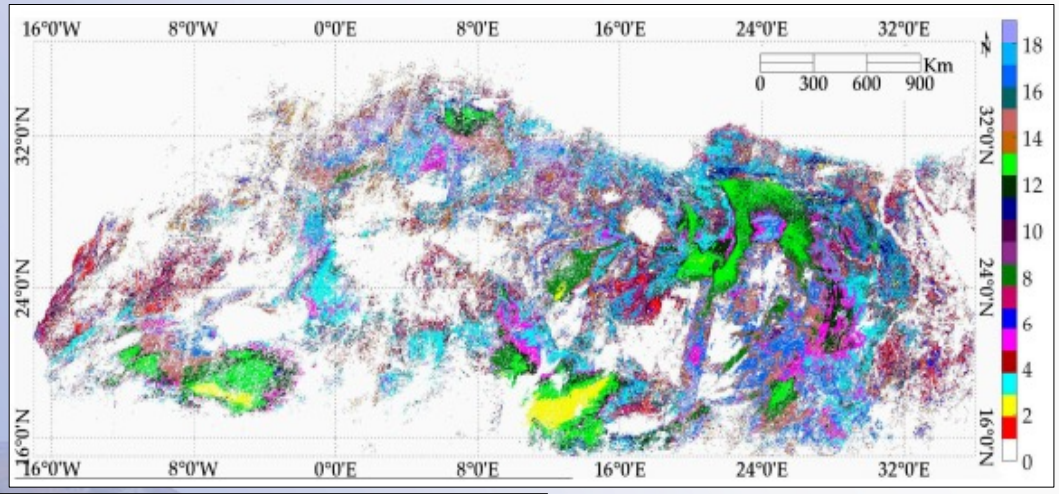
- Performed over **North Africa** Latitude : -15° to 36°, Longitude : 18° to 35°.
- K-means clustering technique used. **19 clusters identified**.
- **300 m spatial resolution** data cubes containing temporal mean TOA reflectance – 8 Landsat 8 bands, temporal standard deviation, temporal uncertainty and pixel count (input to the clustering technique).
- **Filters applied**: Pixels with temporal uncertainty (ration of standard deviation and mean TOA reflectance) larger than 5% and with pixel count lower than 25 were excluded for further analysis.
- Focused on **bright targets**.

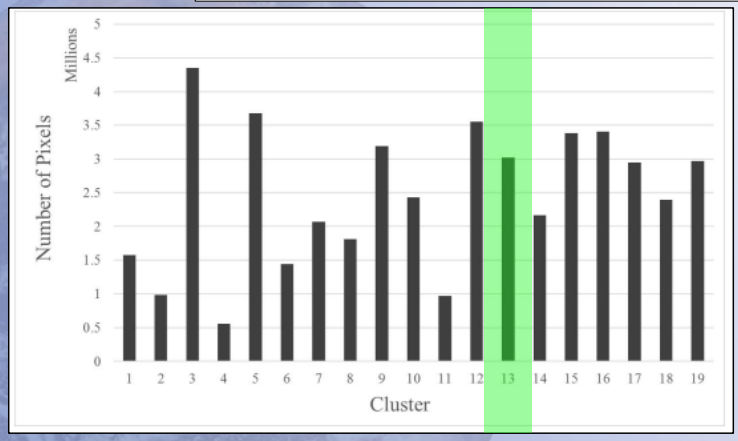
Global EPICS



- Performed **on a global scale** Latitude : -45° to 45°, Longitude : -180° to 180°.
- K-means clustering technique used. **300 clusters identified**
- **30 m spatial resolution** data cubes containing temporal mean TOA reflectance – 8 Landsat 8 bands, temporal standard deviation, temporal uncertainty and pixel count (input to the clustering technique).
- **No filters were applied** to allow the classification of pixels with different spectral characteristics, waterbodies, dark targets and more variable sites.
- **No constraints** in the spectral characteristics of the target.

Finding Stable pixels: EPICS selection

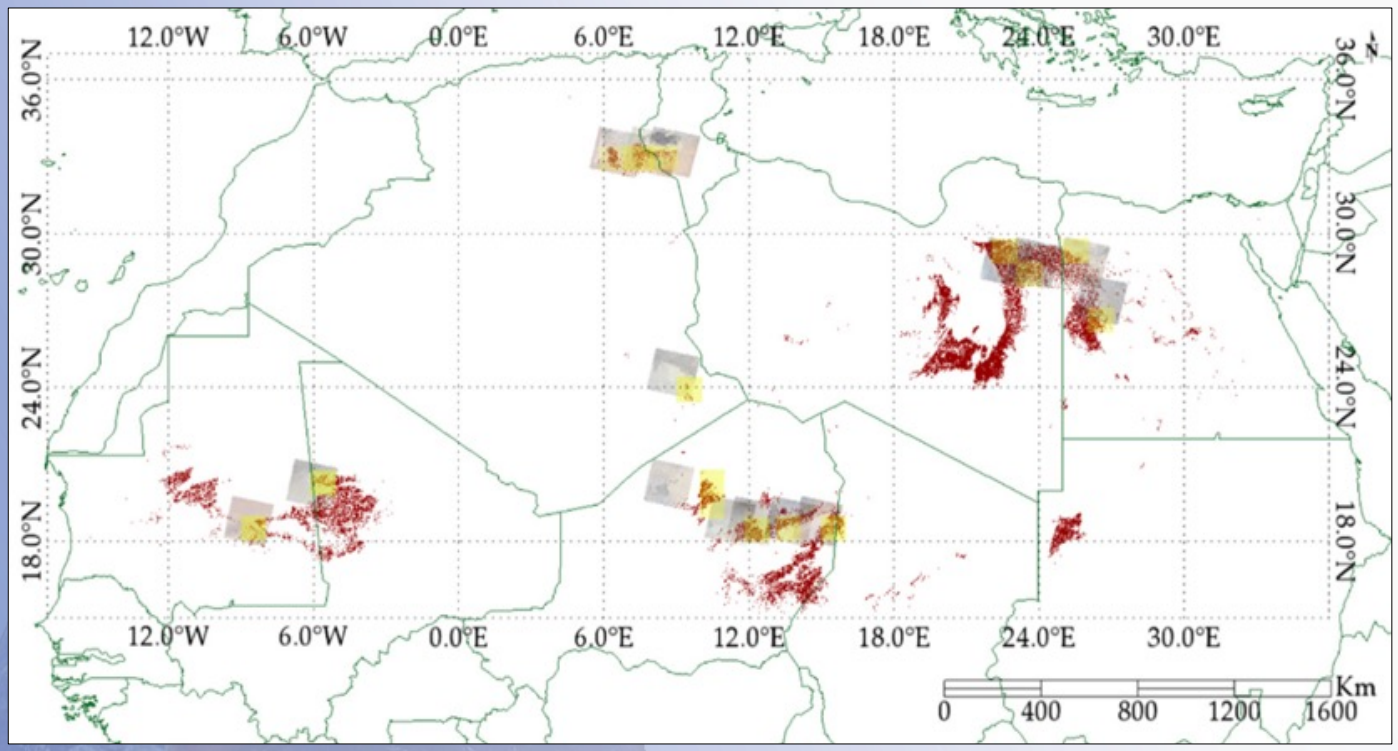




Cluster 13 was selected as EPICS-NA considering:

- It is expanded across the continent with pixels aggregated together
- It contains Libya 4 –ROI pixels
- It has a large pixel count

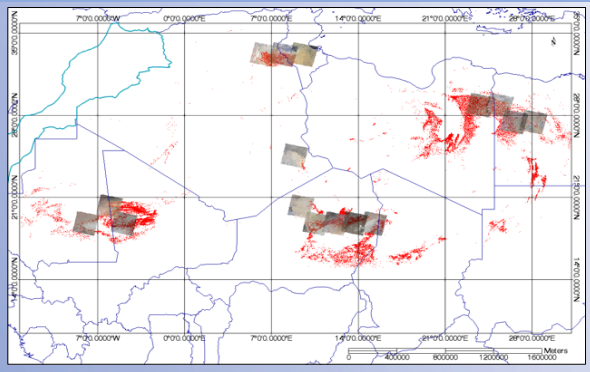
Continental EPICS-NA



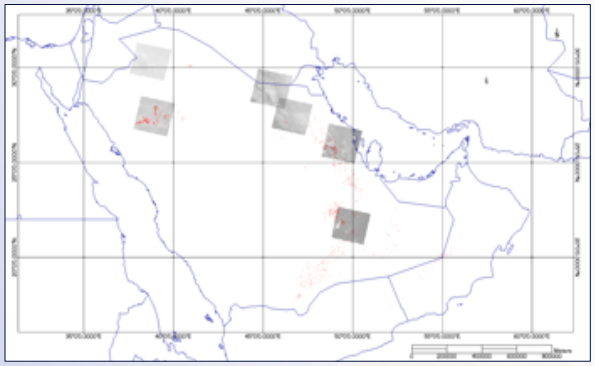
16 WRS-2 Path/Row over North Africa

Because of the potential showed by EPICS-NA, for the global classification, a cluster with similar spectral and spatial characteristics was selected as an EPICS-Global

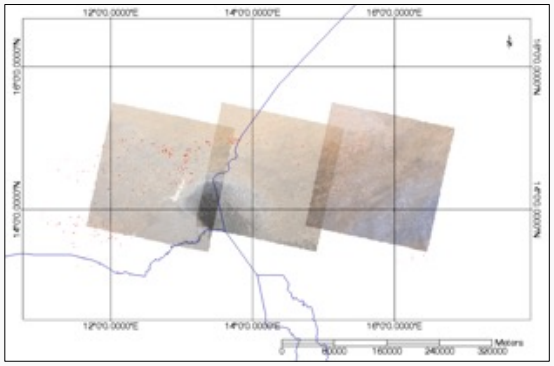
EPICS - Global



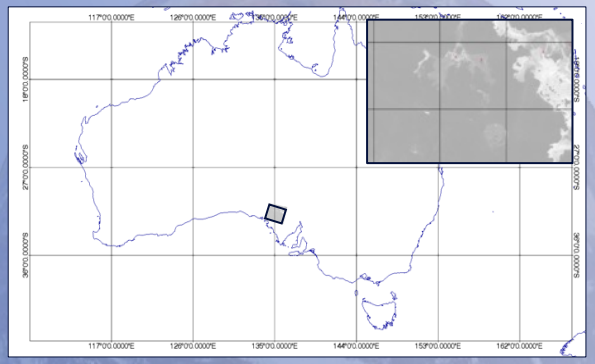
North Africa



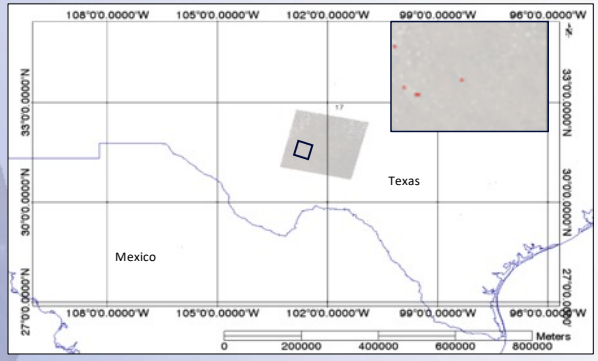
Middle East



Central Africa



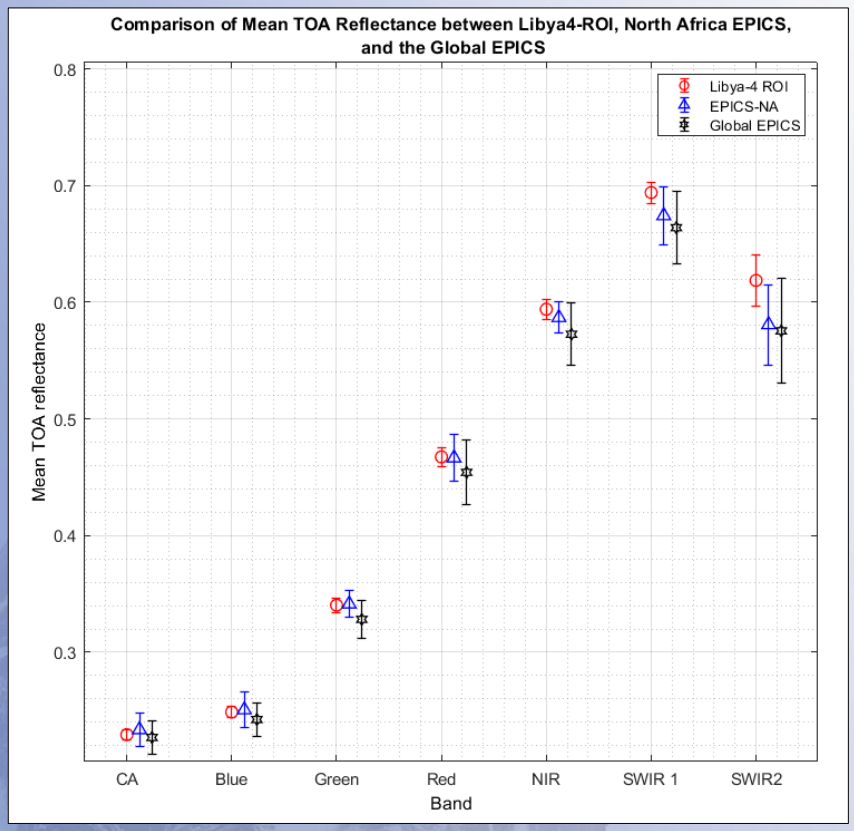
Australia



North America

33 WRS-2 Path/Row around the world

Traditional Libya 4-CNES ROI vs EPICS-NA and EPICS-Global



		Landsat 8 bands						
		CA	Blue	Green	Red	NIR	SWIR1	SWIR 2
Libya 4 - ROI	Mean TOA reflencance	0.229	0.249	0.34	0.468	0.594	0.694	0.619
	Temp. standard deviation	0.002	0.002	0.003	0.004	0.004	0.005	0.011
North Africa EPICS	Mean TOA reflencance	0.234	0.251	0.341	0.467	0.587	0.674	0.581
	Temp. standard deviation	0.007	0.008	0.006	0.01	0.007	0.012	0.017
Global EPICS	Mean TOA reflencance	0.227	0.242	0.328	0.454	0.573	0.664	0.576
	Temp. standard deviation	0.007	0.007	0.008	0.014	0.013	0.016	0.022

- Using **Libya4 – ROI**, One image every **19 days** on average.
- Using **EPICS-NA**, One image every **3 days** on average
- Using **EPICS-Global**, One or more scenes **every day** on average!

Creation of the EPICS global Zonal Masks

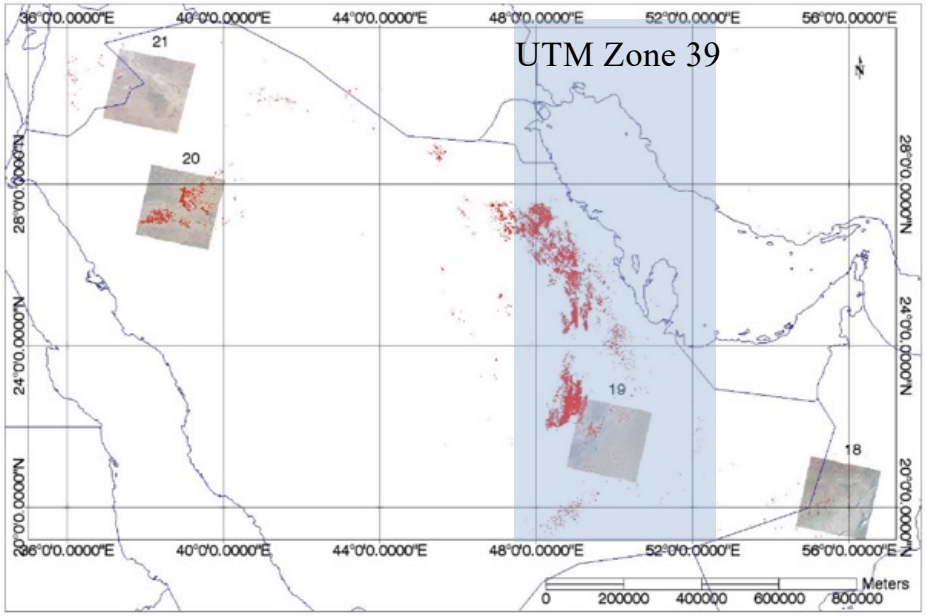


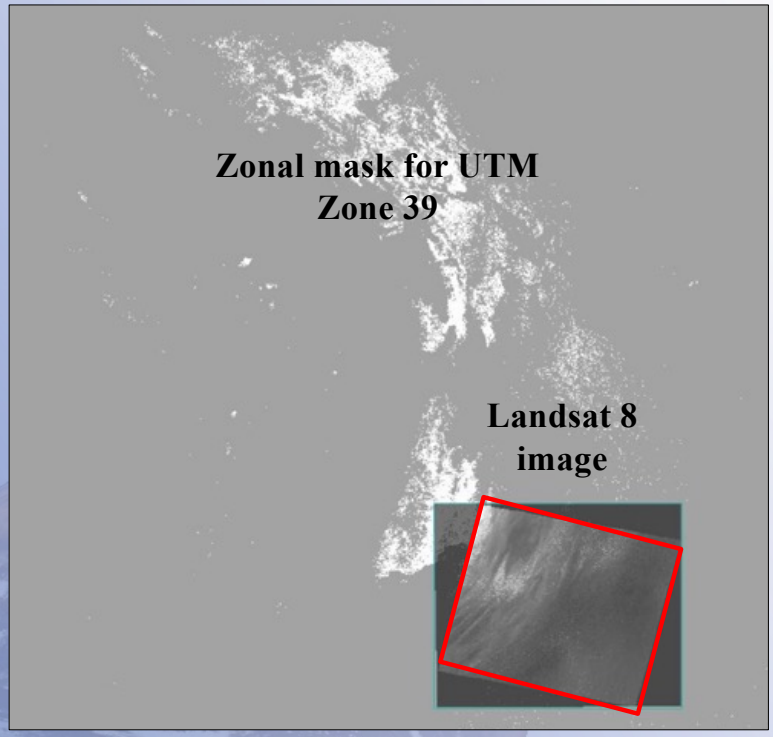
Figure : Cluster 13 pixel masks (shaded regions) UTM zone 39

Translator library for raster and vector geospatial data formats

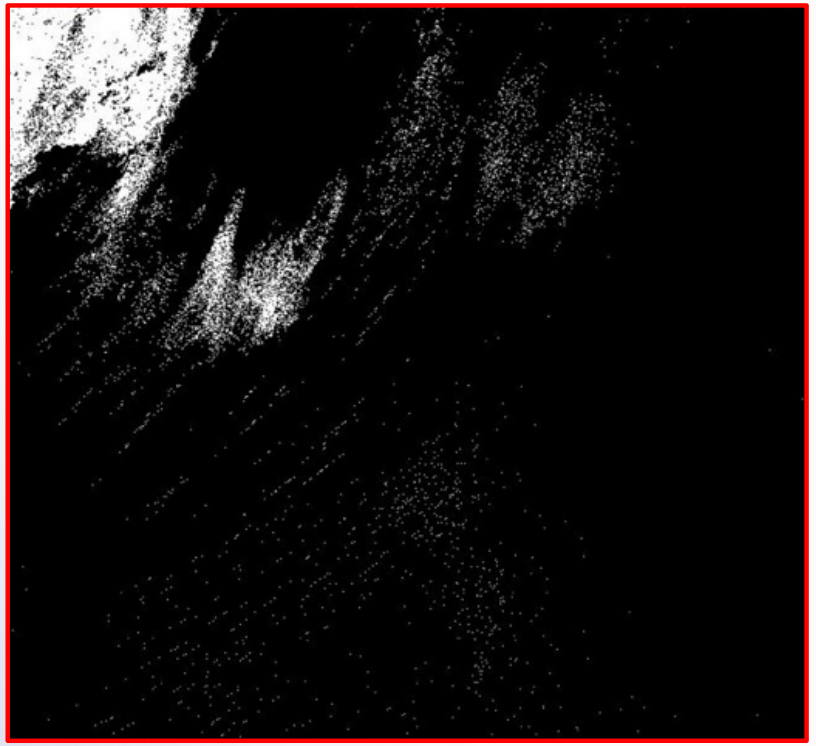
gdalwarp function is used to create the masks

- Masks were created considering UTM zone dimension oversized approximately 10 km to account for images positioned in two different UTM zones.
- 28 zonal masks across the globe were generated to obtain top of atmosphere reflectance in future processing

Application of the EPICS global Zonal Masks



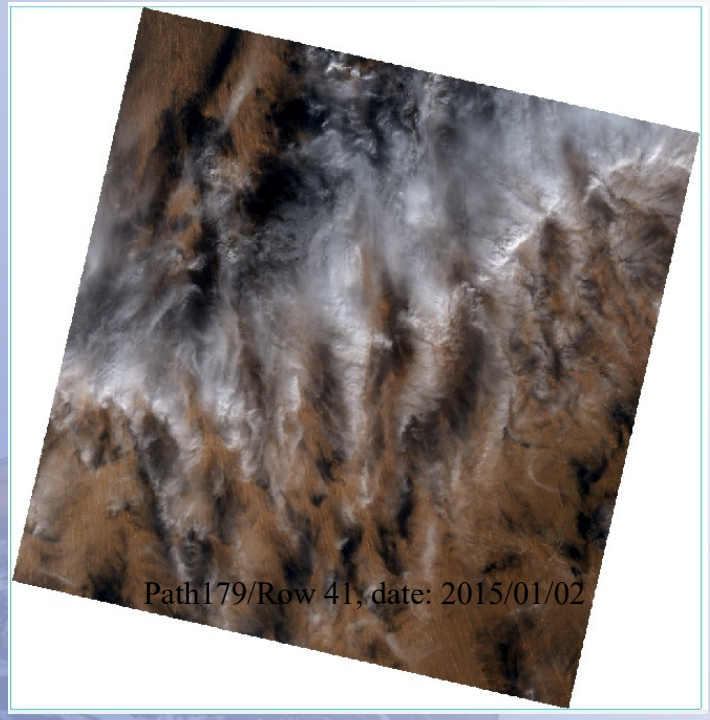
Application of zonal mask for WRS-2 Path 163/Row 45-Middle East



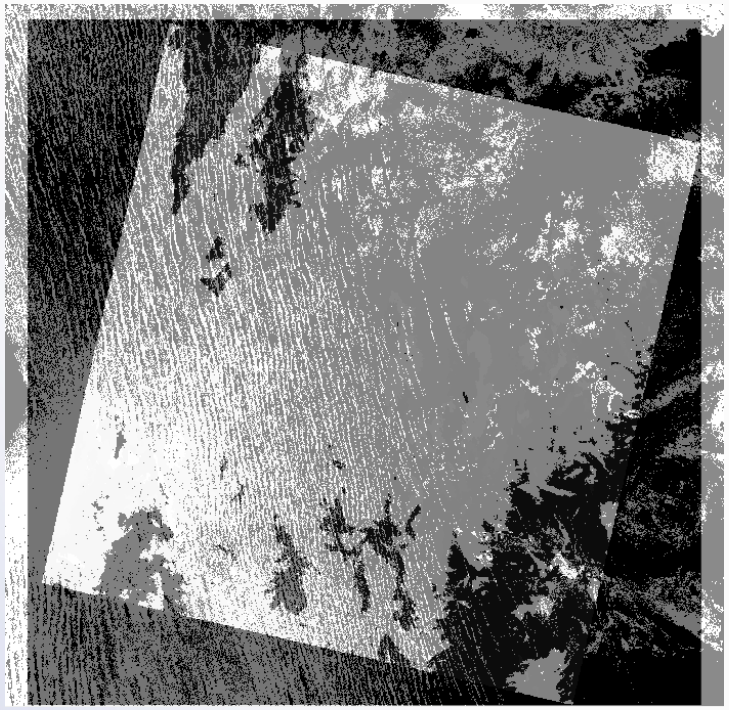
Resulting image of EPICS for WRS-2 Path 163/Row 45

The resulting binary image of EPICS – global is later used to mask the corresponding Landsat 8 image.

Filtering Process Using the BQA Data



Landsat 8 image

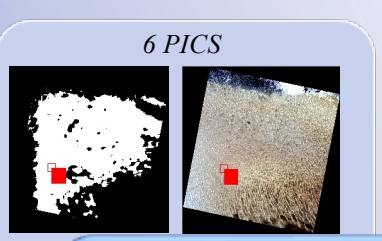


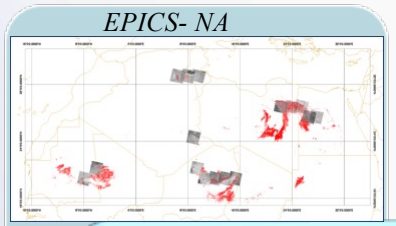
Cloud free Binary mask intersecting EPICS global

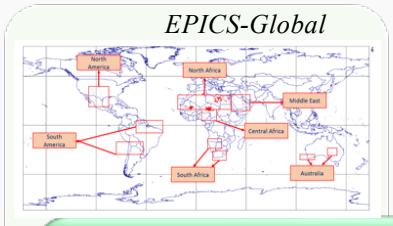
If 50% or more of the pixels intersecting EPICS global have presence of clouds, the image is rejected for further analysis

Techniques using continental and global EPICS

Satellite Calibration and stability monitoring Methodology







L7, L8, L9, S2A, S2B

Data up to Mar 2022

PICS
- **Trending Analysis**
  - ***Libya1, Libya4,***
  - ***Niger1, Niger2,***
  - ***Egypt1, Sudan1***

L8 vs L9
5 months on orbit

EPICS-NA
Trending Analysis
- **ExPAC Double Ratio**
- **Cross Cal**
- **Trend to Trend**

EPICS-Global
Trending Analysis
- **Cross Cal**
- **Trend to Trend**

Temporal Res:

1 point Every 16 days
(1 WRS-2 Path/row)

1 point every 2-3 days
(16 WRS-2 Path/row)

2-3 points daily
(33 WRS-2 Path/row)

Trending Analysis Process

Data Processing

- TOA Reflectance, data until May 2022
- EPICS-NA, EPICS-Global & 6 PICS (L1,L4,N1,N2,E1,S1)
- L7, L8, L9, S2A and S2B

BRDF Normalization

- 4 Angle BRDF Model, Spherical to Cartesian coordinates

$$x_1 = \sin(SZA) * \sin(SAA)\ ;\ y_1 = \sin(SZA) * \cos(SAA),$$
$$x_2 = \sin(VZA) * \sin(VAA)\ ;\ y_2 = \sin(VZA) * \cos(VAA),$$

- BRDF Normalization

$$Reflectance = \beta_0 + \beta_1 y_1^2 + \beta_2 x_1^2 + \beta_3 y_2^2 + \beta_4 x_2^2 + \beta_5 x_1 y_1 + \beta_6 x_1 y_2 + \beta_7 x_2 y_2 + \beta_8 x_2 y_1 + \beta_9 y_1 y_2 + \beta_{10} x_1 x_2 + \beta_{11} x_1 + \beta_{12} y_1 + \beta_{13} x_2 + \beta_{14} y_2$$

Trending Analysis

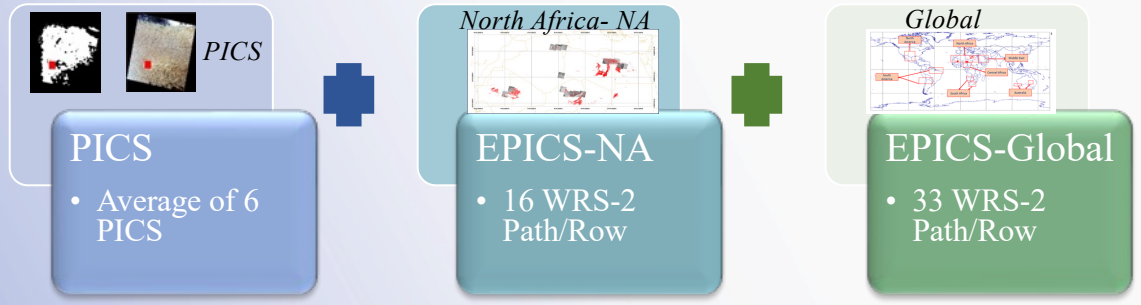
- Linear fit with Uncertainties (Monte Carlo Simulation): Spatial Standard deviation and Satellite Calibration Uncertainty
- Determine Drift per year
  - 6 PICS results and Weighted Average
  - EPICS-NA, EPICS-Global

Trending Analysis Results

L7, L8, L9, S2A, S2B

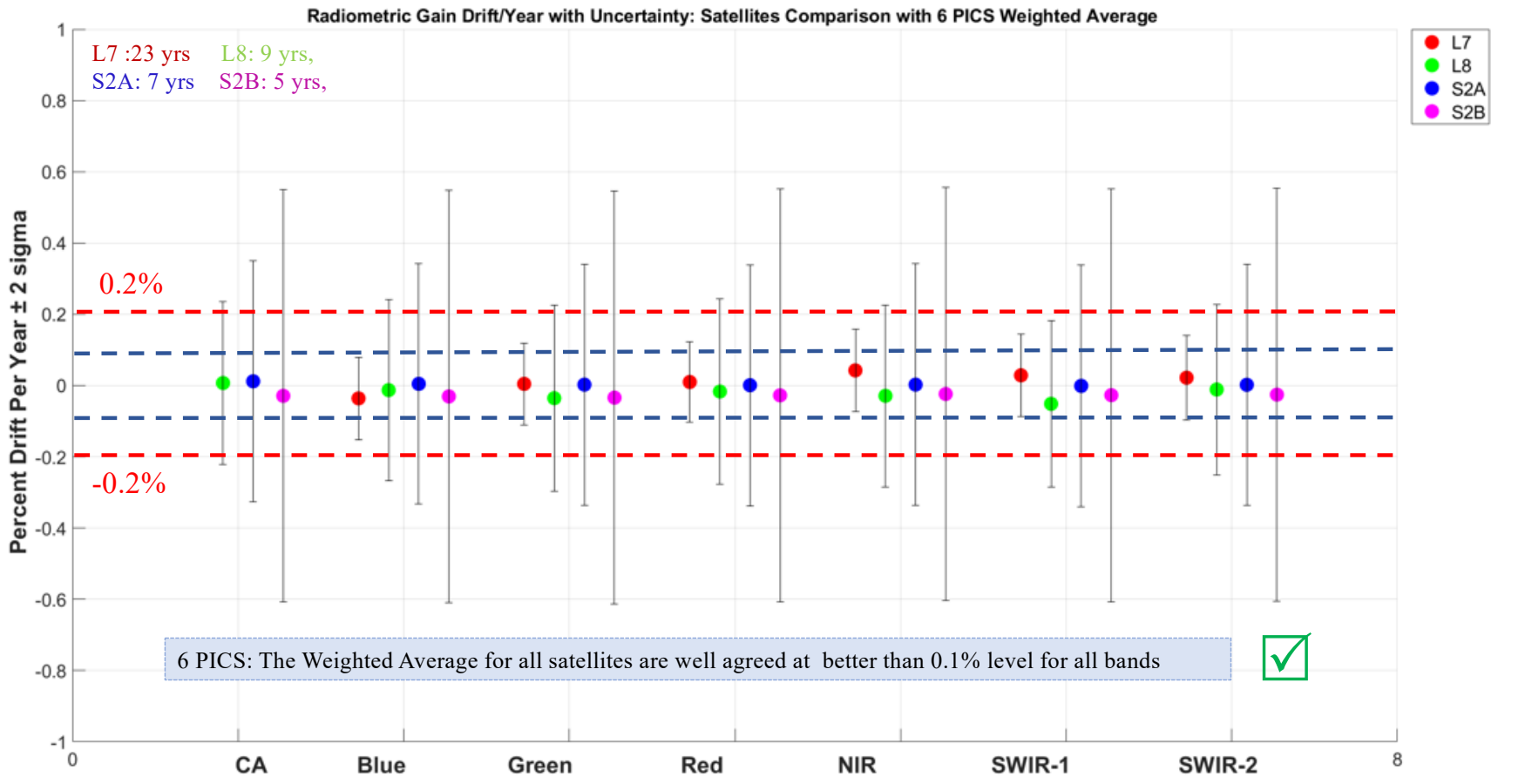
Results from each target:

E1, L1, L4, N1, N2, S1, W. Average, EPICS-NA, EPICS-Global



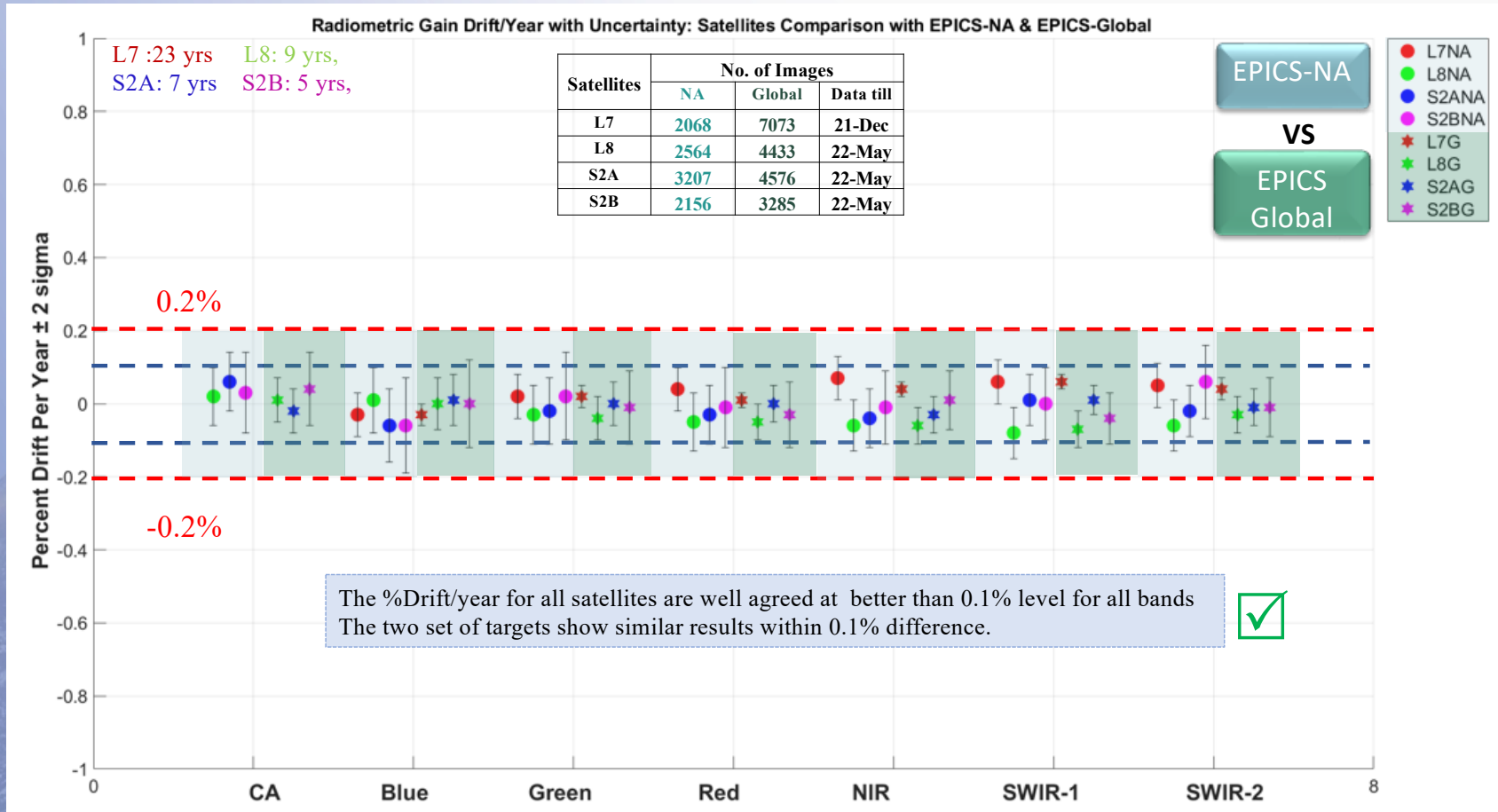
Trending Analysis

6 PICS Weighted Average



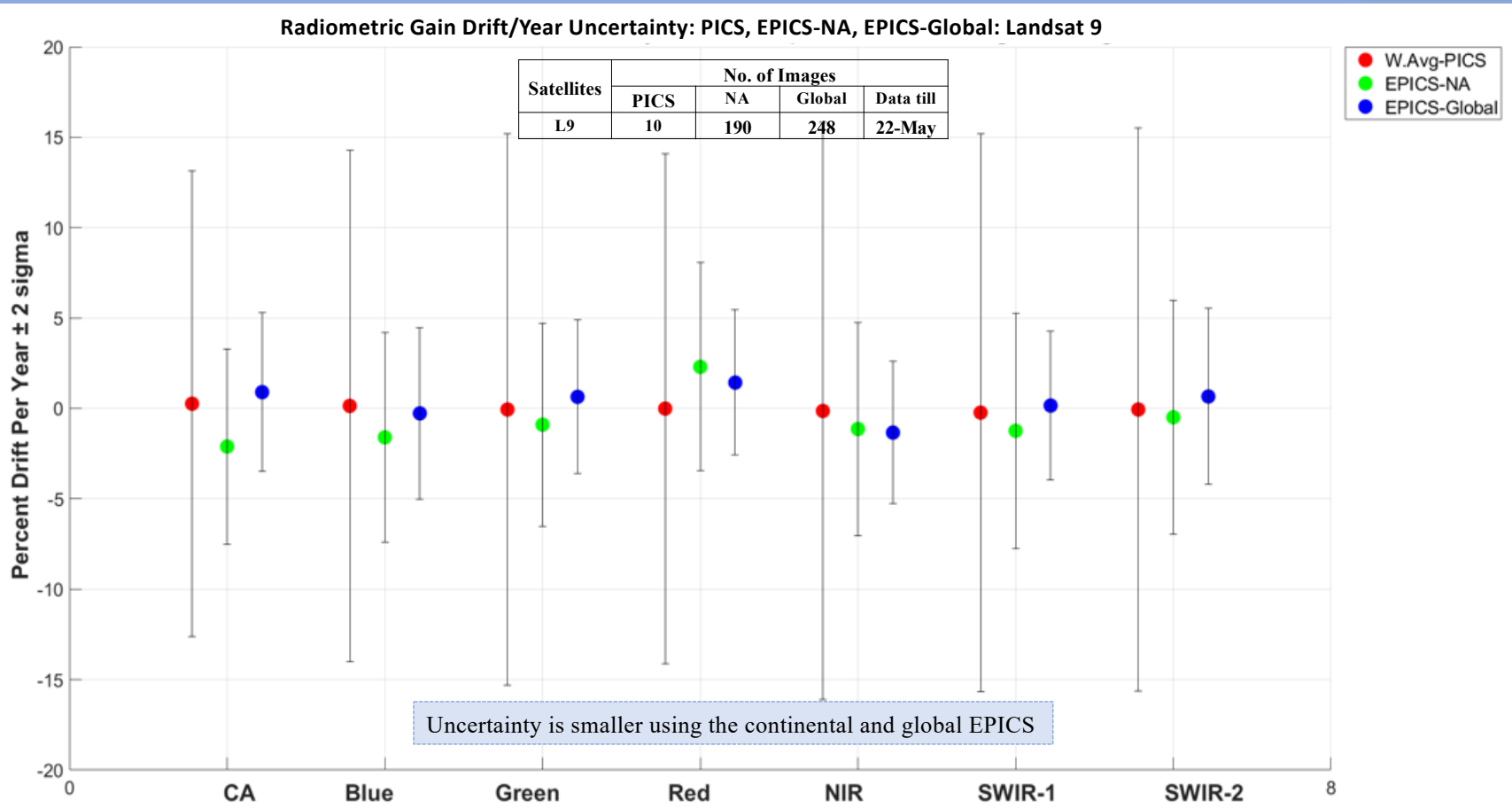
Trending Analysis

EPICS-NA vs EPICS GLOBAL



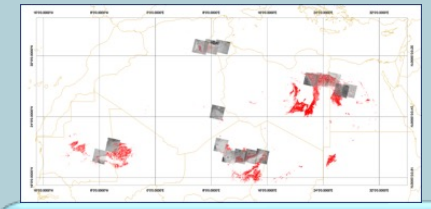
Trending Analysis – Landsat 9 (5months)

EPICS-NA vs EPICS GLOBAL vs 6PICS



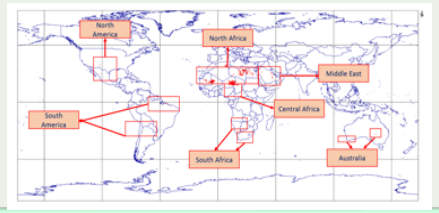
Stable Pixels: Extended PICS (**EPICS**) at Global Scale

Satellite Calibration Methodology



EPICS-NA (C13-NA)

- **ExPAC Double Ratio**
- **Trend to Trend**



EPICS-Global (C13-Global)

- **Trend to Trend**

L8 vs L9
5 months in orbit

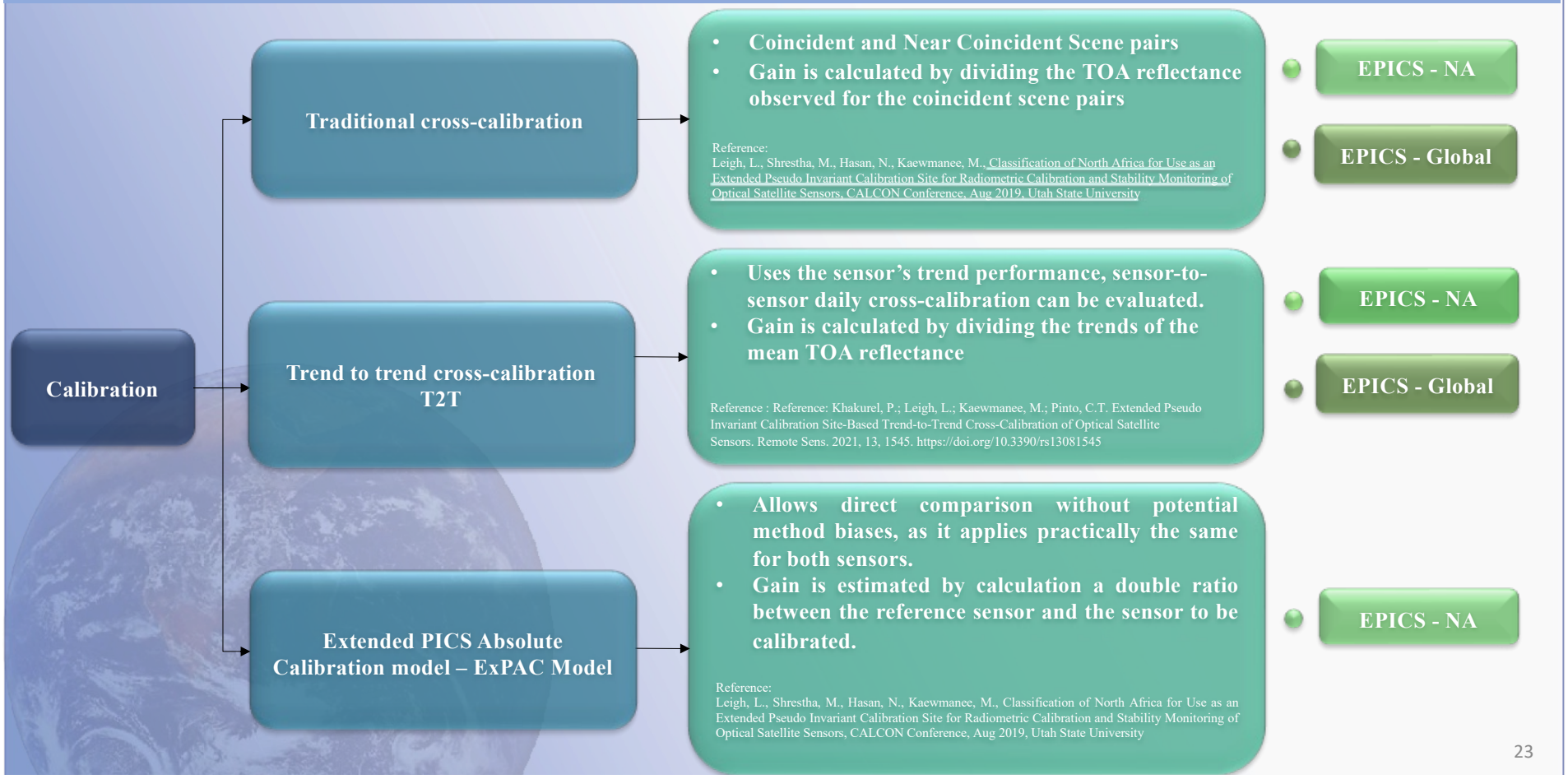
1 point every 2-3 days

2-3 points daily

Evaluation Landsat 9 vs Landsat 8 during OIV

Stable Pixels: Extended PICS (**EPICS**) at Global Scale

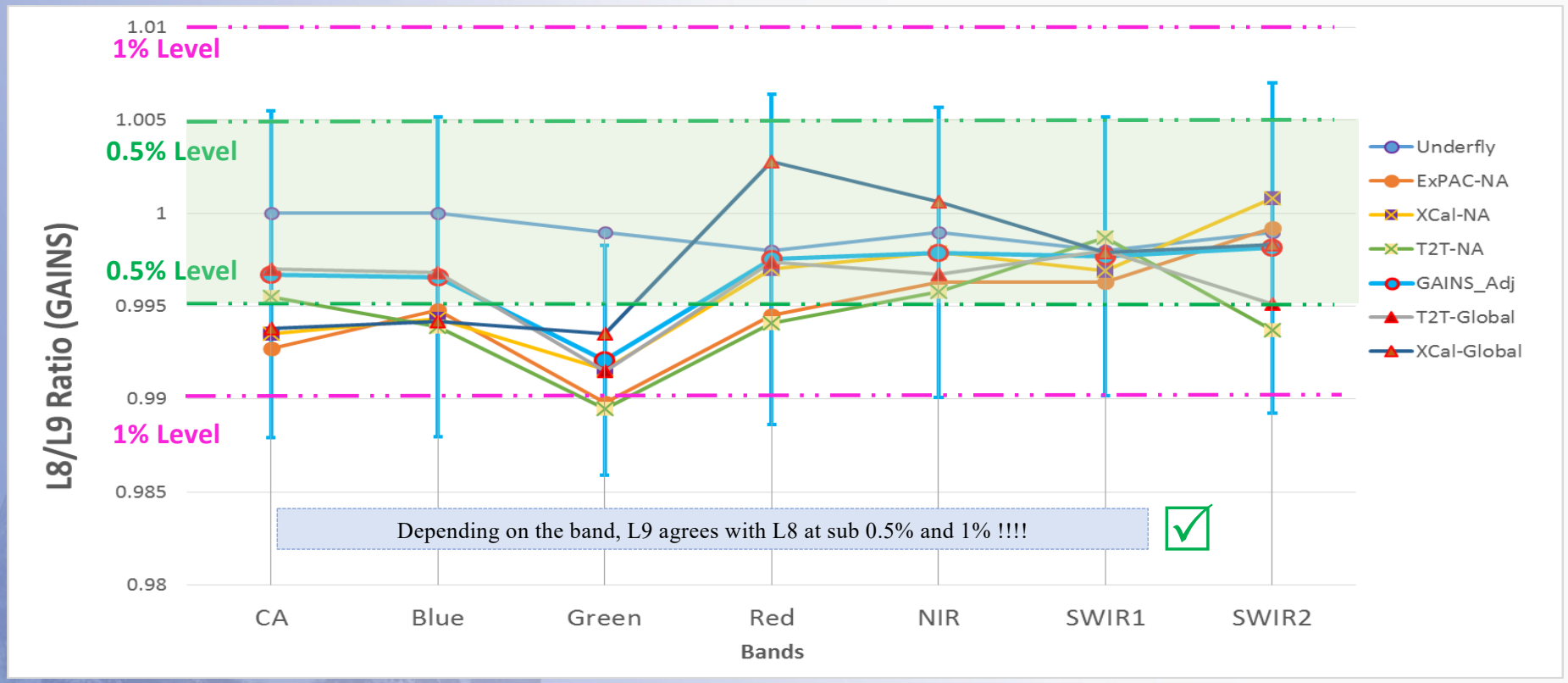
Satellite Calibration Methodology



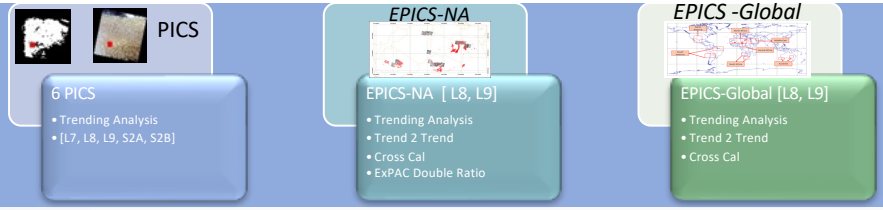
Summary L8/L9 Ratio (Gains) & SDSU Gain Estimated

L8/L9

All techniques combined



Conclusions



- Utilizing EPICS allows satellite calibration analysis to be performed with large datasets in short period of time: ***at least 1 data point per day***
  - Provide confidence in analysis
- Trending Analysis
  - Satellites [L7, L8, L9, S2A & S2B] are performing well on orbit and stable with degradation better than 0.1% per year for all bands,
  - all targets [6 PICS, EPICS-NA, EPICS-Global] confirmed same level of degradation better than 0.1%
- Cross Calibration: ExPAC Double Ratio, Traditional Cross Cal and Trend to Trend analysis
  - L8 and L9 are at sub 0.5% agreement for all bands except green band, which shows difference at ~1% level
  - 3 cross calibration methods give similar results with agreement well within 0.5%
- Newly developed techniques have provided consistent cross calibration results between Landsat 8 and Landsat 9
  - Applicable to all satellites taking advantage of stable pixels on a continental and global scale
  - Dense dataset for calibration on a daily basis

Thank you!

South Dakota State University
Image Processing Lab