South Dakota State University

L8-L9 OIV Cross Calibration

By

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South Dakota State University
Image Processing Lab

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Outline

- OIV Monitoring TOA Radiance and Reflectance *Gains : L8/L9*
  - ExPAC Double Ratio
  - Traditional Cross Cal Ratio
  - Trend to Trend Analysis (T2T)
  - Underfly
  - SDSU Gains Estimated
- Trending Analysis
  - L8 vs L9

Under fly / OIV approaches.....

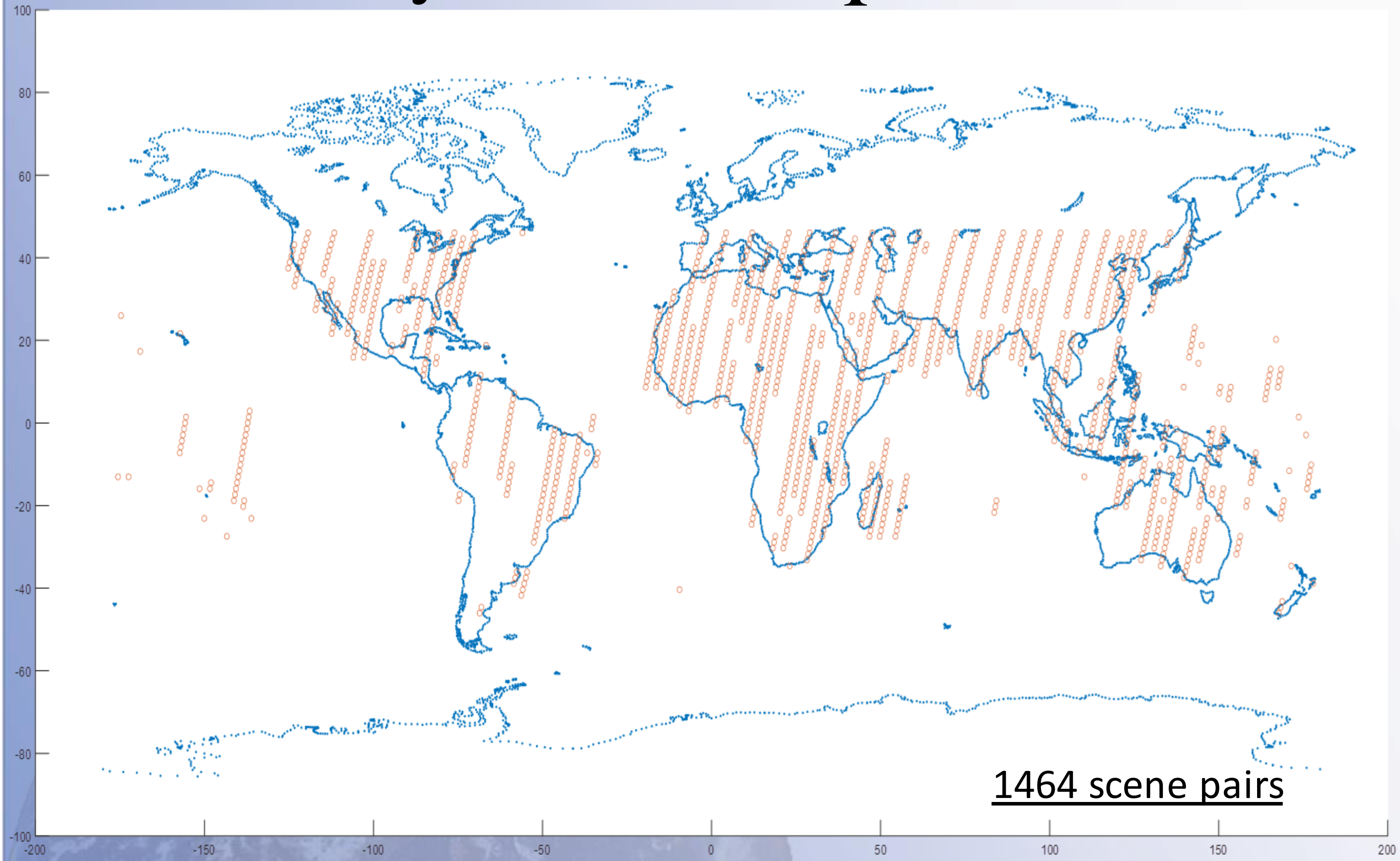
- Never want to rely on one method for calibration, so for the underfly and the greater OIV (On-orbit Initialization and Verification) the team investigated calibration accuracy using the following methods.
  - Underfly: Global
    - ❖ Several land cover types as calibration targets during 3 days acquisition with 992 scenes used to assess the calibration ratio, estimated uncertainty 0.5-1%.
  - Double Extended PICS Absolute Calibration (ExPAC): North African Region
    - ❖ SDSU absolute calibration model developed to account for sensor spectral differences, BRDF, seasonality using North African desert sites, with calibration points every 2-3 days, estimated uncertainty is ~2%.
  - Traditional Extended PICS Cross Calibration: North African Region
    - ❖ Using traditional cross calibration method over large area in North African deserts (Cluster13-19C) , with calibration points every 2-3 days, estimated uncertainty is ~2%.
  - Trend to Trend Global EPICS: Global
    - ❖ Utilizing Global EPICS (Cluster 13-300C) for cross calibration (2 or more points per day) by calculating trend of response of Landsat through time series analysis, Gains are calculated between two sensors, uncertainty level ~2-3%

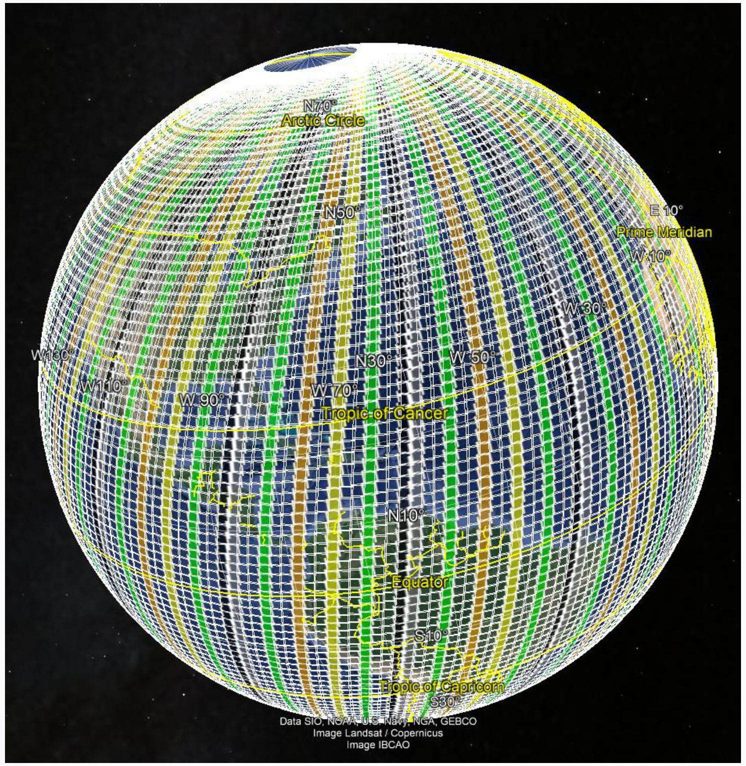
Data & Methodology

- Data from OIV period was used, in real time, to assess performance.
  - OIV time period: Nov 2, 2021 – Mar 31, 2022
  - Underfly time period: Nov 12, 2021 – Nov 17 2021

- Data for all methods are chosen using an in-house 30x30 meter pixel global classification.
  - Method uses the archive of Landsat 8 globally/regionally to identify stable pixels, and to spectrally classify those into up to 500 classes.

Underfly Data Acquisition:





13 Nov 2021 14-15 Nov 2021 16 Nov 2021

All locations for which the two both collected during the underfly where captured and analysis for this process, during the 4 days of “most coincident collect”

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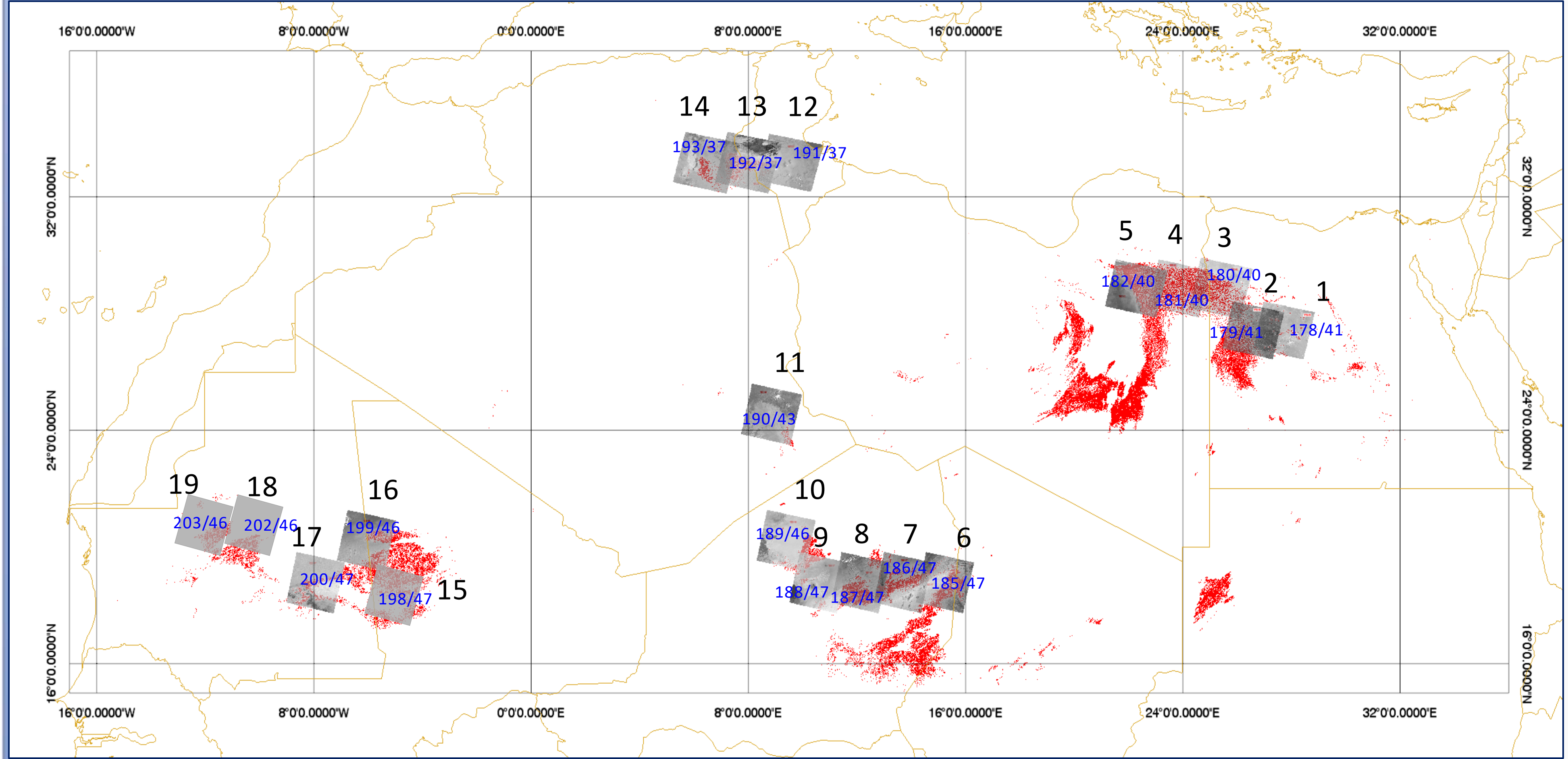
Cluster13 Northern African Region : C13-19 - 19 Path/Row



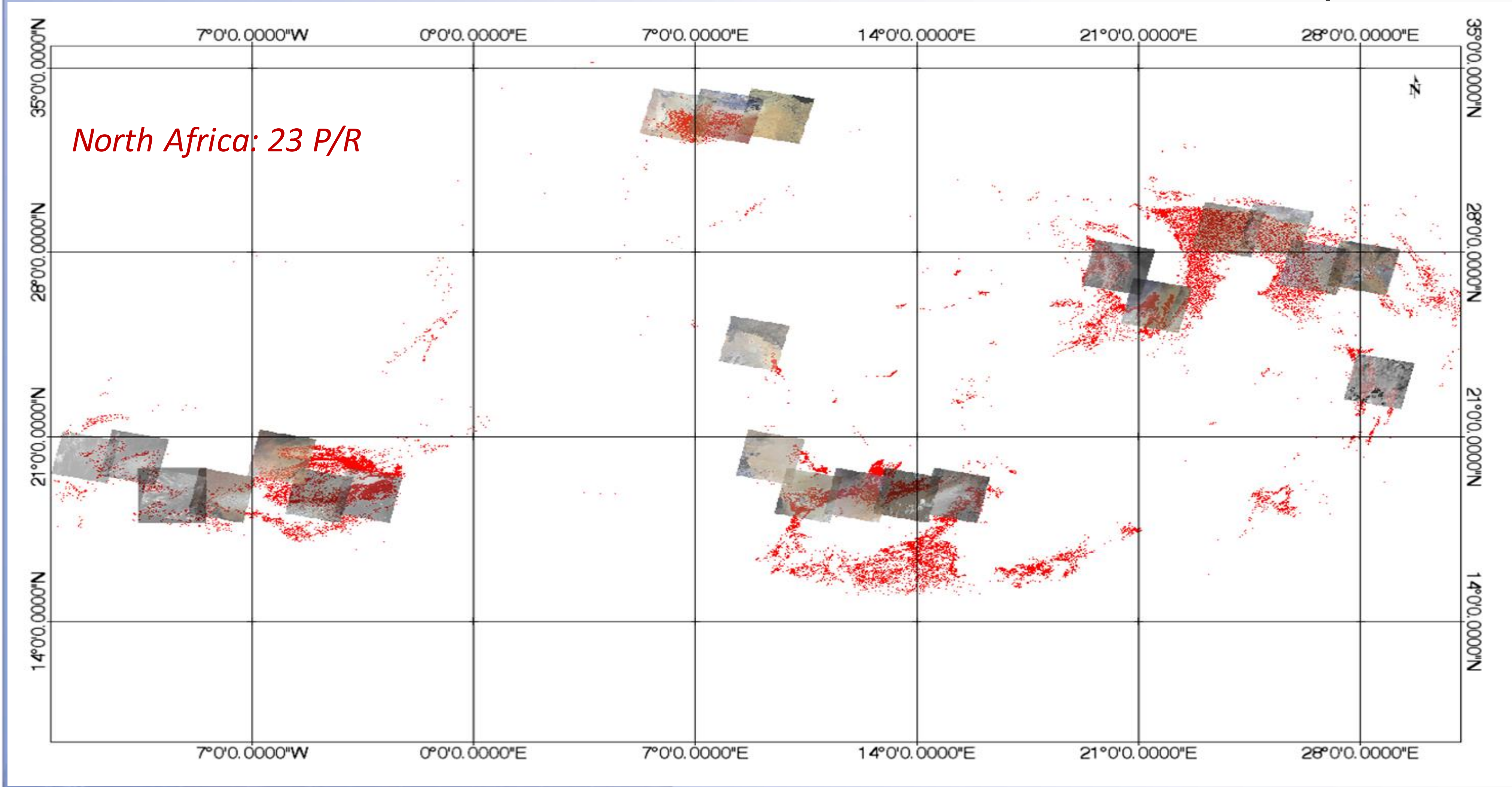
The red regions represent a single class determined to be a single spectral type (specific kind of sand in this case), that is determined to be invariant. (referred to be “cluster 13”)

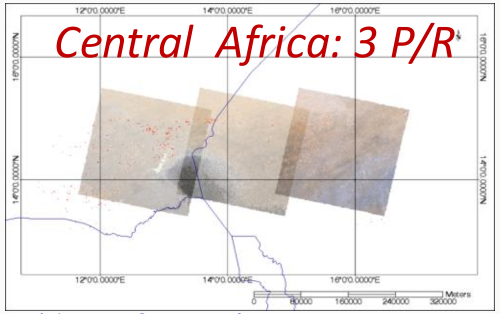
All data marked as cloud free for the period of the OIV was used for the **Double EXPAC, Traditional Cross Calibration** and **Trending**.

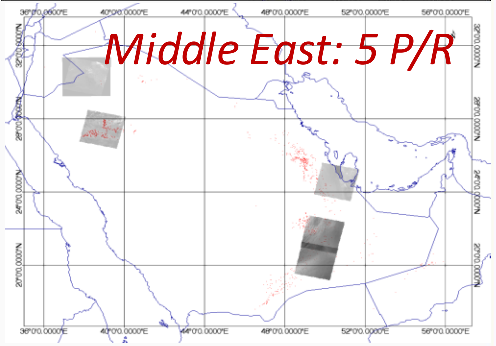
References

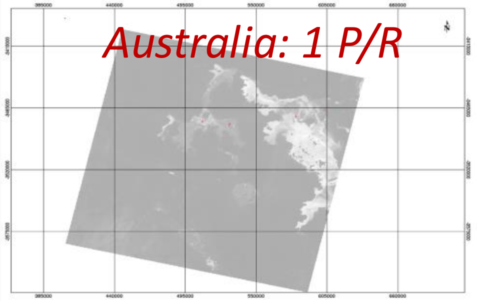
1. Classification of North Africa for Use as an Extended Pseudo Invariant Calibration Sites (EPICS) for Radiometric Calibration and Stability Monitoring of Optical Satellite Sensors, M Shrestha, L Leigh, D Helder - Remote Sensing, 2019
2. Evaluation of an Extended PICS (EPICS) for Calibration and Stability Monitoring of Optical Satellite Sensors MN Hasan, M Shrestha, L Leigh, D Helder - Remote Sensing, 2019

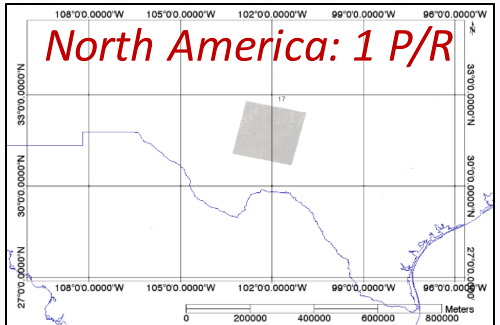
Cluster13 Global Classification: C13-300 – 33 Path/Row











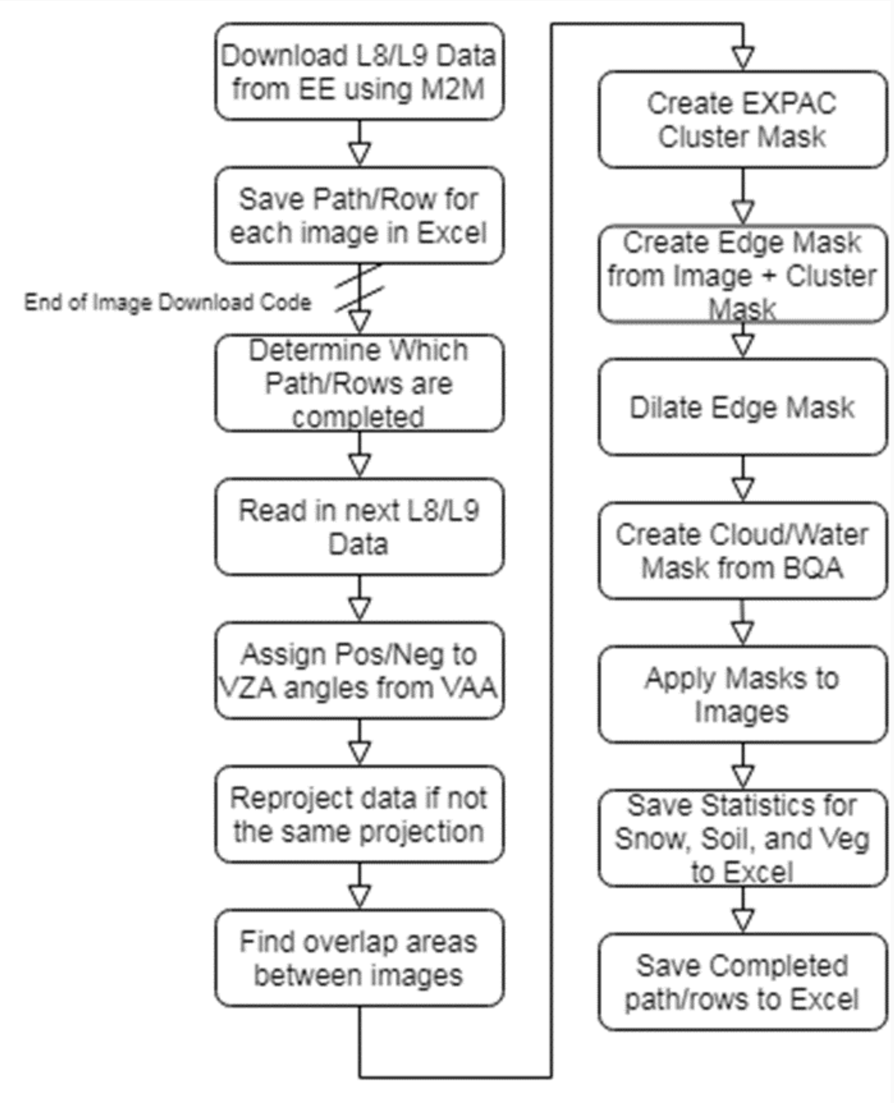
Extension of the previous method to include more "redundant paths" and locations identified as the same Class/Sand around the world, Used for Trend to Trend Approach.

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. - https://doi.org/10.3390/rs13173350

Cross Calibration Methods -Underfly

Details - Underfly

- Acquired all coincident Scenes (~1500 pairs) from the Underfly Dates Nov. 12 – Nov. 17
- After filtered, 992 Scene pairs
  - Goal of filtered: to use sites where impacts of SBAF and BRDF/Pointing uncertainties are reduced to sub 1% (goal is sub 0.5%)



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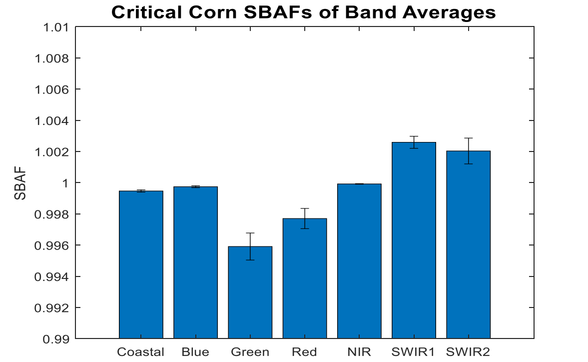
Details – Underfly: Uncertainty Analysis

- **Spectral Band Adjustment Factor** (SBAF) research showed the spectral differences between OLI and OLI-2 sensors at worst case were within tenths of a percent of each other, for the chosen cover types.
  - Easily stay within 1% error budget
- **Bidirectional Reflection Distribution Function** (BRDF) analysis showed that smaller view zenith angle differences (VZAD) between the sensors and larger sensor/sun azimuth angle differences (VAAD) resulted in less the BRDF uncertainty.
- **Pointing Error** at 1 pixel offset was small due to homogenous region selection and edge masks.
  - L1T images ~10m RMSE
  - Error is far less than 1%

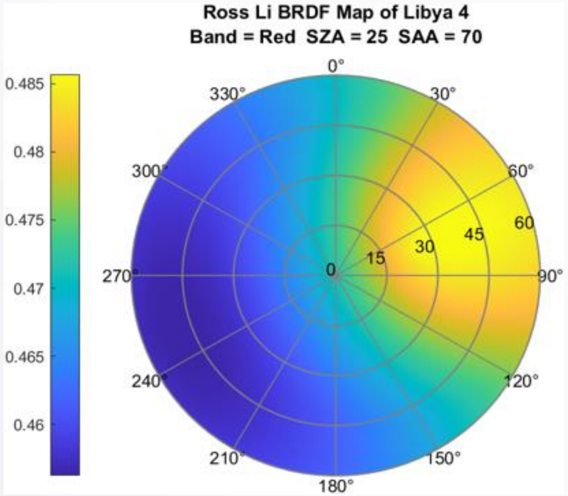
IGBP 16	v4					v5					v6				
VAA	100	105	110	115	120	100	105	110	115	120	100	105	110	115	120
Red	±5	±4	±3	±3	±2	±1	±1	±1	±1	±1	0	0	0	0	0
NIR	±4	±3	±3	±2	±2	±1	±1	±1	0	0	0	0	0	0	0
Blue	±5	±4	±3	±3	±2	±1	±1	±1	±1	±1	0	0	0	0	0
Green	±5	±4	±3	±3	±2	±1	±1	±1	±1	±1	0	0	0	0	0
SWIR1	±4	±3	±3	±2	±2	±1	±1	±1	±1	0	0	0	0	0	0
SWIR2	±5	±4	±3	±3	±2	±1	±1	±1	±1	0	0	0	0	0	0

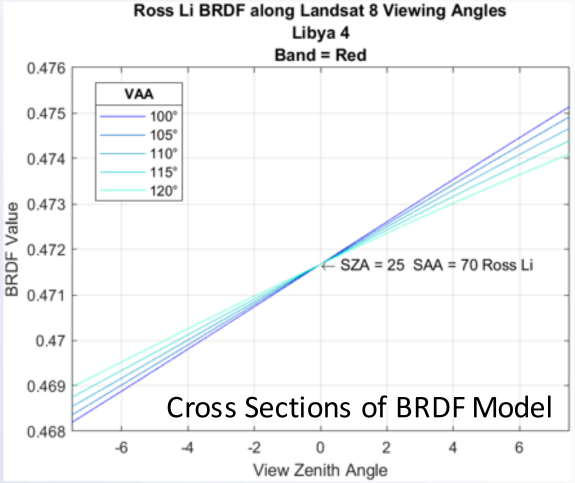
IGBP Location have various impacts on uncertainty, we choose to keep sub 1%



L8/L9 SBAFs for Critical Stage Corn Crop

As an example "not knowing" the SBAF for corn would have sub 0.2% impact for all bands except green which has ~0.5%





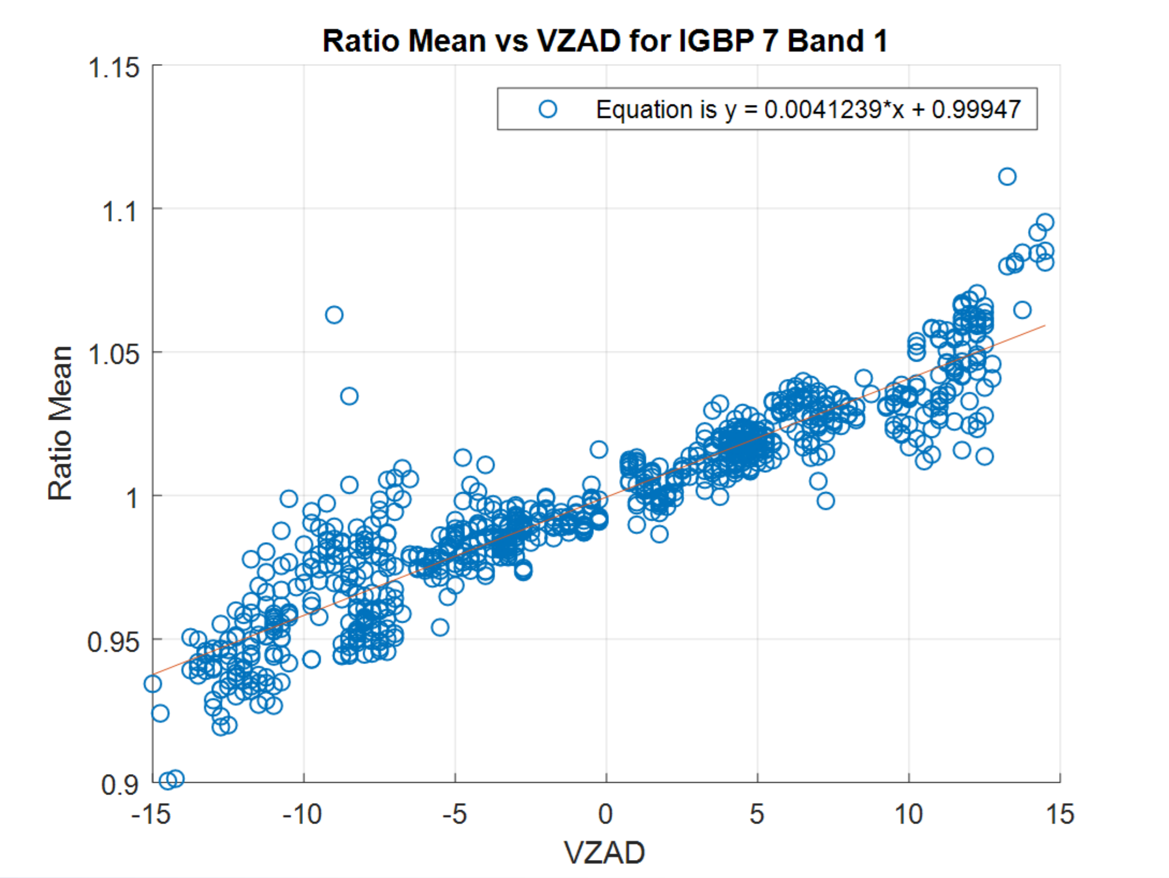
Cross Sections of BRDF Model

Looking at BRDF, the effects for "small angles" are linear and minimized for the geometries seen during underfly if hotspots geometries are avoided.

Filtered data to avoid

Details – Underfly: Acquiring Cross Cal. Values

- Main cause of differences between cross cal. values was related to the View Zenith Angle relationship / BRDF (Which was predicted and expected)
- Best way to extract NADIR cross cal. Value was a mean vs View Zenith Angle Difference graph (VZAD)
- Acquire the intercept as the cross cal. Value
- Filtered out values with less than 5000 pixels / Scene.



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Cross Calibration Methods –Traditional Cross Calibration

Traditional Cross Calibration Methodology–

- All scene pairs acquired in a 7 day window over Extended PICS collected during OIV
- SBAF : Using ALL Hyperion data acquired over EPICS
  - Apply SBAF to L9 to match L8
- Apply BRDF Normalization
  - *Based on the 4 angles of solar and view geometry.*
- Reference Sat vs Satellite near co-incident pair *(many to one)*
  - *Compared to all images pairs in a 7 day window.*
- Cross Cal Ratio= (NormBRDF_Ref)/NormBRDF_Sat)
- Calculate Mean and Std. (Cross Cal Ratio)

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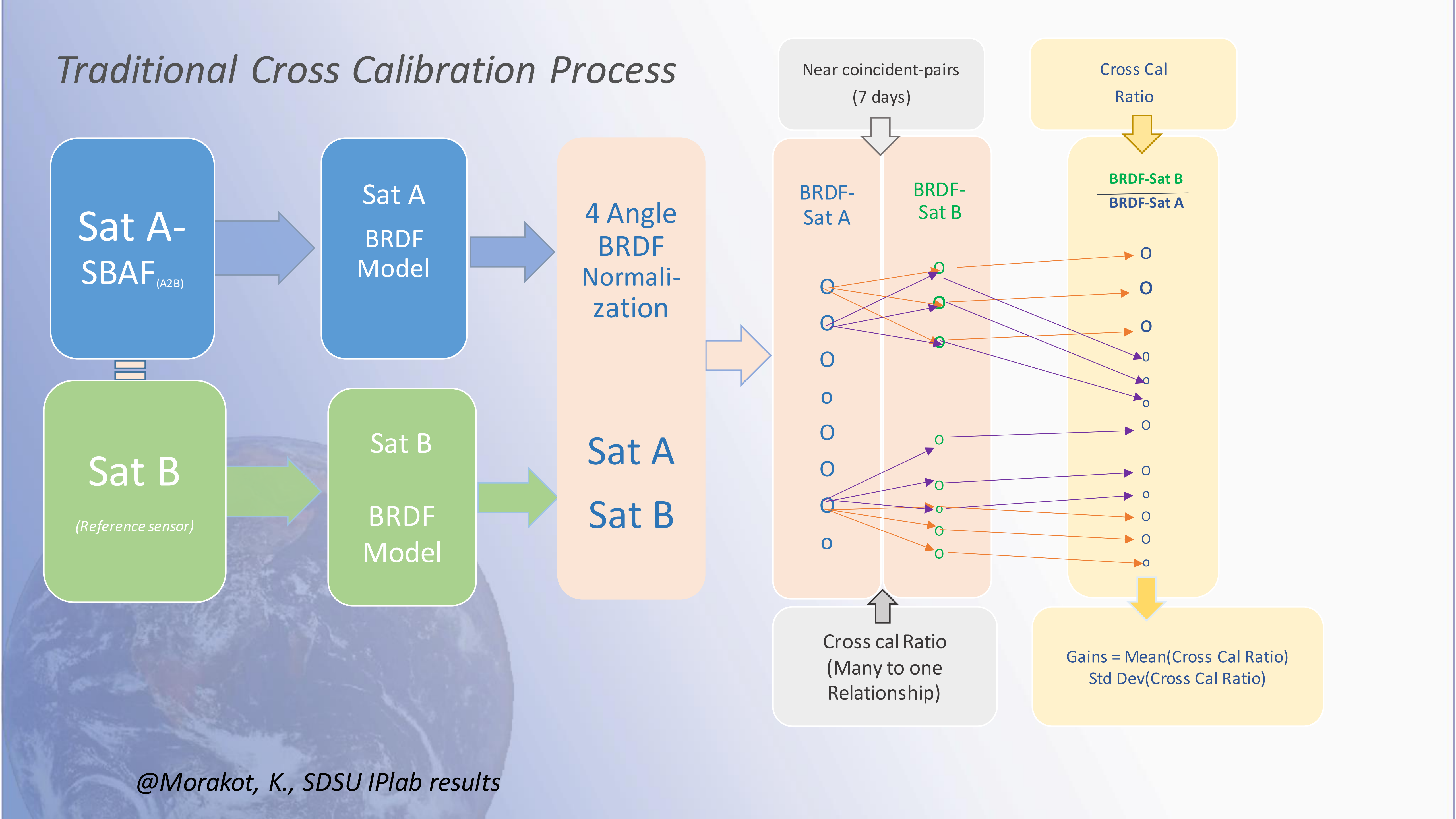
Traditional Cross Calibration Process
Sat A-SBAF(A2B)
Sat B
(Reference sensor)
Sat A BRDF Model
Sat B BRDF Model
4 Angle BRDF Normali-zation
Sat A
Sat B
Near coincident-pairs (7 days)
BRDF-Sat A
BRDF-Sat B
Cross cal Ratio (Many to one Relationship)
Cross Cal Ratio
BRDF-Sat B / BRDF-Sat A
Gains = Mean(Cross Cal Ratio)
Std Dev(Cross Cal Ratio)
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Cross Calibration Methods – Double EXPAC

ExPAC Model- C13-19C

$$\boldsymbol{\rho}_{C13}(\lambda, \boldsymbol{X_1}, \boldsymbol{Y_1}, \boldsymbol{X_2}, \boldsymbol{Y_2}) = \boldsymbol{B}(\lambda) * \rho_{\boldsymbol{h}}(\lambda) + \boldsymbol{X_1^2} * \boldsymbol{C_1}(\lambda) + \boldsymbol{Y_1^2} * \boldsymbol{C_2}(\lambda) + \boldsymbol{X_2^2} * \boldsymbol{C_3}(\lambda) + \boldsymbol{Y_2^2} * \boldsymbol{C_4}(\lambda) + \boldsymbol{X_1 X_2} * \boldsymbol{C_5}(\lambda) + \boldsymbol{Y_1 Y_2} * \boldsymbol{C_6}(\lambda)$$

$X_1 = \sin(SZA) * \sin(SAA)$; $Y_1 = \sin(SZA) * \cos(SAA)$,
$X_2 = \sin(VZA) * \sin(VAA)$; $Y_2 = \sin(VZA) * \cos(VAA)$,

where SZA = Solar Zenith Angle, SAA = Solar Azimuth Angle
VZA = Sensor Zenith Angle, VAA = Sensor Azimuth Angle

ExPAC BRDF Model: Angle Limitation
VZA +/- 0-30°
SZA range +/- 15-65°
VAA +/- (270-280° & 90-100°)
SAA +/- 80-165°

BRDF Intercept = $\boldsymbol{B}(\lambda) * \rho_{\boldsymbol{h}}(\lambda)$

- $\rho_h(\lambda)$ = The ExPAC C-13 Hyperspectral data ; derived from 6 days near coincident pairs (Hyperion-L8), SZA <35, and VZA <5 degrees (58 scenes)
- B(λ) = Hyperion Cross Scale factor, to place sensor's derived spectral profile to match L8 BRDF Intercept

$\boldsymbol{C_1(\lambda)}, \ldots \boldsymbol{C_6(\lambda)}$ = The ExPAC BRDF coefficients for X_1^2, Y_1^2, X_2^2, Y_2^2 , X_1X_2, $Y_1 Y_2$

The ExPAC model is a predictive model developed for the Cluster 13 region, built on extensive data from L8, Hyperion and Sentinel 2 A/B to predict the response of the region for a range of geometries and spectral regions.

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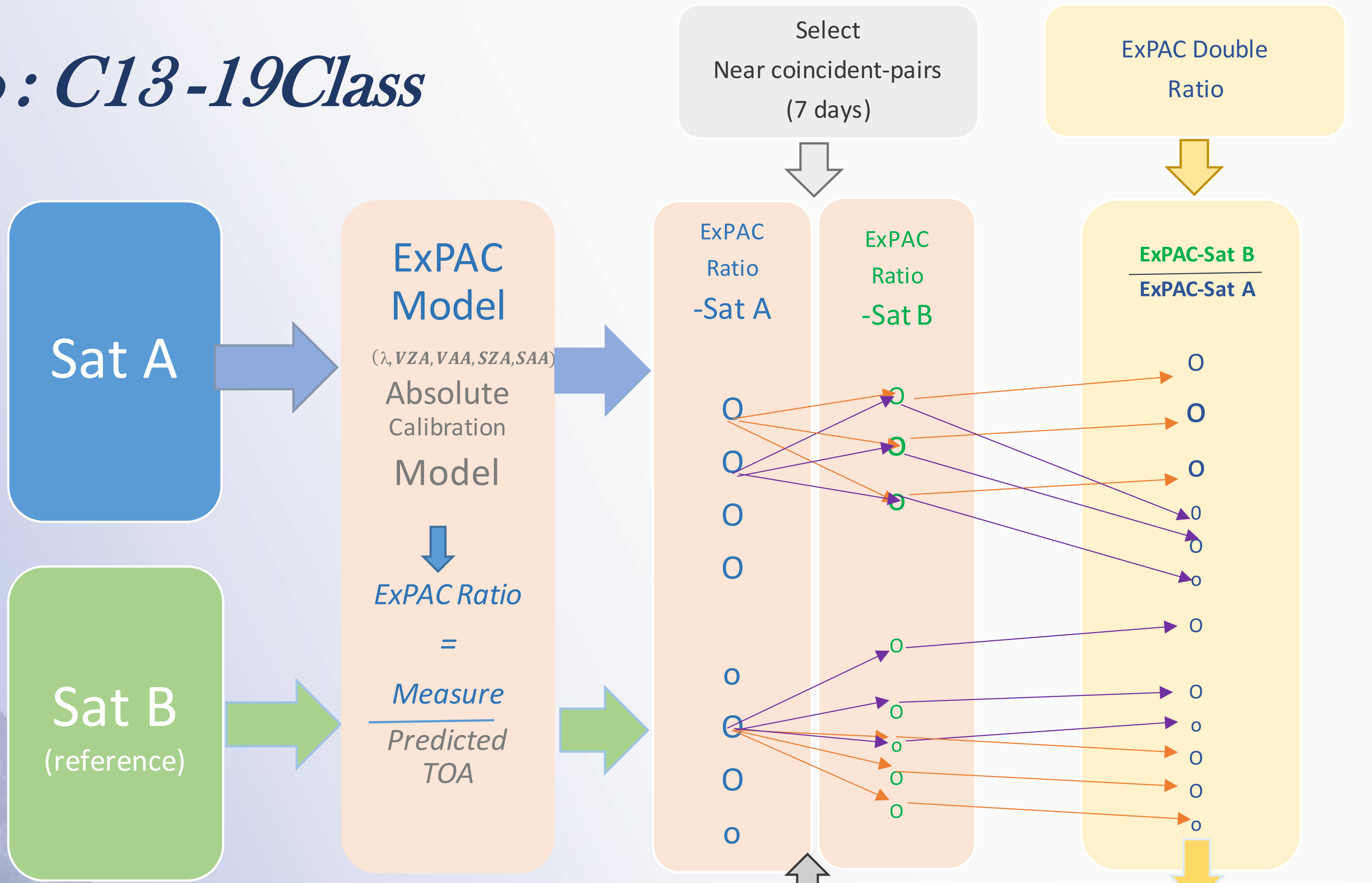
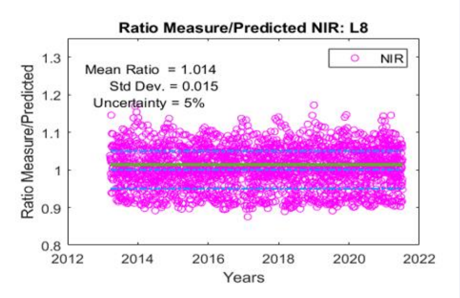
ExPAC Double Ratio : C13-19Class

ExPAC predictions are made for each near coincident pair, and rationed to the actual data. The ratios of each satellite is then ratio-ed to each other.

Doing this removes and potential bias in the EXPAC model, while removing the effects of BRDF and SBAF.





Double Ratio allows direct comparison without potential method biases, as it applies practically the same for both sensors.

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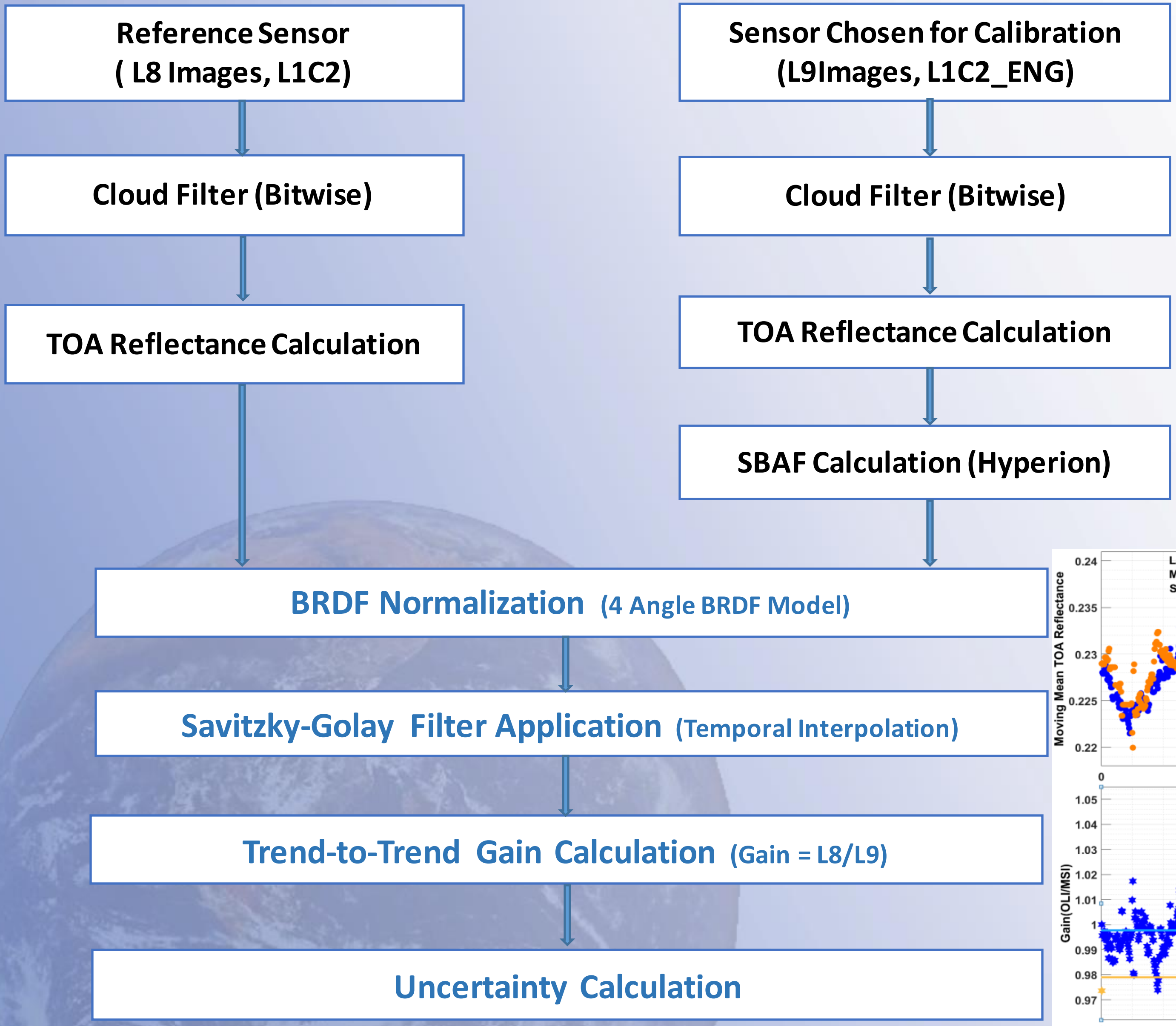
Cross Calibration Methods – Trend 2 Trend

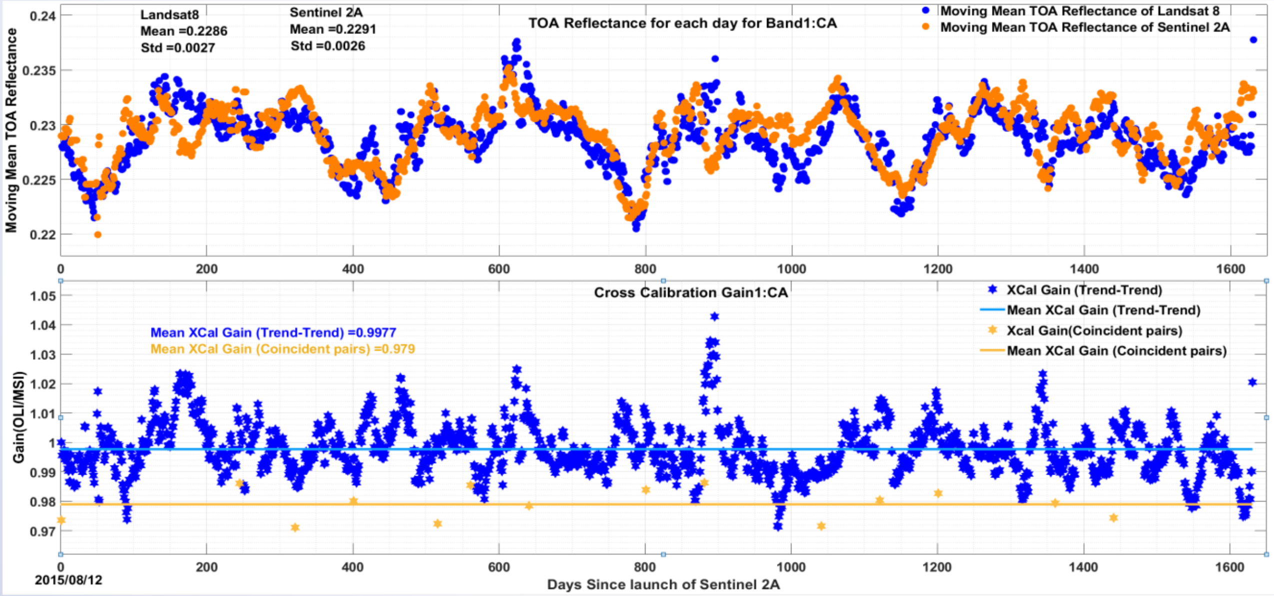
Trend to Trend Cross Calibration (T2T) with C13-300 Class



Trend to trend technique uses all data globally available over EPICS, filters clouds, corrects normalizes BRDF Effects, adjusts for SBAF and develops a daily trend.

This daily trend is ratio-ed with another daily trend for different sensor. Again reduces/removes biases in the process.

Also allows detection of real time change in Cross Calibration Gains.



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Cross Calibration Results: Reflectance

Underfly: Gains before and after reprocessing update

Cross Cal. Value Original vs Reprocessed

- Looking at the data acquired during the underfly, differences of as much as 5.6% was detected.
- After calibration adjustments implemented by USGS, difference dropped below a tenth of a percent.

	Original (CPF Update)		**Reprocessed**	
	Mean	±Sigma	Mean	±Sigma
CA	1.056	0.001	**1.000**	0.001
Blue	1.05	0.001	**1.002**	0.001
Green	1.04	0.003	**0.999**	0.002
Red	1.032	0.002	**1.001**	0.001
NIR	1.021	0.003	**1.001**	0.001
SWIR-1	0.994	0.001	**1.001**	0.002
SWIR-2	1.002	0.002	**1.001**	0.002

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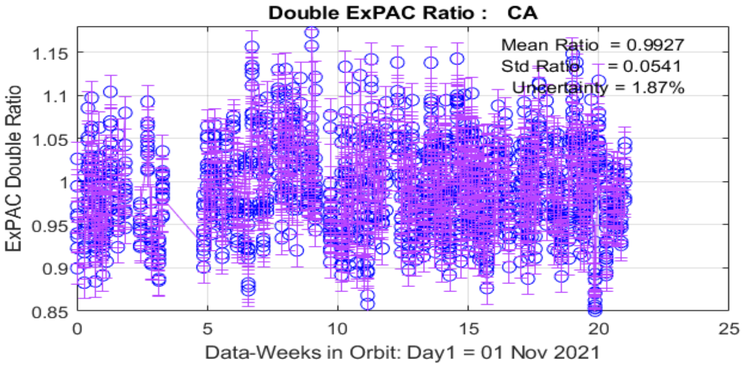
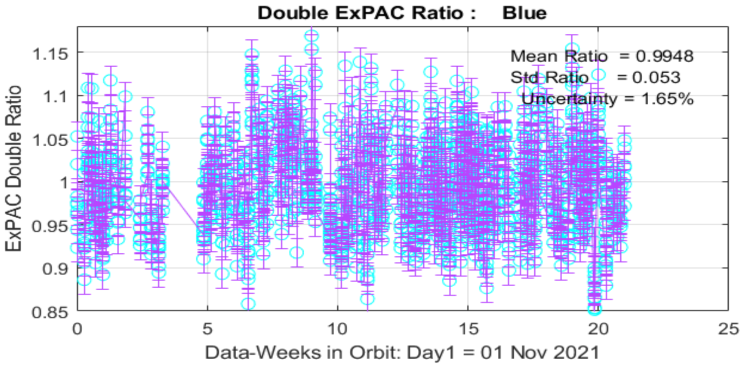
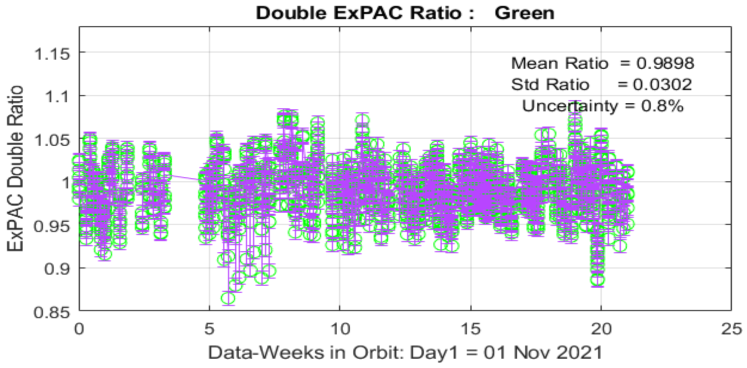
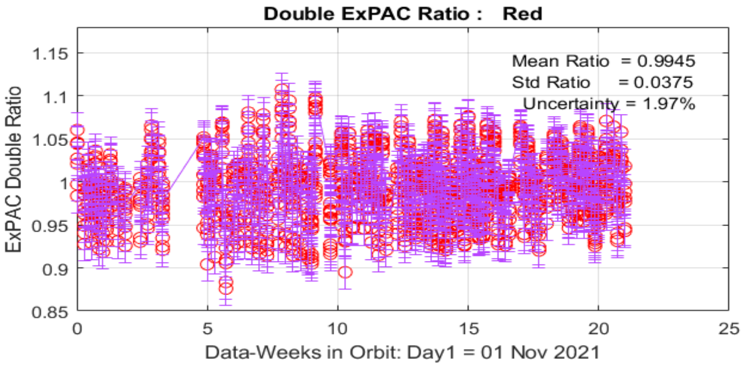
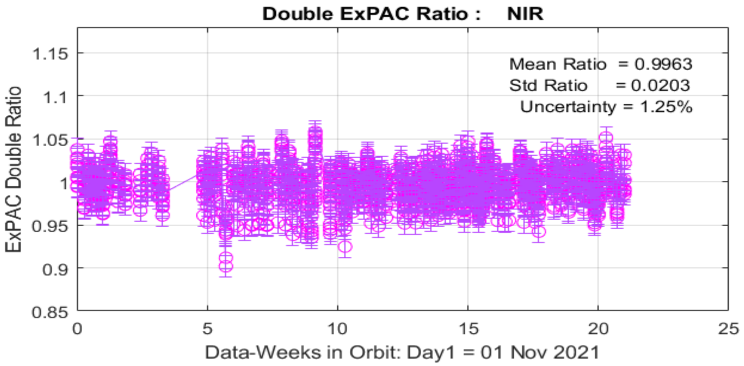
ExPAC Double Ratio L8/L9 results: After reprocessing Gains

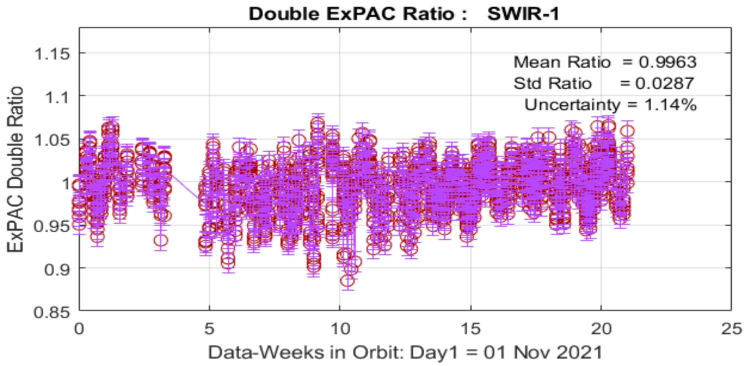


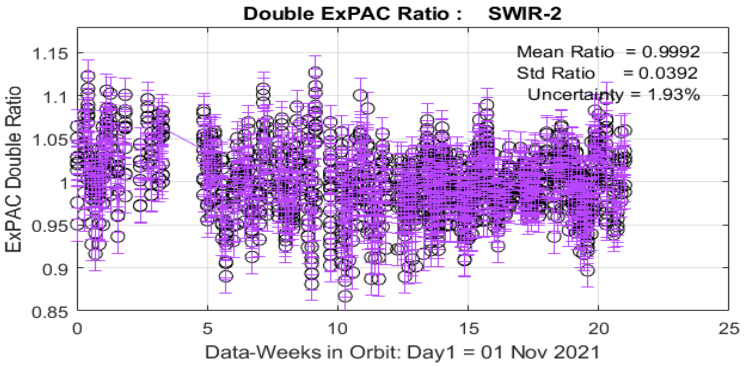












GAINS	CA	Blue	Green	Red	NIR	SWIR1	SWIR2
ExPAC_D	**0.9927**	**0.9948**	**0.9898**	**0.9945**	**0.9963**	**0.9963**	**0.9992**
Std.Dev	0.0541	0.0530	0.0302	0.0375	0.0203	0.0287	0.0392
Unc.%	1.87%	1.65%	0.80%	1.97%	1.25%	1.14%	1.93%

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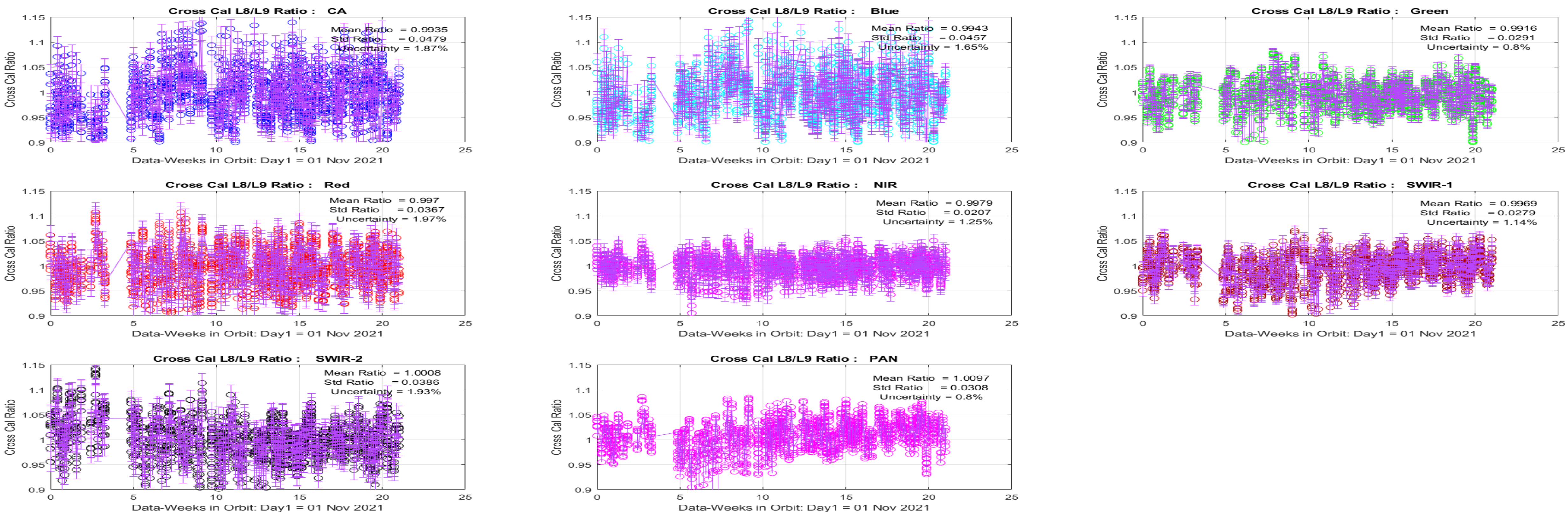
Traditional Cross Cal L8/L9 results



GAINS	CA	Blue	Green	Red	NIR	SWIR1	SWIR2	PAN
Cross Cal	**0.9935**	**0.9943**	**0.9916**	**0.9970**	**0.9979**	**0.9969**	**1.0008**	**1.0097**
Std.Dev	0.0479	0.0457	0.0291	0.0367	0.0207	0.0279	0.0386	0.0308
Unc.%	1.87%	1.65%	0.80%	1.97%	1.25%	1.14%	1.93%	0.008

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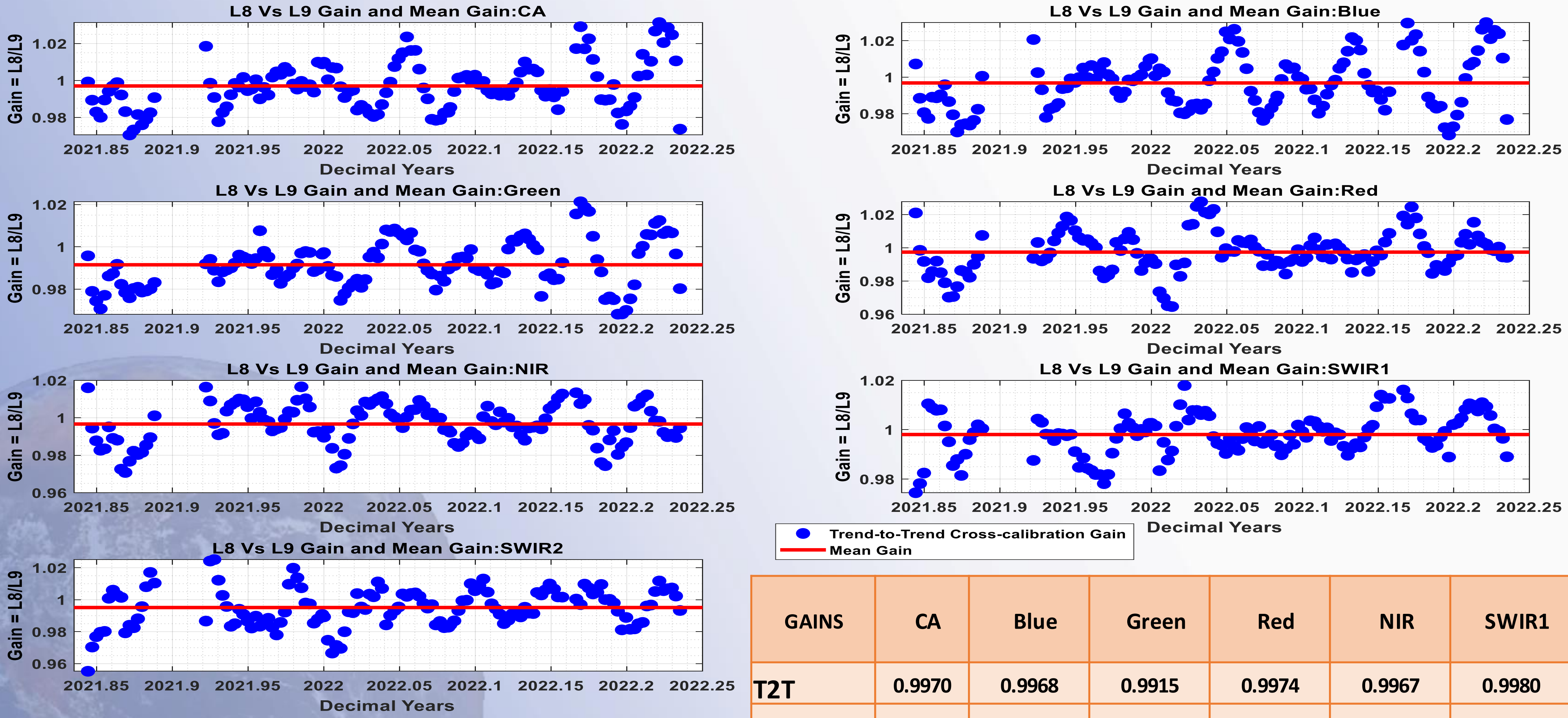
Trend 2 Trend Cross Calibration : C13 – 300 Class or Global EPICS



GAINS	CA	Blue	Green	Red	NIR	SWIR1	SWIR2
T2T	0.9970	0.9968	0.9915	0.9974	0.9967	0.9980	0.9951
Std.Dev	0.0128	0.0147	0.0110	0.0123	0.0103	0.0085	0.0120
Unc.%	2.01%	1.79%	0.87%	2.06%	1.88%	1.71%	1.56%

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Summary: TOA Reflectance Gains Monitoring

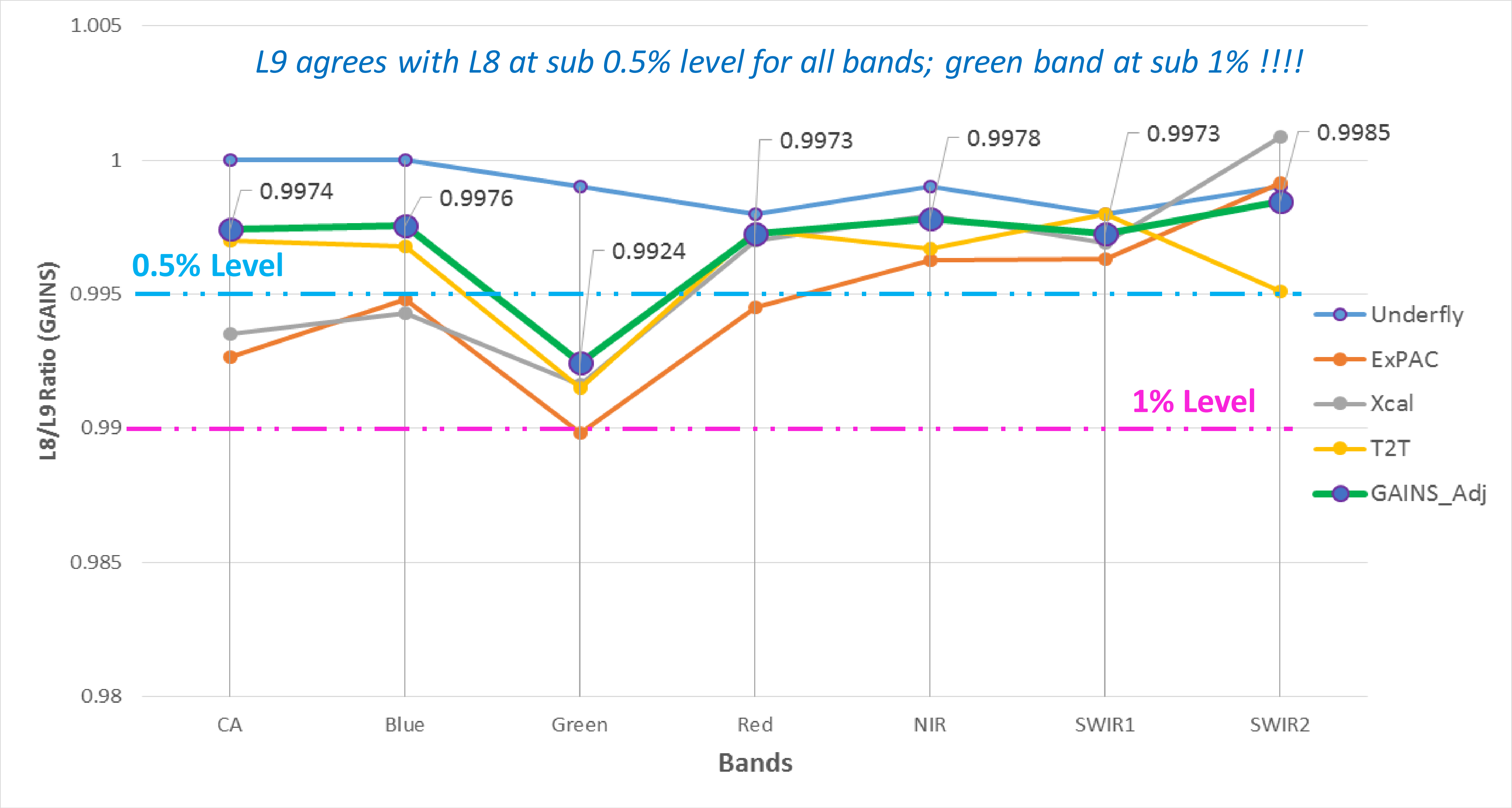
- Estimating Uncertainty Combining different measurements of the same quantity
  - Best estimate = weighted mean
  - $Gain\_estimate = \frac{\sum_{i=1}^{n} G_i \cdot (\frac{1}{\partial G_i})^2}{\sum_{i=1}^{n} (\frac{1}{\partial G_i})^2}$
  - $Uncertainty\_estimate = \sqrt{\frac{1}{\sum_{i=1}^{n} (\frac{1}{\partial G_i})^2}}$

Where G_i = Gain from each technique
∂G_i = uncertainty from each technique

SDSU_GAINS	CA	Blue	Green	Red	NIR	SWIR1	SWIR2	PAN
Underfly	**1.000**	**1.000**	**0.999**	**0.998**	**0.999**	**0.998**	**0.999**	**1.000**
Std.Dev	0.000	0.001	0.002	0.001	0.001	0.002	0.002	0.005
Unc.%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.00%
ExPAC_D	**0.9927**	**0.9948**	**0.9898**	**0.9945**	**0.9963**	**0.9963**	**0.9992**	
Std.Dev	0.0541	0.0530	0.0302	0.0375	0.0203	0.0287	0.0392	
Unc.%	1.87%	1.65%	0.80%	1.97%	1.25%	1.14%	1.93%	
Cross cal	**0.9935**	**0.9943**	**0.9916**	**0.9970**	**0.9979**	**0.9969**	**1.0008**	**1.0097**
Std.Dev	0.0479	0.0457	0.0291	0.0367	0.0207	0.0279	0.0386	0.0308
Unc.%	1.87%	1.65%	0.80%	1.97%	1.25%	1.14%	1.93%	0.008
T2T	**0.9970**	**0.9968**	**0.9915**	**0.9974**	**0.9967**	**0.9980**	**0.9951**	
Std.Dev	0.0128	0.0147	0.0110	0.0123	0.0103	0.0085	0.0120	
Unc.%	2.01%	1.79%	0.87%	2.06%	1.88%	1.71%	1.56%	
GAINS_Est	**0.997**	**0.998**	**0.992**	**0.997**	**0.998**	**0.997**	**0.998**	**1.008**
Unc_Est	**0.74%**	**0.70%**	**0.43%**	**0.76%**	**0.62%**	**0.59%**	**0.72%**	**0.43%**

L9 agrees with L8 at 0.2-0.8% level

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



Cross Calibration Results: Radiance
Methods: Underfly, Traditional Cross Cal

Underfly: Reprocessed data after CPF update

- Radiance calibration tended to be closer then the reflectance calibration during OIV, with difference as large as ~2% being detected.

- After calibration update, difference ~1% or better.

	Reprocessed Underfly		Original Underfly	
	Mean	±Sigma	Mean	±Sigma
CA	**1.000**	0.000	1.0198	0.0007
Blue	**1.000**	0.001	1.0003	0.0006
Green	**0.999**	0.001	0.9885	0.0025
Red	**0.998**	0.002	1.0033	0.0014
NIR	**0.999**	0.002	1.0268	0.0020
SWIR-1	**0.991**	0.002	0.9976	0.0041
SWIR-2	**0.989**	0.003	1.004	0.0061
TIRS-1	**0.997**	0.009	0.932	0.009
TIRS-2	**1.008**	0.008	0.954	0.008

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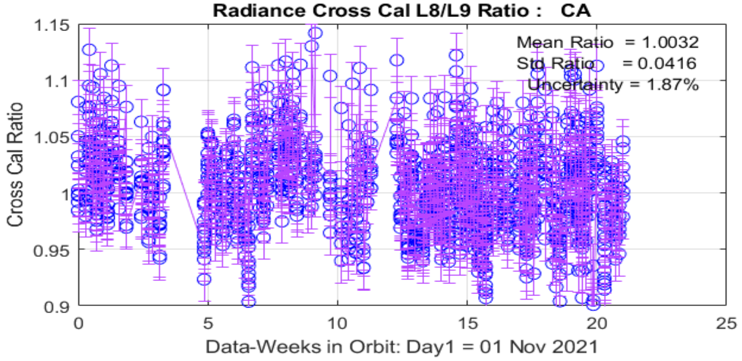
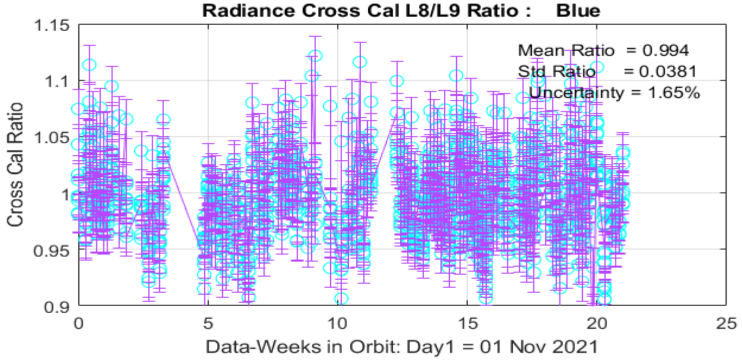
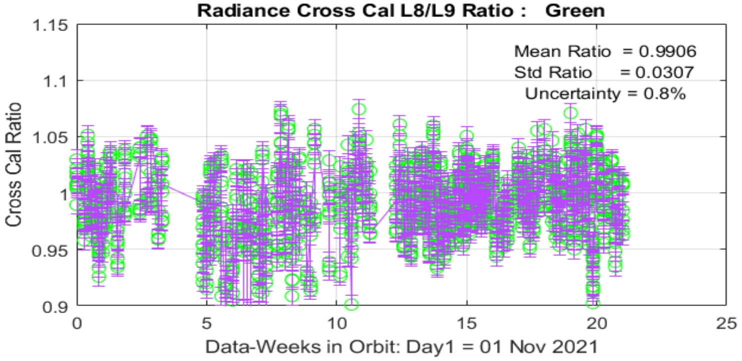
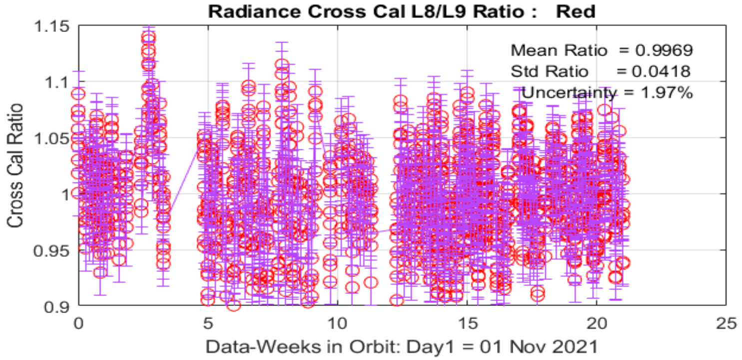
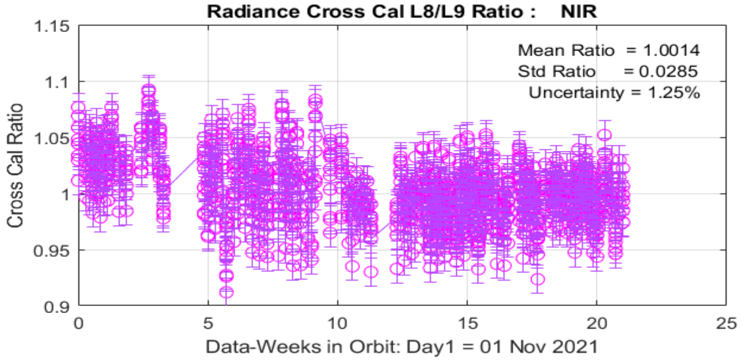
Traditional Cross Cal L8/L9 results: TOA Radiance

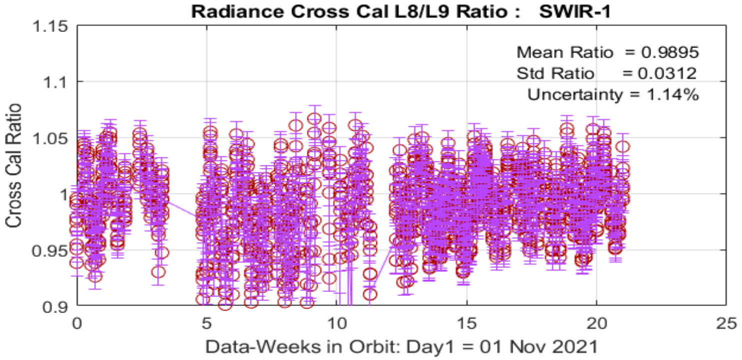


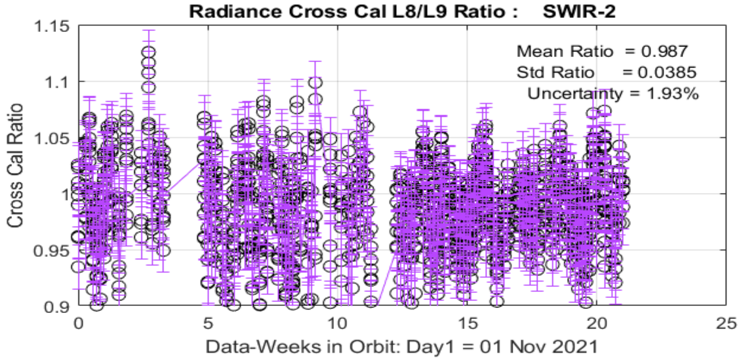


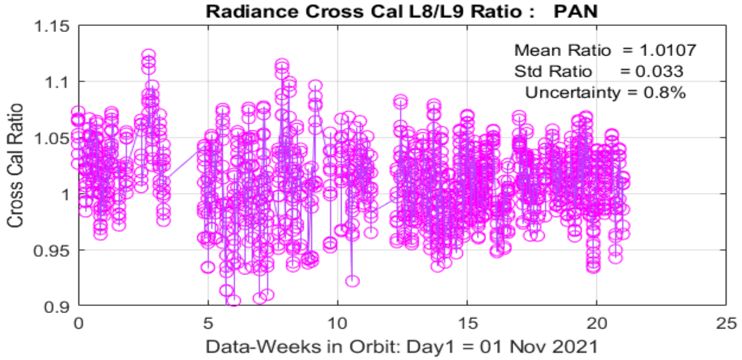












@Morakot, K., SDSU IPlab results

OIV L8-L9 TOA Radiance Ratio

- TOA Radiance Cross Cal Ratios from both methods are similar
  - Cross Cal Ratios are within Cross Cal Ratio Uncertainty with ~ 1 to 2%
    - ❖L8 and L9 Ratio are consistently agreed well at sub 1% level except PAN with ~1.1%

Radiance Ratio	CA	Blue	Green	Red	NIR	SWIR-1	SWIR-2	PAN
Underfly	1.000	1.000	0.999	0.998	0.999	0.998	0.999	1.000
Std	0.000	0.001	0.001	0.002	0.002	0.004	0.004	0.003
Cross-Cal	1.0032	0.9940	0.9906	0.9969	1.0014	0.9895	0.9870	1.0107
Std	0.0416	0.0381	0.0307	0.0418	0.0285	0.0312	0.0385	0.0330
SDSU_Est	**1.001**	**0.998**	**0.994**	**0.998**	**1.000**	**0.994**	**0.996**	**1.008**
Unc_Est	**0.88%**	**0.86%**	**0.62%**	**0.89%**	**0.78%**	**0.75%**	**0.89%**	**0.80%**

L8, L9 Trending Analysis

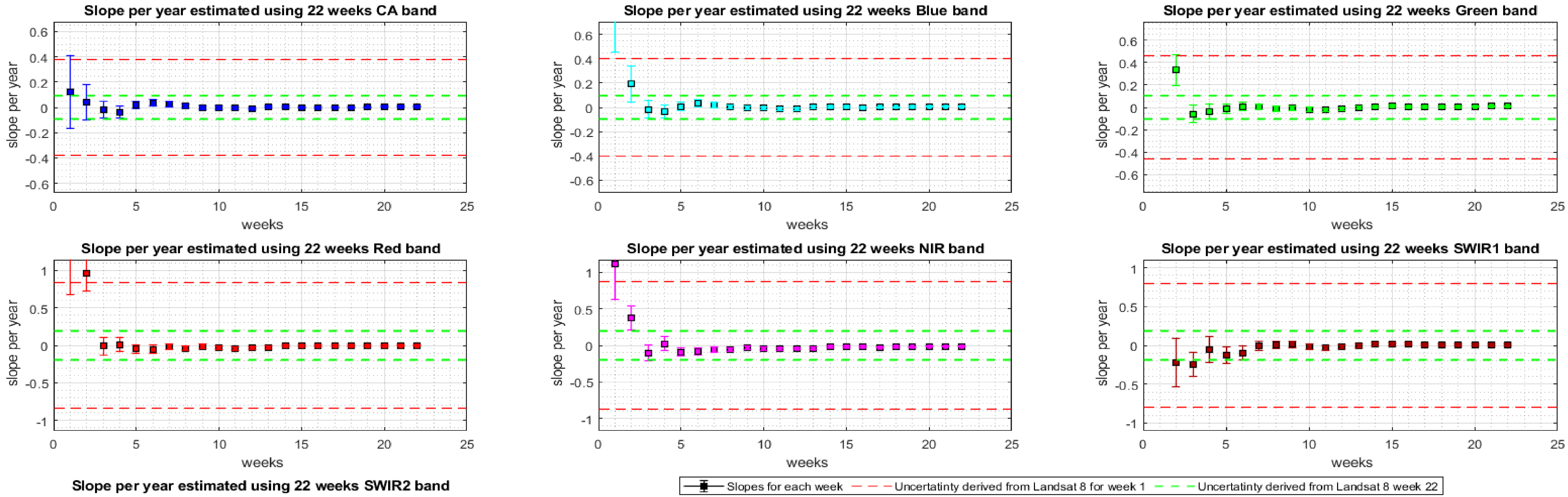
Juliana Fajardo

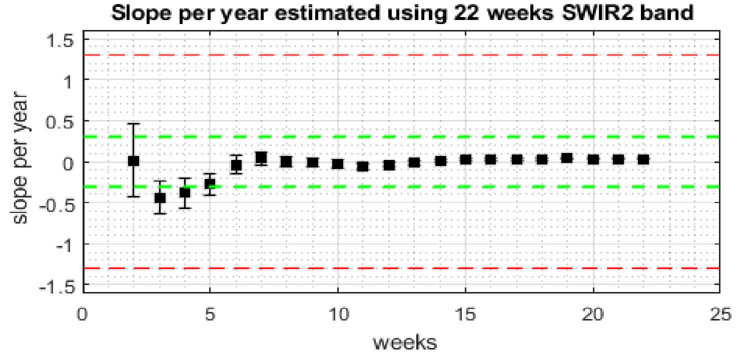
Trending Analysis: L8 , L9

Not only is absolute difference important to understand, but the stability of the sensor is critical as well. So stability trending was performed.

- EPICS Global Cluster, Cluster 13-300C: 33 Path/Row(s)
  - Global EPICS nominally provide a data point every day of OIV.
- 4 Angle BRDF Model: Full BRDF Model
  - BRDF model derived from our understanding of L8s lifetime view of global EPICS.
- Linear fit to calculate Slope and %Drift per year
- Compare L8 and L9 trending analysis results

Landsat 9 slopes per week using the Global Cluster 13 – 300 class for Landsat 9





Number of observations achieved using global cluster 13 - 300 class																					
W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22
5	11	18	21	26	34	41	50	63	69	81	90	103	114	127	137	153	162	172	182	189	189

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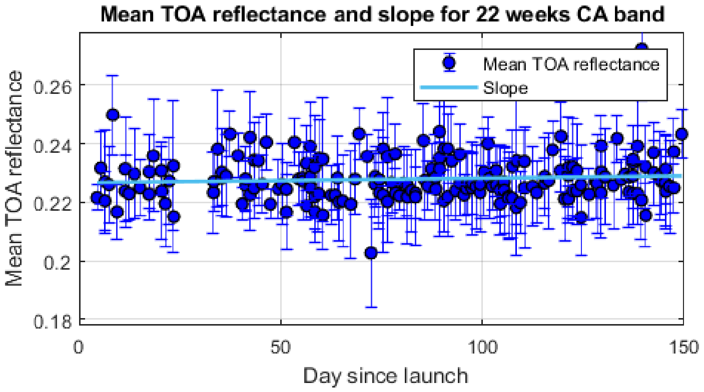
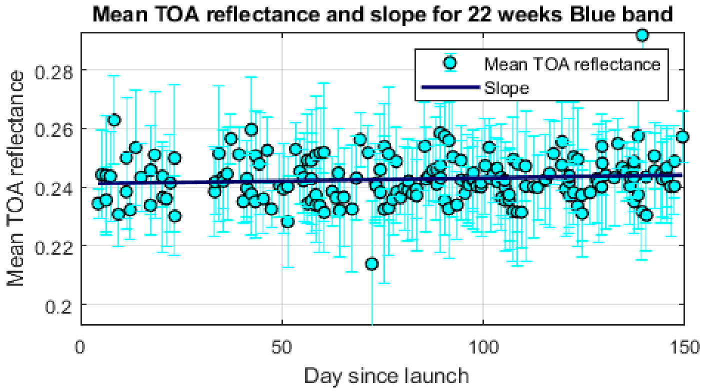
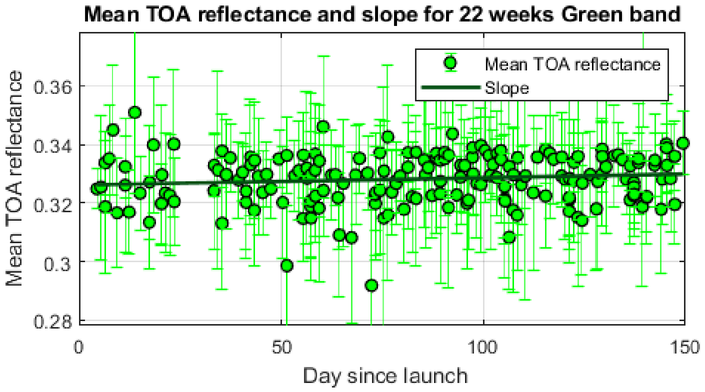
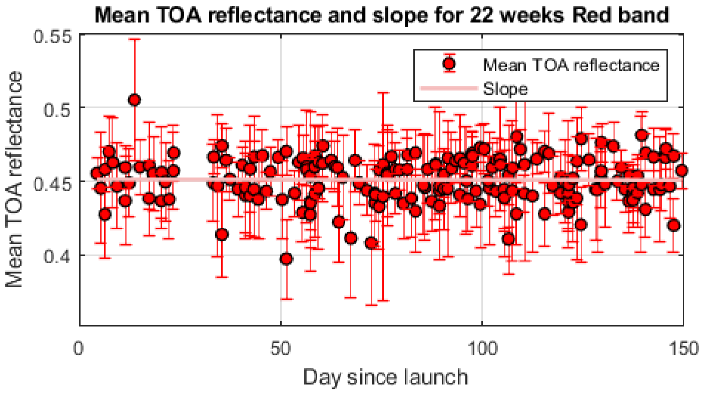
The method really does require ~5 weeks plus of data, to drop the uncertainties to level that can detect the very small trends that might exist.

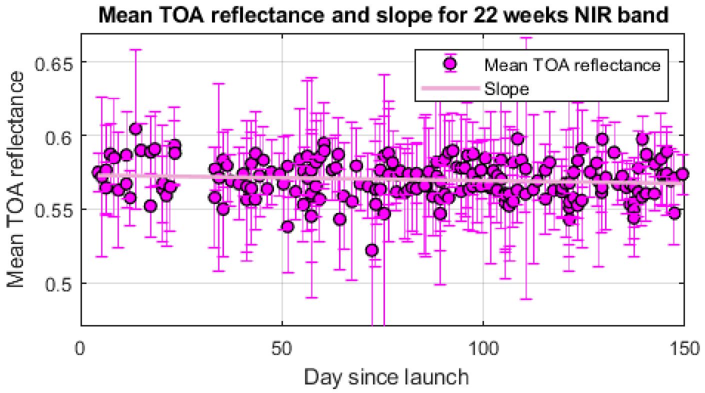
Trending Analysis over Global Cluster 13 – 300 class for Landsat 9

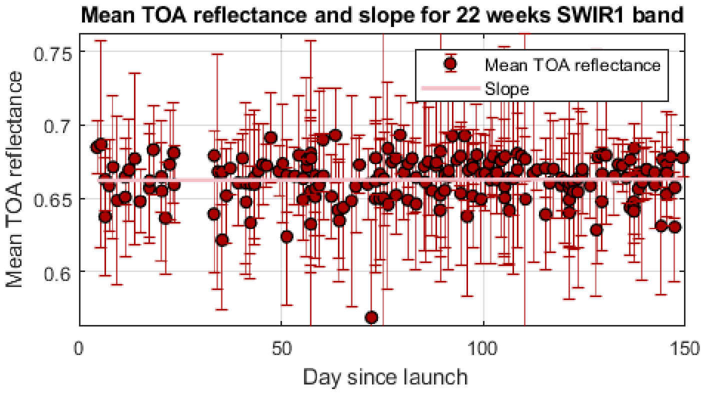


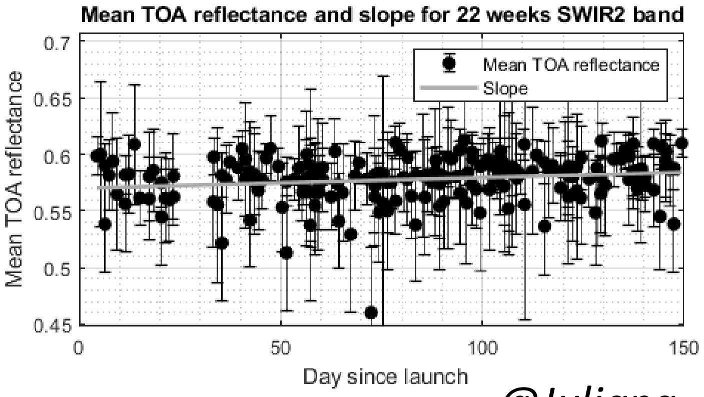












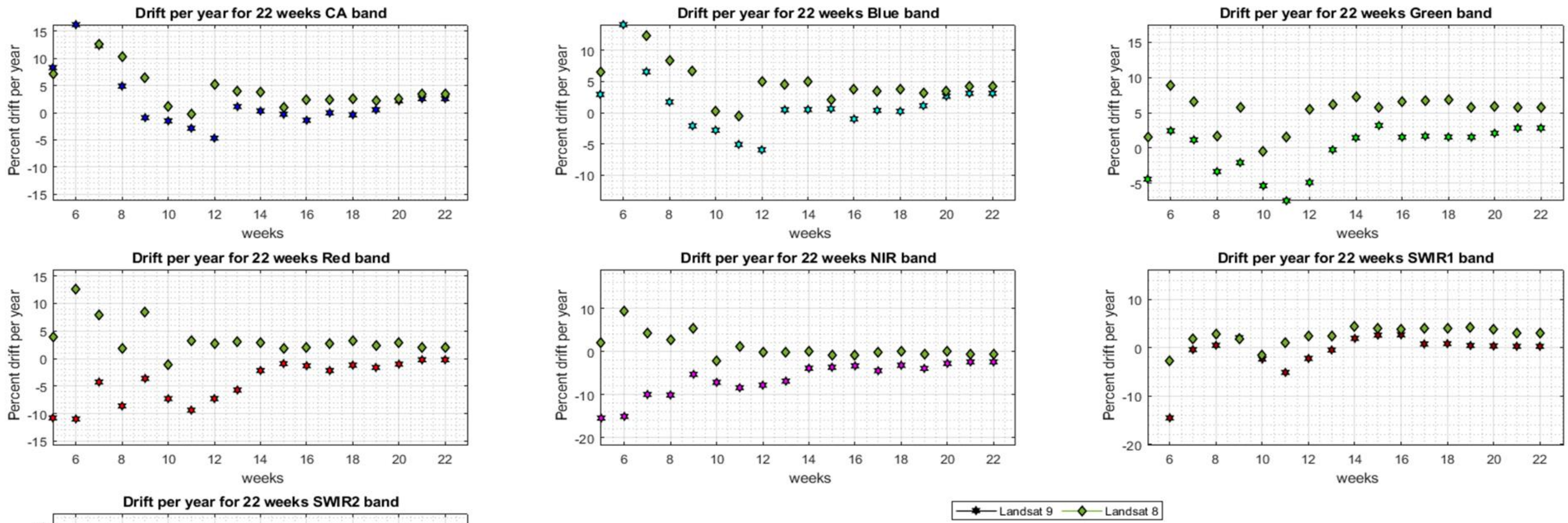
Using all the data available, and the uncertainties associated with each point linear fits where performed to determine if any significant drift has occurred.

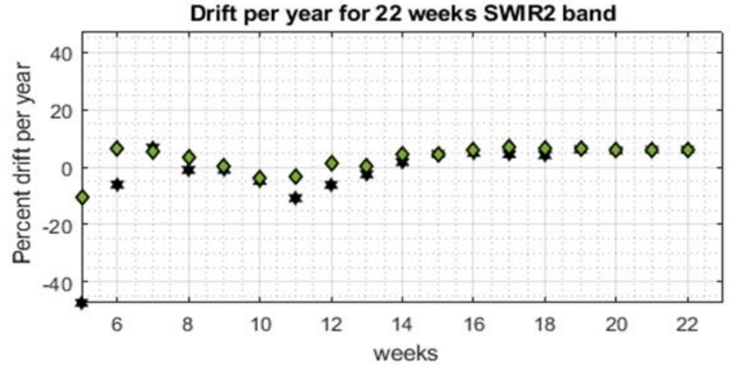
No significant drifts are detected.

	Slope using 22 weeks	Uncertainty of Landsat 8 for week 22 (sigma of 1000 slopes)
CA	0.0059	0.0885
Blue	0.0074	0.0933
Green	0.0092	0.1059
Red	-0.0010	0.1917
NIR	-0.0137	0.1979
SWIR1	0.0020	0.1866
SWIR2	0.0344	0.3056

@Juliana, F., SDSU IPLab results

%Drift per year using Global Cluster 13 – 300 class for Landsat 8 and Landsat 9





$$Drift\ /year = \frac{Slope * 365 * 100}{Intercept}$$

	%Drift per year for Landsat 8			%Drift per year for Landsat 9		
	20 weeks	21 weeks	22 weeks	20 weeks	21 weeks	22 weeks
CA	2.57	3.39	**3.39**	2.18	2.58	**2.58**
Blue	3.51	4.21	**4.21**	2.63	3.08	**3.08**
Green	5.90	5.72	**5.72**	2.09	2.83	**2.83**
Red	2.93	2.06	**2.06**	-1.02	-0.23	**-0.23**
NIR	0.15	-0.54	**-0.54**	-2.74	-2.39	**-2.39**
SWIR1	3.87	3.13	**3.13**	0.37	0.31	**0.31**
SWIR2	5.95	6.09	**6.09**	5.72	6.04	**6.04**

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Trending Analysis Summary

- L9 is stable behaving similarly to L8 within uncertainties

Additional slides