Assessing Long Term Stability of Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI

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Outline

- Introduction / background
- Landsat Collection 1 radiometric updates
- Stability trending updates
- Comparison of OLI and ETM+ PICS trends
- Temporal uncertainties
- Summary

Introduction

Satellite	Launched	Status	Sensor
Landsat 5 (L5)	March 1, 1984	Decommissioned on June 5, 2013	Thematic Mapper (TM)
Landsat 7 (L7)	April 15, 1999	Operational	Enhanced Thematic Mapper Plus (ETM+)
Landsat 8 (L8)	February 11, 2013	Operational	Operational Land Imager (OLI)

- **Long term stability of L5 TM and L7 ETM+ was characterized in 2011 using image statistics from various Pseudo Invariant Calibration Sites (PICS)**
  - For ETM+, degradation of up to -0.21% per year was observed in all bands
    - This led to an update of L7 ETM+ calibration in 2012
  - For TM, drifts of -0.27 and -0.15% per year were observed in Blue and Red bands
    - L5 TM calibration was updated in 2007 based on the PICS trends, cross calibration with L7 ETM+ and prelaunch calibration
    - Therefore, another calibration update was due

Introduction

- **Performance of OLI is continuously monitored using well defined sets of on-board calibrators, operated at various time intervals:**
  - Three stim lamp sources
  - Two solar diffusers
- **From the on-board calibrator trends, a steep decline followed by a gradual decrease of about 0.1% per year observed in Coastal Aerosol (CA) band**
  - Other bands stable to within ~0.3%
- **Vicarious sources, such as Moon and PICS, are used to complement the on-board calibrators**

Landsat Collection 1 Radiometric Updates

- **Landsat data archive has been restructured into a formal tiered data Collection (Collection 1)**
  - OLI, ETM+ and most of TM data reprocessing completed in Spring 2017
- **OLI relative and absolute gains (up to ~1.5% worst case)**
- **TM life-long gain adjustment (effect of ~2.1%)**
  - Adjustment of cross calibration gain between L5 TM and L7 ETM+ for all bands, due to update in L5 TM bias estimation method in 2012
  - Original exponential+linear gain model replaced with a double exponential model
- **Reflectance based cross-calibration**
  - Reflectance-based calibration transferred from L8 OLI to previous Landsat sensors
    - Up to 5% change in estimated TOA reflectance for TM and ETM+ data
- **All the PICS radiometric trends were updated to include Collection 1 changes**
  - More than 1000 scenes from Libya 4, Libya 1, Sudan 1, Egypt 1 were reprocessed

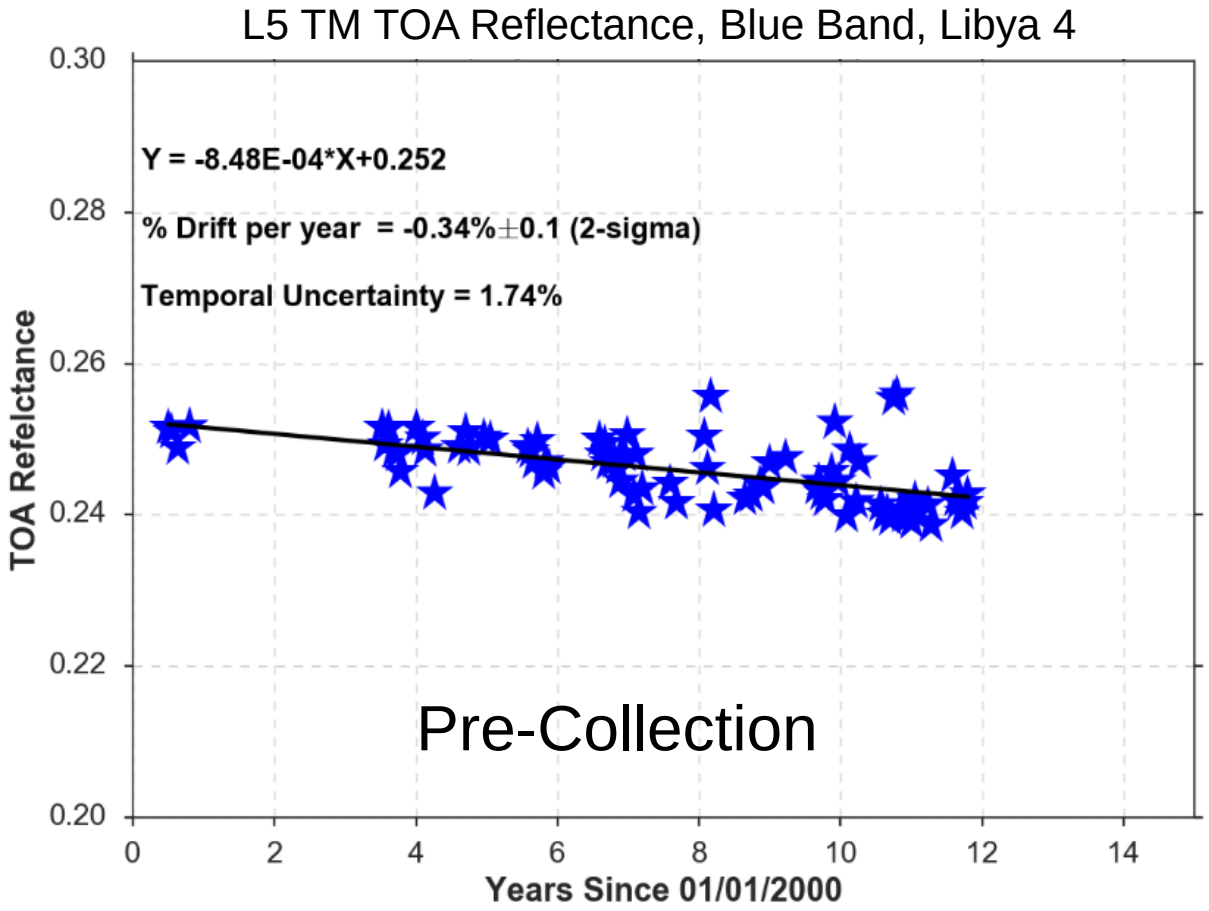
PICS Based Stability Monitoring

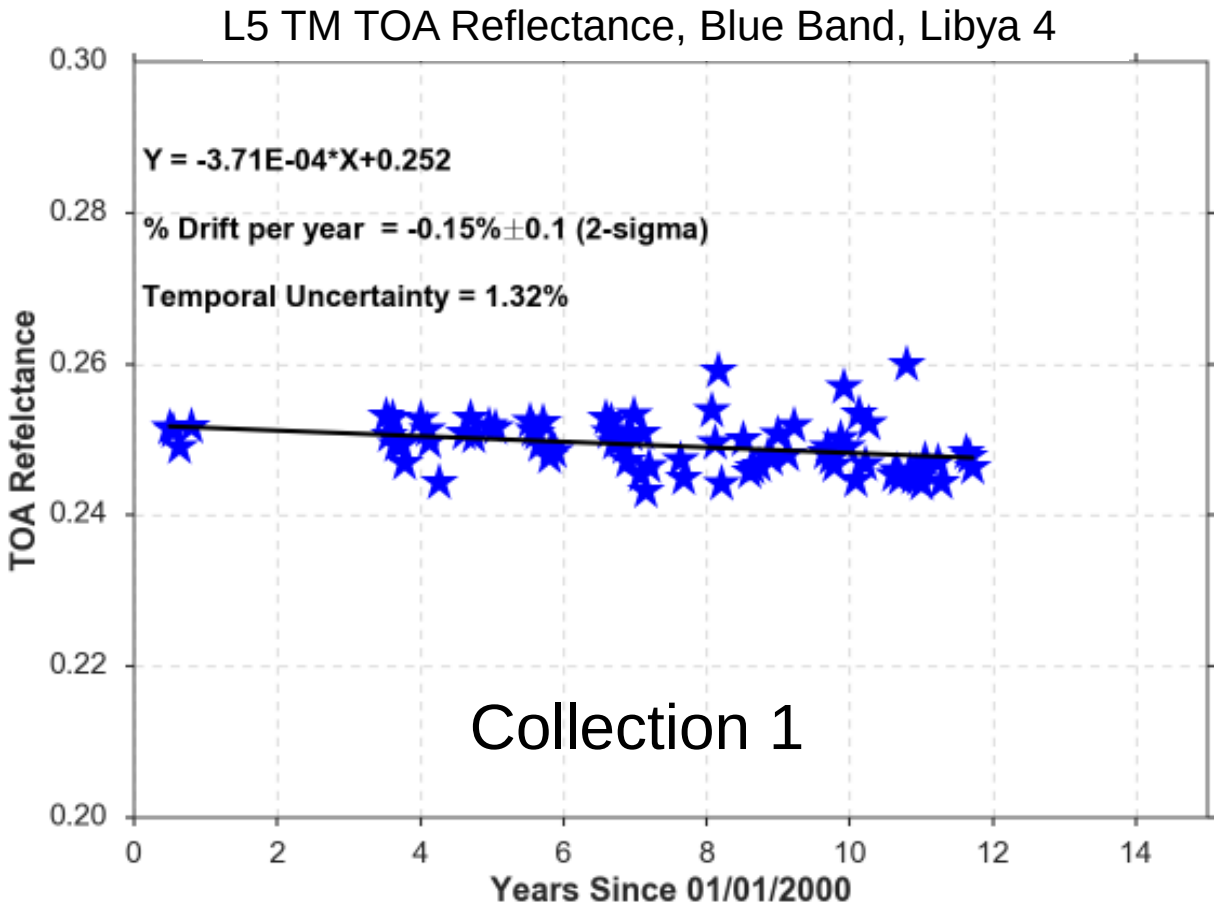
- **Responses of TM, ETM+ and OLI over North African PICS are continuously trended for stability monitoring**
  - For TM and ETM+, PICS based method acts as a primary method for stability monitoring
    - Couple years after launch, the on-board calibrators were found unreliable for long term stability monitoring
  - For OLI, PICS based method acts as a backup to on-board calibrators
- **Drift (percent change per year) is calculated using linear regression**
- **Processed through Landsat Image Assessment System (IAS) to Top-Of-Atmosphere (TOA) reflectance and trended for stability monitoring**
  - Band averages over the standard Regions of Interest (ROIs)
  - Filtered for clouds
  - Bidirectional Reflectance Distribution Factor (BRDF) correction
    - Empirical model based on linear regression of the solar zenith angle and TOA reflectance

L5 TM PICS Trends Update

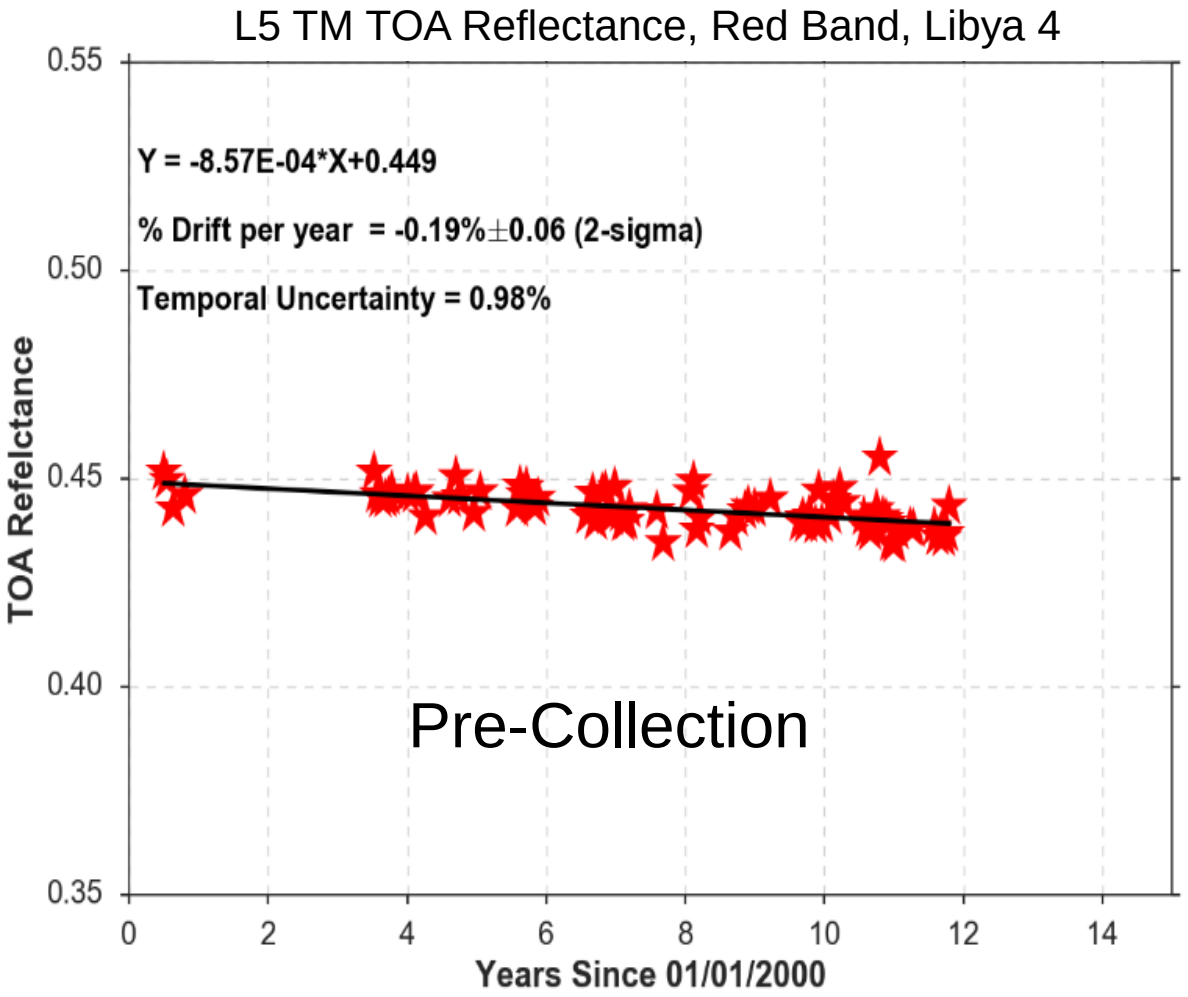
- **L5 TM PICS statistics were updated to reflect the update in TM gain model**
  - Old Exponential+Linear model replaced with double exponential model
- **L5 TM has very limited PICS coverage outside Libya 4**
  - Various ROIs within Libya 4 were used to validate the updated model
  - Algeria 3 was also used for validation, but there are much fewer scenes than for Libya 4
- **Update in the absolute gain model in blue and red band improves the temporal stability of L5 TM over PICS**
  - Remaining residual drifts under further investigation

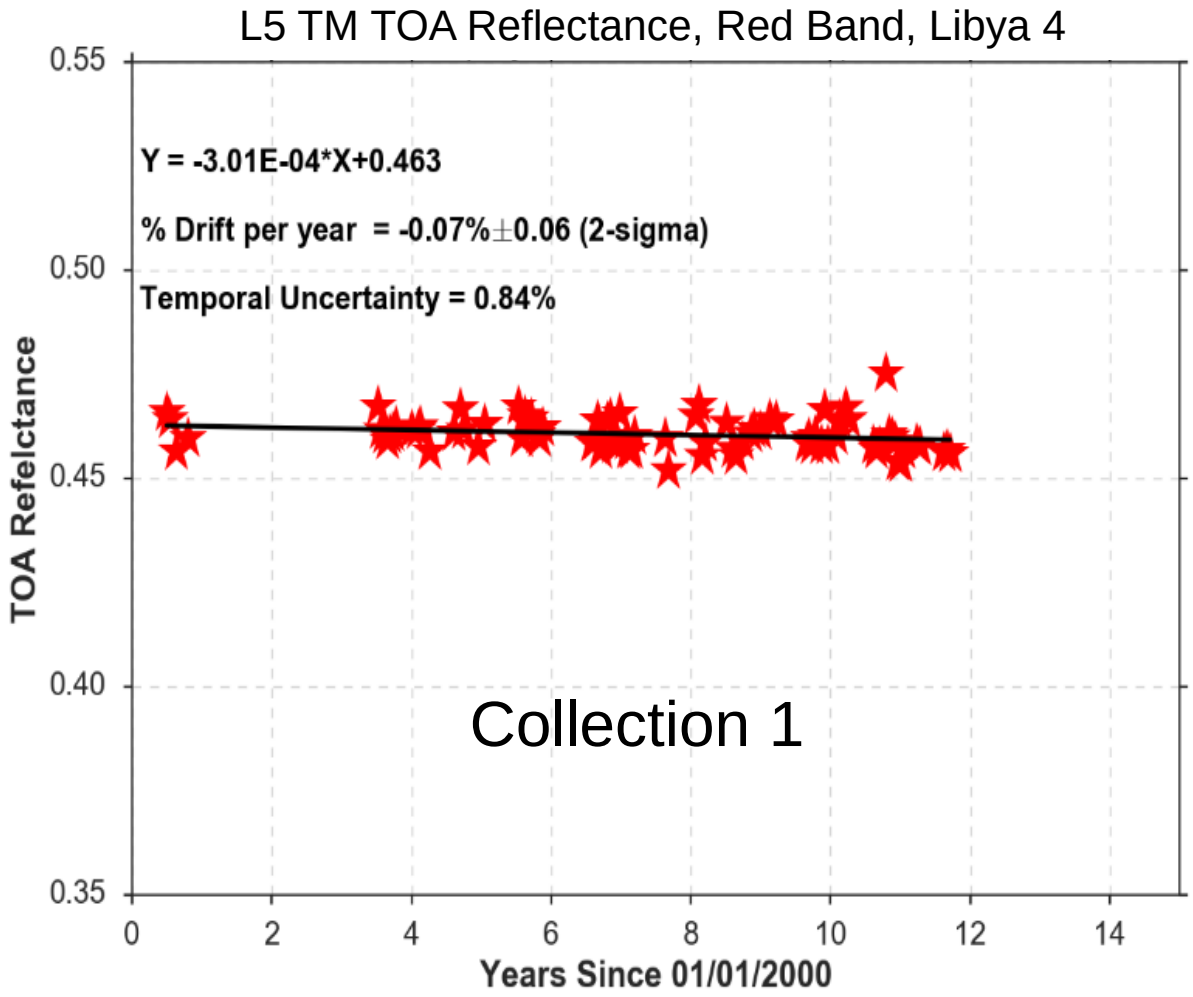
PICS Trending for L5 TM, Blue Band





PICS Trending for L5 TM, Red Band

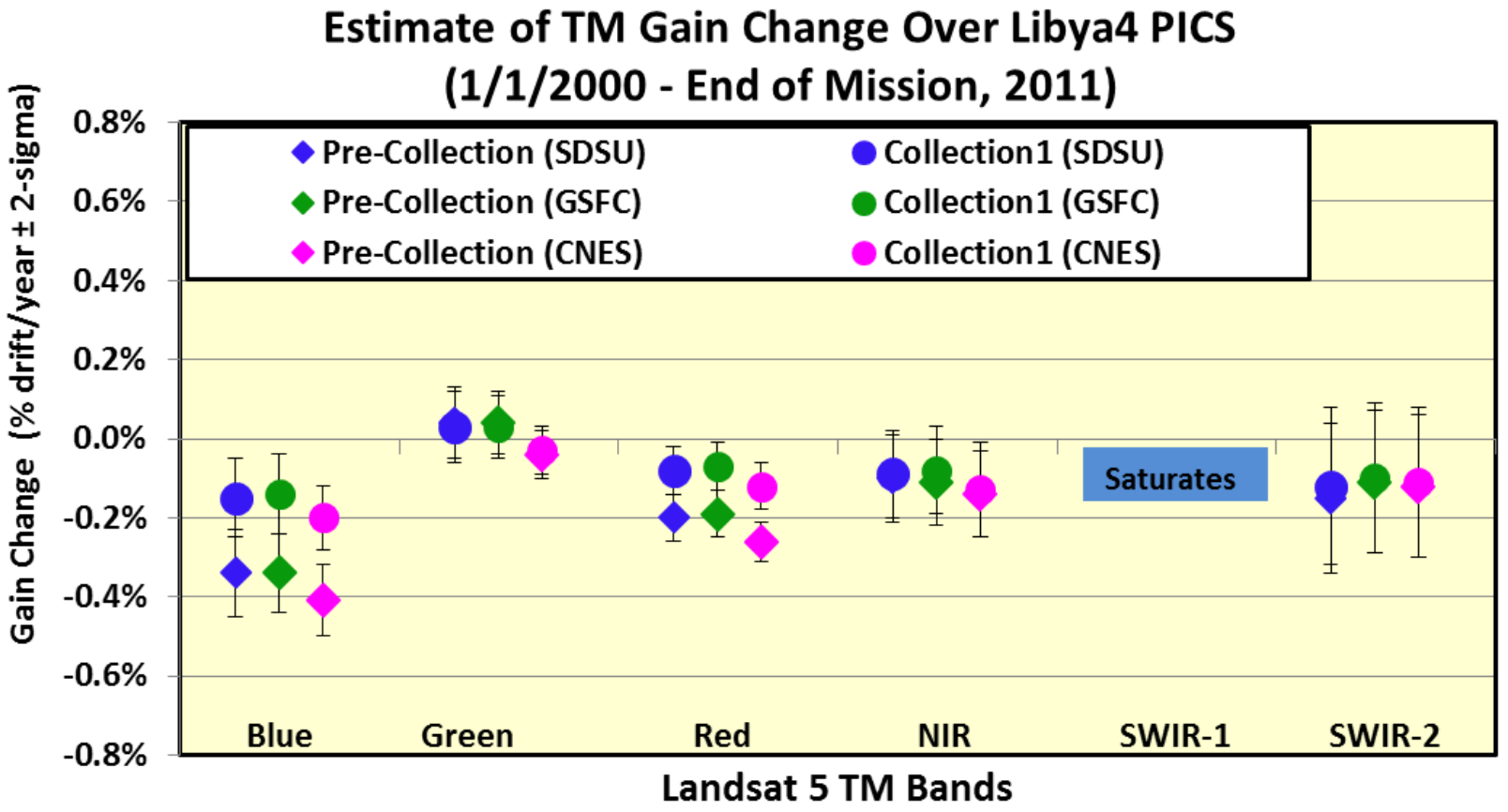




Drift Analysis for L5 TM

- The updated gain model reduced drifts in the lifetime gain trends to about 0.15% per year
- The residual drift in the trend is believed to be related to inconsistent data processing
- Modeling will be repeated when more PICS data become available

LANDSAT 5 TM	% CHANGE/YEAR ±2-SIGMA
BLUE	-0.15±0.10
GREEN	0.03±0.08
RED	-0.07±0.06
NIR	-0.13±0.11
SWIR-1	SATURATES
SWIR-2	-0.10±0.18



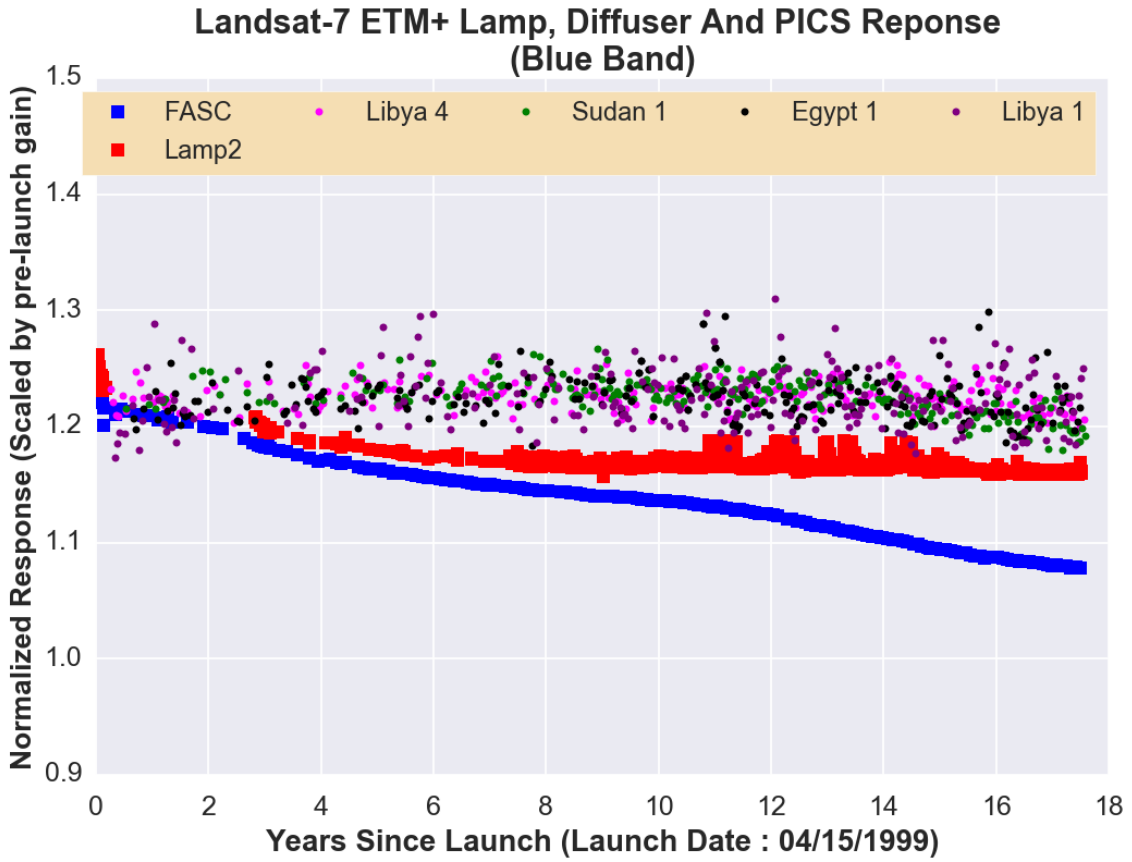
L7 ETM+ PICS Trends Update

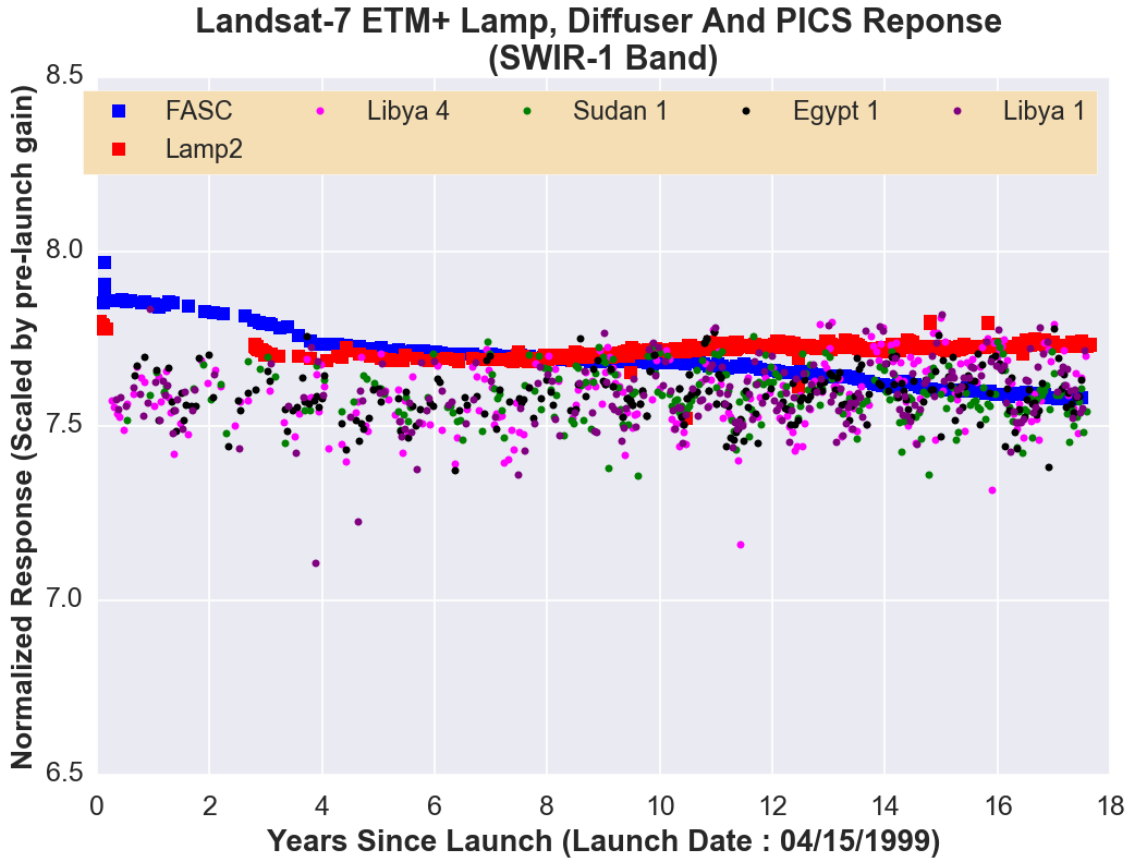
- **The temporal gain model was derived in 2013 using data from 2000-2012**
  - The CPF extrapolates the model for forward processing
- **All the L7 ETM+ trending updated with Collection 1 data**
  - Includes the new ESUN values to calculate TOA reflectance
  - The stability estimates essentially have not changed
  - Sites include Libya 4, Libya 1, Sudan 1, Egypt 1, Niger 1 and Niger 2
- **Overall, the instrument looks stable to about ±0.05% per year**

- **L7 ETM+ trending after 2013 is then compared to L8 OLI trending to assess sensors' stability estimates over the same time period**

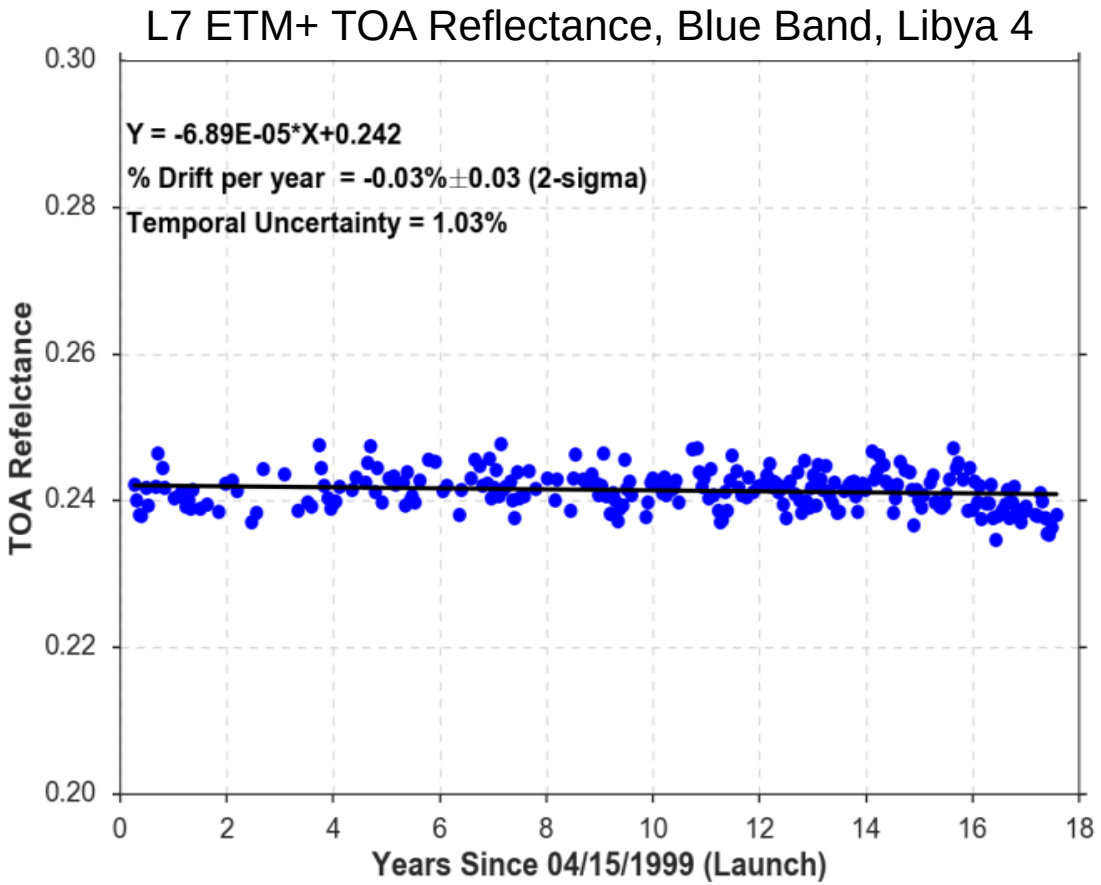
ETM+ Radiometric Trending

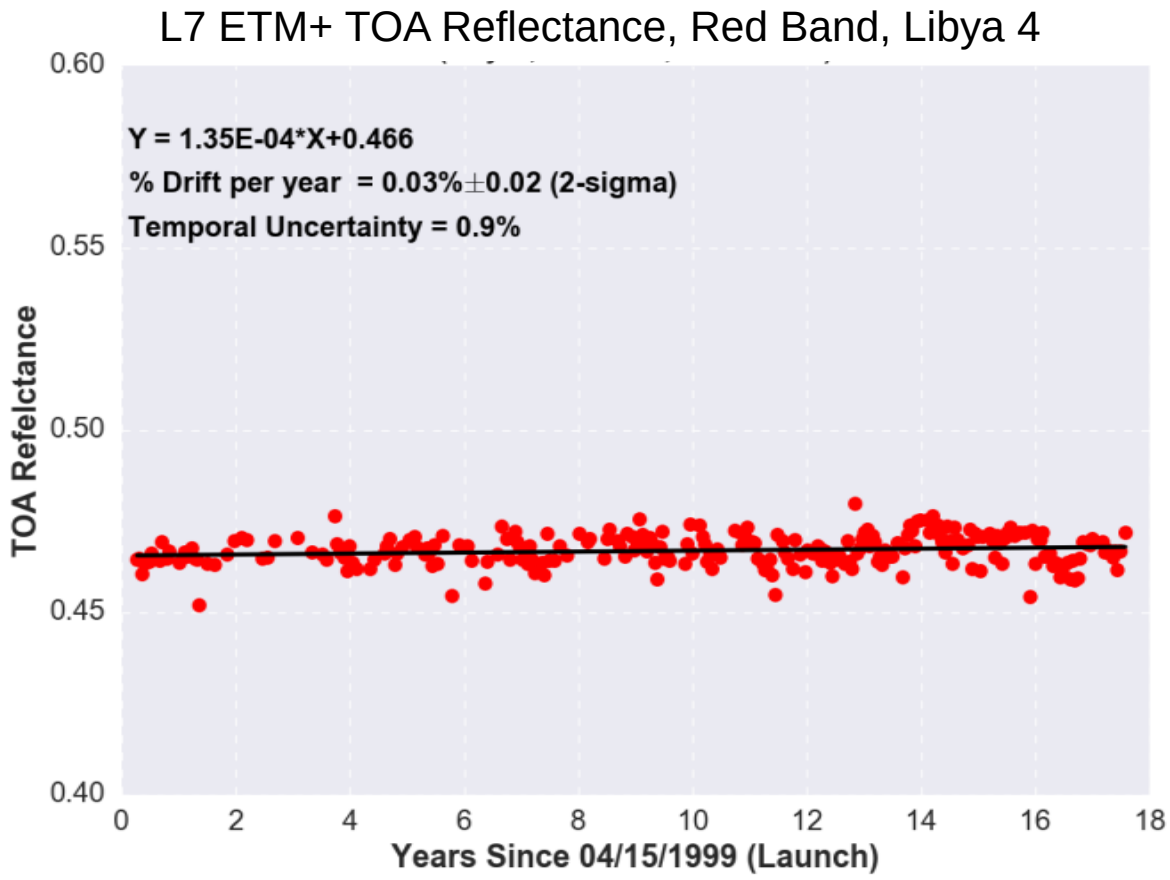
- **On-board calibrators (2- lamps and a diffuser) were deemed unreliable after few years since launch**





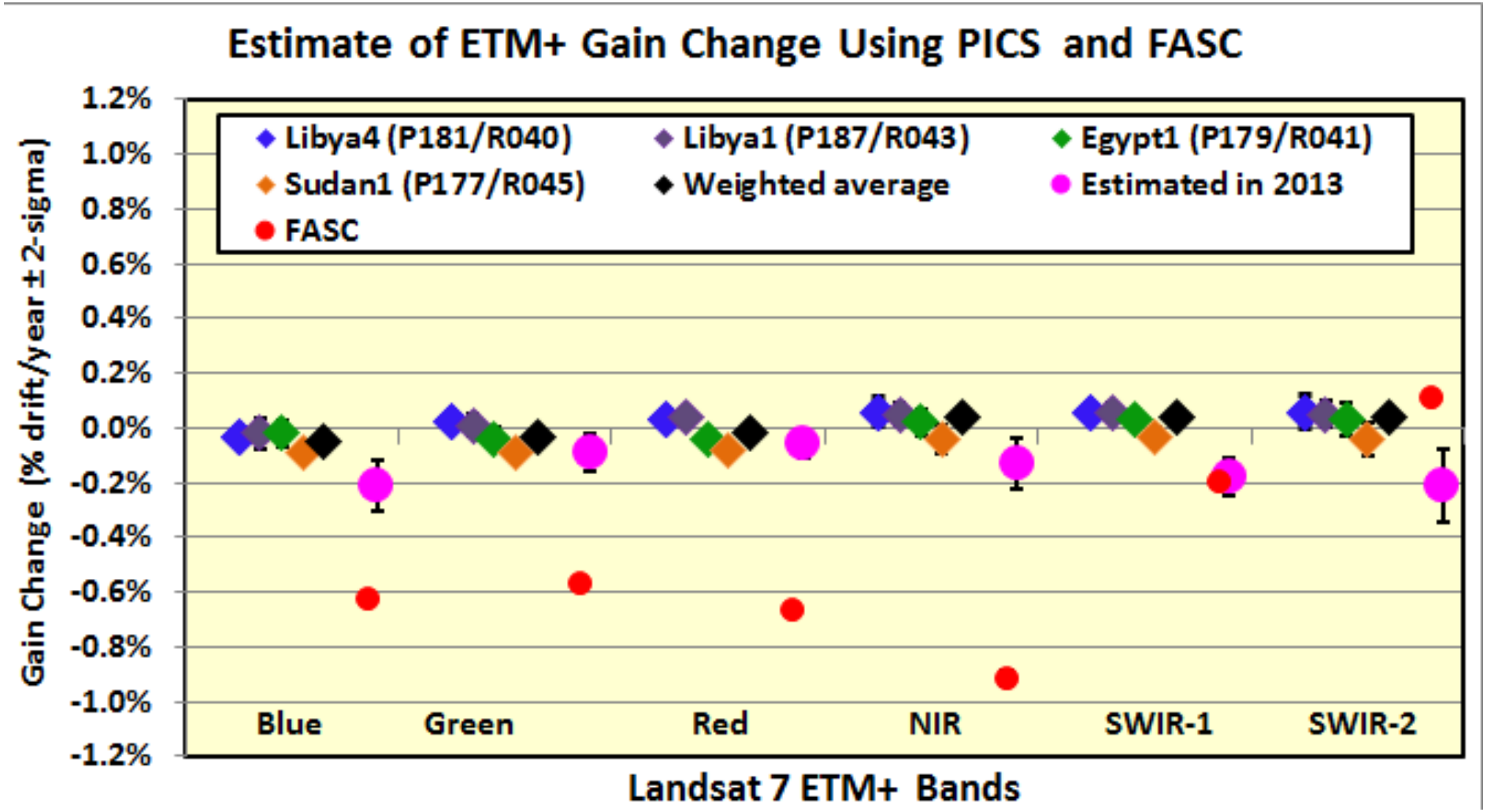
Update of L7 ETM+ PICS Trends





- **Over the mission of the instrument (~18 years), ETM+ bands are very stable (generally within ±0.05% per year)**

L7 ETM+ Stability Estimate

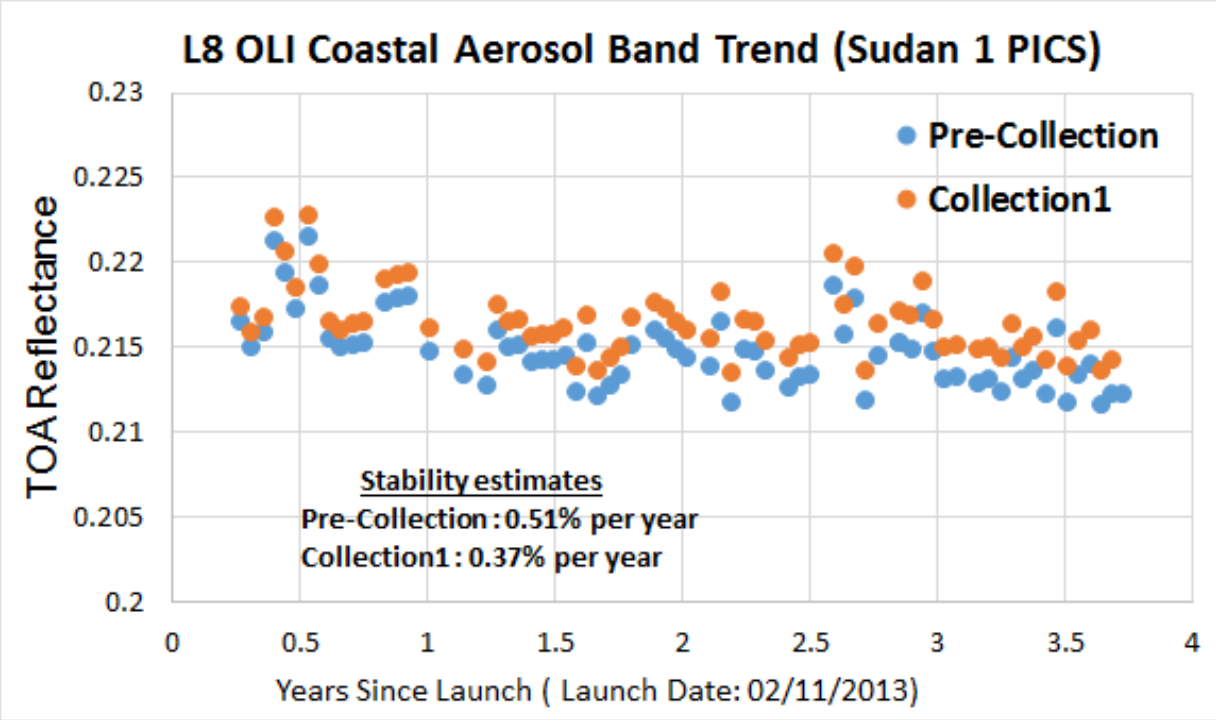


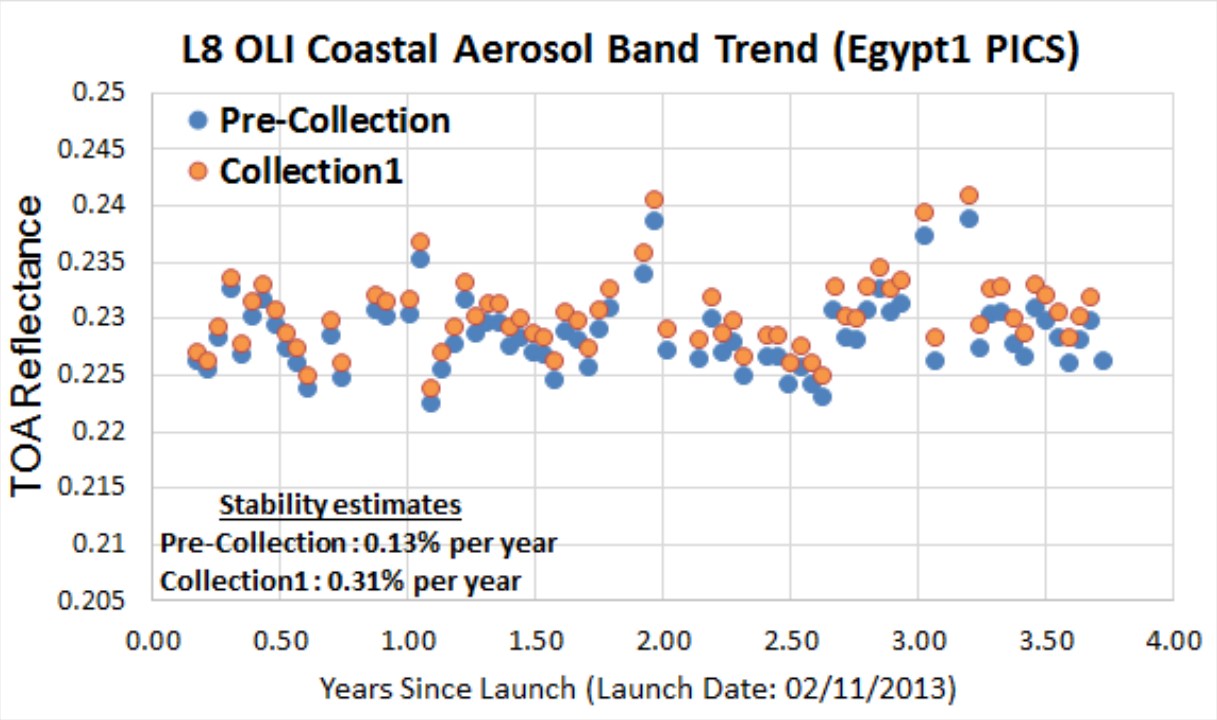
- Stability across all solar reflective bands is about 0.05% per year

L8 OLI Trend Update

- **Collection 1 update**
  - Correction for the decay in Coastal-Aerosol band calibration trend
  - Accounts for ~0.2% short-term step increase in trends of VNIR bands (attitude anomaly followed by safe hold, September 2013)
  - Detector relative gains in all bands
- **Coastal Aerosol Band Validation**
  - Collection 1 updates were validated using several PICS
  - For comparison with On-board calibrators, pre-collection calibration parameters were used

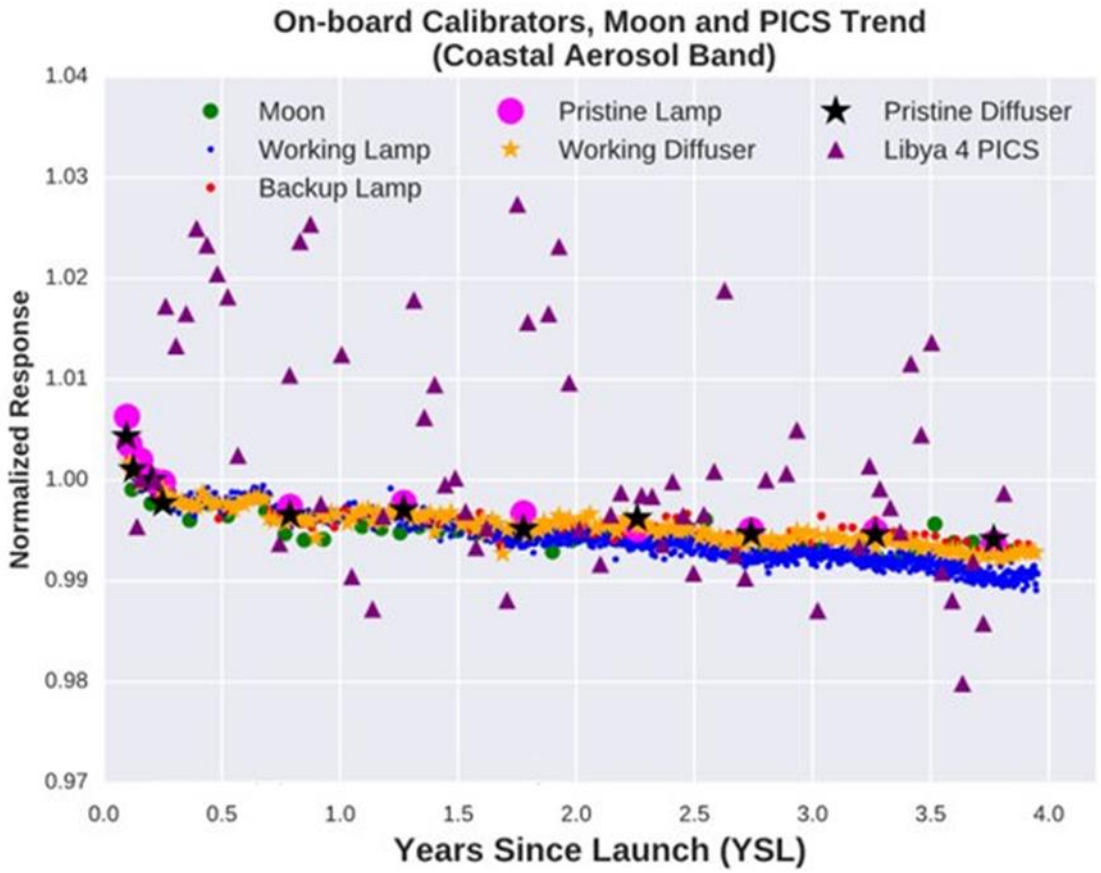
L8 CA Band PICS Trends

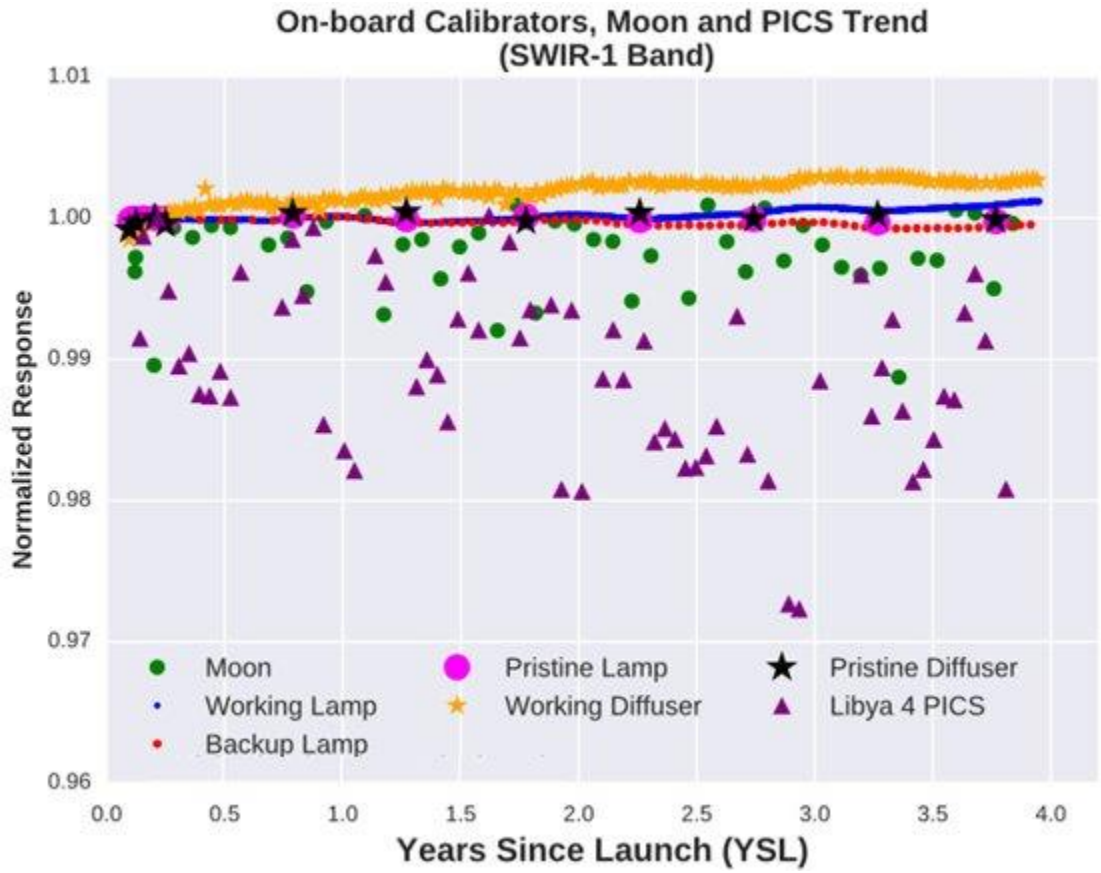




- **Collection-1 processing indicates changes in the CA band PICS trends of ~0.2% per year, which is consistent with the desired update**

OLI Radiometric Trending

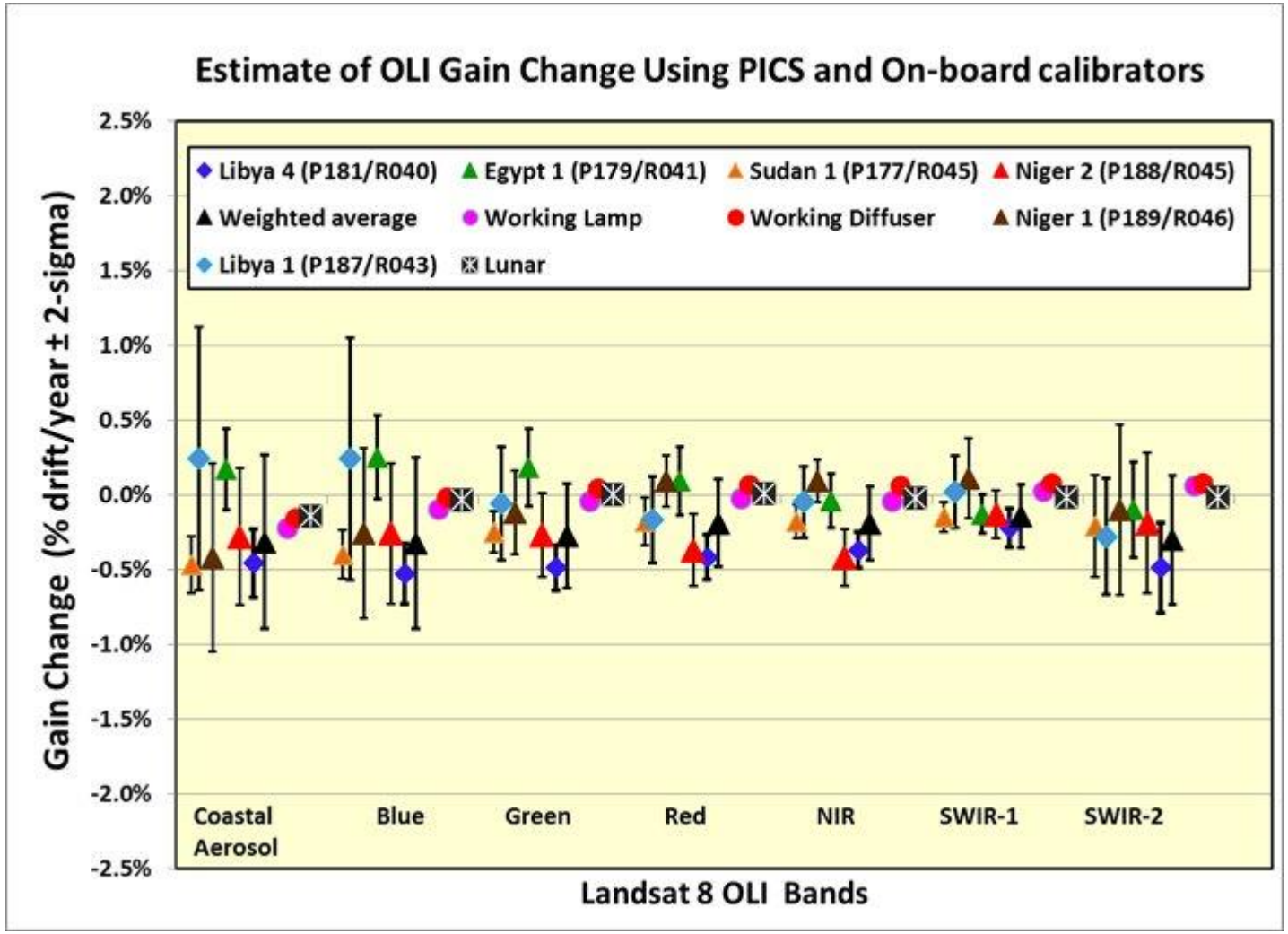




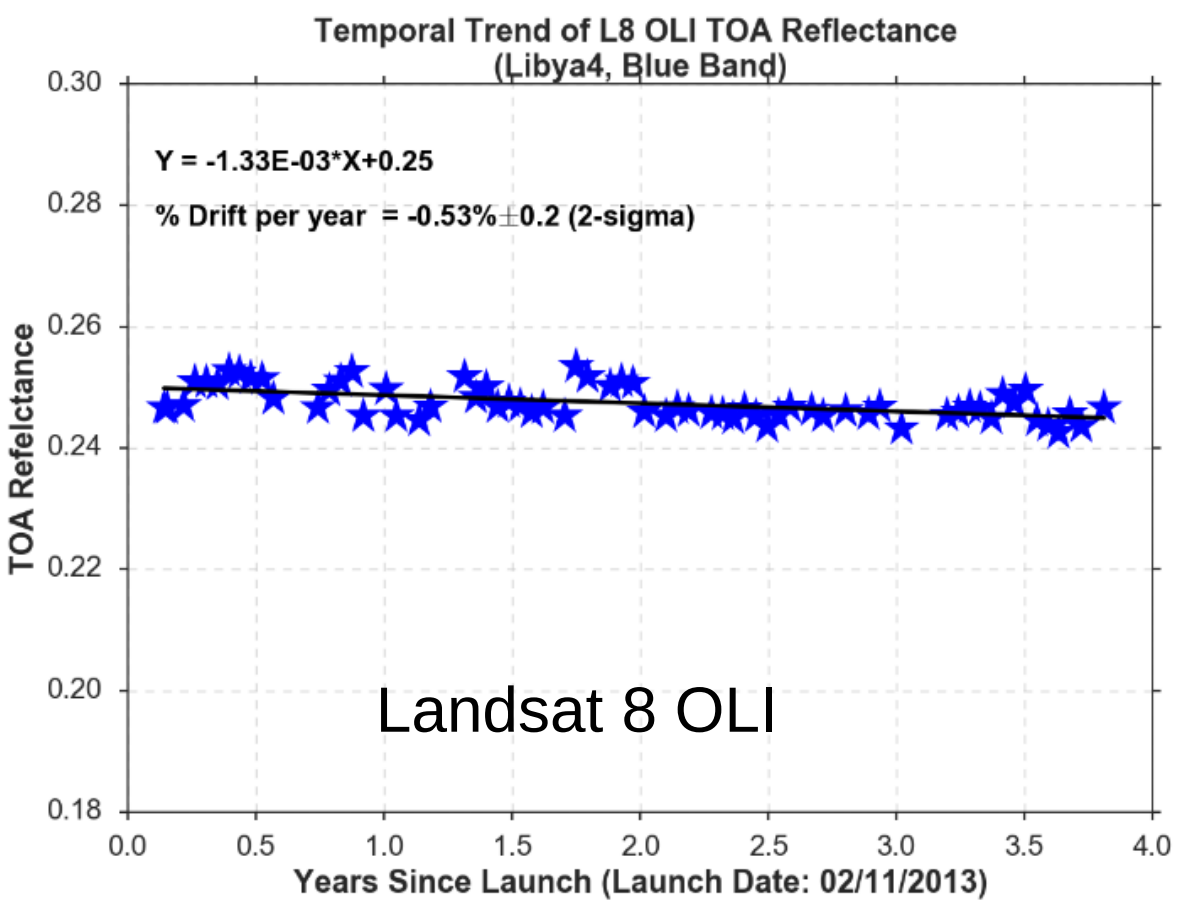
- On-board calibrators and lunar observations are much more precise than PICS
- PICS tend to indicate larger drift than on-board calibrators and moon across all the bands

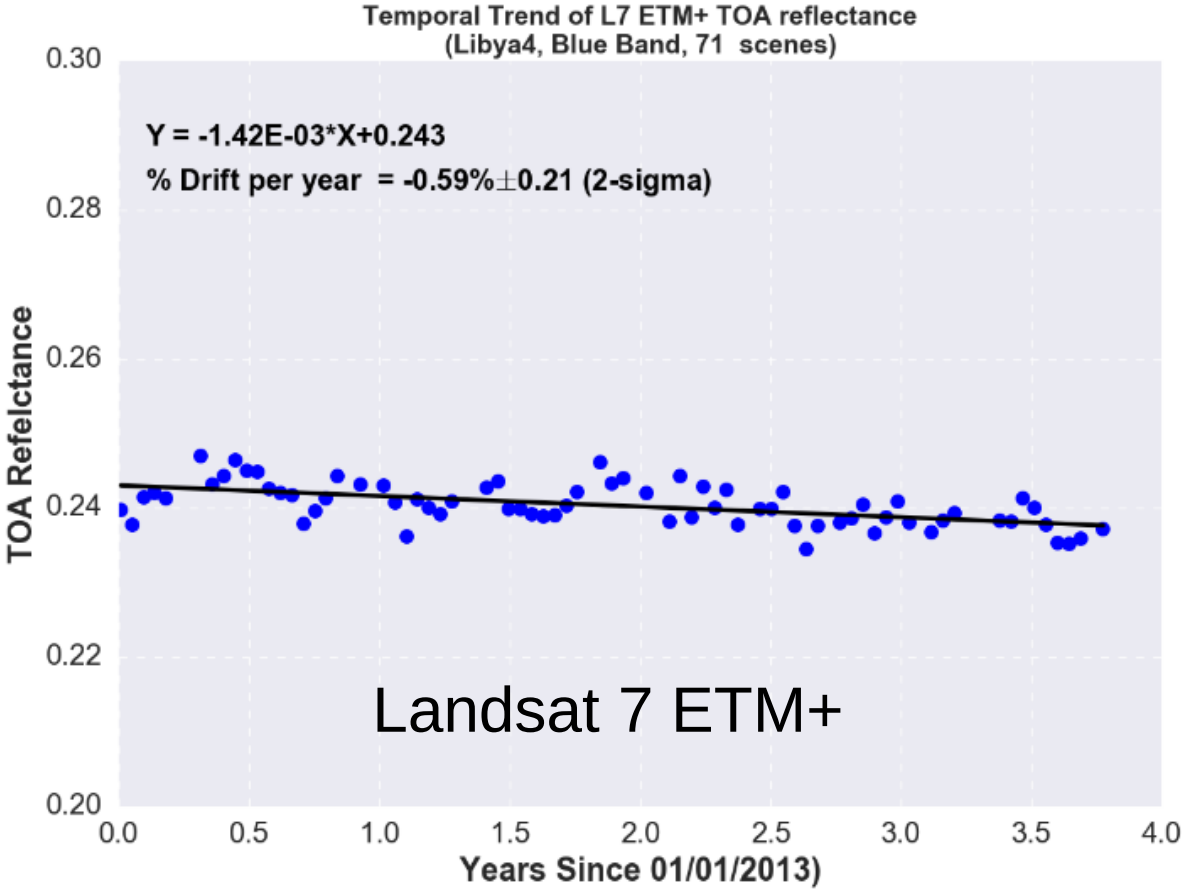
Landsat 8 OLI Stability Estimate

- **For comparison purposes, the updated gain for the C/A band not applied in the PICS calculations**
- **On average, PICS estimates differ from the on-board calibrators and moon by 0.35%**
  - PICS tend to disagree more with each other in the C/A & blue bands and the uncertainties in the estimates are higher too
  - A previous analysis with ETM+ data indicated that about 6-8 years of data were needed for gain estimate to start converging



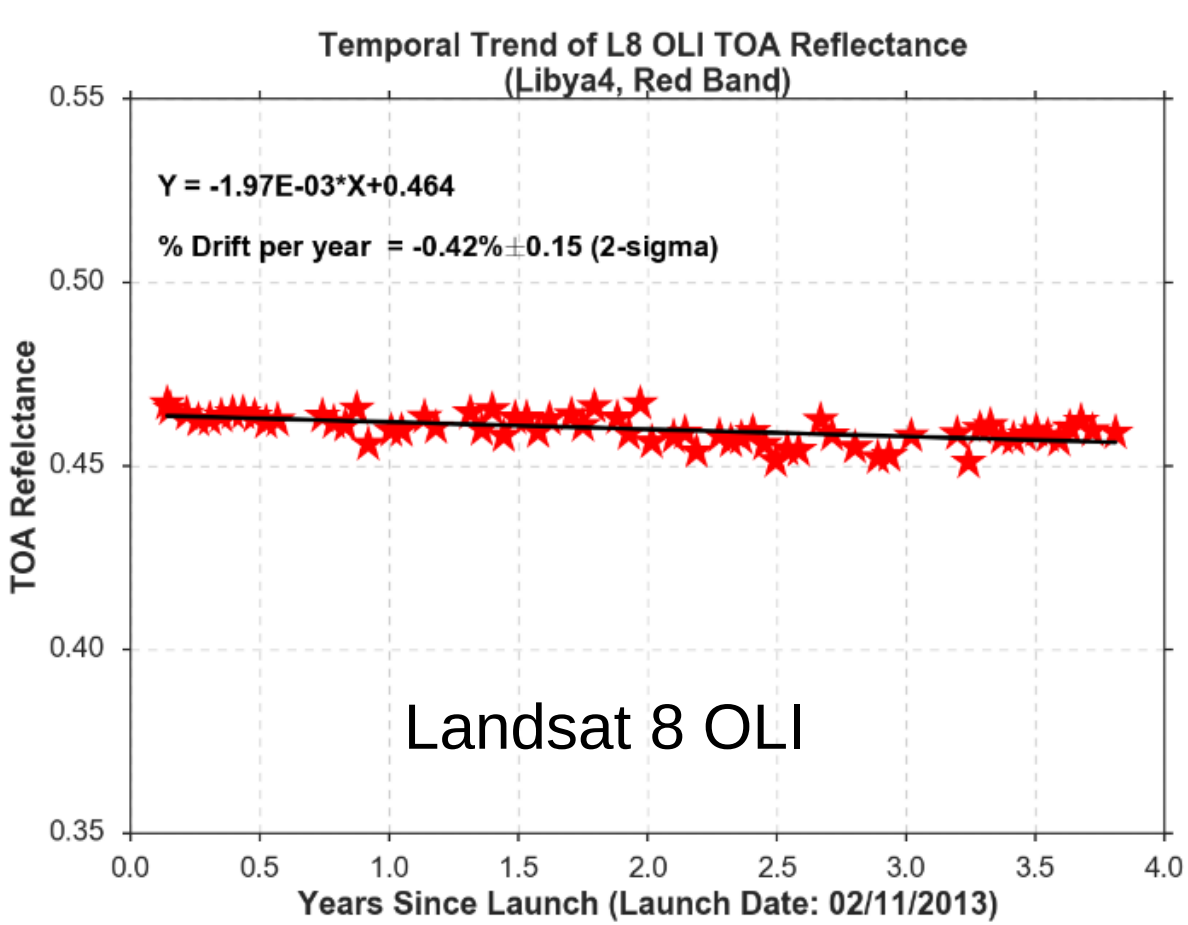
Comparison of ETM+ & OLI Trends

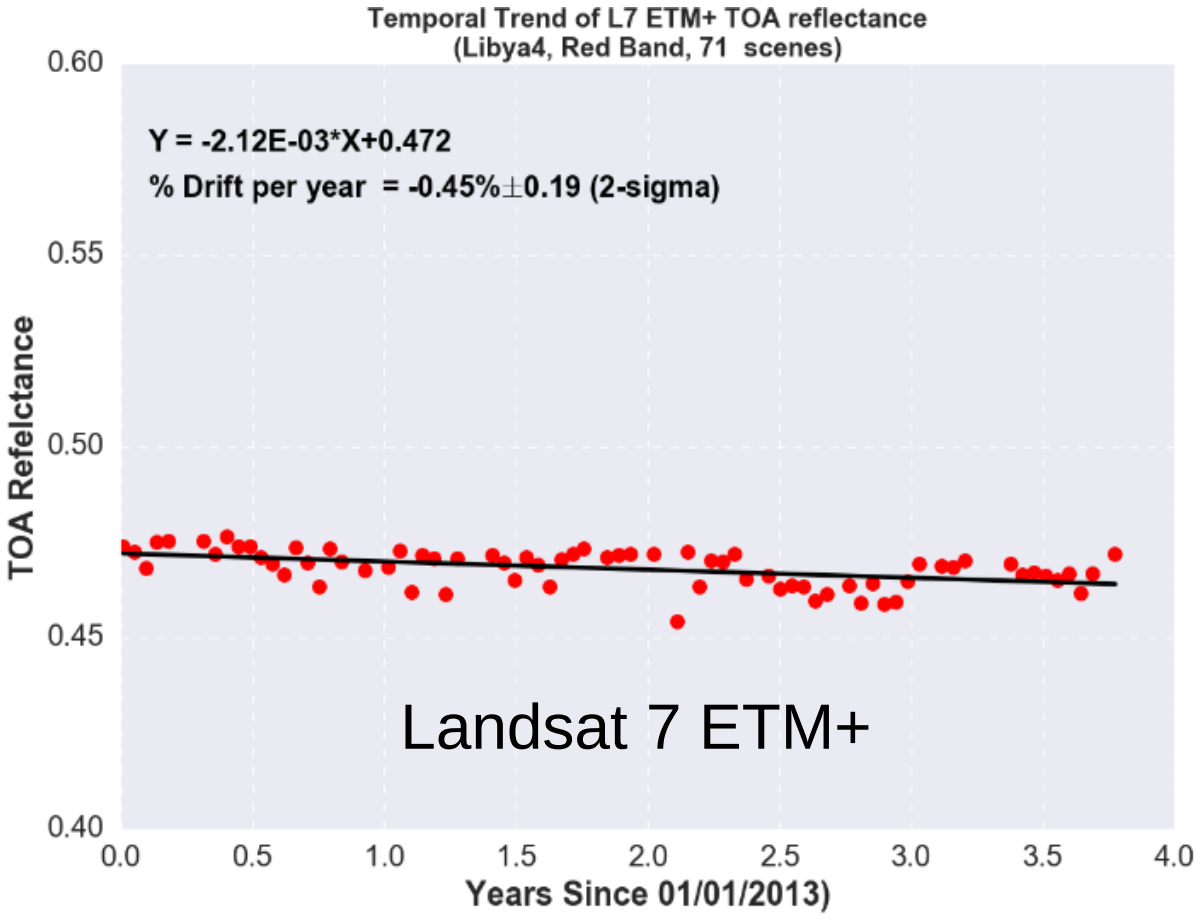




- **Similar trends over Libya 4 for the same time period**

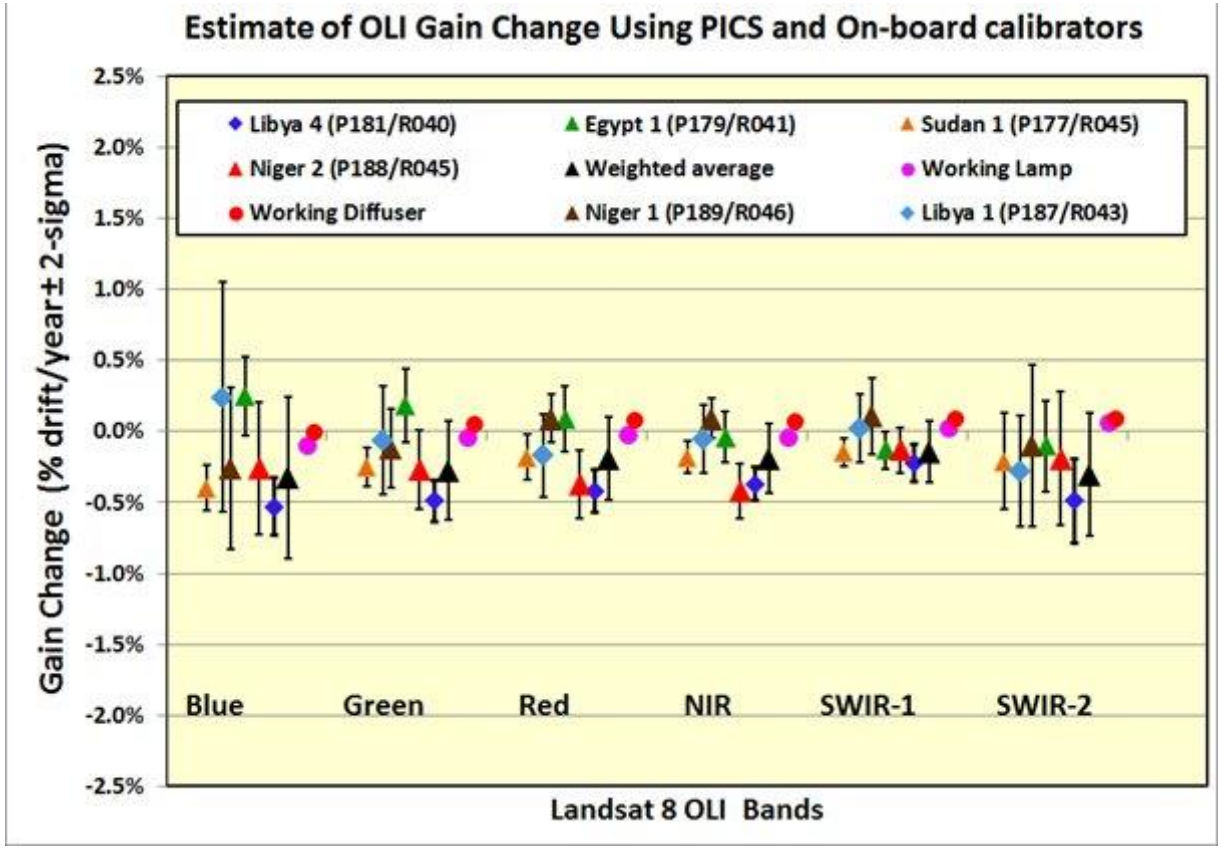
Comparison of ETM+ & OLI Trends

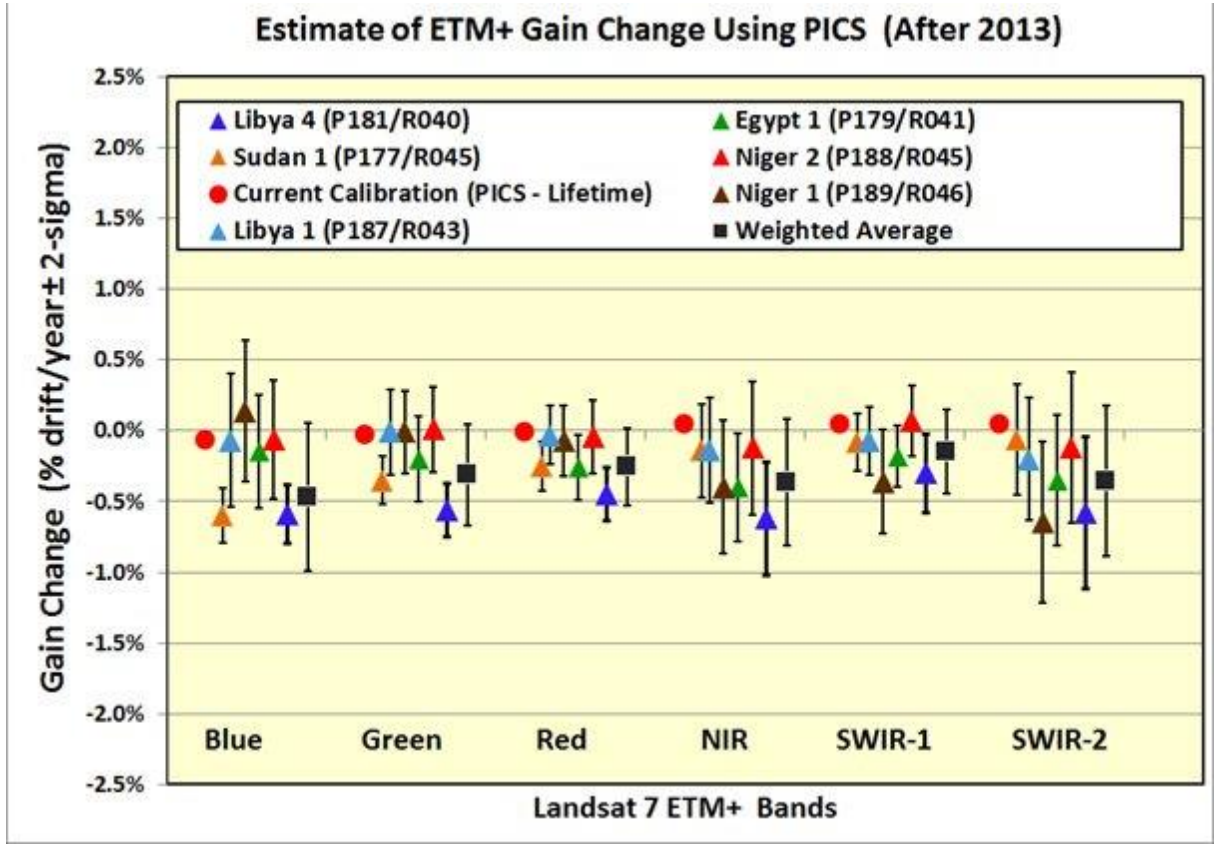




- **Similar trends over Libya 4 for the same time period**

Comparison of ETM+ and OLI PICS Trends





- **The gain change estimates for ETM+ and OLI are similar and differ from the on-board calibrators' based calibration by about 0.35%**
  - For a reliable estimate, more than 4 years of PICS data are needed

Comparison of ETM+ and OLI PICS Trends

Landsat Bands	Gain change (%/year ±2-Sigma)		
	L8 OLI (2013-2016)	L7 ETM+ (2013-2016)	L7 ETM+ (1999-2016)
Blue	-0.62±0.21	-0.59±0.21	-0.02±0.04
Green	-0.51±0.16	-0.56±0.19	0.010±0.03
Red	-0.42±0.16	-0.45±0.19	0.02±0.04
NIR	-0.30±0.12	-0.52±0.4	0.04±0.05
SWIR-1	-0.21±0.14	-0.3±0.28	0.05±0.02
SWIR-2	-0.47±0.32	-0.58±0.54	0.04±0.06

Temporal Uncertainty

- **Temporal uncertainty estimated from PICS data is due to two components: sensor uncertainty and calibration site uncertainty**
- **We can try to decouple the site uncertainty from OLI PICS data by assuming**
  - The components are independent
  - Sensor uncertainty includes the on-board calibrator uncertainties
- **Using 'known' site uncertainties, we can then estimate the L5 TM and L7 ETM+ sensor uncertainties**

Band	Temporal uncertainty (percents)		
	Landsat 8 OLI	Landsat 7 ETM+	Landsat 5 TM
Coastal Aerosol	0.07		
Blue	0.11	0.8	0.8
Green	0.09	0.6	0.3
Red	0.07	0.4	0.2
NIR	0.05	1.8	1.7
SWIR 1	0.04	1.1	
SWIR 2	0.07	2.0	2.7

Summary

- **PICS trends indicate L5 TM to be stable to around 0.15% per year**
  - Absolute gain model in some bands may need a re-visit if more data become available to fill gaps in PICS trends
- **L7 ETM+ is extremely stable, within 0.05% per year across all bands**
- **The stability of OLI is monitored primarily using the on-board lamps and diffusers**
  - After the calibration update, all bands are stable to within 0.05% per year
- **PICS based stability estimates for OLI do not agree well with on-board calibrators and the moon**
  - Differences of ~0.35% per year, on average
  - OLI and ETM+ show similar trends across PICS over the same time period indicating the changes in site behavior rather than the sensors
- **Temporal uncertainties for TM and ETM+ estimated to better than 2% over the instruments' lifetimes**