USGS Report to CEOS WGCV

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Greg Stensaas, USGS, EROS, stensaas@usgs.gov
Tom Cecere, USGS, Reston, tcecere@usgs.gov
Ron Morfitt, USGS EROS, rmorfitt@usgs.gov

Overview

- **Landsat Mission Status**
  - Observatory statuses
  - Instrument performance and cal/val
- **Additional Activities Relating to Cal/Val**
  - GCP improvement
  - PICS Trending
  - Imagery assessments
  - National and Federal Earth Observation Assessment (EOA)
  - Land Product Characterization System (LPCS)
  - Land Surface Imaging – Virtual Constellation (LSI-VC)
- **On-going Work**
- **Future Collaboration**

Landsat 7 Spacecraft Status

≈ 16 years of on-orbit operations

Power Subsystem

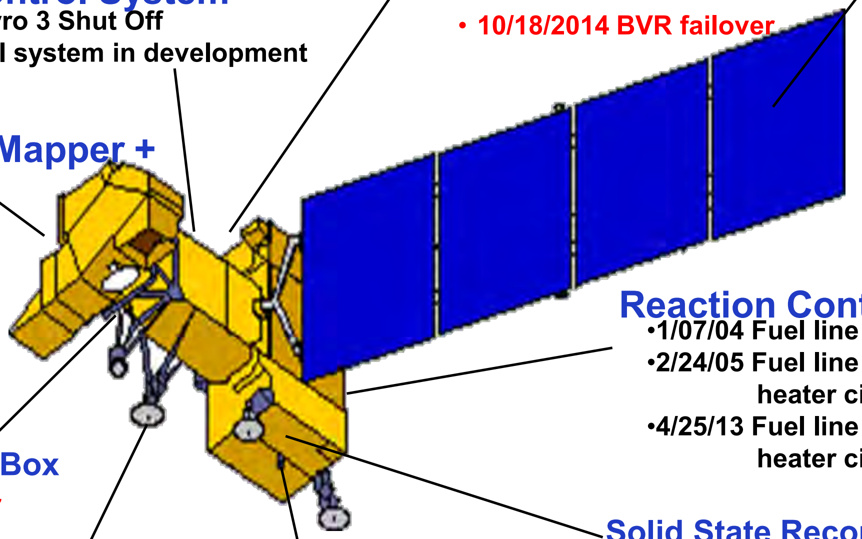
Batteries
Performance nominal

Power Control Unit
- 10/18/2014 BVR failover

Solar Array
- 5/14/2002 Circuit #14 Failure
- 5/16/2005 Circuit # 6 Failure
- 8/13/2008 Circuit #14 partial recovery
- 14 circuits remain operating
- no impact to ops

Attitude Control System
- 05/05/2004 Gyro 3 Shut Off
- 1-gyro control system in development

Enhanced Thematic Mapper +
- 5/31/2003 SLC Failure
- 4/01/2007 Bumper mode



Reaction Control System
- 1/07/04 Fuel line #4 thermostat #1a failure
- 2/24/05 Fuel line #4 thermostat failure; Primary heater circuit disabled
- 4/25/13 Fuel line #2 thermostat failure; Redundant heater circuit disabled

Remote Tlm Cmd (RTC) Box
- 09/27/2014 RTC A Failover

Solid State Recorder
- 11/15/1999 SSR PWA #23 Loss
- 02/11/2001 SSR PWA #12 Loss
- 12/07/2005 SSR PWA #02 Loss
- 08/02/2006 SSR PWA #13 Loss
- 03/28/2008 SSR PWA #22 Loss
- 09/03/2008 SSR PWA #23 Recovered
- 10/12/2013 SSR PWA #11 Loss
- Each PWA is 4% loss of launch capacity
- Boards are likely recoverable

X-band System
Performance nominal

S-band System
Performance nominal

Landsat 8 Spacecraft Status

≈ 2 years of on-orbit operations

Operational Land Imager

RF Communications

S-band System

Thermal Control System

Propulsion Subsystem

Attitude Control System

Electrical Power System

Batteries

Solar array

Thermal Infrared Sensor

- 10/1/2014 - Side-A SSM Encoder

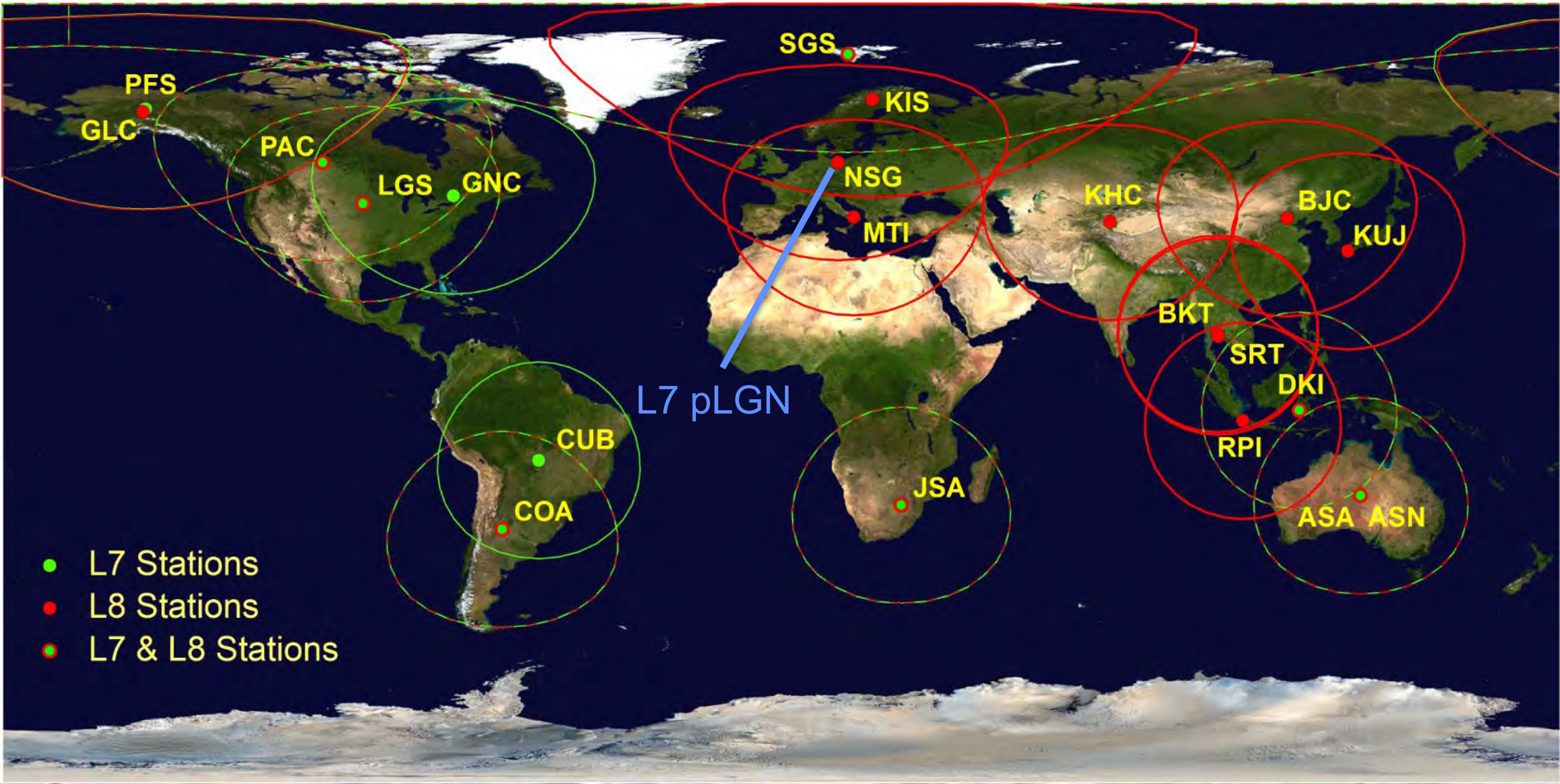
X-band System

Command & Data Handling System

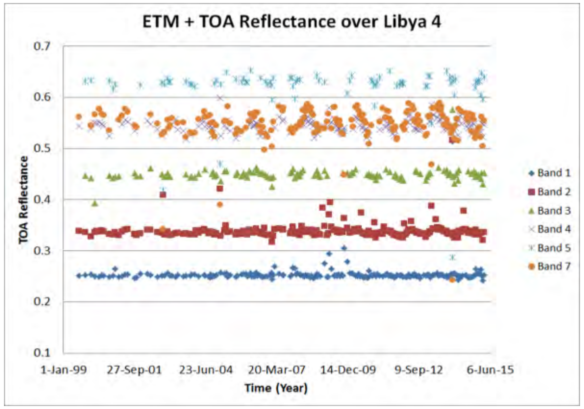
Solid State Recorder

Active Landsat International Ground Stations

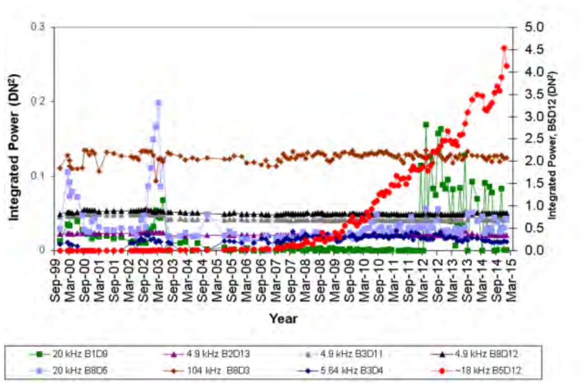
10 Active L7 Stations **17 Active L8 Stations**



Landsat-7 Radiometric Performance



Lifetime TOA reflectance based on PICS stable with seasonal variations

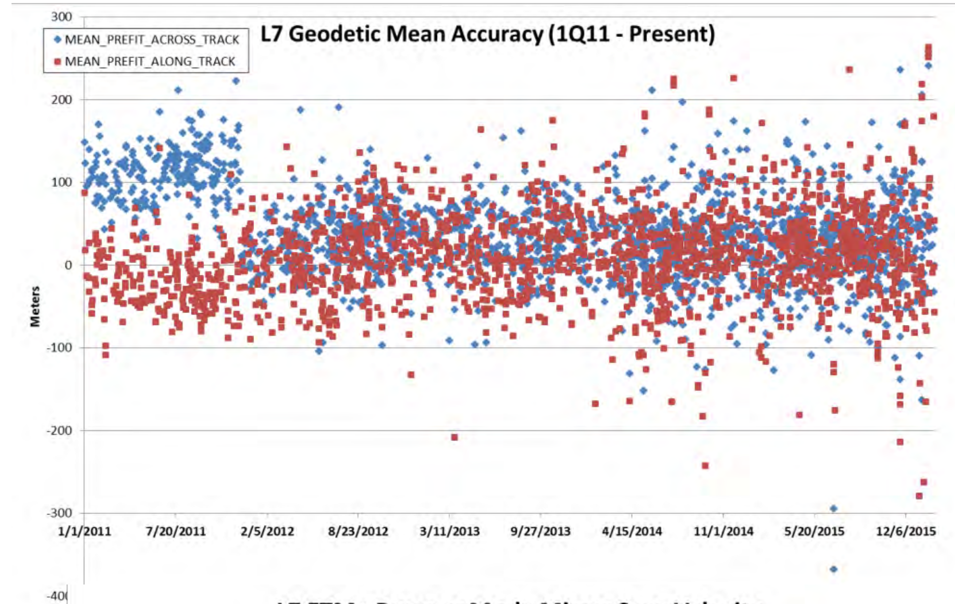


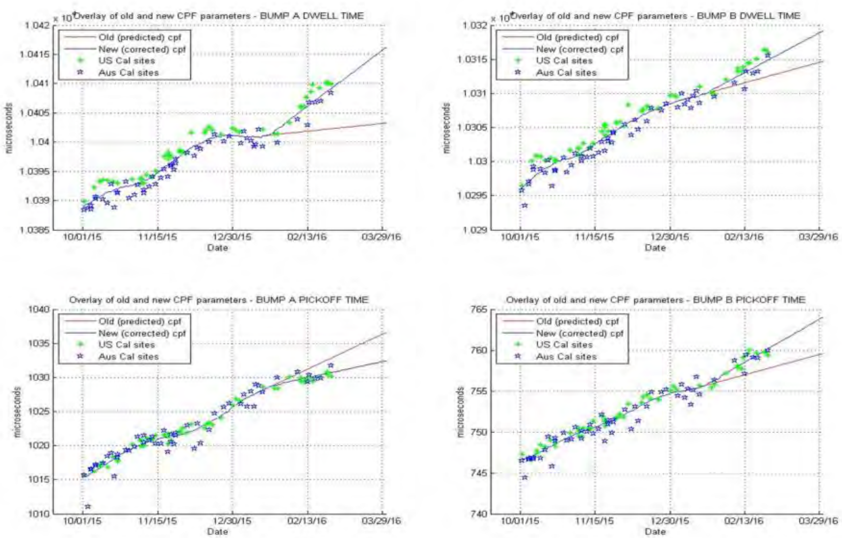
Coherent noise component continues to increase

- **Continuing quarterly ETM+ absolute gain updates**
- **Planning to propagate L8 OLI reflectance based calibration to L1-7**

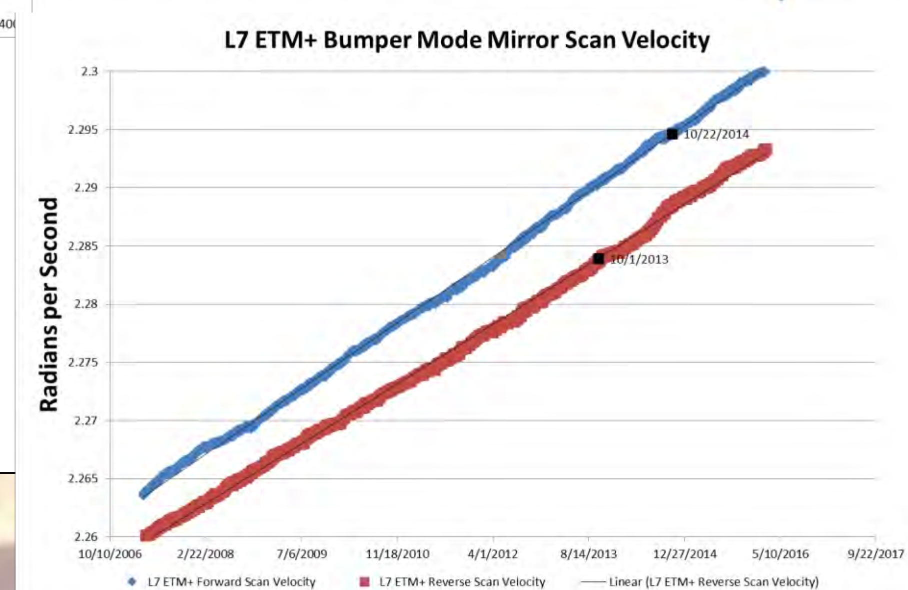
Landsat-7 Geometric Performance

Geodetic accuracy improved since 2012





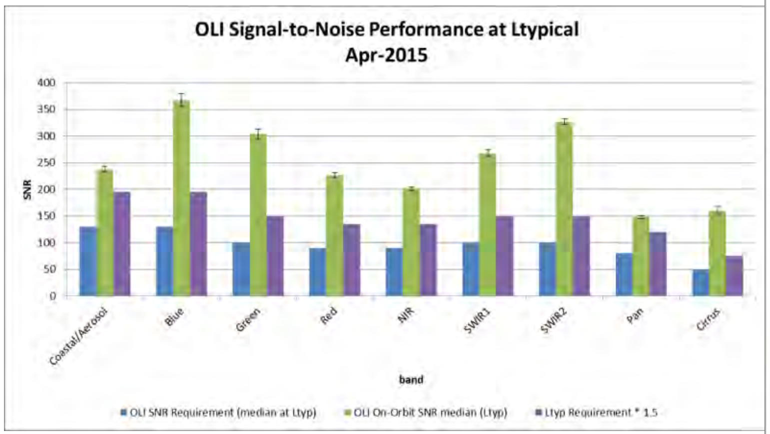
Bumper mode parameters continue to be updated ~2 weeks

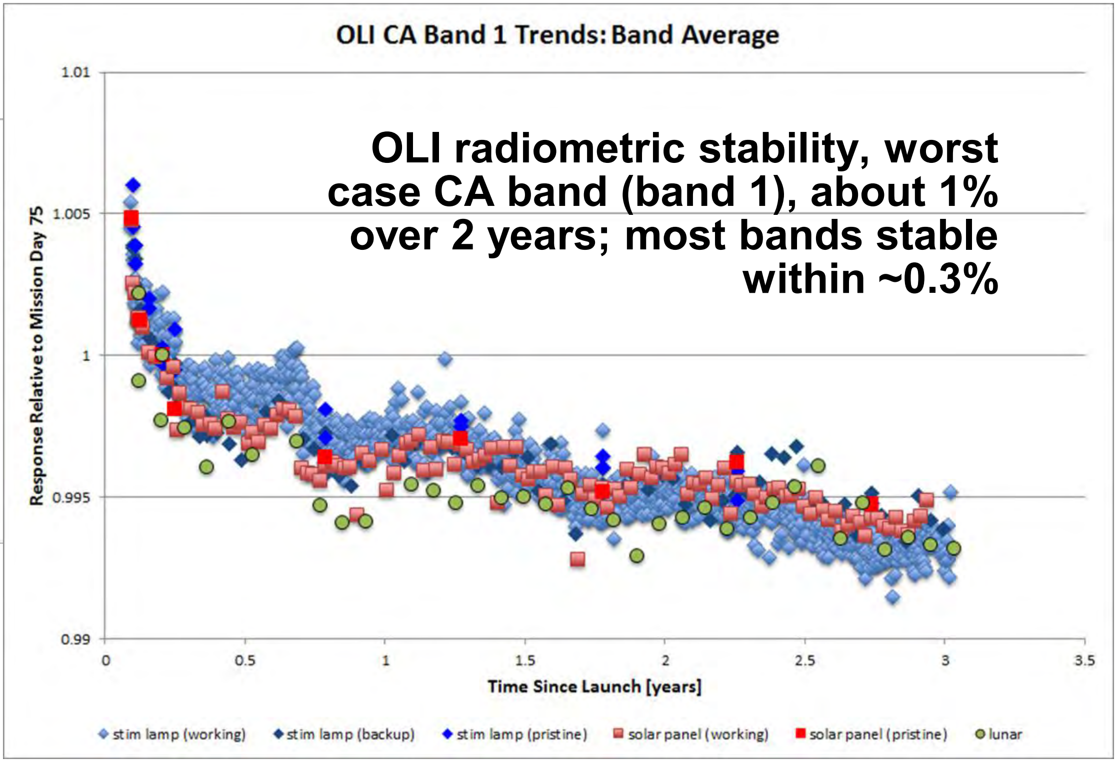


Mirror velocity surpassed Landsat-5 TM velocity

Landsat-8 Radiometric Performance

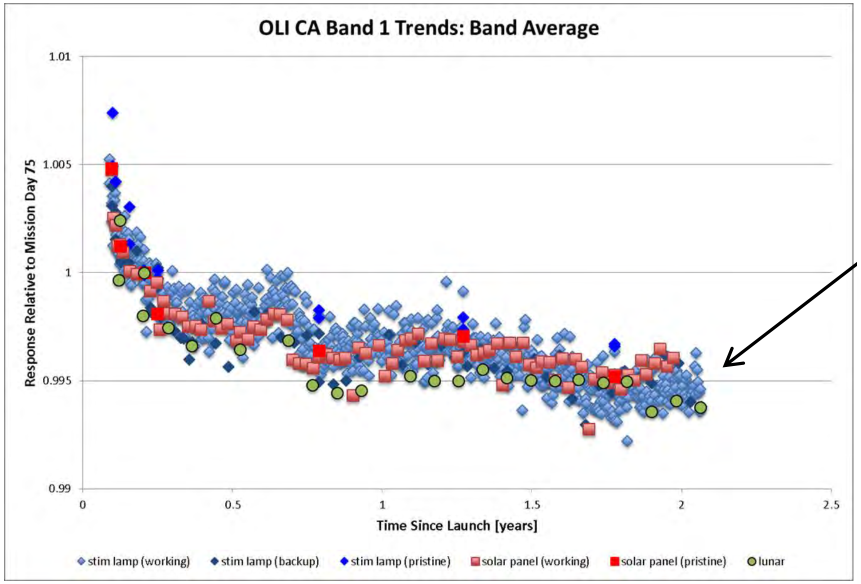
SNR continues to exceed requirements





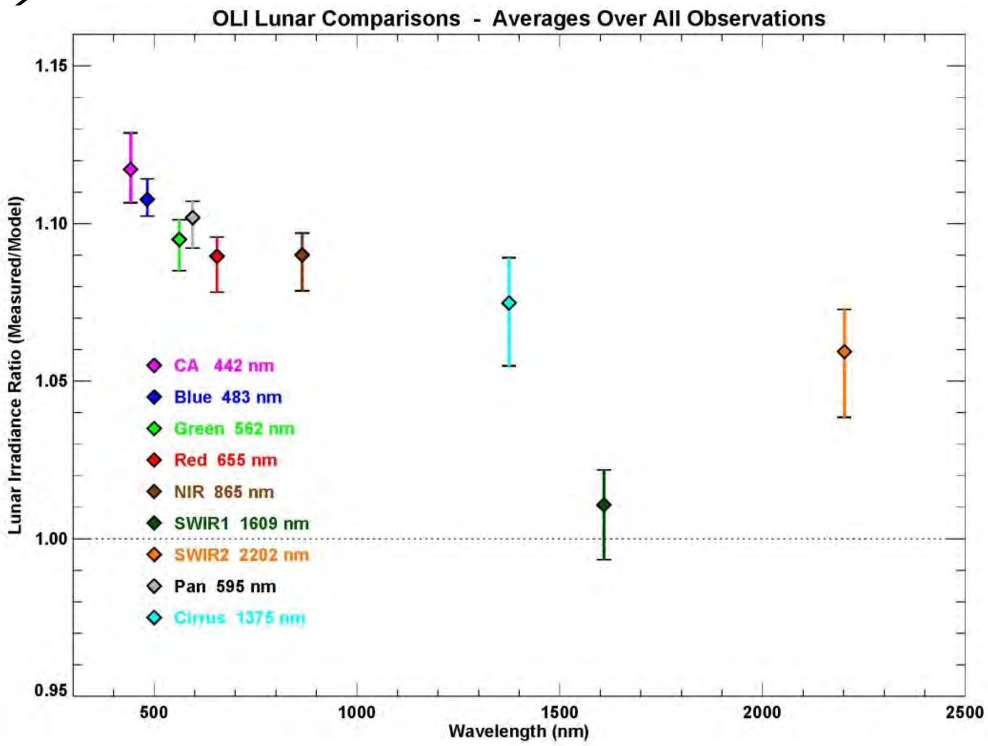
- **Continuing quarterly relative gain updates**
- **Update planned for next reprocessing**
  - Correct for a decay in CA band calibration trend
  - Account for small short-term increase in trends of VNIR bands
- **Reflectance calibration agrees generally to 3-5% with vicarious techniques**
  - Working on transfer of reflectance absolute calibration back to ETM+, TMs and MSS sensors

L8 OLI Lunar Calibration



Lunar trending follows other cal methods

lunar



Absolute offsets are relatively large — cause is being studied

Reflectance based archive Calibration

- **Goal is to transfer L8 OLI reflectance based calibration to other Landsat sensors**
  - New gain parameters have been derived (by SDSU) for L7 ETM+, L5 TM, L4 TM, L5 MSS and L4 MSS
  - Some inconsistencies in L3 MSS calibration need to address to perform reflectance calibration of rest of the MSS sensors

Gains When forced Through 0,g(n,L,λ)						
	Bands1	Band2	Band3	Band4	Band5	Band7
OLI-ETM+	529.02	468.93	497.36	339.86	356.88	376.37
ETM-5TM	783.37	378.51	442.05	366.11	555.81	399.16
5TM -4TM	931.43	416.31	467.5	366.53	565.05	406.71
5TM-5MSS	697.18	535.25	413.17	274.58	NA	NA
5MSS-4MSS	609.32	492.15	397.9	257.1	NA	NA

$$\rho_{8,\lambda} = (M_{8,\rho,\lambda} {}^{*}\, DN_{8,\lambda} + A_{8,\rho,\lambda})/\cos\alpha_8$$

$$\rho_{7,\lambda} = (L_{7,\lambda} {}^{*} g_{7,\text{averaged post launch gain}} / g_{7,L,\lambda})^{*} \frac{d^2{}_7}{\cos\alpha_7}$$

$$\rho_{5,\lambda} = ((L_{5,\lambda} {}^{*} (g_{cpf\_band\_avg} / g_{correctddrift}(t))^{*} g_{5,\text{Normalized gain}}) / g_{5,L,\lambda})^{*} \frac{d^2{}_5}{\cos\alpha_5}$$

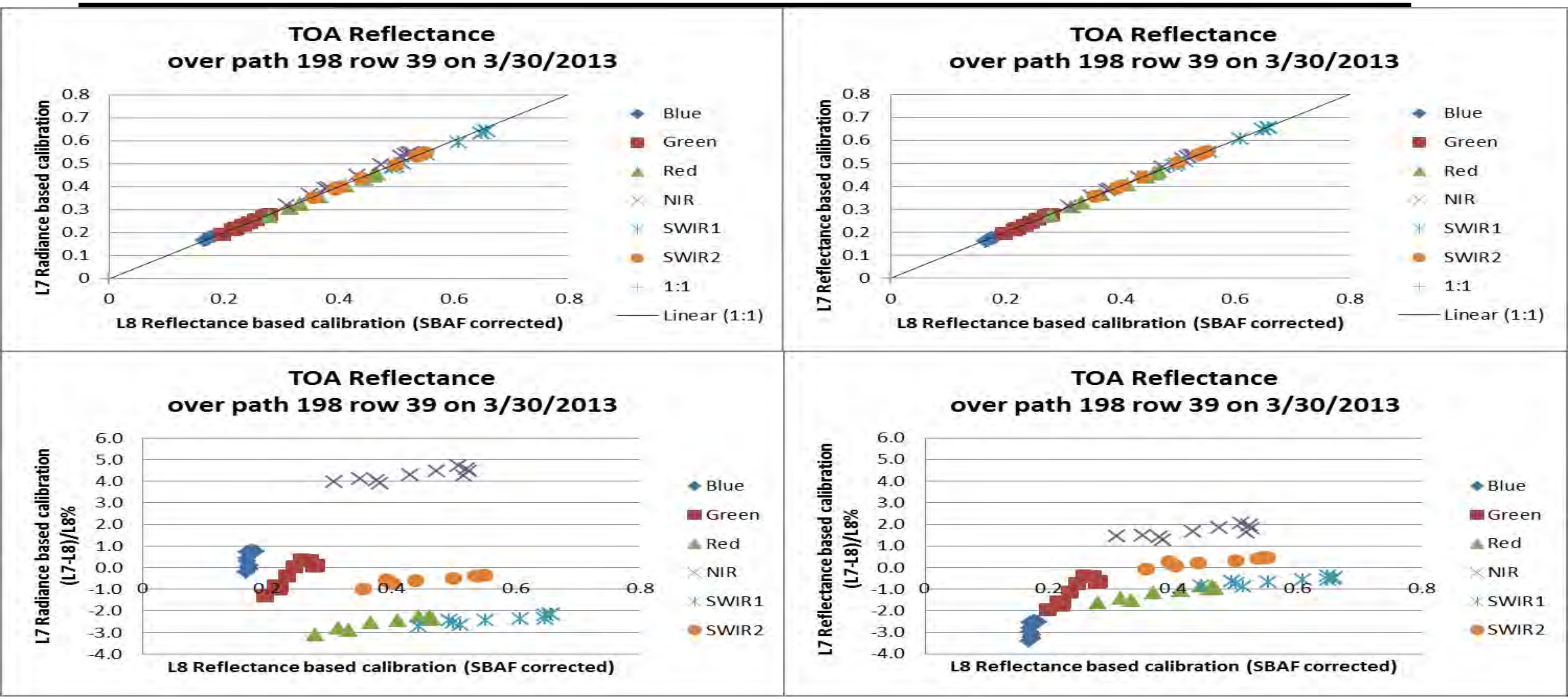
$$\rho_{4TM,\lambda} = ((L_{5,\lambda} {}^{*} (L4TM, CPF\ day1\ launch\ Average\ band\ gains) / g_{4,L,\lambda})^{*} \frac{d^2{}_5}{\cos\alpha_5}$$

$$\rho_{5MSS,\lambda} = ((L_{5MSS,\lambda} / g_{5\text{abs gain}} - \text{bias}) / (g_{5\text{cross cal}} {}^{*} \text{TDF})) / g_{5MSS,L,\lambda} {}^{*} \frac{d^2{}_5 MSS}{\cos\alpha_5 MSS}$$

$$\rho_{4MSS,\lambda} = ((L_{4MSS,\lambda} / g_{4\text{abs gain}} - \text{bias}) / (g_{4\text{cross cal}} {}^{*} \text{TDF})) / g_{4MSS,L,\lambda} {}^{*} \frac{d^2{}_4 MSS}{\cos\alpha_4 MSS}$$

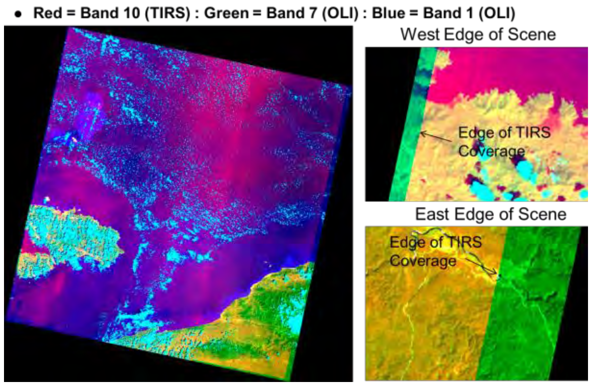
Y-axis: $\rho_{8,\lambda}$, $(SBAF_{\frac{8}{7}} {}^{*} \rho_{7,\lambda})$ $(SBAF_{\frac{8}{5}} {}^{*} \rho_{5,\lambda})$, $(SBAF_{8/4TM} {}^{*} \rho_{4TM,\lambda})$, $(SBAF_{\frac{8}{5MSS}} {}^{*} \rho_{5MSS,\lambda})$, $(SBAF_{\frac{8}{4MSS}} {}^{*} \rho_{4MSS,\lambda})$

Validation of L7 Reflectance Based Calibration

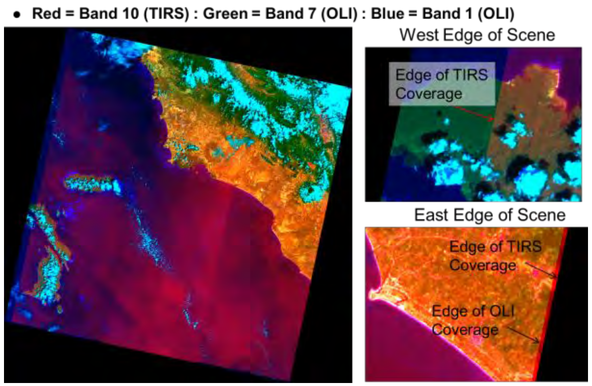


- L7 reflectance agrees better with L8 reflectance
  - Except band 1 and may be band 2
- L7 reflectance of bands 1, 2 and 4 will be darker (maximum in band 1 ~ 3.2%)
- L7 reflectance of bands 3, 5 and 7 will be brighter (maximum in band 5 ~ 1.9%)

TIRS Scene Select Mirror Anomaly



Typical OLI-TIRS alignment

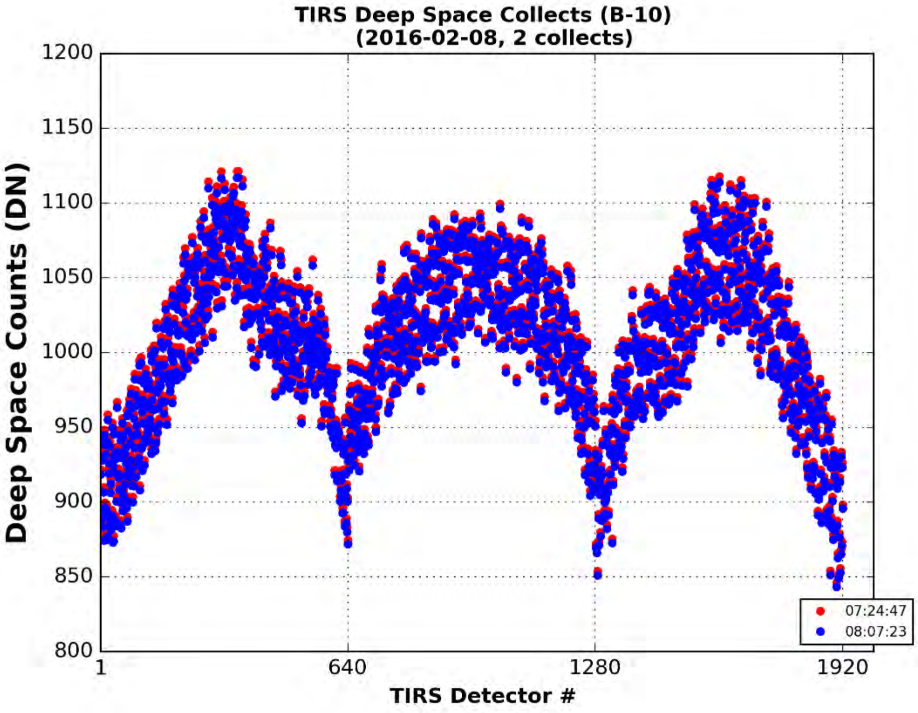


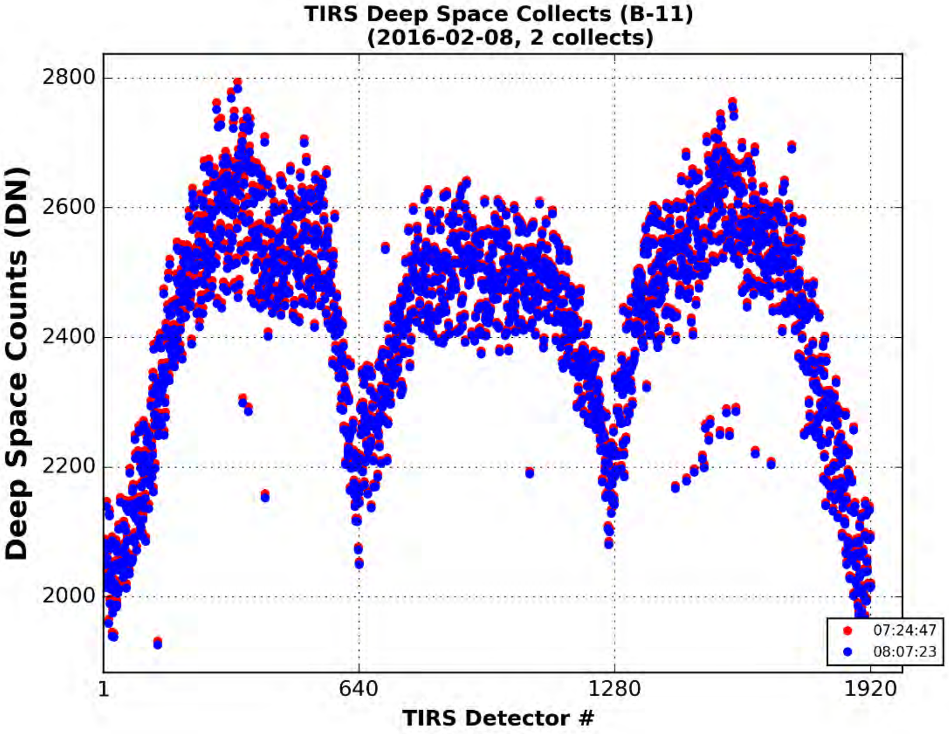
OLI-TIRS alignment without encoder

- **SSM encoder current began increasing Summer/Fall 2014**
- **Reached yellow limit December 19, 2014**
  - Encoder powered down
  - Product generation system couldn't handle no encoder
  - TIRS imagery zeroed through early March
    - Software updated April 23, 2015
- **TIRS electronics switched to side-B March 4, 2015**
- **The TIRS SSM has been operating in mode 0 (mostly) since 29 October 2015.**
  - After the switch to mode 0, the encoder is powered off and provides no further SSM position measurements
- **For subsequent data processing, SSM position is estimated using a model of SSM motion fitted to:**
  - Encoder measurements taken immediately following switch
  - TIRS-to-OLI calibration scene measurements
  - SSM motion is less repeatable than hoped, more telemetry needed

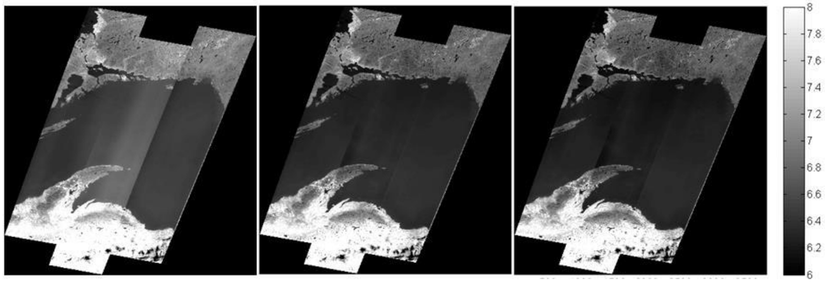
Thermal Cal Trends

- **TIRS is currently operating on Side-B electronics**
- **Deep space and Black Body Cal are acquired every 2 weeks**



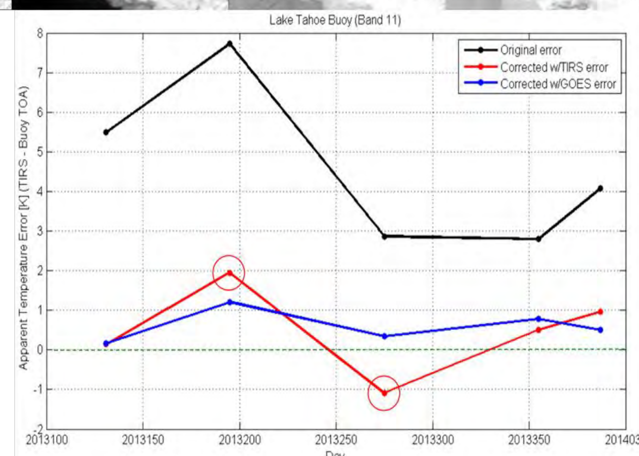


TIRS Stray Light Correction



Original GOES Correction TIRS Correction

- **Model of stray light determined by optical model**
  - Effectively a point spread function for each detector
  - Verified by comparing PSF to special lunar scans



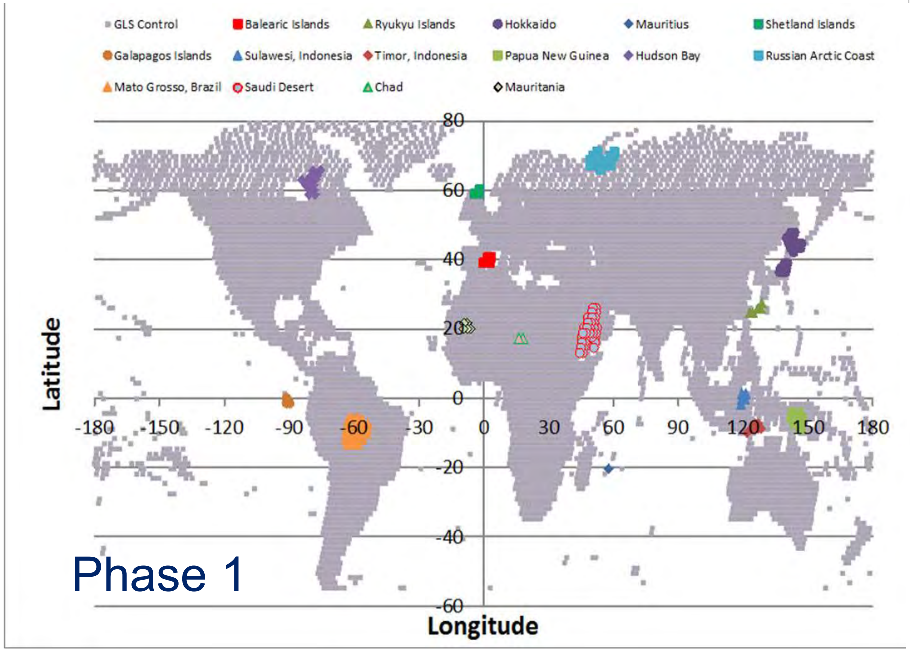
Update on TIRS Stray Light

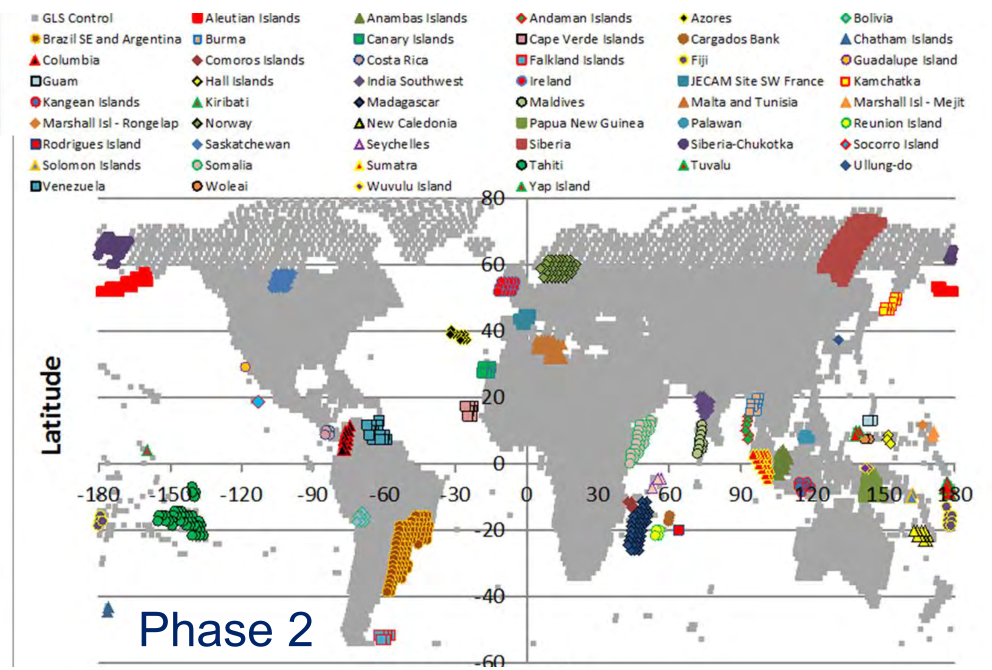
- **Convolving PSF with TIRS imagery, scene before and after, or TIRS nearest pixels; Subtract stray light estimate from TIRS image**
- **TIRS stray light correction algorithm is currently implemented in ST and Cal/Val is validating the algorithm**
- **Last Landsat Science Team meeting and decided to go ahead with the correction implementation**
- **The plan is to implement the algorithm in IAS; Tentatively summer of 2016**

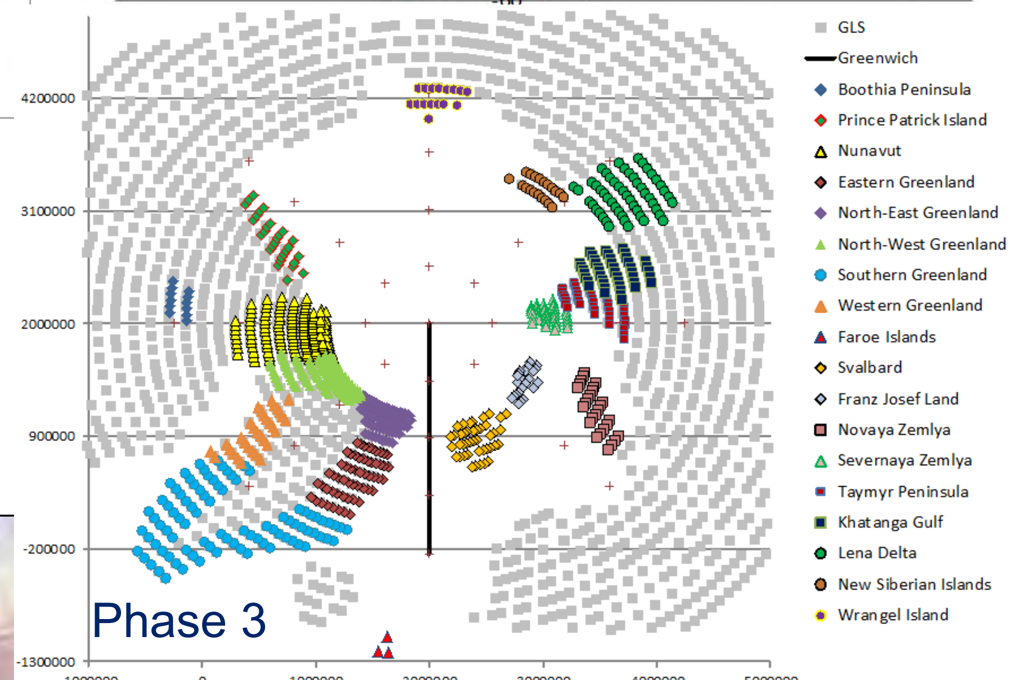
Landsat GCP Improvement Goals

- **L8 geolocation accuracy has identified areas where the GLS-derived global GCP library is deficient**
  - Regions of poor accuracy are being re-triangulated using Landsat 8 data, with new OLI GCPs added where needed
- **Triangulation updates are proceeding in four phases**
  - The first three phases are complete
  - Phase 4 was added to make the GLS control consistent with the Sentinel-2 global reference image base (GRI)
- **The original control library image chips are all Landsat 7 ETM+ (8-bit) circa 2000**
  - Once the triangulation updates are complete, new 16-bit OLI image chips will be extracted for all scenes

GCP Improvement Phase 1-3







- Phase 1: high priority areas completed September 3, 2014
- Phase 2: low latitude areas near completion (54/61 blocks complete)
    - Geosciences Australia requested that we rework several areas that were not on our original problem list to better harmonize the GLS framework with their national imagery database
- Phase 3: high latitude areas complete

USGS

Sentinel-2A Analyses Performed

- **Sentinel-2A MSI L1C data geometric performance was assessed relative to Landsat 8 requirements, not S2A MSI requirements**
  - The MSI L1C data were preprocessed for compatibility with Landsat 8 geometric characterization tools
  - Absolute geolocation accuracy – S2A MSI data could be used in conjunction with Landsat 8 OLI data to improve the accuracy of the GLS ground control point framework. Once the MSI global reference image infrastructure is complete, we will need to investigate methods for harmonizing the MSI and GLS geometric references.
  - Internal geometric accuracy – S2A MSI data exhibit minimal internal distortion. Residual MSI/OLI offsets should be low frequency biases inherited from the GLS framework.
  - Band-to-band registration – S2A MSI L1C band registration appears to be similar to or slightly better than L8 OLI performance, including MSI bands 5, 6, and 7 which have no corresponding OLI band.
- **S2A MSI data will be geometrically consistent and interoperable with L8 OLI data once residual issues with the Landsat GLS control framework (and possibly with the GLS digital elevation model at high latitudes) are resolved.**

Credit: Jim Storey, USGS EROS/SGT

Revised Geometric Reference

- **Proposed global re-triangulation of the GLS (outside Australia) to improve consistency with Sentinel-2 MSI framework.**
  - Sentinel-2 will use a set of global reference images (GRI) to ensure multi-temporal registration.
  - Australian GLS has already been registered to the AGRI reference provided by Geoscience Australia
  - This reference is being established through a series of continental-scale triangulation blocks of MSI data.
- **Schedule will depend upon availability of Sentinel-2 reference images (GRI).**
  - Blocks will be worked as GRI become available but would likely not be released until all are complete.
    - Europe is first with other regions to follow.
    - Timing will depend upon availability of suitably cloud-free MSI imagery.
- **Updates should mostly be subpixel but will still require complete archive reprocessing / new collection when complete.**
  - Timing should work well for coordinated DEM upgrade.

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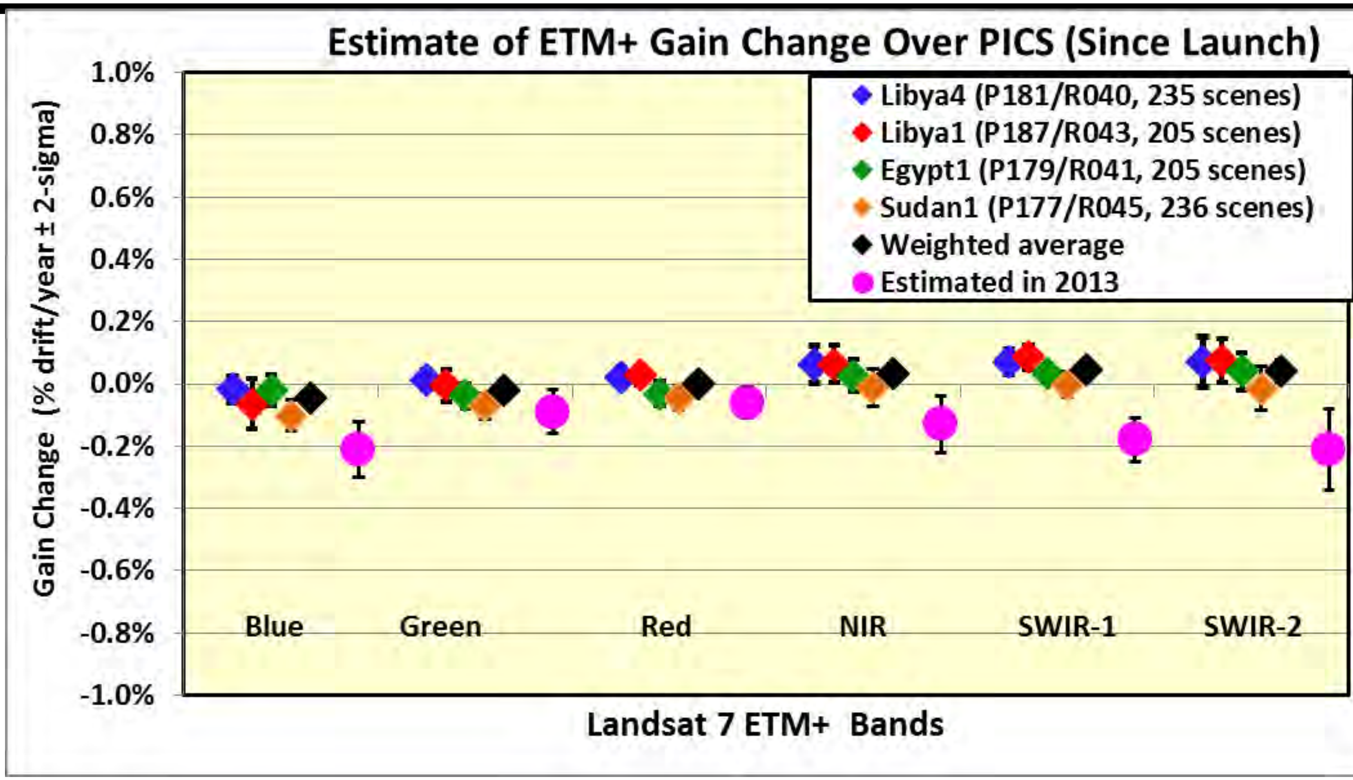
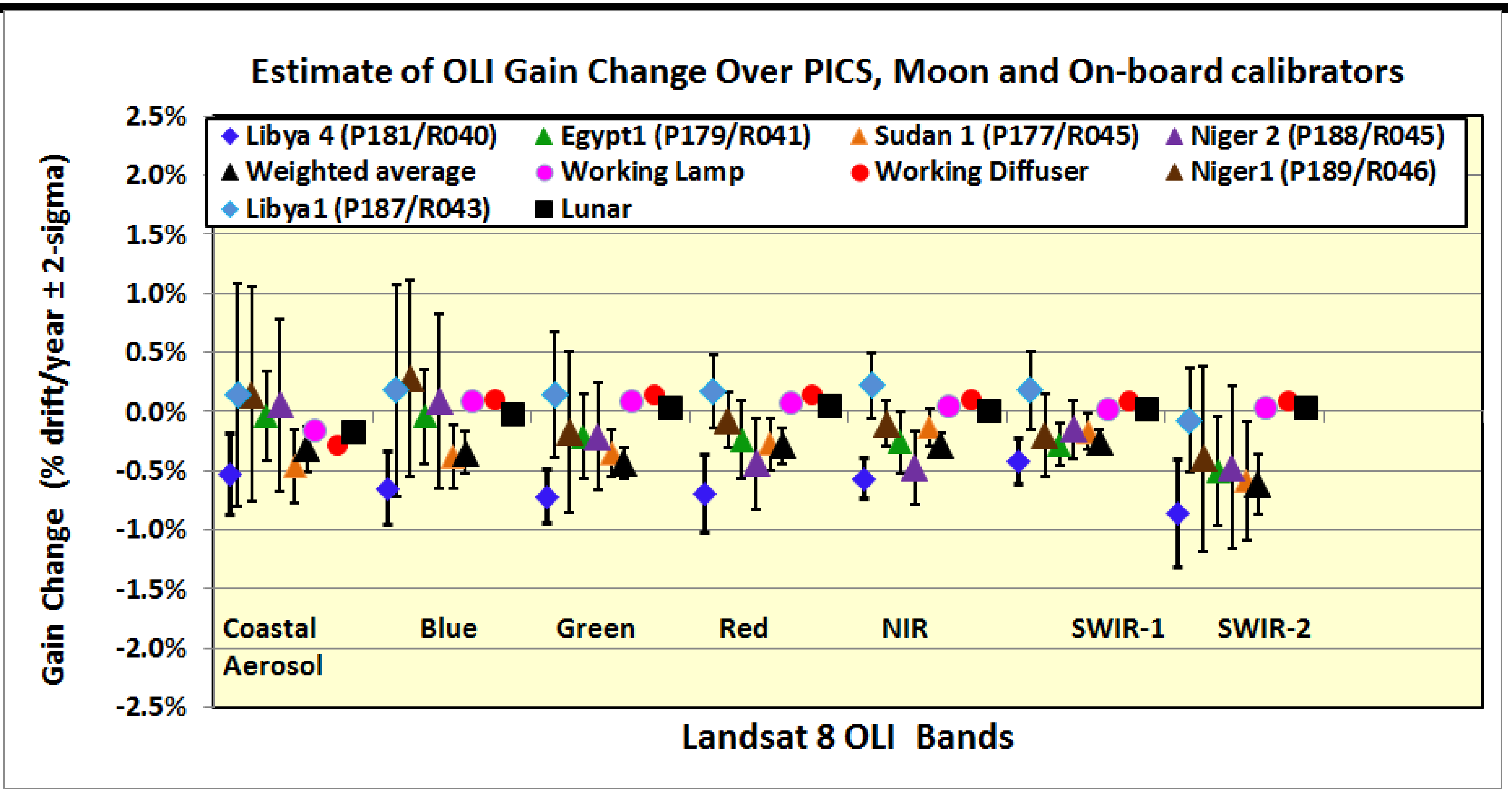
L7 ETM+ Estimated Gain Changes using PICS



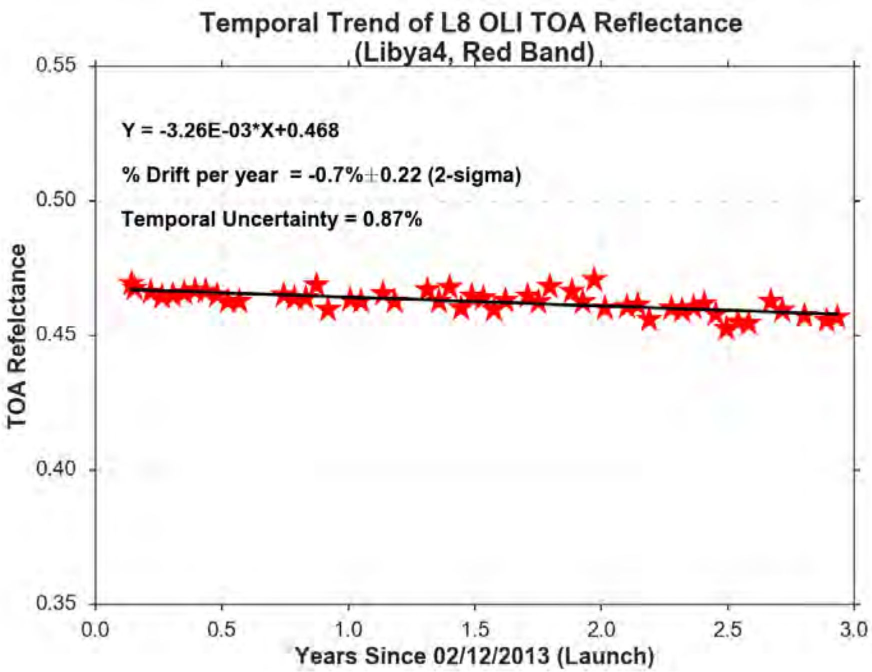
- Across different Sahara PICS, the observed drifts are well within 0.1% per year.
- The weighted average drift shows that the gain change is less than 0.05% per year!

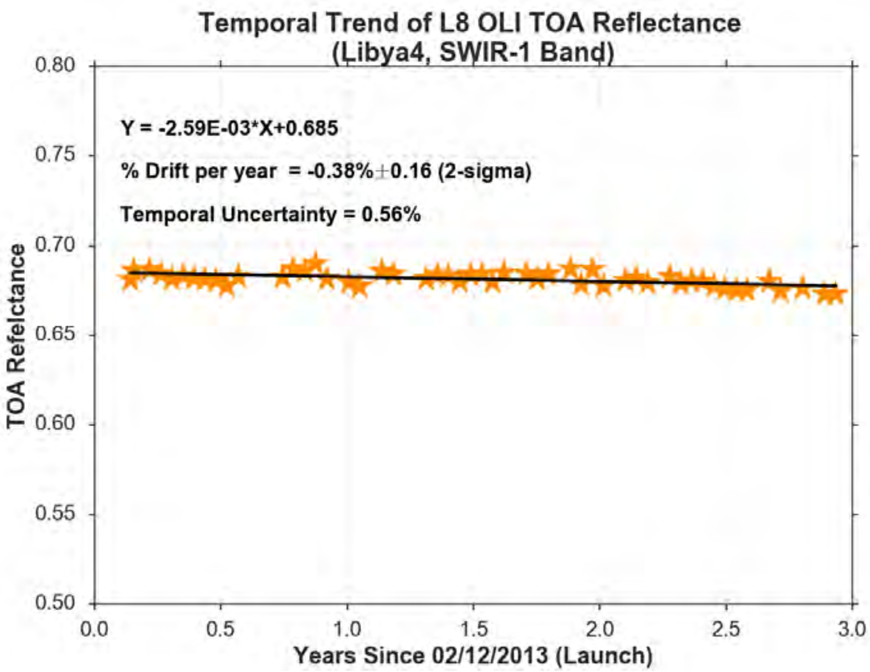
PICS Based Stability



- The plot shows that three years after launch average OLI PICS trends finally agree with on-board calibrators within a half percent.

PICS Trending





- **Libya 4 PICS data suggest possible calibration drifts in all bands**
- **An analysis using ETM+ and MODIS instruments has indicated that the site is probably drifting, not the sensor**

NOAA/USGS Land Product Characterization System

A web-based system that is designed to use moderate- to high-resolution satellite data for the characterization and validation of CEOS-endorsed time series products, including GOES-R ABI, Landsat-8/Sentinel-2, and the Land Science products from MODIS and VIIRS.

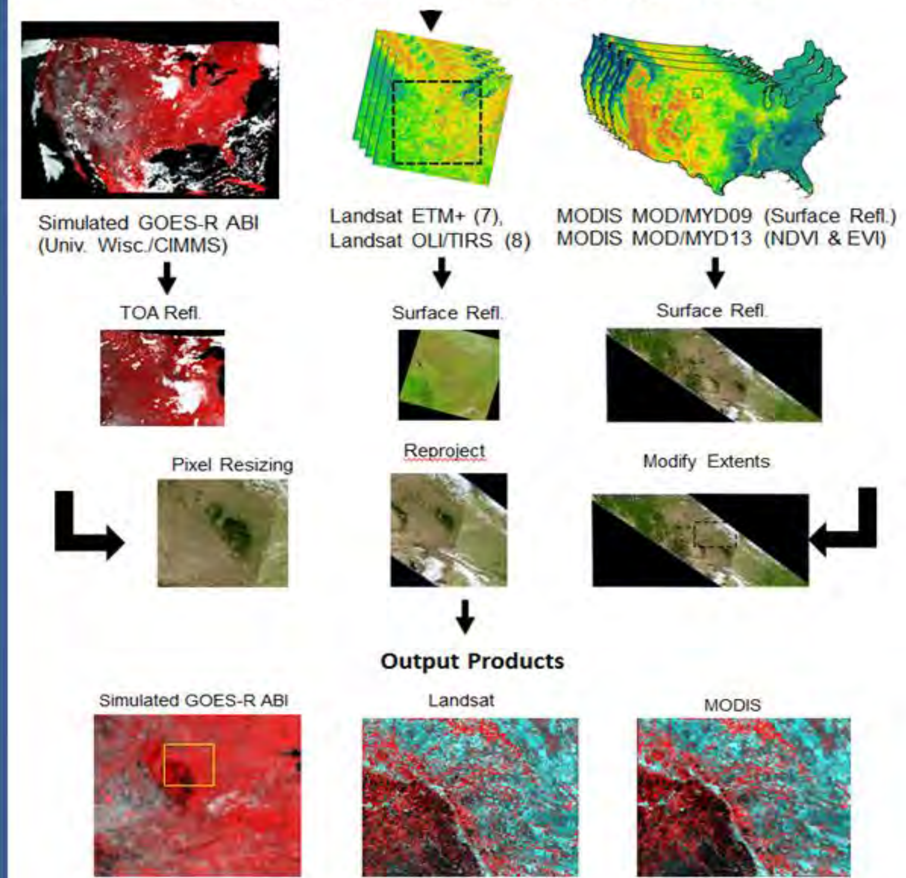
The LPCS includes:

- **data inventory**
- **access and**
- **analysis functions**

that will permit selection of data to be easily identified, retrieved, co-registered, and compared statistically through a single interface.

Kevin Gallo: NOAA/NESDIS/STAR
John Dwyer: USGS/EROS
Greg Stensaas: USGS/EROS
Ryan Longhenry: USGS/EROS

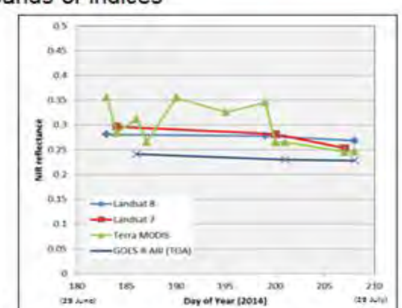
Input Products in Native Projections



Tables and charts of individual bands or indices

	A	B	C	D	E	F	G
1	DATE	DOY	MINIMUM	MAXIMUM	MEAN	STDDEV	VALID
2	7/2/2014	183	854	6850	3562.327	693.2124	yes
3	7/3/2014	184	349	8094	2836.911	495.3851	yes
4	7/5/2014	186	290	6780	3122.295	493.9331	yes
5	7/6/2014	187	308	4667	2653.052	575.2196	yes
6	7/9/2014	190	815	5553	3545.954	658.4303	yes
7	7/14/2014	195	191	7778	3254.757	636.479	yes
8	7/18/2014	199	1253	5621	3455.974	681.7747	yes
9	7/19/2014	200	343	5165	2643.97	393.5894	yes
10	7/20/2014	201	404	8447	2648.748	691.372	yes
11	7/26/2014	207	309	5266	2452.574	376.6008	yes
12	7/27/2014	208	457	4713	2462.386	465.7057	yes
13							

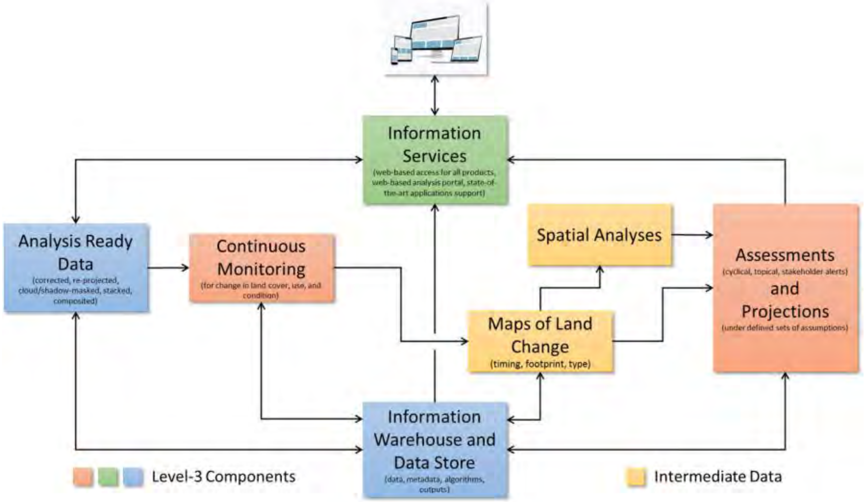
Mean, minimum, maximum, standard deviation

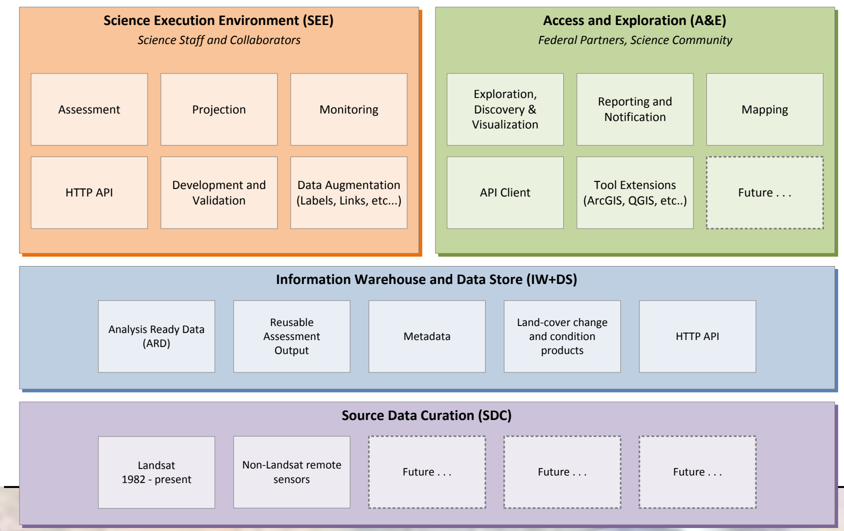


Near-IR time series inter-comparisons

Land Change Monitoring, Assessments and Projections (LCMAP)

- **The EROS LCMAP mission and the science objectives it supports require an architecture that exploits analysis ready data and its derivatives in a highly *distributed, highly scalable execution environment*..**
- **Provide users and science models with direct focused access to a vast amount of ARD.**
- **Assess and project land cover, use, and condition.**
- **Continuously monitor and classify changes.**
- **Support decision making relevant to environmental management and policy.**
- **Enable discovery, access and distribution of information derived by science models through many channels, to many user communities.**





- **series of prototype releases throughout 2016**
- **followed by a series of operational releases in 2017 and beyond.**
- **prototype seeks to validate the science and technology well in advance of the 2017 initial operating capability.**

LCMAP Landsat-based ARD

Figure 3 provides a conceptual data flow for LCMAP Landsat-based ARD. This flow highlights the necessary building blocks and is not intended to provide a map of all components needed to generate the products.

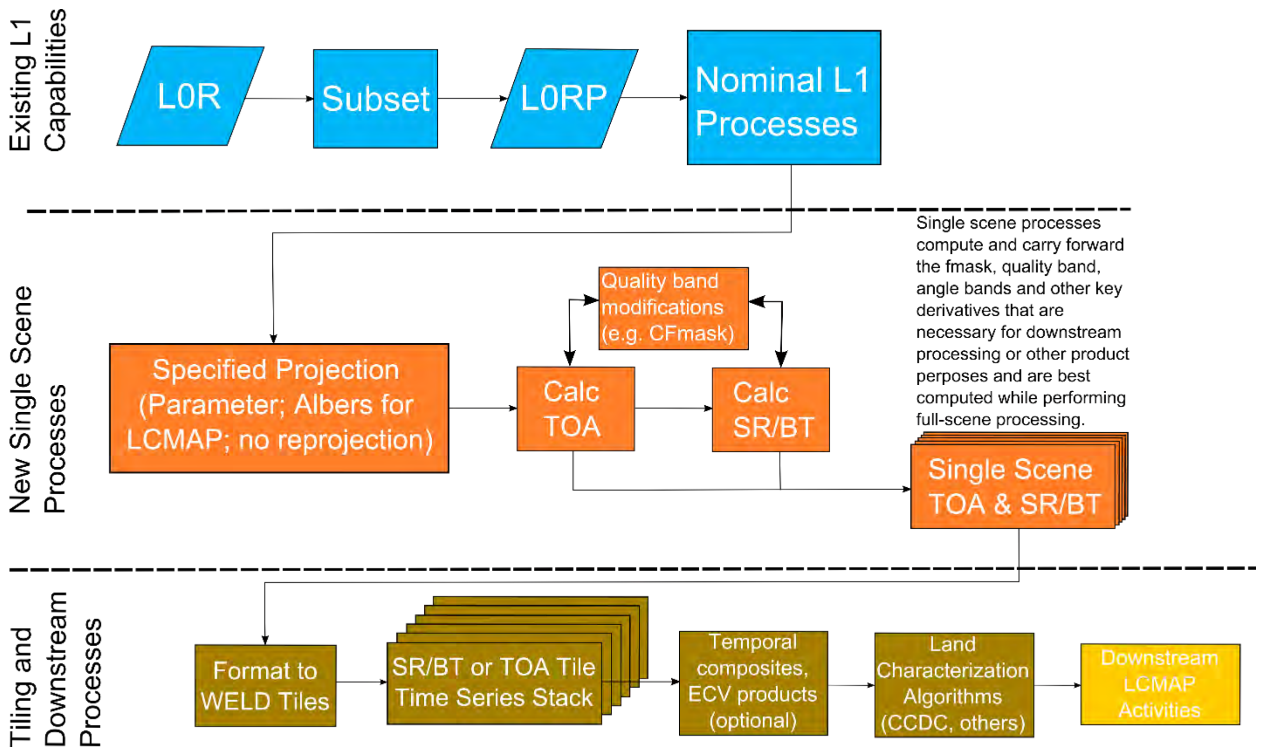


Figure 3 Summary of ARD product flow for LCMAP

ARD Key Product

Key Product	Key Product Attributes
Level-2 Top of Atmosphere Reflectance, Surface Reflectance, and Brightness Temperature	Collection-based with clearly documented version control; consistently calibrated instrument record and standardized retrieval of geophysical parameters with known uncertainties. Contains pixel-level information (QA band) identifying terrain occlusion, radiometric saturation, and the presence of cloud, cloud shadow, snow/ice, and cirrus. Scene level metadata attributes include sun and sensor viewing angles, and definition of sensor, date acquired, and product version.

Geoscience Australia implementation of pixel quality

Figure 2 Geoscience Australia implementation of pixel contiguity, radiometric saturation, land/sea, and topographic shadowing are examples of additional QA attributes that could be added to Level-1 or Level-2 products.

Pixel Quality (PQ) band

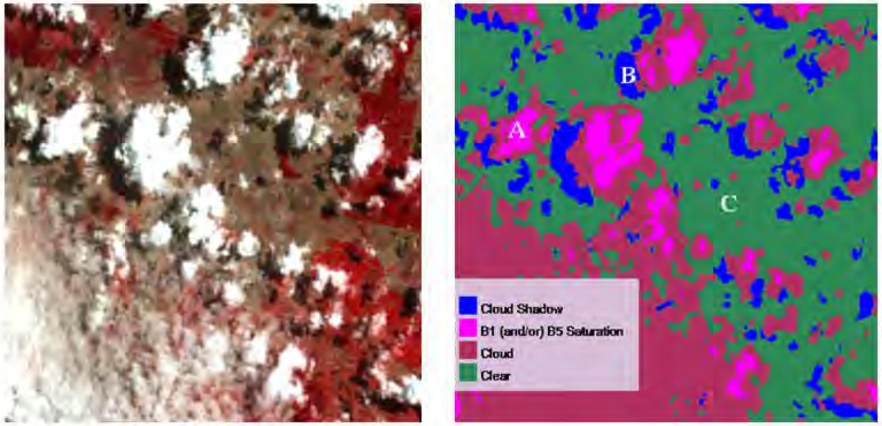
16-bit PQ band

Test	Bit	Value	Cumulative Sum
Saturation band 1	0	1	1
Saturation band 2	1	2	3
Saturation band 3	2	4	7
Saturation band 4	3	8	15
Saturation band 5	4	16	31
Saturation band 61*	5	32	63
Saturation band 62*	6	64	127
Saturation band 7	7	128	255
Contiguity	8	256	511
Land/Sea	9	512	1023
ACCA	10	1024	2047
Fmask	11	2048	4095
Cloud Shadow (ACCA)	12	4096	8191
Cloud Shadow (Fmask)	13	8192	16383
Topographic Shadow *	14	16384	32767
To be determined *	15	32786	65535

* Designed to match Landsat 7 ETM+. The thermal band for Landsat 5 TM will correspond to band 61, and the result is duplicated into band 62.

** Currently not set. A method for calculating topographic shadow has been developed, and will be added to the PQ. A final 16th test has yet to be investigated and developed.

PQ is currently produced for both Landsat 5 TM and Landsat 7 ETM+ L1T products.



False colour (4,3,2 RGB) image and the corresponding PQ band. In this picture all saturated pixels are also cloudy pixels. The binary representation of the cumulative sum indicates a pass (1) or fail (0) for each quality test (reads right to left).

A: 0011001111101110 (13294)
Bands 1 & 5 are saturated; both ACCA and Fmask detected cloud.
B: 0000111111111111 (4095)
Cloud shadow detected, all other tests passed.
C: 0011111111111111 (16383)
Pixel is clear, all tests passed.

ARD Processing Levels in LCMAP

- **In the context of LCMAP, there are three distinct processing levels associated with the generation of ARD**
  - Level-1 processing refers to the generation of the radiometrically calibrated and orthorectified Level-1T data products.
  - Level-2 processing refers to the generation of the ARD with Top of Atmosphere Reflectance, Surface Reflectance, Brightness Temperature, and possibly Surface Temperature being the geophysical units for these products.
  - Level-3 processing refers to temporal composites and science products (burned area, dynamic surface water extent, fraction of snow covered area, spectral indices) derived from the lower levels of ARD.
  - standard definitions for the various processing levels associated with the NASA EOS Program

LCMAP Products Tiers

- **The USGS defined three basic categories of products**
  - NRT (Near-real time) – products that are processed using ancillary data such as predicted ephemeris or bumper mode parameters that may be improved by reprocessing
  - Tier 1 – products that meet the criteria for the collection definition (i.e. enable time-series stacking, <11.9m RMSEr)
  - Tier 2 – products that do not meet the criteria for the collection definition and have been processed using the best known ancillary data

A single collection (i.e. "collection 1") for all sensors (excluding MSS) as opposed to a separate collection per sensor

USGS Imagery Assessments and Activities

- **Assessments**
  - ResourceSat-2 AWiFS-2, VNREDSat-1, KOMPSAT-3, WorldDEM™, PROBA-V, Planet Labs, SkyBox-1 & 2, …, Future assessments: Planet Labs, CBERS-4, KompSat-3A, DMC- follow-on
  - Higher-Level Product Quality Monitoring
- **Joint Agency Commercial Imagery Evaluation (JACIE) Workshop with ASPRS; 40+ papers**
  - April 12-14, 2016, Ft Worth, TX, http://conferences.asprs.org/Fort-Worth-2016/blog
  - http://calval.cr.usgs.gov/satellite-sensor-characterization/rst-presentations-publications/
  - USGS presenting on Sentinel-2, RapidEye, Vricon DEM, Single-photon Lidar
  - Engaged in multi agency assessment of PlanetLabs with NGA and DOD
- **ESA Sentinel-2a**
  - Archive Level 1c products available via USGS Earth Explorer; http://earthexplorer.usgs.gov/
  - Sentinel-2 Geometric/Geodetic Assessment
    - Verifying against L8 standards, S-2 internal geometry is excellent
    - Begin to work with ESA to harmonize/improve GCP framework worldwide
- **ISRO ResourceSat-2**
  - Starting agreement to archive ResourceSat-2 products over the U.S.
- **Land Change Monitoring, Assessments and Projections (LCMAP)**
  - Architecture being built and tested, and Analysis Ready Data definition being worked
- **Working toward Landsat-9 launch (Dec 2020) with NASA GSFC**
- **Landsat 10 planning beginning**
  - Studies: Sensor type, resolution, platform type or types, swath width, coverage, ….,

Requirements Capabilities and Analysis for Earth Observations (RCA-EO)

- Strong partnership between USGS and NOAA for infrastructure development, data sharing, and assessment civil Earth Observation user requirements and capabilities

- Supporting and benefitting from the OSTP National Earth Observation Assessments (EOA)

- Collaborating with DOI and other civil agencies in assessing their needs

http://remotesensing.usgs.gov/rca-eo/

Purpose:

- Support program planning and budget justifications – informed by user needs
- Improve the impact of USGS science and operational products and services
- Quantitative analyses to guide decisions for research investments and technology innovations
- Identify new Earth Observation solutions or capability gaps to better meet user needs

National Earth Observation Assessment

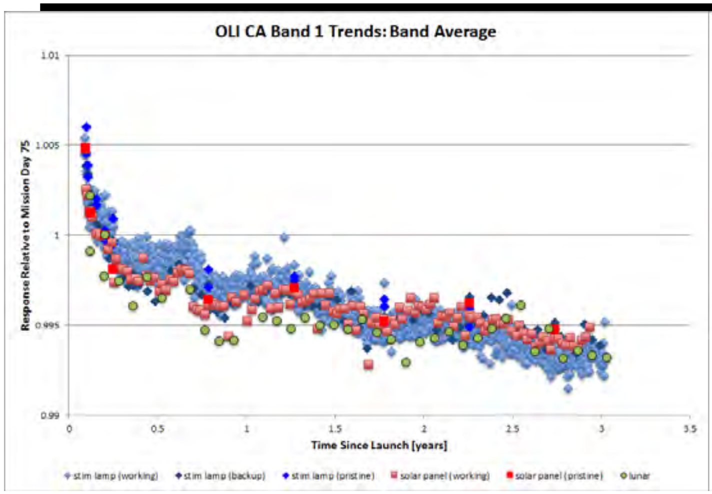
- **National Earth Observation Assessment (EOA 2012)**
  - http://www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/national_plan_for_civil_earth_observations_-_july_2014.pdf
  - Conducted to inform the National Plan for Civil Earth Observations
  - Identified a portfolio of observing systems relied upon by the Federal agencies
  - Provided a cross-cutting and integrated look at observing capabilities (satellite and non-satellite systems)
  - Quantified the impact of those observing systems in delivering societal benefit
- **Second National Earth Observation Assessment (EOA 2016) underway**
  - Refined process to capture details related to impacts and allow analysis of value information
  - Tri-annual National Federal Government assessment
- **Both use an organizing framework for the assessment of 13 Societal Benefit Areas (SBAs) plus Reference Measurements**
  - Reference Measurements include geodesy, bathymetry, topography, geolocation, etc.
  - Agriculture & Forestry, Biodiversity, Climate, Disasters, Ecosystems (Terrestrial & Freshwater), Energy & Mineral Resources, Human Health, Ocean & Coastal Resources & Ecosystems, Space Weather, Transportation, Water Resources, Weather
  - SBA Teams each produced an assessment for their SBA

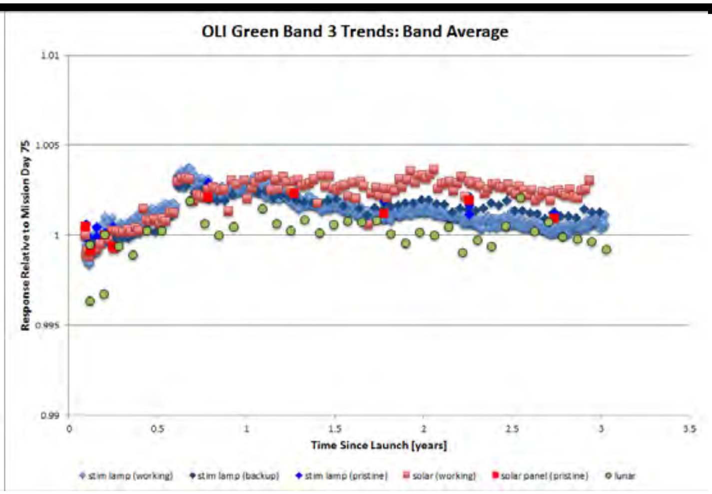
Future Collaboration

- **USGS to become CEOS Chair in November 2017**
  - Supporting SIT, SEC, WGCV, WGISS, WGCapD, WGC, LSI-VC, …
- **Continued support of WGCV subgroups**
  - IVOS has many critical tasks happening
  - Recommend strong coordination with WGC and validation (LPV)
  - USGS supports CEOS WGCV TMSG – Gesch and Danielson
- **Jointly support CEOS efforts**
  - Landsat ground control point improvement effort, and Common DEM
  - Data Quality and Interoperability
    - Common Calibration processes and test sites - RadCalNet and PICS
    - QA4EO process, error / uncertainty / traceability
    - Analysis Ready Data Process and LCMAP
    - LPCS
    - GSICS efforts and Lunar Cal
- **Joint Agency efforts - Cross calibration/comparison, data interoperability**
- **Potential future opportunity to support CEOS Sensor Requirements**

Questions and Back-up

L8 Bands 1- 4


OLI CA Band 1 Trends: Band Average
Response Relative to Mission Day 75
Time Since Launch [years]
stim lamp (working)
stim lamp (backup)
stim lamp (pristine)
solar panel (working)
solar panel (pristine)
lunar


OLI Green Band 3 Trends: Band Average
Response Relative to Mission Day 75
Time Since Launch [years]
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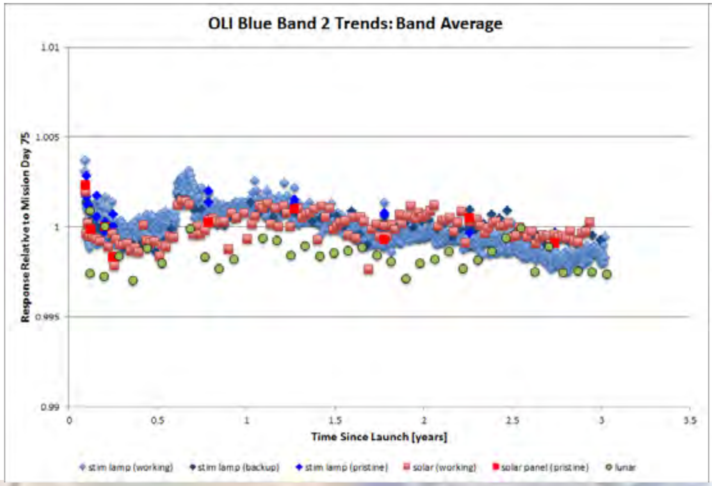
solar panel (pristine)
lunar


OLI Blue Band 2 Trends: Band Average
Response Relative to Mission Day 75
Time Since Launch [years]
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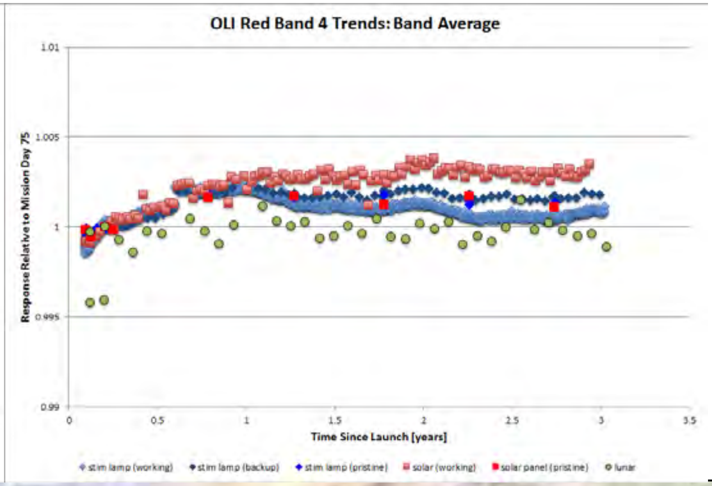
solar panel (pristine)
lunar


OLI Red Band 4 Trends: Band Average
Response Relative to Mission Day 75
Time Since Launch [years]
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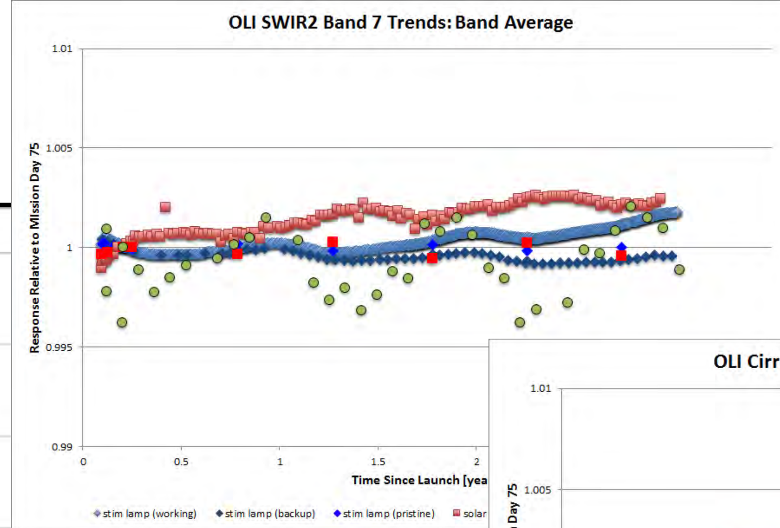
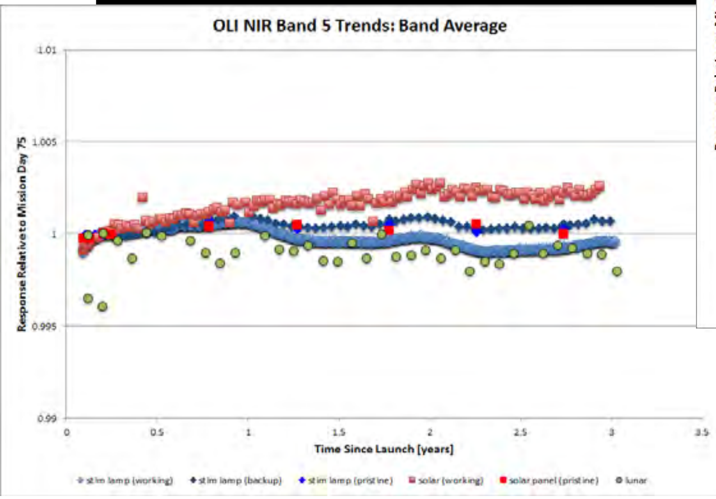
stim lamp (backup)
stim lamp (pristine)
solar (working)
solar panel (pristine)
lunar

L8 Bands 5 - 9


OLI SWIR2 Band 7 Trends: Band Average
Response Relative to Mission Day 75
Time Since Launch [yea
stim lamp (working)
stim lamp (backup)
stim lamp (pristine)
solar


OLI NIR Band 5 Trends: Band Average
Response Relative to Mission Day 75
Time Since Launch [years]
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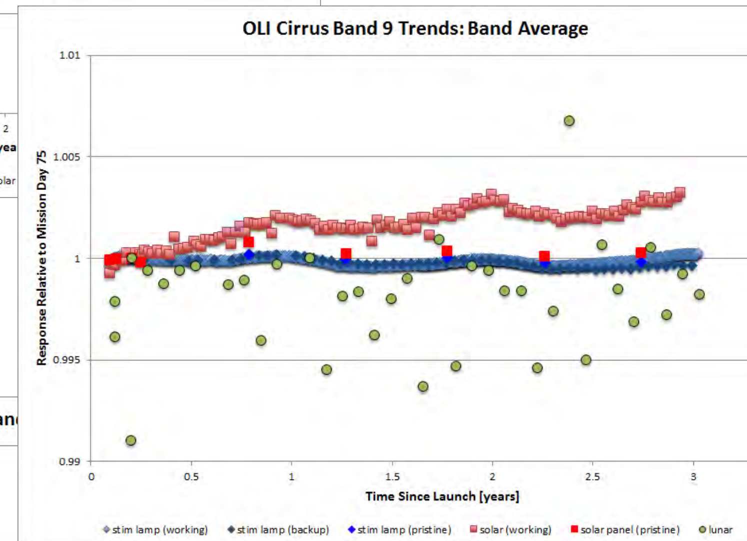
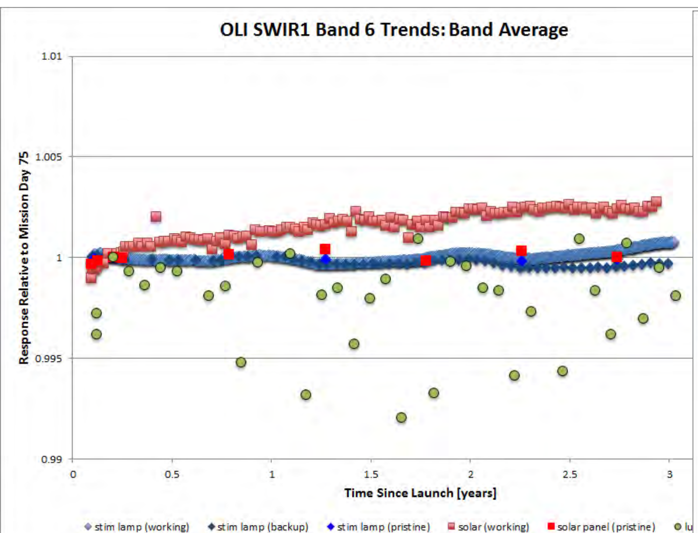
stim lamp (backup)
stim lamp (pristine)
solar (working)
solar panel (pristine)
lunar


OLI Cirrus Band 9 Trends: Band Average
Response Relative to Mission Day 75
Time Since Launch [years]
stim lamp (working)
stim lamp (backup)
stim lamp (pristine)
solar (working)
solar panel (pristine)
lunar


OLI SWIR1 Band 6 Trends: Band Average
Response Relative to Mission Day 75
Time Since Launch [years]
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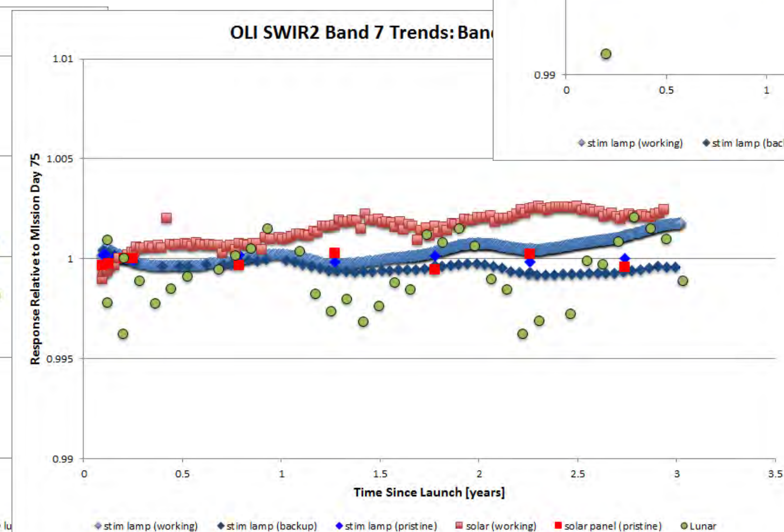
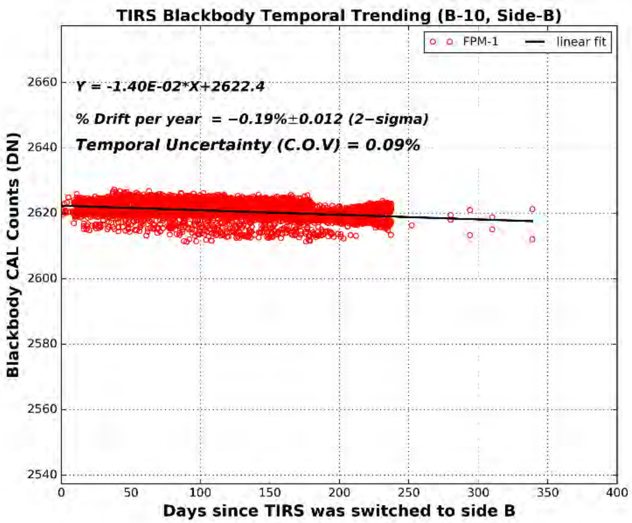
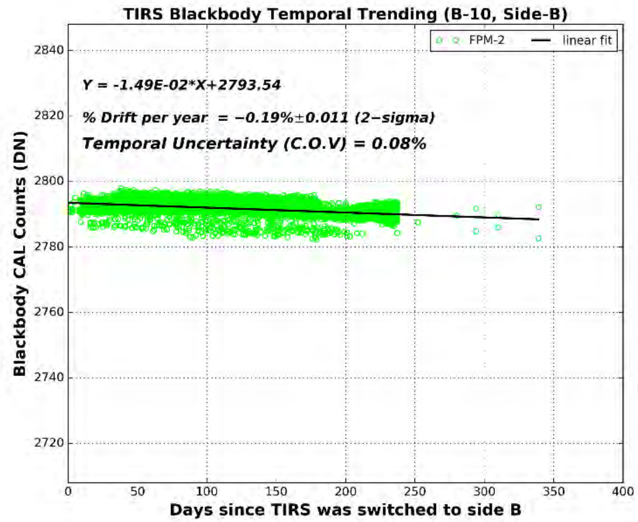
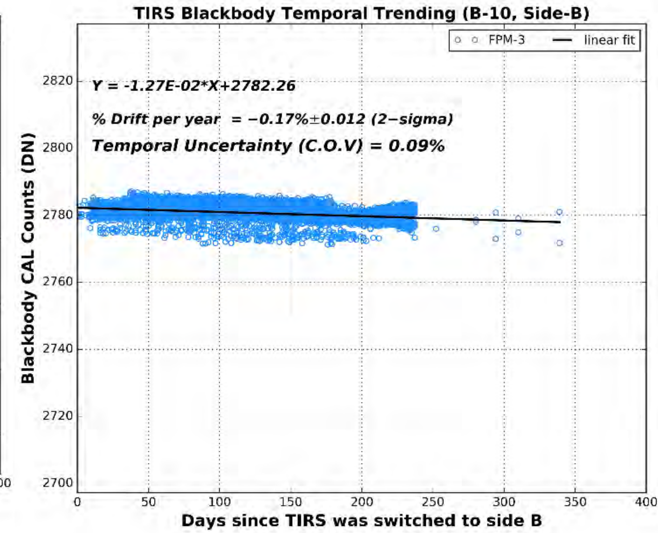
solar panel (pristine)

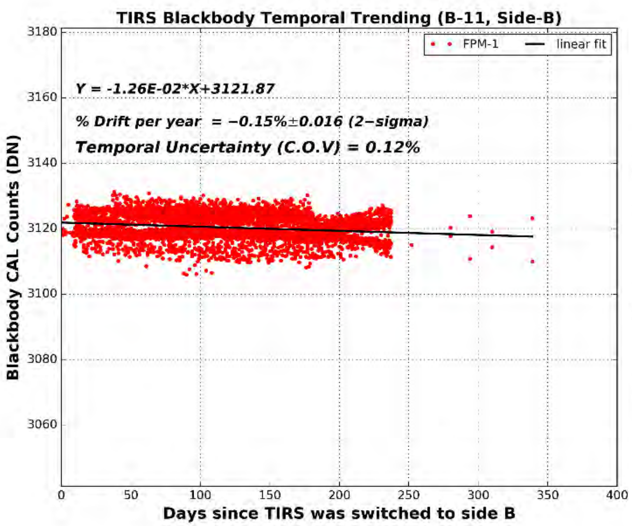

OLI SWIR2 Band 7 Trends: Ban
Response Relative to Mission Day 75
Time Since Launch [years]
stim lamp (working)
stim lamp (backup)
stim lamp (pristine)
solar (working)
solar panel (pristine)
Lunar

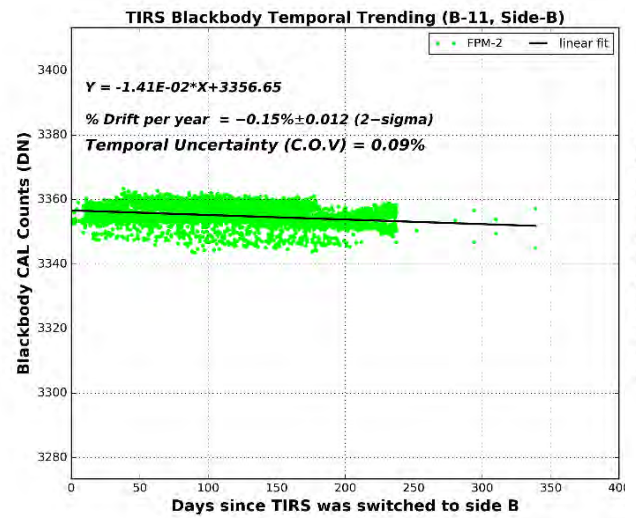
TIRS BB-CAL Stability

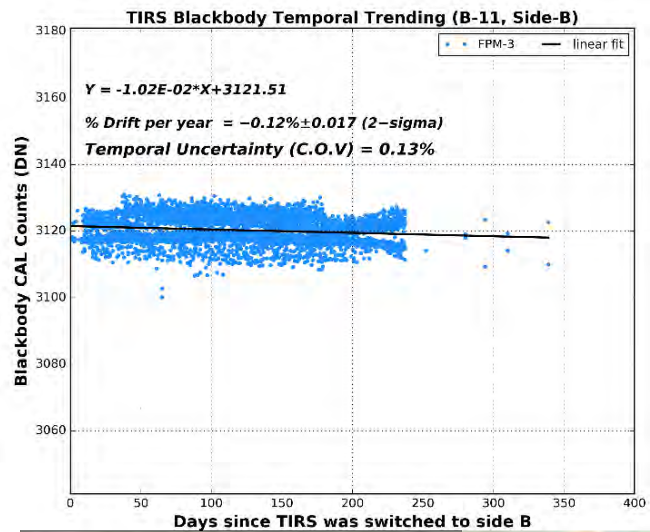




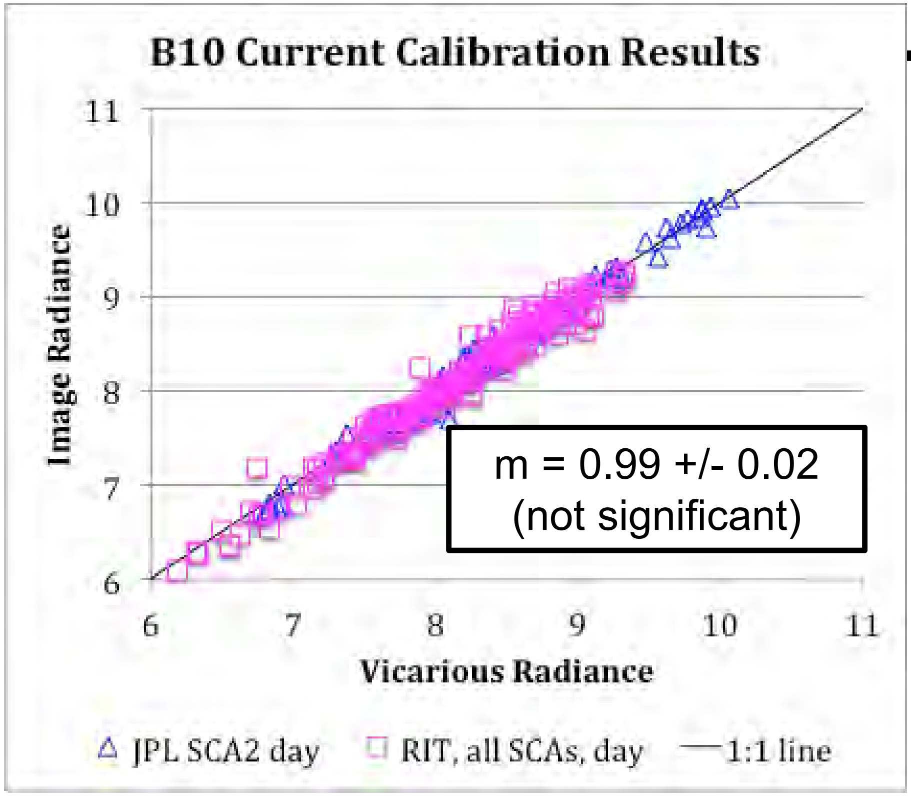


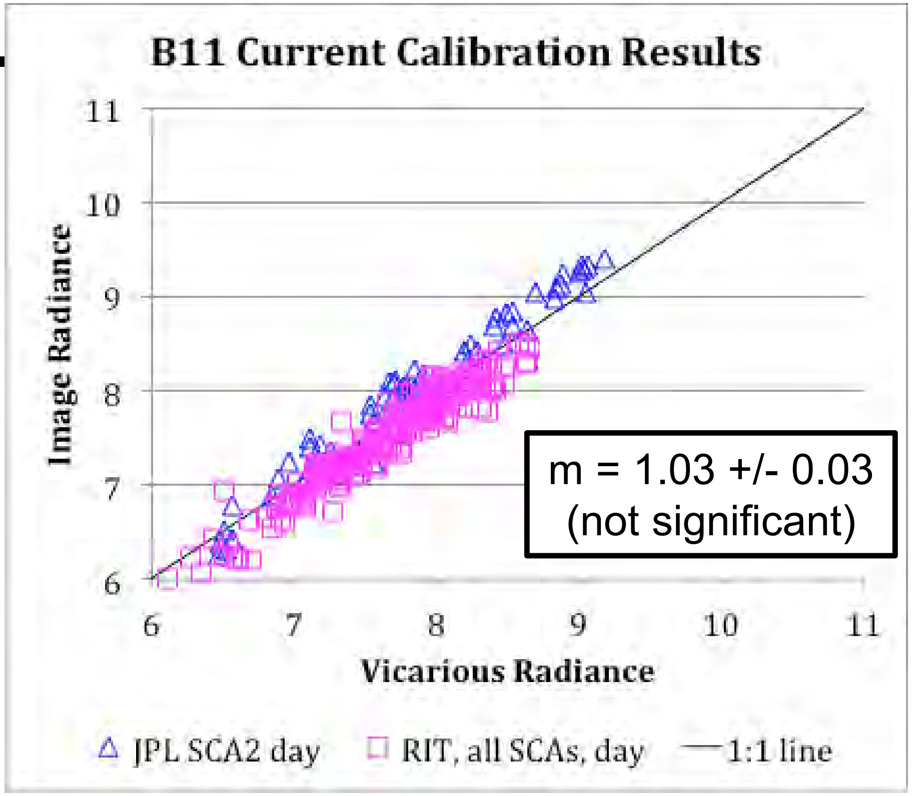






TIRS vicarious Calibration





- **All data here has been processed with the Jan 2014 bias correction**

TIRS Bands	Radiance Offset [W/m²/sr/um]	Temperature Offset [K @ 300K]
10	-0.29 +/- 0.12	-2.1 +/- 0.8
11	-0.51 +/- 0.2	-4.4 +/- 1.75

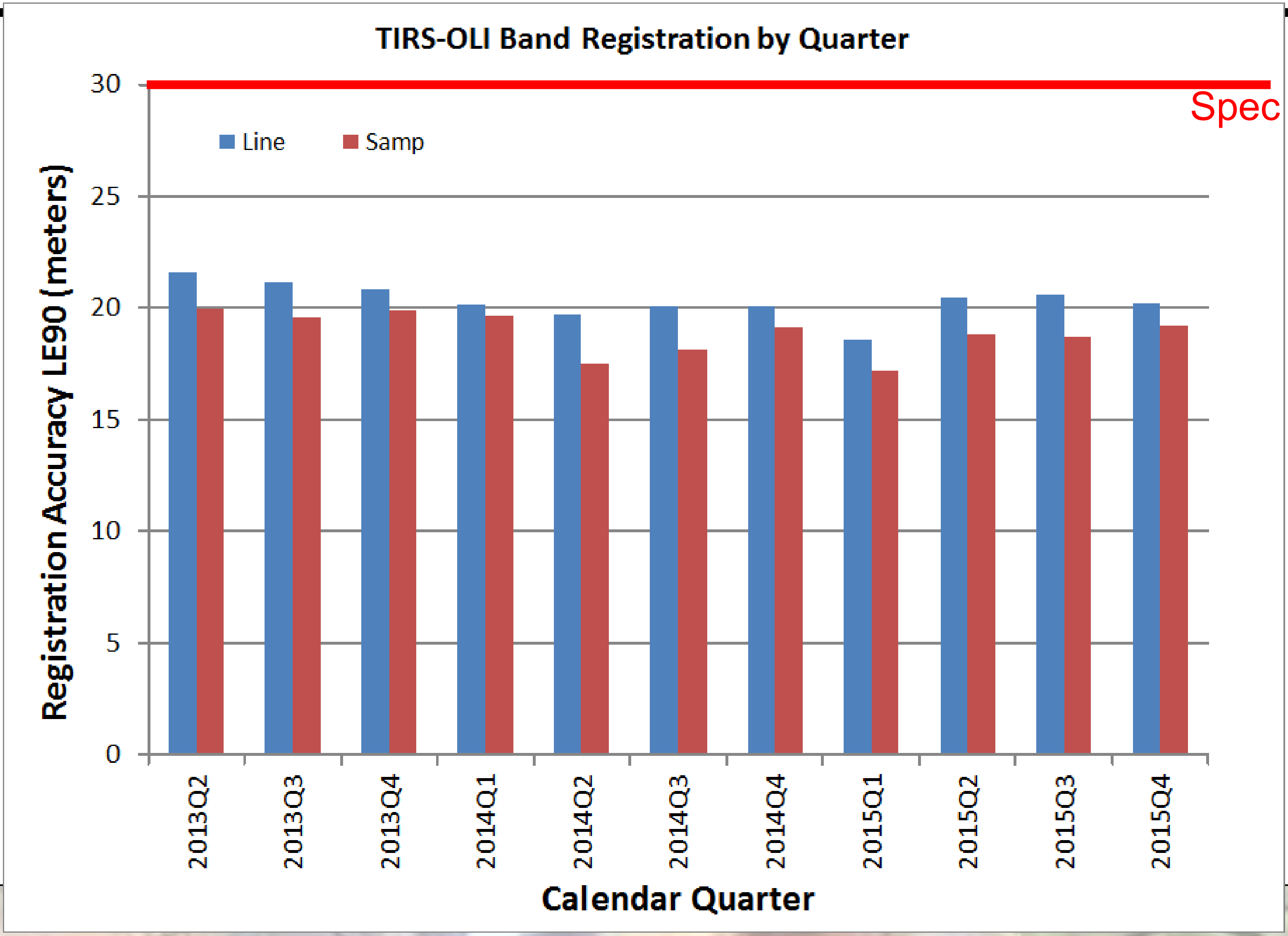
OLI Band Registration Accuracy

- **Band registration accuracy is evaluated using cloud-free scenes of selected (mainly desert) test sites**
- **Results from Earth acquisitions:**
  - 143 non-cirrus Earth scenes (since last MMO)
  - 56 high-altitude Earth scenes for cirrus band assessment (last 12 months)
  - OLI band registration accuracy (worst band pair)
    - Line Direction: 4.48 meters LE90 (with cirrus)
    - Sample Direction: 4.39 meters LE90 (with cirrus)
    - Specification: 4.50 meters LE90
    - Line Direction: 3.15 meters LE90 (no cirrus) (KPR #7)
    - Sample Direction: 3.07 meters LE90 (no cirrus) (KPR #7)
    - Incentive Threshold: 3.80 meters LE90 (KPR #7)

TIRS Band Registration Accuracy

- **TIRS 10.8 μm to 12.0 μm band registration**
  - 19 TIRS test scenes since last MMO (none from 2016)
  - All results are from side B
  - TIRS band registration accuracy
    - Line Direction: 7.8 meters LE90
    - Sample Direction: 8.6 meters LE90
    - Specification: 18.0 meters LE90
- **TIRS to OLI band registration**
  - 19 TIRS-to-OLI test scenes since last MMO (none from 2016)
  - All results are from side B
  - TIRS-to-OLI band registration accuracy (worst band pair)
    - Line Direction: 20.2 meters LE90
    - Sample Direction: 19.6 meters LE90
    - Specification: 30.0 meters LE90

TIRS-OLI Registration by Date



Geodetic Accuracy

- **Geodetic accuracy is evaluated by measuring the offsets between OLI L1G (systematic) images and ground control points (GCPs).**
  - Geometric supersites (DOQ/GPS control) and Global Land Survey anchor sites (NGA control) were used for geodetic accuracy characterization.
- **OLI Geodetic Accuracy based upon 35687 characterization scenes:**
  - Absolute Accuracy: 32.8 meters CE90
  - Last MMO: 34.9 meters CE90
  - Specification: 65.0 meters CE90
  - Relative Accuracy: 18.8 meters CE90
  - Last MMO: 19.7 meters CE90
  - Specification: 25.0 meters CE90
- **Improved accuracy attributed to phase 2 GCP updates.**

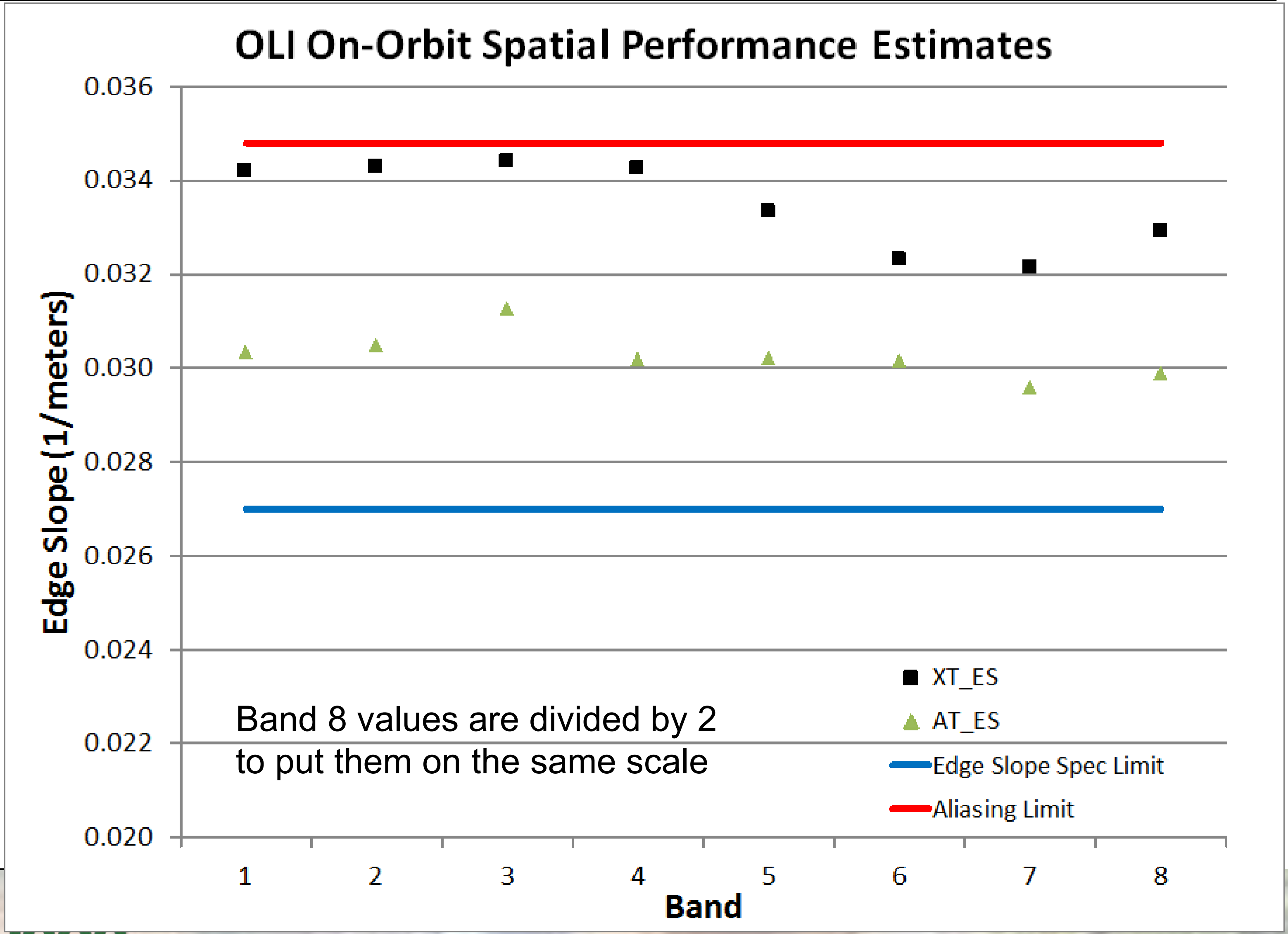
Geometric Accuracy

- **Geometric (Level 1T product) accuracy is evaluated by measuring the accuracy of L1T products using independent validation GCPs**
  - Sites with sufficient GCPs have a subset withheld from the precision correction process to serve as independent validation points
    - Only NGA anchor sites are used for geometric accuracy characterization although the GCP improvement project has shown that the anchor sites are not much better than average
    - Plan to identify a globally distributed set of higher quality sites
- **OLI Geometric Accuracy using all data since commissioning**
- **Based upon 872 calibration site scenes (DOQ control):**
  - L1T Accuracy: 6.8 meters CE90
- **Based upon 25654 anchor site scenes (GLS control):**
  - L1T Accuracy: 11.2 meters CE90
  - Specification: 12.0 meters CE90

OLI Spatial Performance

- **Bridge targets are used to characterize the OLI system transfer function on-orbit**
  - Level 1R image samples are interleaved to construct oversampled bridge profiles
  - Transfer function parameters are varied to make the modeled bridge profile best fit the image profile
  - Best fit model is used to generate spatial parameters
- **Analysis of 419 bridge targets in 187 scenes indicates that OLI is meeting spatial edge slope and half edge extent requirements**
  - All bands well above minimum edge slope requirement (KPR #4)
  - Some bands are close to the upper limit set by the aliasing requirement
    - Both limits are shown on the following plot

OLI Edge Slope By Band



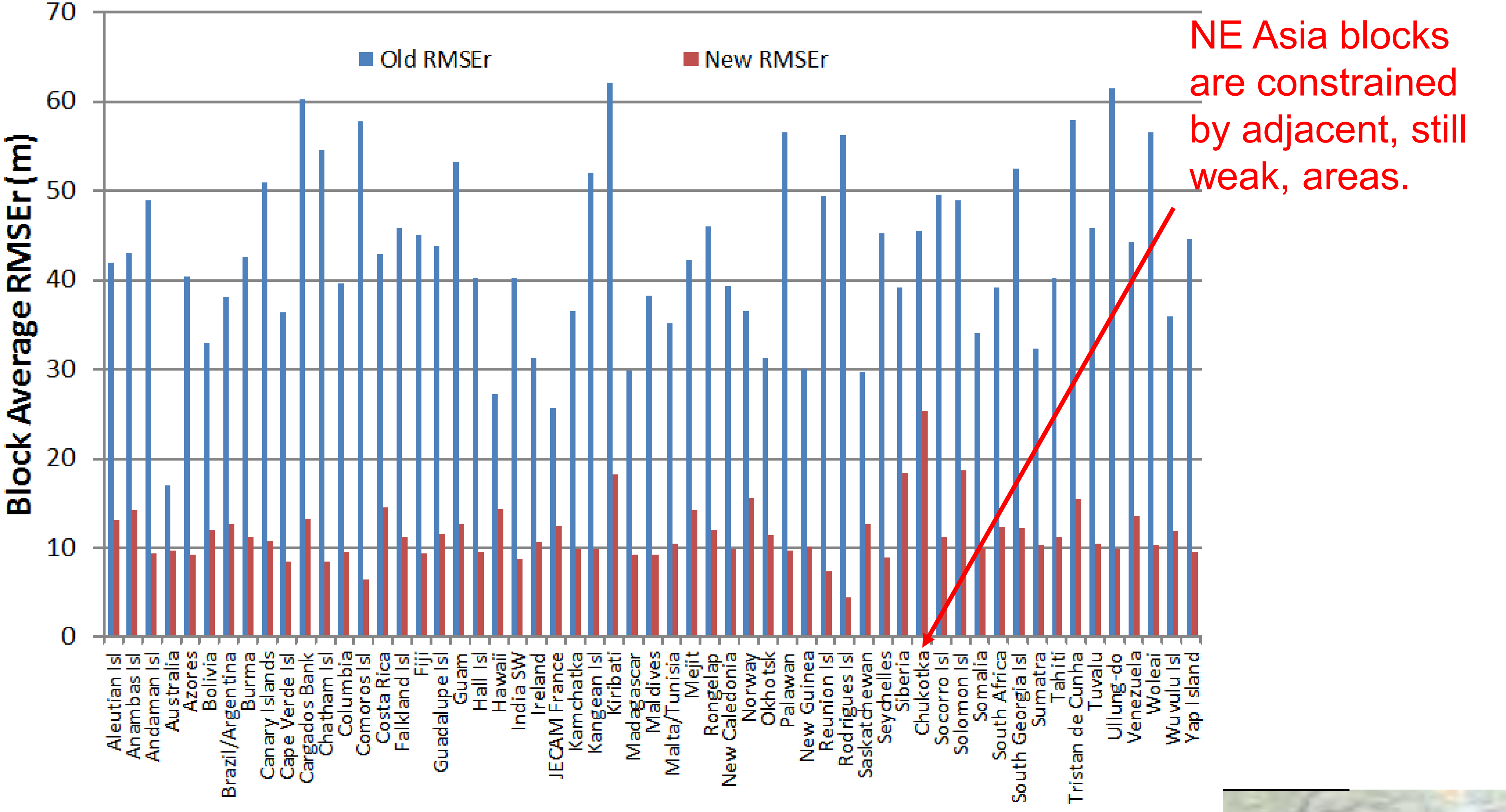
L8 Performance Summary

- **Landsat 8 on-orbit geometric performance is excellent and meets all requirements**

Requirement	Measured Value	Required Value	Units	Margin
OLI Swath	190.2	>185	Kilometers	2.8%
OLI MS Ground Sample Distance	29.934	<30	Meters	0.2%
OLI Pan Ground Sample Distance	14.932	<15	Meters	0.5%
OLI Band Registration Accuracy (all bands)	4.48	<4.5	meters (LE90)	0.4%
OLI Band Registration Accuracy (no cirrus)	3.15	<4.5	meters (LE90)	30.0%
Absolute Geodetic Accuracy	32.8	<65	meters (CE90)	49.5%
Relative Geodetic Accuracy	18.8	<25	meters (CE90)	24.8%
Geometric (L1T) Accuracy	11.2	<12	meters (CE90)	6.7%
OLI Edge Slope	0.02958	>0.027	1/meters	9.6%
TIRS Swath	185.9	>185	Kilometers	0.5%
TIRS Ground Sample Distance	103.424	<120	Meters	13.8%
TIRS Band Registration Accuracy	8.6	<18	meters (LE90)	52.2%
TIRS-to-OLI Registration Accuracy	20.2	<30	meters (LE90)	32.7%

Phase 2 Before and After

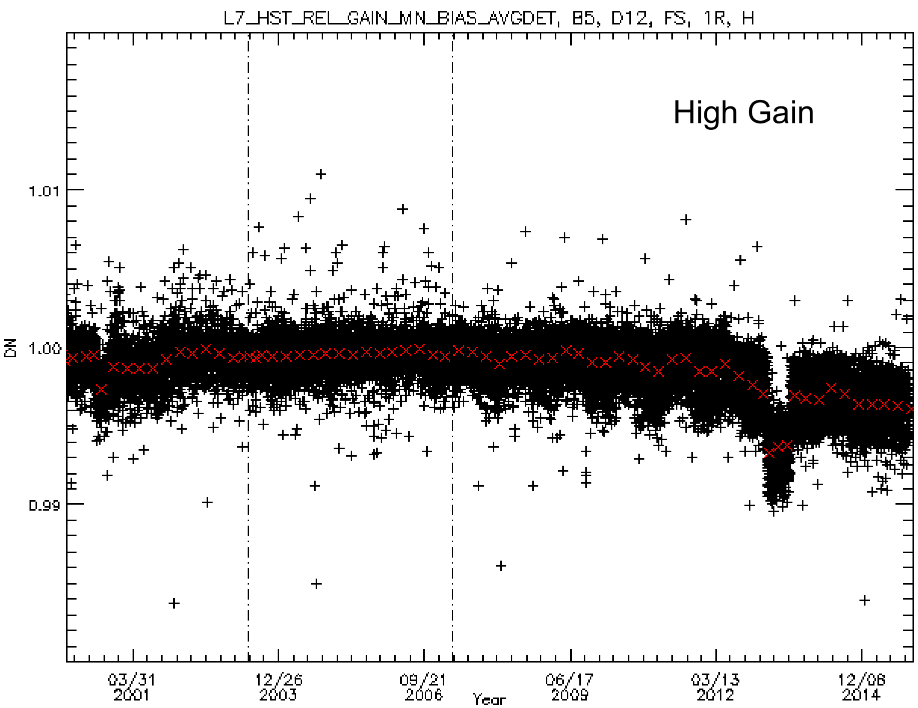
- **All blocks now meet GLS specification of 25m RMSEr**

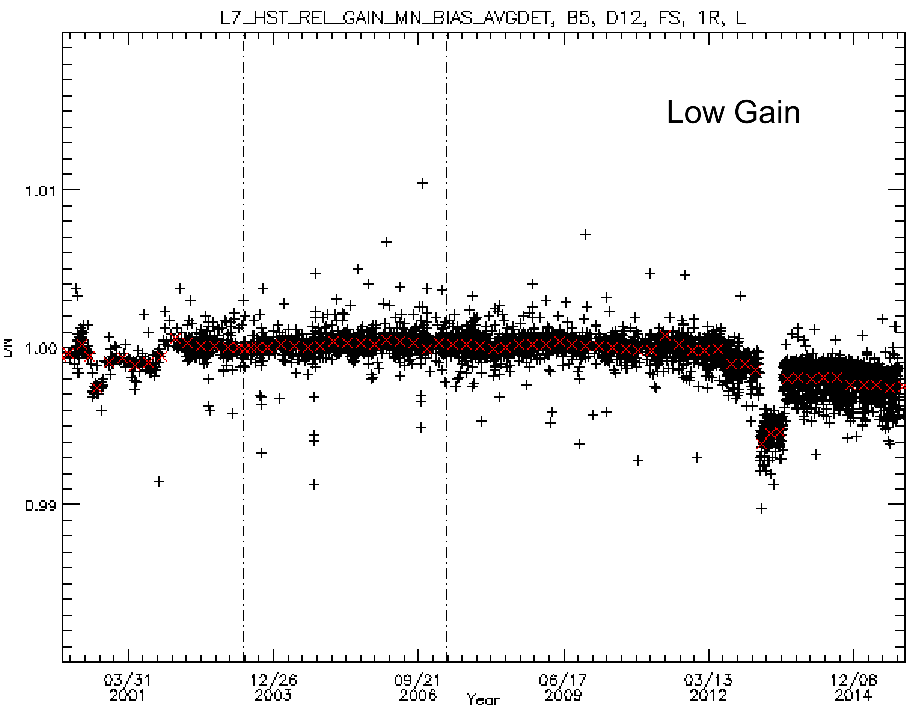


USGS

Lifetime Relative Gain, B5D12

- **Both FASC and Histogram derived RGs of L5 D12 show lifetime degradation**
    - Plots show lifetime RG model estimated by quarterly average
    - Approximate drop ~ 0.3% (may not be a good estimation due to noise)
    - Stripes are not visible in image data, CPF update is not necessary now





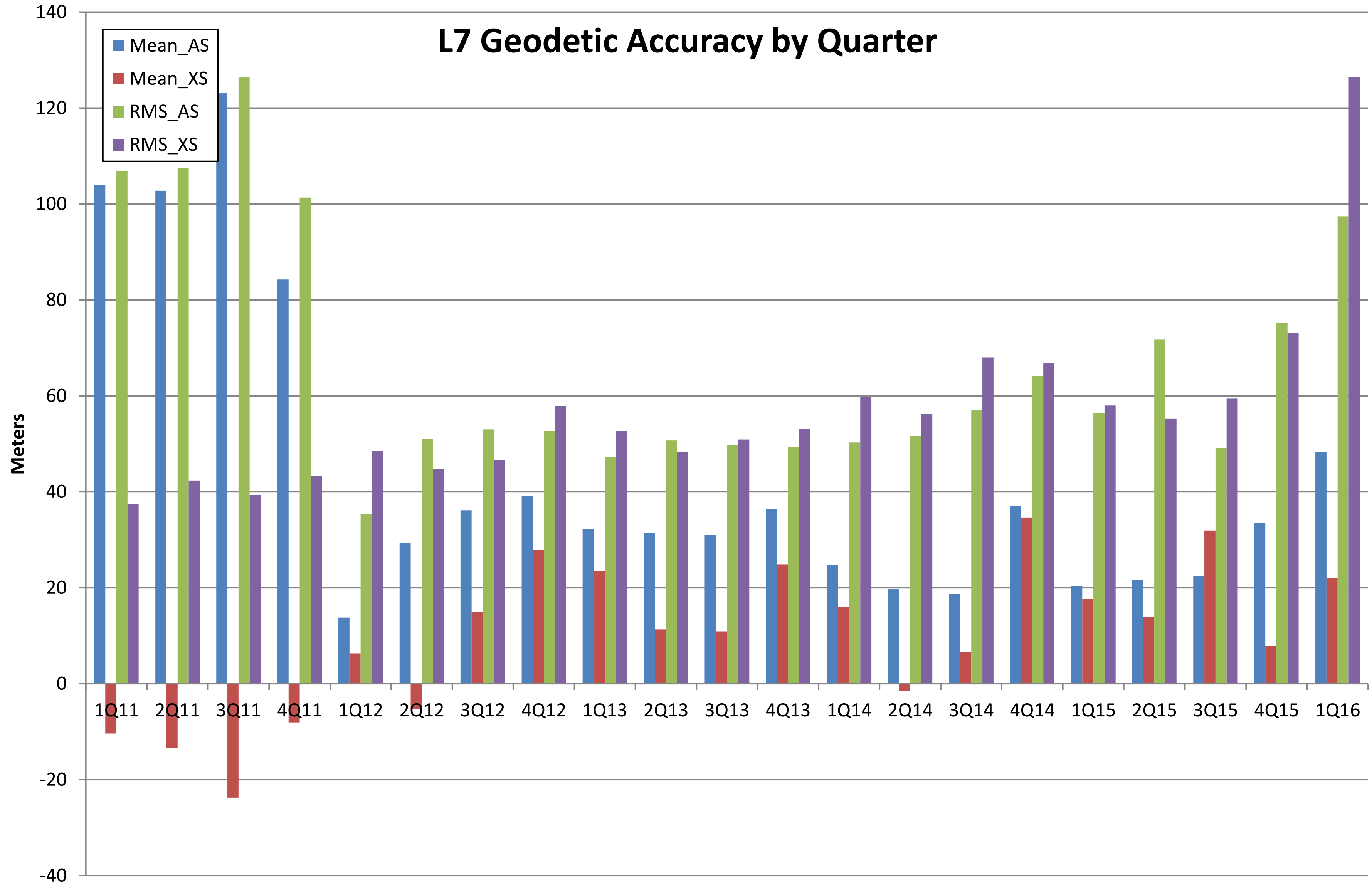
Implementation of Reflectance Calibration

- Plan is to implement ETM+ and TM with upcoming collection release
- Two approaches are under consideration
  - Update IAS/LPGS to apply reflectance calibration
    - Software change required
    - CPF update (new parameter definitions) required to provide new reflectance gain
  - In CPF update ESUN values corresponding to reflectance calibration gain
    - No software change required
    - No change in CPF structure required
    - Convenient but CPF provided ESUN values will not correspond to any standard solar model

L7 Bands	Gain (reflectance cal)	Esun (new)	Esun (current)
1	529.02	2036	1970
2	468.93	1856	1842
3	497.36	1525	1547
4	339.86	1071	1044
5	356.88	221.6	225.7
7	376.37	81.36	82.06

    - Note that reflectance calibration gain for L7 Panchromatic band has not derived
  - For L5 TM, in addition to above changes in CPF, the current gains need to be updated
  - For MSS, at this point it seems like a software update is necessary
- L5 implementation involves changes in product values (while L4 and L7 don't)

L7 Geodetic Accuracy Characterization



Preprocessed MSI Data

- The GCP and reference image assessments were performed on "Landsat-like" WRS-2 image units (example image window shown below):

MSI 4:3:2 @ 30m for R051_199/036

OLI 4:3:2 @ 30m for 199/036

- All tiles from the same UTM zone for each product were combined in a single mosaic for band registration assessment.
  - MSI bands 1, 2, 3, 4, 5, 6, 7, 8, 8A, 11, and 12 were converted to 20m GSD for band-to-band registration assessment.

Expected Landsat/Sentinel-2 Registration

- **The Landsat GLS framework is not being used to constrain the Sentinel-2 geometric framework.**
  - Registration accuracy will thus depend upon the absolute accuracies of the two systems.
- **Taking the RSS of the respective accuracies of the GLS (25 m RMSEr) and GRI (10 m 2-sigma), predicts registration on the order of 37 m 2-sigma.**
- **Landsat / Sentinel misregistration of up to several MSI pixels can be expected.**
  - Better registration is highly desirable and will likely be demanded by the science community.
  - Provides motivation to improve the GLS while making it consistent with the Sentinel-2 GRI framework.

GCP Improvement Phase 4 Landsat/Sentinel Harmonization

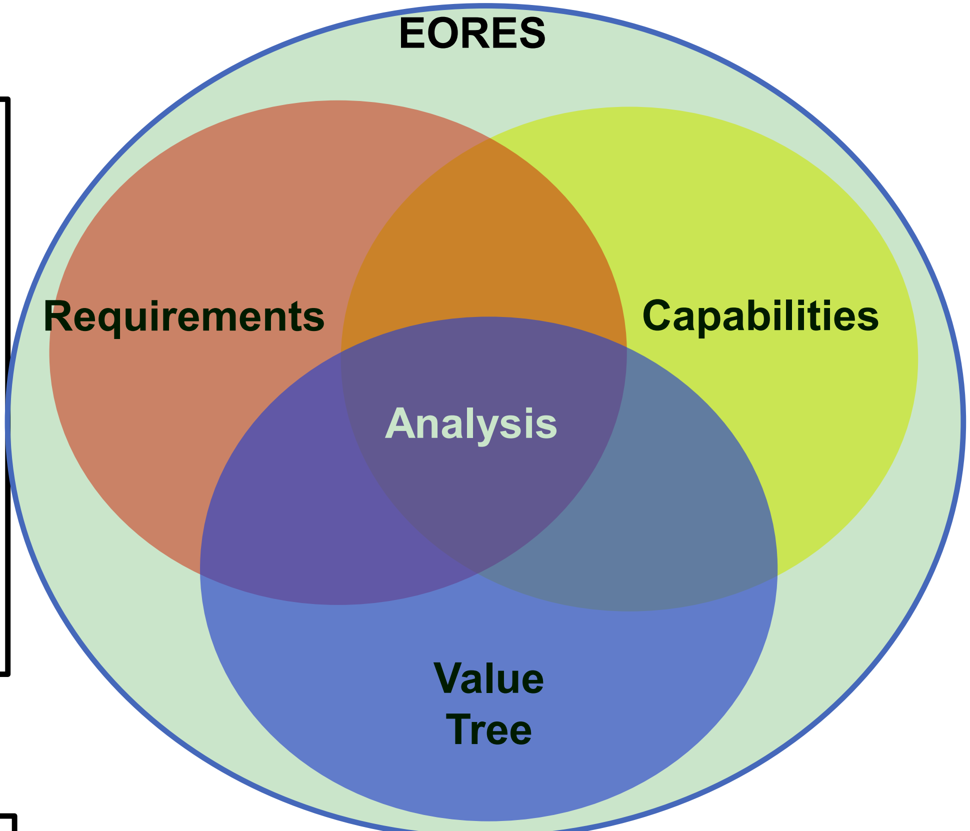
- **Propose global readjustment of the GLS using L8 data with sparse ties to Sentinel-2 GRI.**
  - Global scale version of what was done for the Australian AGRI during the phase 2 GCP improvement.
  - Block areas of up to ~1000 scenes are practical.
- **Blocks can be designed and run unconstrained (based upon L8 geometry) prior to GRI completion.**
  - Allows time consuming block layout and scene selection processes to get started prior to GRI availability.
- **MSI control will be added when available to support a second, constrained triangulation solution.**
  - Some MSI control will be withheld to test the triangulation.
  - Validate using OLI-MSI image registration measurements.

RCA-EO Components

RCA-EO Components

- **User Requirements**
  - Database of system-independent user needs
- **Observing Systems Capabilities**
  - Database of current and future Earth observing systems
- **Value Tree Information (VTI)**
  - Organizational program Earth observing input and capabilities mapped to the organization's goals and objectives

Earth Observation Requirements Evaluation System (EORES) and Analysis

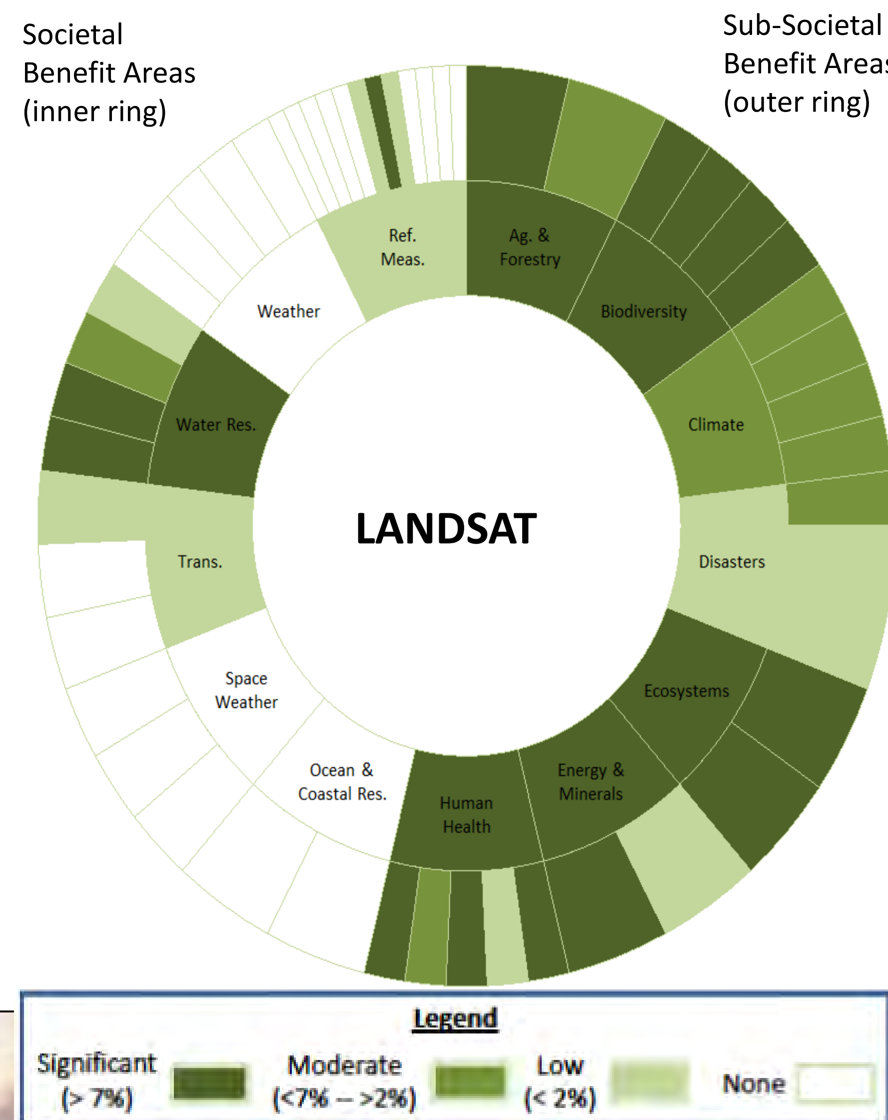


- **Using EOA VTI to elicit User Requirements**
  - Across all Civil Federal Agencies

RCA-EO is driving toward a user needs driven business management process to address mission priorities, and incorporate evolving Earth observing technology

Landsat – EOA 2012 Results

- **Assessment of 362 US Earth Obs. Systems (EOS) (space, air, land, and sea platforms) contributions to 13 Societal Benefit Areas (SBAs)**
- **Landsat was 3rd out of total, and Landsat 2nd "most critical SBA impact" of 132 satellite systems (GPS=1)**
- **10 of 13 (77%) SBAs use Landsat data**
- **Landsat has a Significant Impact on 6 SBAs;**
  - Ranked #1 for contributions in Biodiversity, Ecosystems, and Energy
  - Ranked #2 for contributions in Agriculture/Forestry, Climate, Human Health, and Water
- **31 of 52 (60%) Sub-SBA Areas utilize Landsat**
  - Landsat had a Significant Impact on 15 Sub-SBAs and a Moderate Impact on 6 Sub-SBAs



ARD

- ARD are processed to a level that enables direct use in quantitative applications including exploratory data analysis, numerical modeling, and geospatial, multispectral, and multi-temporal manipulation for purposes of data reduction, analysis, and interpretation.
- Characteristics of analysis-ready data include scaled or standardized physical units and data types, consistent spatial coverage and cartographic projection, common data format, and accompanying metadata of sufficient detail on data provenance, geographic extent, scaling coefficients, and processing history to enable independent reconstruction of the dataset.
- These characteristics further enable the generation of seamless, mosaicked data that include the temporal aggregation of individual cloud-free pixels according to user prescribed decision rules.

NASA ESDIS EOS Defined Processing Levels

- The NASA Earth Science Data and Information Systems (ESDIS) project has provided standardized definitions for the various processing levels for data acquired by the instruments flown on the fleet of satellites that constitute the Earth Observing System (EOS) program:
-
- <u>Level-0</u>: Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed. (In most cases, the EOS Data and Operations System (EDOS) provides these data to the data centers as production data sets for processing by the Science Data Processing Segment (SDPS) or by a Science Investigator Processing System (SIPS) to produce higher-level products.)
-
- <u>Level-1A</u>: Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (e.g., platform ephemeris) computed and appended but not applied to Level 0 data.
-
- <u>Level-1B</u>: Level 1A data that have been processed to sensor units (not all instruments have Level 1B source data).
-
- <u>Level-2</u>: Derived geophysical variables at the same resolution and location as Level 1 source data.
-
- <u>Level-3</u>: Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
-
- <u>Level-4</u>: Model output or results from analyses of lower-level data (e.g., variables derived from multiple measurements).

Collection Definition Progress

- **The USGS defined three basic categories of products**
  - NRT (Near-real time) – products that are processed using ancillary data such as predicted ephemeris or bumper mode parameters that may be improved by reprocessing
  - Tier 1 – products that meet the criteria for the collection definition (i.e. enable time-series stacking, <11.9m RMSEr)
  - Tier 2 – products that do not meet the criteria for the collection definition and have been processed using the best known ancillary data

A single collection (i.e. "collection 1") for all sensors (excluding MSS) as opposed to a separate collection per sensor

Near-real Time (NRT) Products

- **Three Modes of NRT data collection that do not satisfy geometric accuracy**
  1. ETM+ products generated using predicted ephemeris data
  2. ETM+ products generated that utilize predicted bumper mode calibration coefficients
  3. OLI_TIRS products that utilize a preliminary line of sight (LOS) model based on “estimated” position of the scene select mirror.
     - TIRS coefficients will initially be updated periodically, initially quarterly, increasing in frequency to twice per month after sufficient telemetry has been collected

- **These products will be made available for download as soon as they are processed and will roll off the download cache once they become Tier-1 or Tier-2 collection products**

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Tier-1 Collection Definition Summary

- **Need to be geometrically corrected to enable multi-spectral time-series stacking**
  - Geodetic accuracy threshold of less than 11.9m radial root mean square error (RMSEr) based on a post fit analysis of data relative to the Global Land Survey (GLS) 2000 ground control
  - Results in about
    - 57% of OLI_TIRS
      - A higher percentage of OLI science are collected over areas without ground control (Antarctic, Coastal Areas, Islands, higher cloud cover)
      - L1GTs can't perform post-fit verification to GLS so they are part of the TIER-2 category
    - 73% of all ETM+
    - 60% of all TM

The intent is to make the full Tier-1 collection available for immediate download

Tier-2 Product

- Products that do not meet the definition of the collection and have been processed using the best known ancillary data
  - Definitive ephemeris
  - Latest bumper mode parameters
  - Latest TIRS LOS coefficients

- **Data will be made available at the highest processing level through the Tier-2 collection or on-demand processing request**

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Collection Identification Product ID / File Name Convention

- **Current Proposed Product ID:**
  - LXSS_LLL_PPPRRR_YYYYDDMM_yyyymmdd_CC_O
    - L = Landsat (constant)
    - X = Sensor (C = OLI/TIRS, E = ETM, T = TM, etc.)
    - SS = Satellite (e.g., 09 for Landsat 9, 10 for Landsat 10)
    - LLL = Processing level (L1T, L1G, L1S)
    - PPP = WRS path
    - RRR = WRS row
    - YYYYMMDD = Acquisition Year (YYYY) / Month (MM) / Day (DD)
    - yyyymmdd = Processing Year (yyyy) / Month (mm) / Day (dd)
    - CC = Collection number (e.g., 02)
    - O = “Optional” _R for Real-time or _N for Non-Collection

    Example:
    LE07_L1T_029030_20140715_20140805_02