USGS Report to CEOS WGCV

Sep 6, 2016

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Landsat 7 Spacecraft Status

≈ 17 years of on-orbit operations(1999)

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

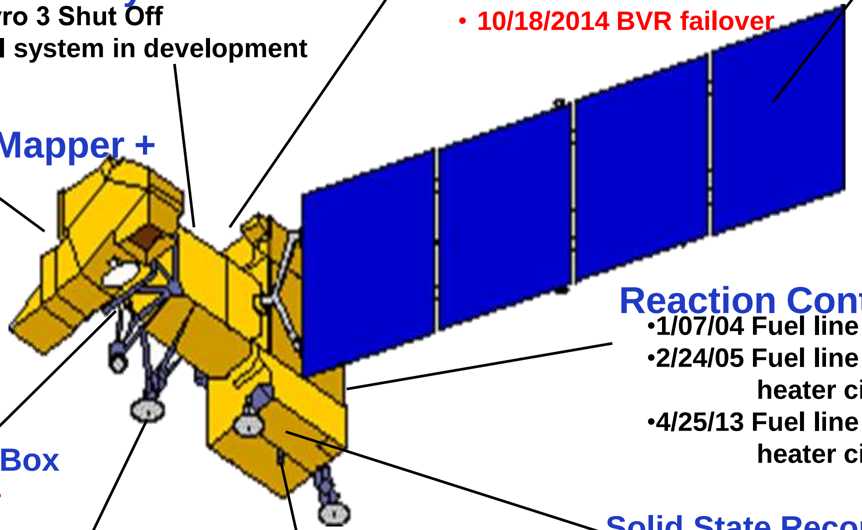
Remote Tlm Cmd (RTC) Box
- 09/27/2014 RTC A Failover

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



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

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

≈ 3 years of on-orbit operations (2013)

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

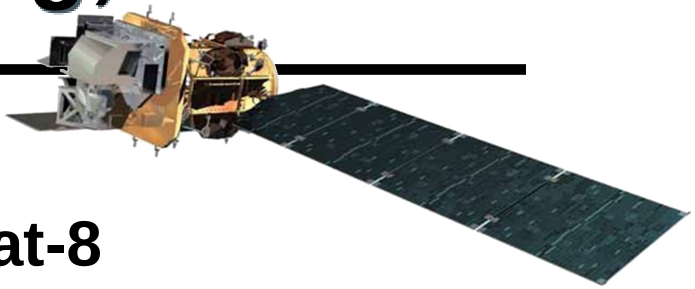
- 10/1/2014 - Side-A SSM Encoder

X-band System

Command & Data Handling System

Solid State Recorder

Sustainable Land Imaging; Landsat-9

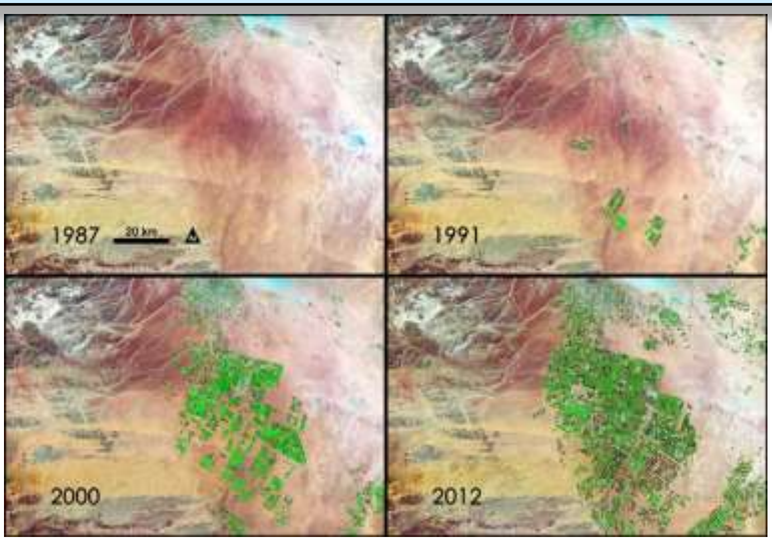


- Landsat-9 is very similar to Landsat-8
- President's FY 17 Budget Submittal to Congress (February 2016) included Landsat 9, with a launch as early as FY 2021.
- Project directed to strive for a late CY 2020 launch date

Landsat 9 Mission Overview

Mission Objectives

- **Provide continuity in the multi-decadal Landsat land surface observations to study, predict, and understand the consequences of land surface dynamics**
  - **Land cover/use change**
  - **Ecosystem dynamics**
  - **Landscape scale carbon stocks**
  - **Resource management/societal needs**
- **Core Component of Sustainable Land Imaging Program**



Increase in pivot irrigation in Saudi Arabia from 1987 to 2012 as recorded by Landsat. The increase in irrigated land correlates with declining groundwater levels measured from GRACE (courtesy M. Rodell, GSFC)

Mission Parameters

- **Single Satellite, Mission Category 1, Risk Class B**
  - 5-year design life after on-orbit checkout
  - At least 10 years of consumables
- **Sun-synchronous orbit, 705 km at equator, 98° inclination**
- **16-day global land revisit**
- **Partnership: NASA & United States Geological Survey (USGS)**
  - NASA: Flight segment & checkout
  - USGS: Ground system and operations
- **Launch: FY2021 (Targeting December 15, 2020), Category 3 Vehicle**

Instruments

- **Operational Land Imager 2 (Ball Aerospace)**
  - Reflective-band push-broom imager (15-30m res)
  - 9 spectral bands at 15 - 30m resolution
  - Retrieves data on surface properties, land cover, and vegetation condition
- **Thermal Infrared Sensor 2 (NASA GSFC)**
  - Thermal infrared (TIR) push-broom imager
  - 2 TIR bands at 100m resolution
  - Retrieves surface temperature, supporting agricultural and climate applications, including monitoring evapotranspiration

Spacecraft & Observatory I&T

- **Competitively Procured: TBD**

Launch Services

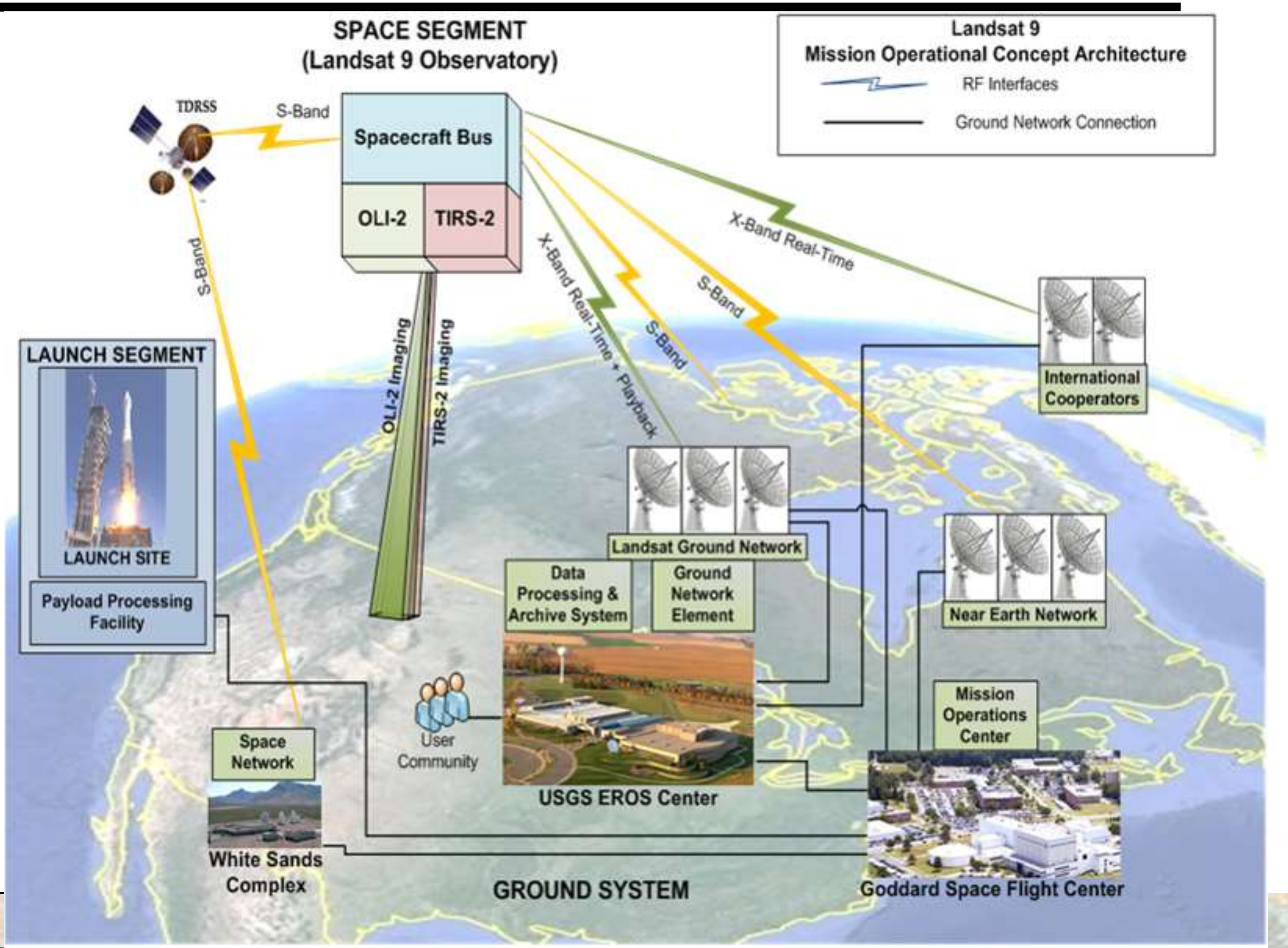
- **Competitively Procured: TBD**

Mission Team

- **NASA Goddard Space Flight Center (GSFC)**
- **USGS Earth Resources Observation & Science (EROS) Center**
- **NASA Kennedy Space Center (KSC)**

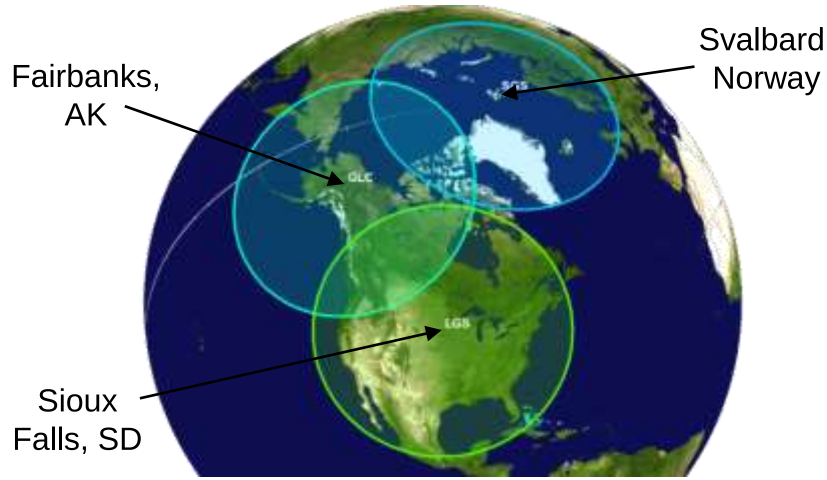
Reference: LST Meeting, 26 Jul 2016, Jenstorm, Nelson

Mission Architecture Identical to Landsat 8



Landsat 9 Ground System

- **Mission Operations Center (MOC)**
  - Flight Operations Team (FOT) performs mission planning and scheduling, command and control, health and status monitoring, orbit and attitude maintenance, mission data management
  - NASA provides MOC and BMOC facility at GSFC as well as NASA institutional services (SN, NEN, NISN, FDF) through on-orbit acceptance
- **Ground Network Element (GNE)**
  - Landsat Ground Network (LGN) stations provide X- and S-band communications with the Observatory
  - LGN stations in Sioux Falls, SD; Fairbanks, AK; and Svalbard, Norway
  - Data Collection and Routing Subsystem (DCRS) gathers mission data from LGN stations into complete intervals to transfer to the DPAS
- **Data Processing and Archive System (DPAS)**
  - Provides data ingest, storage and archive, image assessment, product generation, and data access and distribution
  - DPAS facility at USGS EROS Center



Sustainable Land Imaging; L-10

- **L-10 launch: 2027**
- **Landsat-10 looking at multiple approaches and technologies**
- **L-10 User Requirement Collection and Technology Evaluation (Dec 2016)**
  - Continue building set of user requirements across the broader range of land imaging applications
    - Hyperspectral applications
    - Additional thermal applications
    - Higher resolution applications (~5-20 m range)
    - Higher revisit applications
  - Developing approach to analyze requirements
    - Compare user requirements to potential L 10 configurations; which requirements are met?
      - NASA L10 engineering models
      - Notional systems with expanded resolution or spectral bands

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

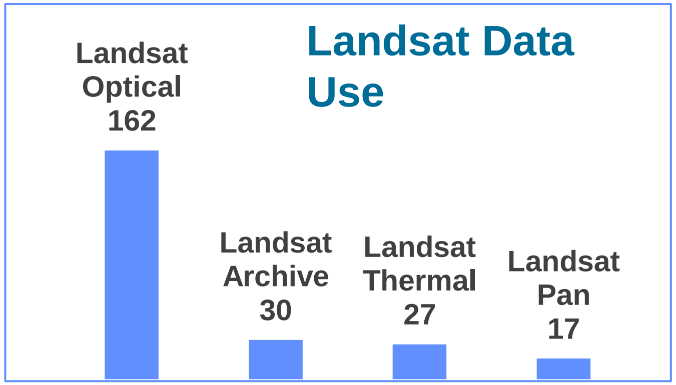
Landsat Use from Earth Observation Assessment 2016 (preliminary)

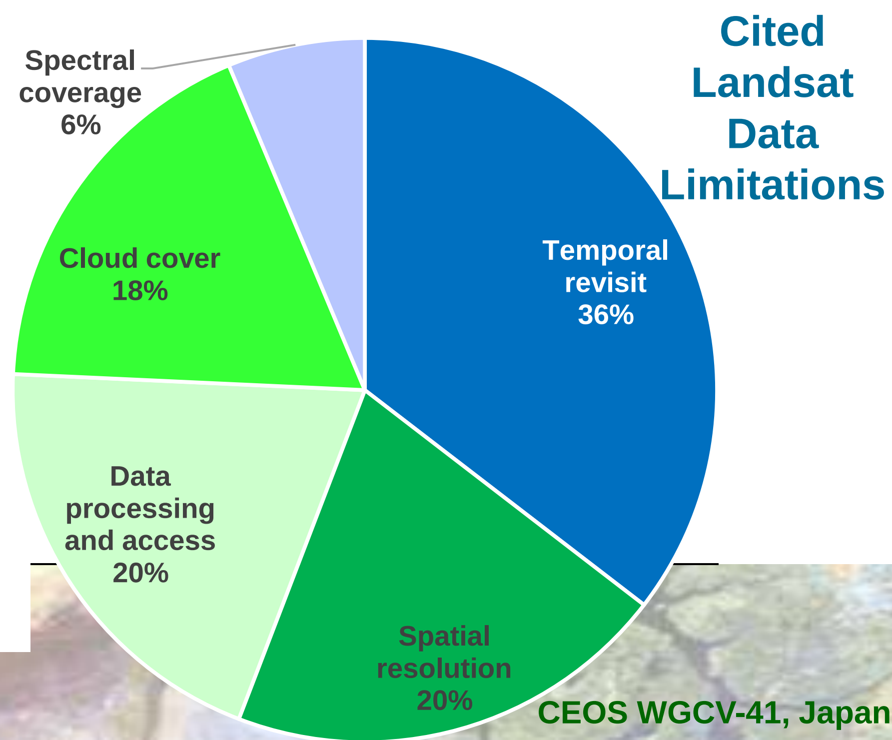
- OSTP-led snapshot of Earth observation (EO) data use across Federal Civil Agencies organized by 13 societal benefit areas; ~1750 key products surveyed
- Preliminary results based on current snapshot Federal civil Landsat users
    - 174 key products from multiple Federal agencies
- Most people use more than one type of Landsat data, and are

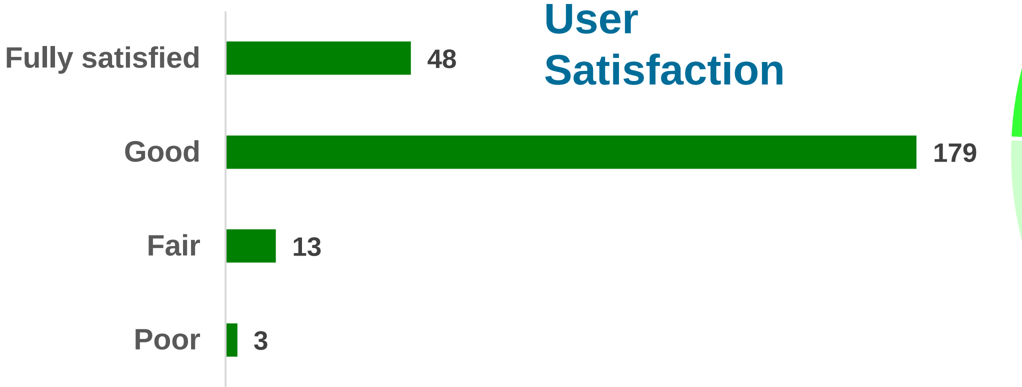
generally satisfied with Landsat data, but did identify some limitations

- Temporal revisit was the most often cited limitation
- Users also identified needs for higher spatial resolution,

  additional processing, and mosaic products







http://landsat.usgs.gov/landsat-science-team-meeting-july-26-28-2016.php

Landsat Science Team Meeting

McCrory Gardens Education and Visitor Center
Brookings, SD
July 26-28, 2016

Meeting Objectives:

1. Identify priorities for future Landsat measurements and technologies.
2. Review Landsat Science Team member research and applications activities.
3. Review the status of Landsat 7-8 and the Landsat archive.
4. Review South Dakota State University science and engineering remote sensing activities.

Landsat 10 Landsat Science Team 1-slide synthesis in ~decreasing order (charge to team in red, Tom will provide template and schedule

1) Continuity / backward compatibility to previous Landsats (wulder, Belward, Loveland, Patrick H, Joe & Kennedy, Dennis)
   - Obviously but also Global climate monitoring principals rationale
   - Multiple satellites would provide continuity "safety" / redundancy and help obj. 1-3

2) ↑ Temporal – need to provide clear application/science rationale
   - 4 days (Martha A. study; A. Whitcraft MODIS cloud study, Ted S. cryospheric change)
(Leo, Jim V., Ted, Cohen, Allen, Ayse, Feng, M. Anderson, Jim Hipple, Dave J.)

3) Coincident/near-coincident 2-band thermal observations (thermal pixels integer multiple of reflective pixel dimensions) (field level ET, hydrological studies, cloud screening) [This is part of the continuity objective] (Allen, Ayse, M. Anderson)

4) ↑ Spatial 10 m all VIS/NIR and perhaps also SWIR bands (anthropogenic monitoring), stackable (Randy W., Feng, Jim Hipple, Dave J.)

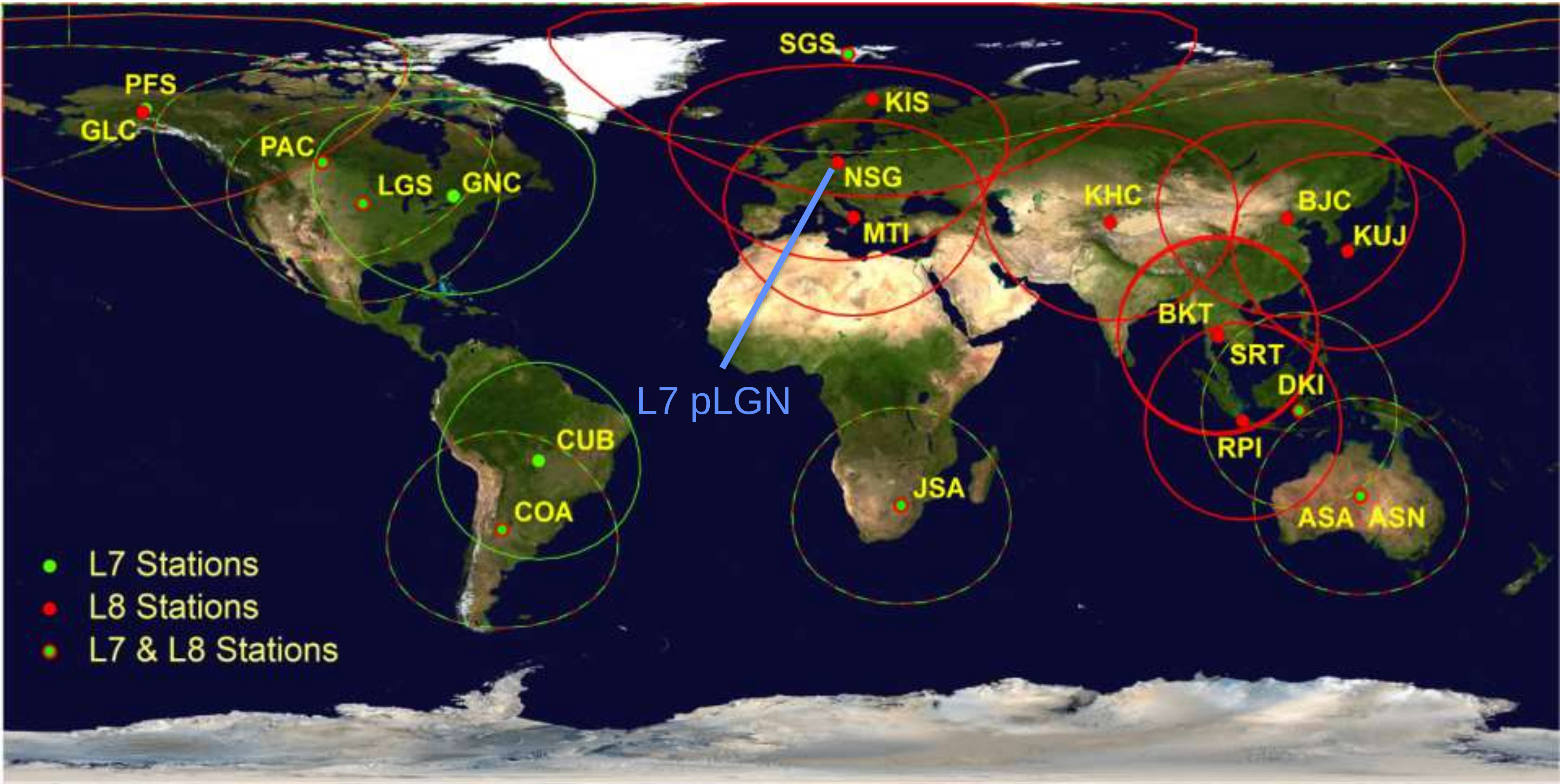
5) ↑ SNR, radiometric resolution ↑ 14 bits (improved retrievals) (Schott, Sheng, Ted)

6) New spectral bands
   - red edge bands (agricultural and vegetation applications, canopy chlorophyll content, nitrogen retrieval)
   - targeted narrow bands (ASTER heritage) / hyperspectral (HYSPIRI folk, Patrick H)
   - water vapor retrieval, deeper blue, polarization bands for improved atmospheric correction (Vermote, Roy, Joel M.)

Recognize need for trade studies: forward modelling, proxy data, case studies etc.

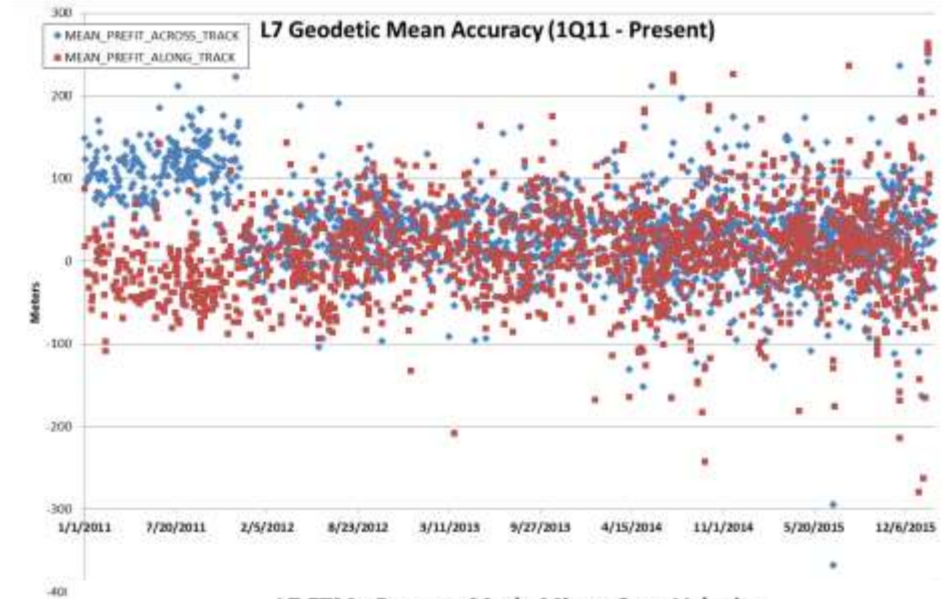
Active Landsat International Ground Stations

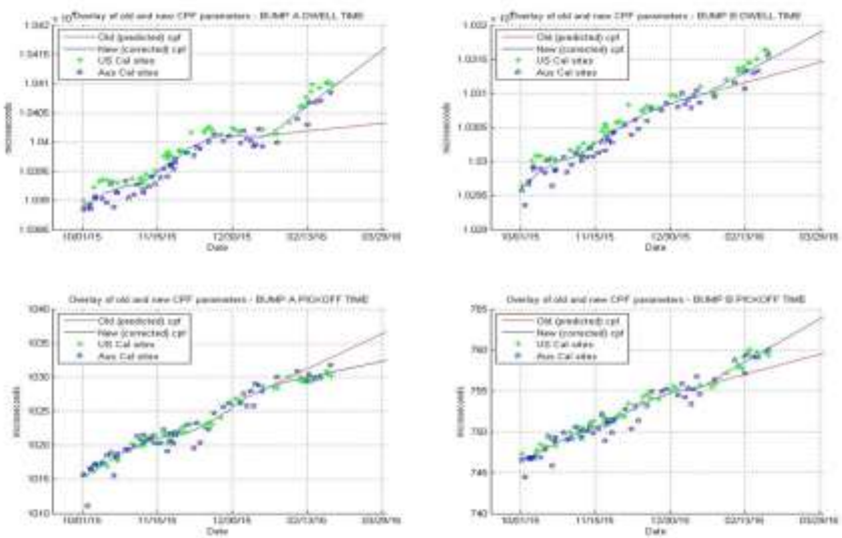
10 Active L7 Stations | **17 Active L8 Stations**



Landsat-7 Geometric Performance

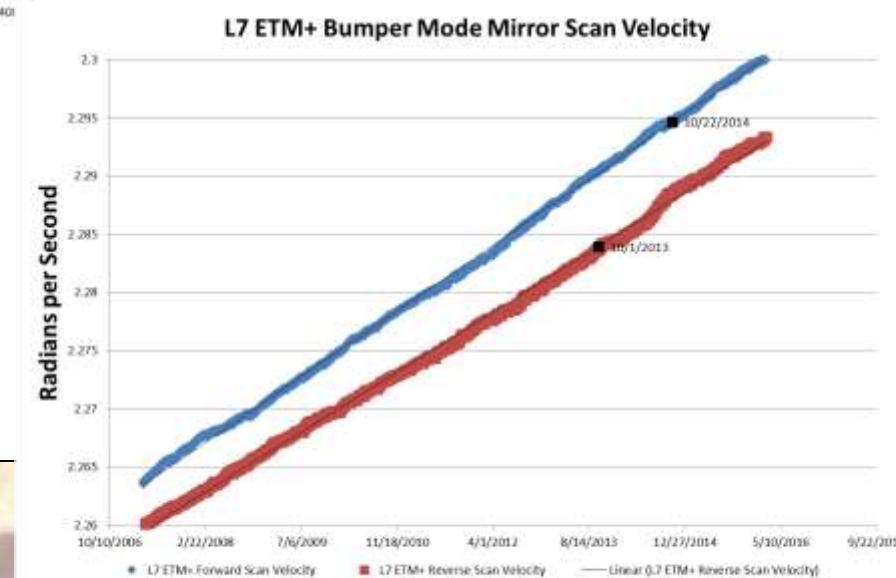
Geodetic accuracy improved since 2012





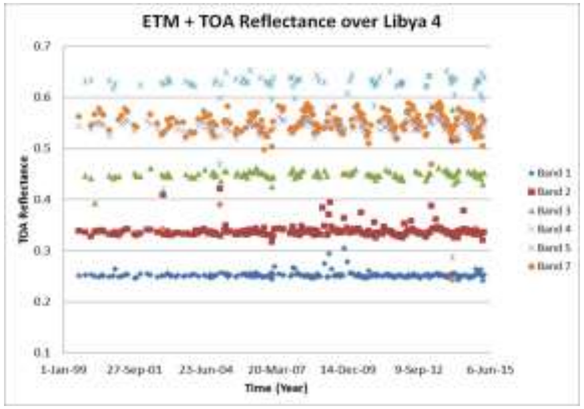
Bumper mode parameters continue to be updated ~2 weeks

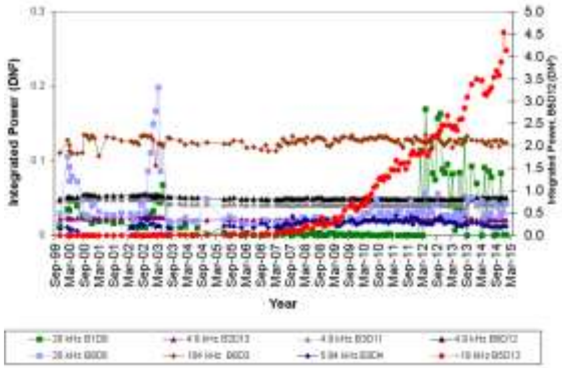
Mirror velocity surpassed Landsat-5 TM velocity



Landsat-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
- Progating L8 OLI reflectance based calibration to L1-7

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

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

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

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

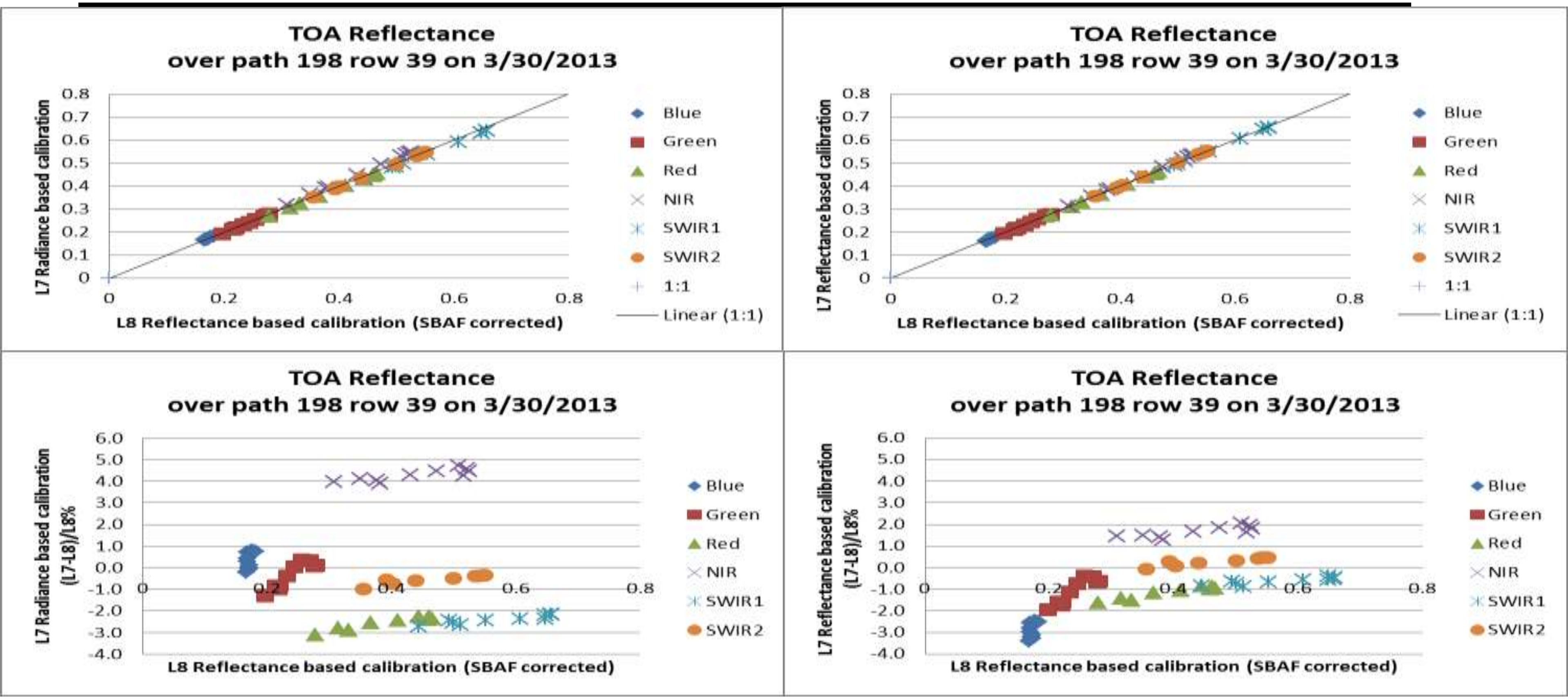
$$\rho_{4TM,\lambda} = ((L_{5,\lambda} * (L4TM, CPF\ day1\ launch\ Average\ band\ gains)/g_{4,L,\lambda})^* \frac{d^2{}_5}{\cos\alpha_5}$$

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

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

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



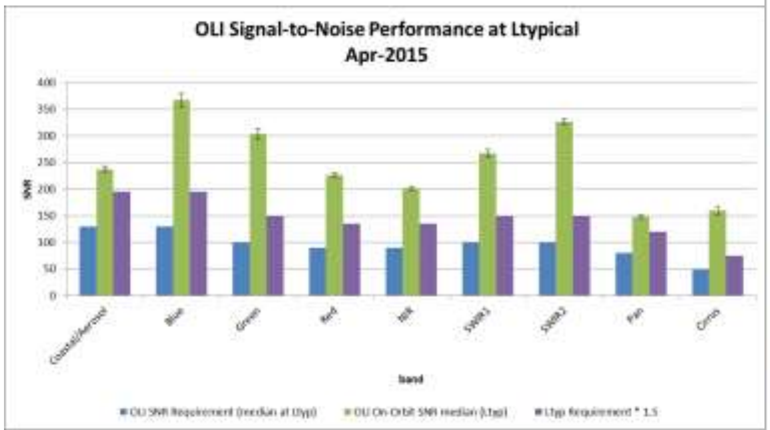
- L7 reflectance agrees better with L8 reflectance
  - Except band 1 and may be band 2
- L7 reflectance of bands 1, 2 and 4 will be darker (maximum in band 1 ~ 3.2%)
- L7 reflectance of bands 3, 5 and 7 will be brighter (maximum in band 5 ~ 1.9%)

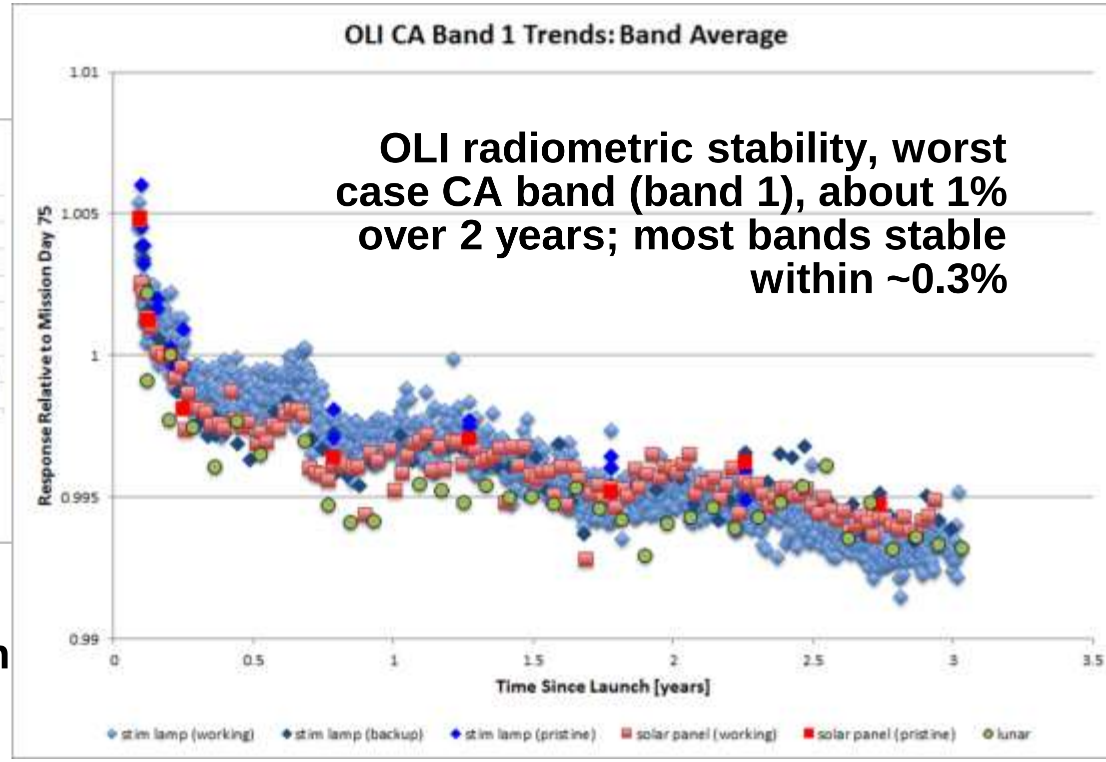
Landsat GCP Improvement Goals

- **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

Landsat-8 Radiometric Performance

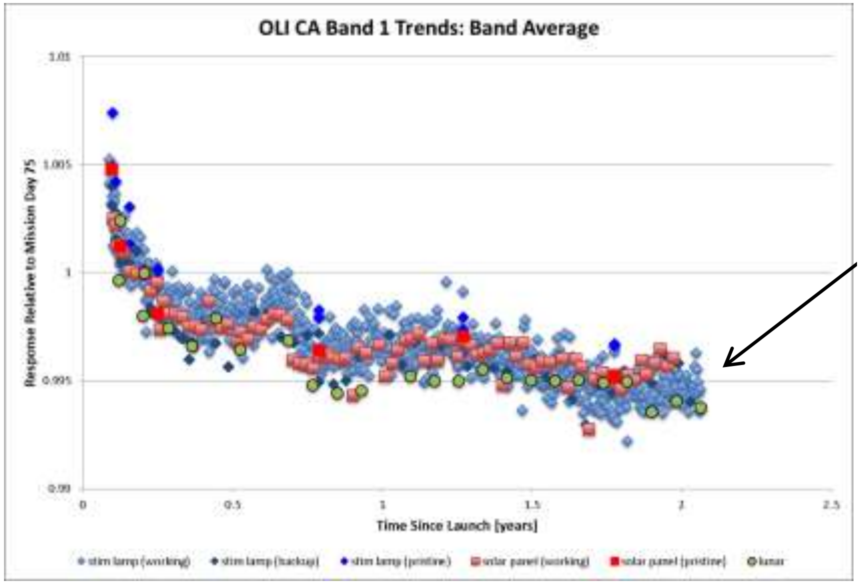
SNR continues to exceed requirements





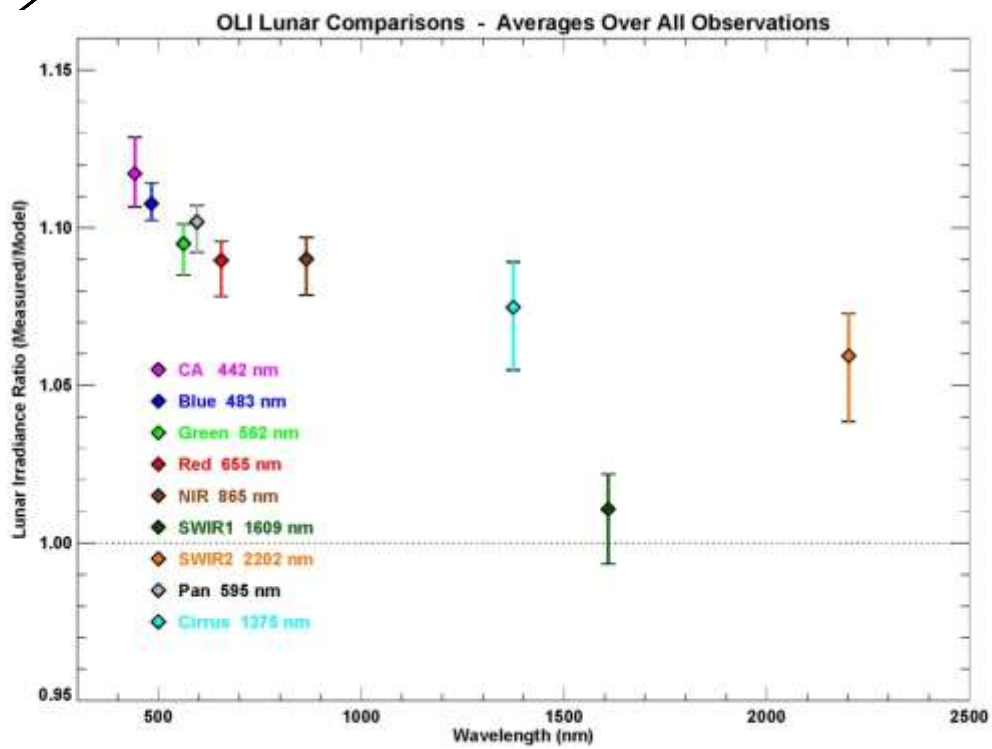
- **Continuing quarterly relative gain updates**
- **Update planned for next reprocessing**
  - Correct for a decay in CA band calibration trend
  - Account for small short-term increase in trends of VNIR bands
- **Reflectance calibration agrees generally to 3-5% with vicarious techniques**
  - Working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

L8 OLI Lunar Calibration



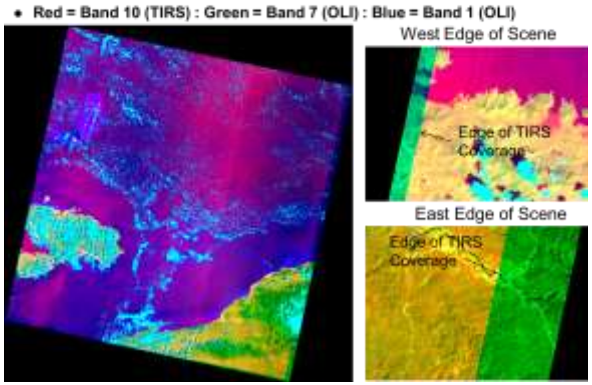
Lunar trending follows other cal methods

lunar

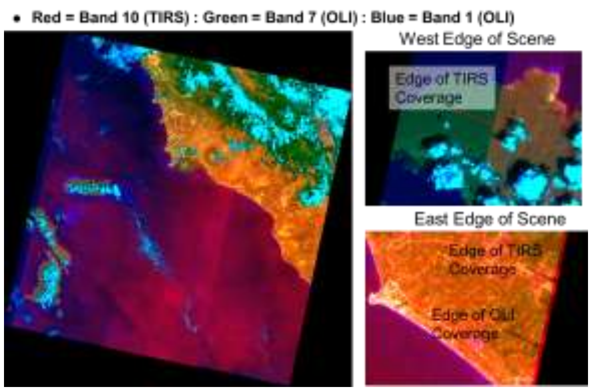


Absolute offsets are relatively large — cause is being studied

TIRS Scene Select Mirror Anomaly



Typical OLI-TIRS alignment



OLI-TIRS alignment without encoder

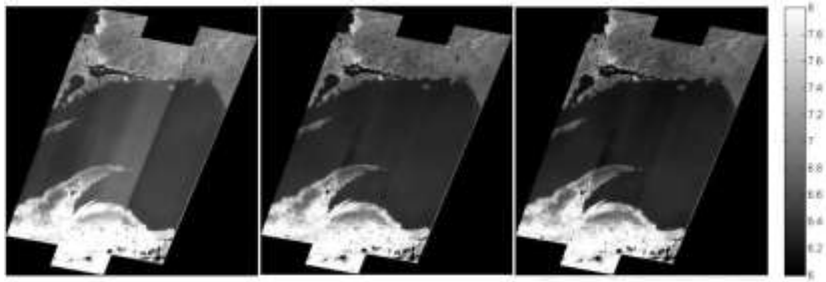
- **SSM encoder current began increasing Summer/Fall 2014**
- **Reached yellow limit December 19, 2014**
  - Encoder powered down
  - Product generation system couldn't handle no encoder
  - TIRS imagery zeroed through early March
    - Software updated April 23, 2015
- **TIRS electronics switched to 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

L8 IAS/LPGS Status & Schedule

- **L8 IAS R3.6.2 & L8 LPGS R2.6.2**
  - Phase 3 GCP updates
  - DEM improvements over Greenland and a couple islands
  - TIRS SSM model fit algorithm
    - Fits TIRS SSM calibration results and populates estimated positions into the database
    - Work orders retrieve estimated TIRS SSM encoder positions from the database
    - Support for reprocessing scenes in LPGS after the final estimated TIRS SSM encoder positions are available
  - **Installed into Operations April 25, 2016**

- **L8 Ingest R4.0**
  - **Adjusted TIRS framing near the poles**
  - **Installed into Operations April 23, 2016**

TIRS Stray Light Correction

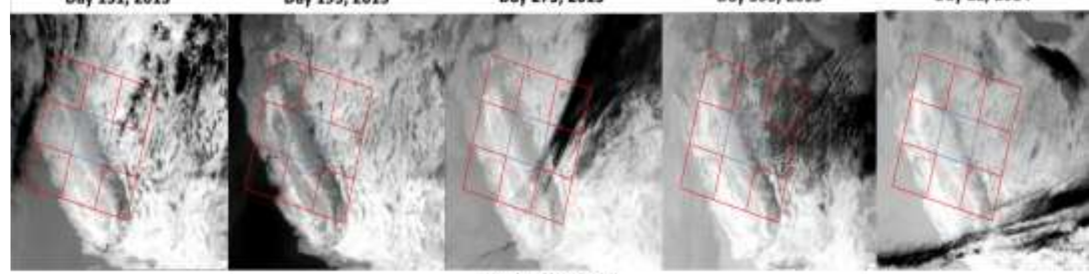


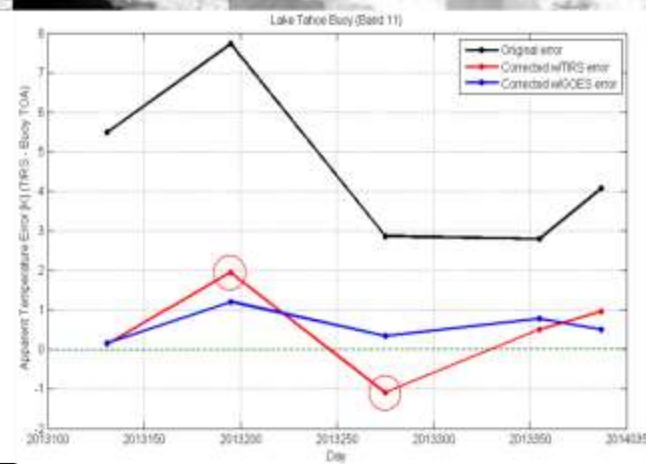
Original GOES Correction TIRS Correction

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**
- **The plan is to implement the algorithm in IAS; summer 2016**

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





L8 IAS/LPGS Status & Schedule

- **L8 LPGS 2.7 / IAS 3.7 (Collection Processing)**
  - New Landsat Product ID
  - Add Albers product for LCMAP
  - Modified CPF and RLUT filenames
  - Support for multiple concurrent software installs (i.e. collections 0 and 1)
  - TIRS Stray Light correction (final approval pending)
  - Remove TIRS band 11 from product (final approval pending)
  - CFmask
    - Turn on as part of release and eliminate weighting of multiple cloud cover algorithms
    - Implement the non-thermal with Cirrus option
    - Minor algorithm fixes
  - Angle Coefficients, & Angle Band Tool (turn on as part of release)
  - Add Truncation Mode to metadata and MTL
  - Remove SCA notches (Cirrus & TIRS bands)

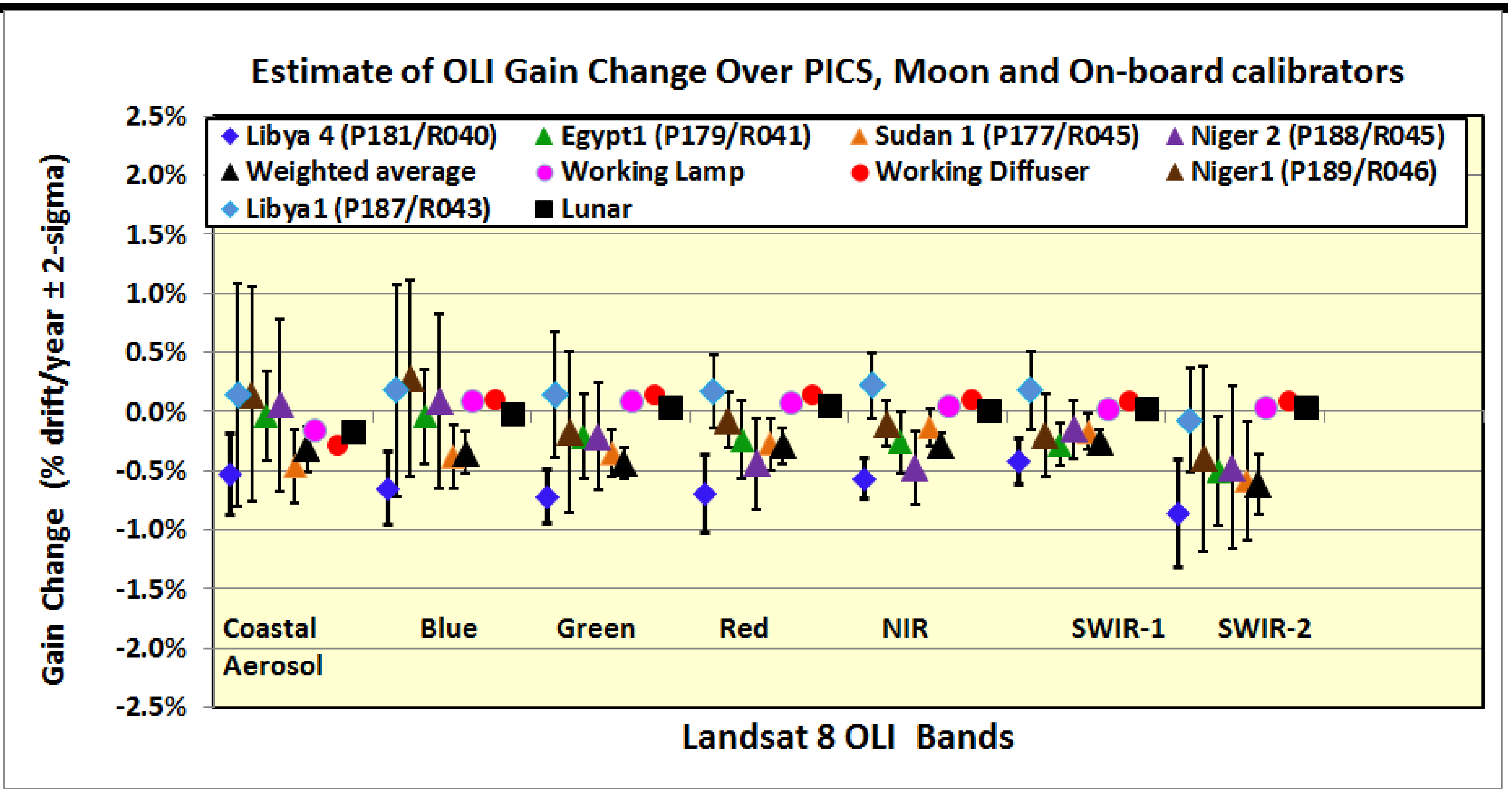
Schedule

- **L8 LPGS 2.7 / IAS 3.7 (Collection Processing - cont)**
  - Quality Band Bits
    - Add saturation
    - Change order of the bits
    - Remove water and vegetation bits
  - Sustaining
    - Add an option to disable the L1R size limit check in create_l1r to support slide slither processing
    - Bug fix for select_control_gcps
    - Allow a split CPF date range to be merged
    - Add BPF and RLUT filenames to the radiometric work order common table
    - Manage the geometric work order common table valid flag in a processing flow aware way
    - Support for automating the initial TIRS SSM model fit
    - Use highest GCP ID in the database to pick starting ID in generate_chips
    - Other potential pending CRs

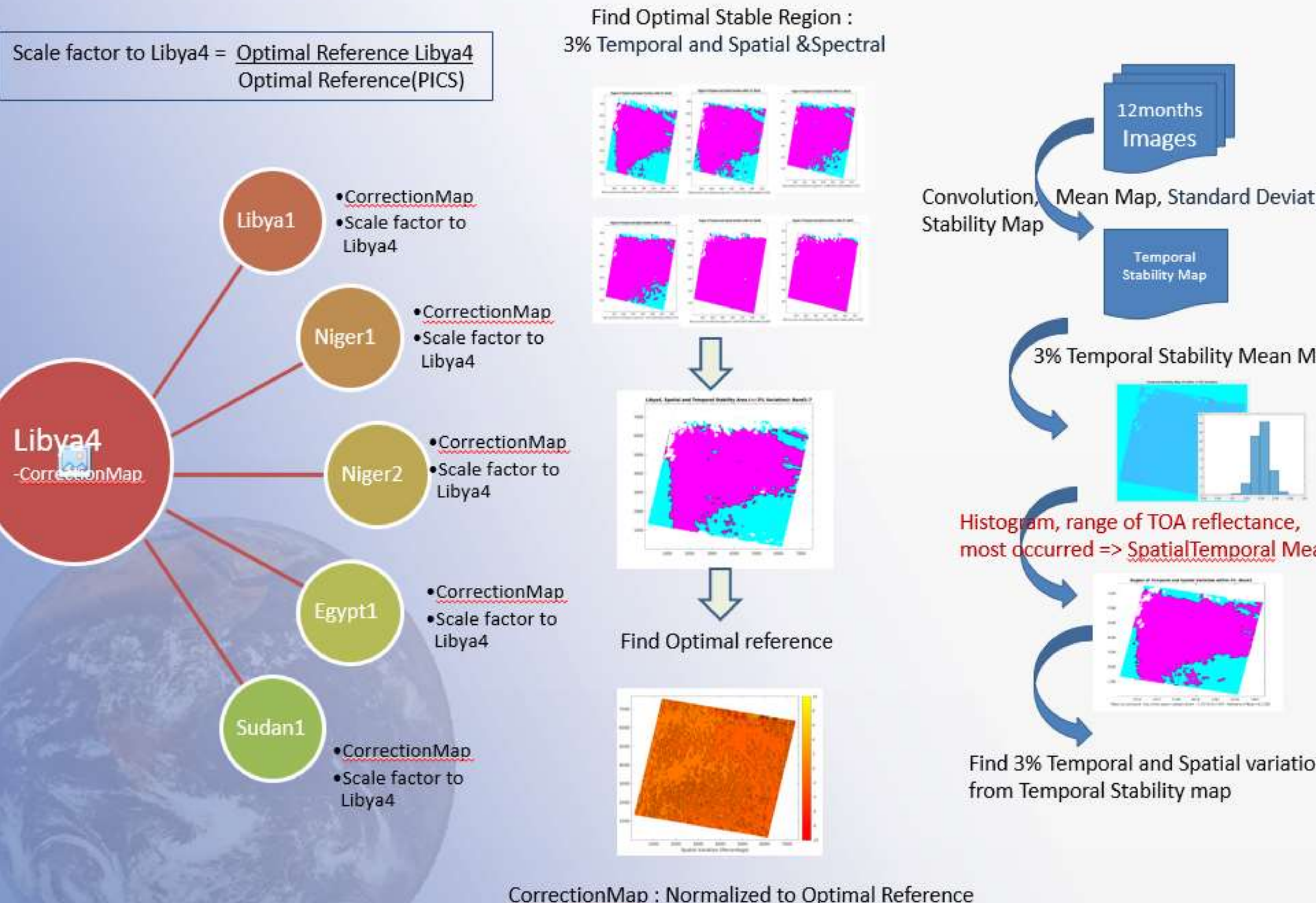
Schedule

- **L8 LPGS 2.7 / IAS 3.7 (Collection Processing - cont)**
  - Removing the following from IAS:
    - Caltest subsystem (not used since everyone uses PWG instead)
    - TIRS Gain Determination algorithm
    - SCA Overlap Characterization algorithm in create_l1r (replaced with algorithm that uses the resampler output)
  - **Install into operations September 30, 2016**

PICS Based Stability

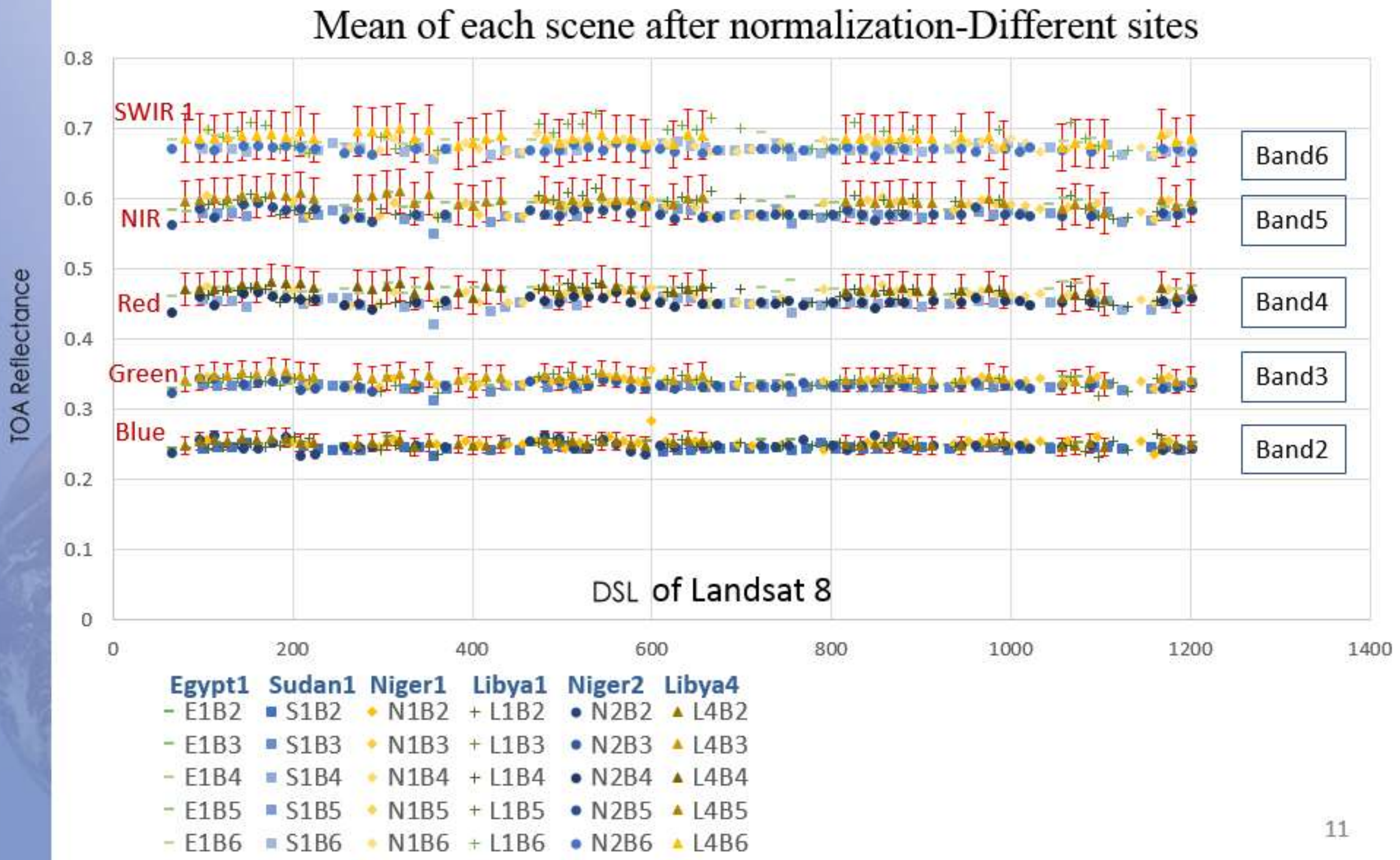


- **The plot shows that three years after launch average OLI PICS trends finally agree with on-board calibrators within a half percent.**


Scale factor to Libya4 = Optimal Reference Libya4 / Optimal Reference(PICS)
Find Optimal Stable Region :
3% Temporal and Spatial &Spectral
12months Images
Convolution, Mean Map, Standard Deviat
Stability Map
Temporal Stability Map
3% Temporal Stability Mean M
Histogram, range of TOA reflectance,
most occurred => SpatialTemporal Mea
Find 3% Temporal and Spatial variatio
from Temporal Stability map
Libya4
-CorrectionMap
Libya1
•CorrectionMap
•Scale factor to Libya4
Niger1
•CorrectionMap
•Scale factor to Libya4
Niger2
•CorrectionMap
•Scale factor to Libya4
Egypt1
•CorrectionMap
•Scale factor to Libya4
Sudan1
•CorrectionMap
•Scale factor to Libya4
Find Optimal reference
CorrectionMap : Normalized to Optimal Reference

PICS Normalization: 6 PICS sites

Showing 5% Error bars on Libya4 –TOA Reflectance after PICS Normalization



JACIE 2016: http://calval.cr.usgs.gov/jacie/

- The *Joint Agency Commercial Imagery Evaluation (JACIE) Workshop* co-located with the American Society for Photogrammetry and Remote Sensing (ASPRS) Imaging and Geospatial Technology Forum (IGTF) in Fort Worth, Texas, USA, April 12-14, 2016.

- **New Sensor plans and calibration**
  - PlanetLabs, TripleSat Constellation (21AT), MUSES/DESIS, …, Harris, SigmaSpace,
  - Sensors calibration – RapidEye, KompSat-3A, CBERS-4, Woldview-3 radiometry (DG group), Landsat-8 and Sentinel, UltraCam Condor, UltraMap, ADS-100, VIRS day/night, TerraBella, …,

- **Processes**
  - Excellent processes w/RadCalNet and Spatial Resolution
  - Sensor Harmonization
  - Can we get documented standardized approach for JACIE sensor types? CEOS?

- **Various sensors all being calibrated geospatially**
  - Aerial lidar & cameras;
  - UAS – many sensors
  - Satellites: Hi-res, medium res, moderate res, ….

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**
  - 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
    - On going geometric and radiometric assessments
- **ISRO ResourceSat-2**
  - 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 and Landsat 10 planning beginning**

Land Product Characterization System (LPCS)

http://landsat.usgs.gov/lpcs.php

http://lpcsexplorer.cr.usgs.gov/

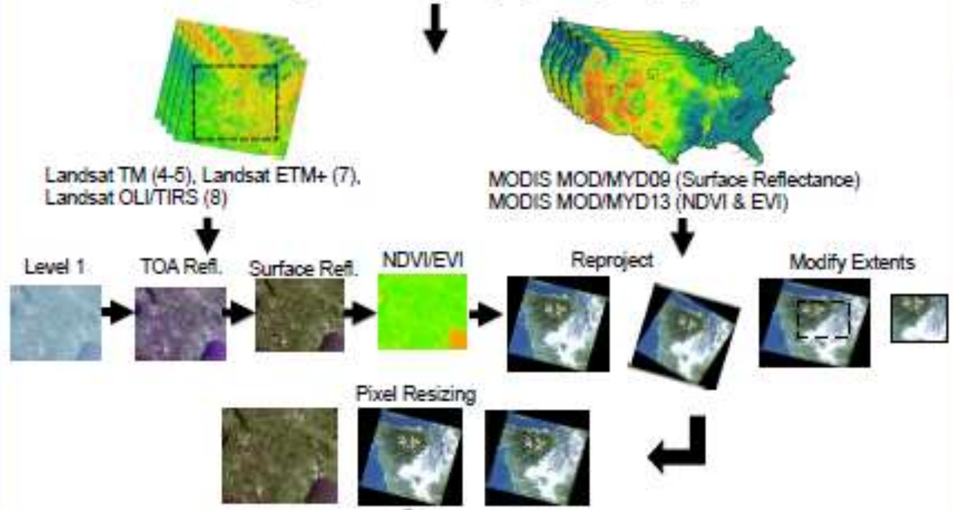
Order Data Products

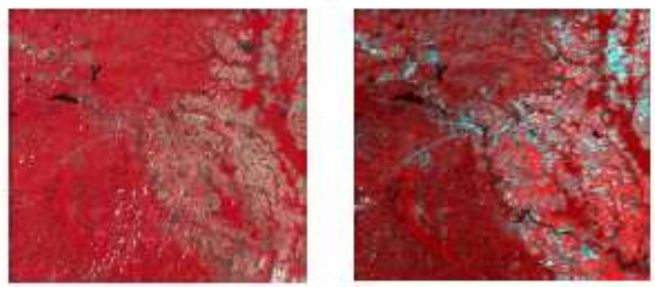
https://espa.cr.usgs.gov

Define output products

Data Transformation

Statistical Characterization & Uncertainty Analysis





Final data sets

Example: Landsat color infrared (left) and MODIS color infrared (right). Sampled to 30 meter spatial resolution, subset to same extent, and projected to Albers Equal Area.

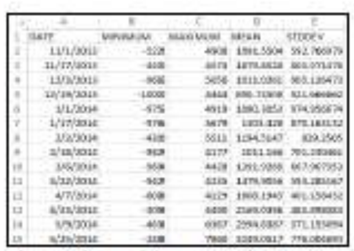
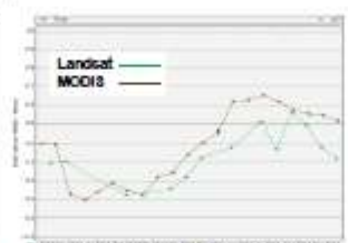


Image date, minimum, maximum, mean and standard deviation



NDVI time series inter-comparisons

Product Information

Example: Sensor or product information includes tables and charts of individual bands or indices.

Future Data Products

Joint Polar Satellite System (JPSS) Visible Infrared Imaging Radiometer Suite (VIIRS)

Geostationary Operational Environmental Satellites - R Series (GOES-R)

European Space Agency (ESA) Sentinel 2

Committee on Earth Observing Satellites (CEOS) validation sites (and other network sites)

April 2015

Future Collaboration

- **Jointly support CEOS WGCV efforts**
  - Interoperability
  - QA4EO
  - Calibration test sites and processes
- **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

- **More of Interoperability later**

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.

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.

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

GCP Improvement Phase 4 Landsat/Sentinel Harmonization

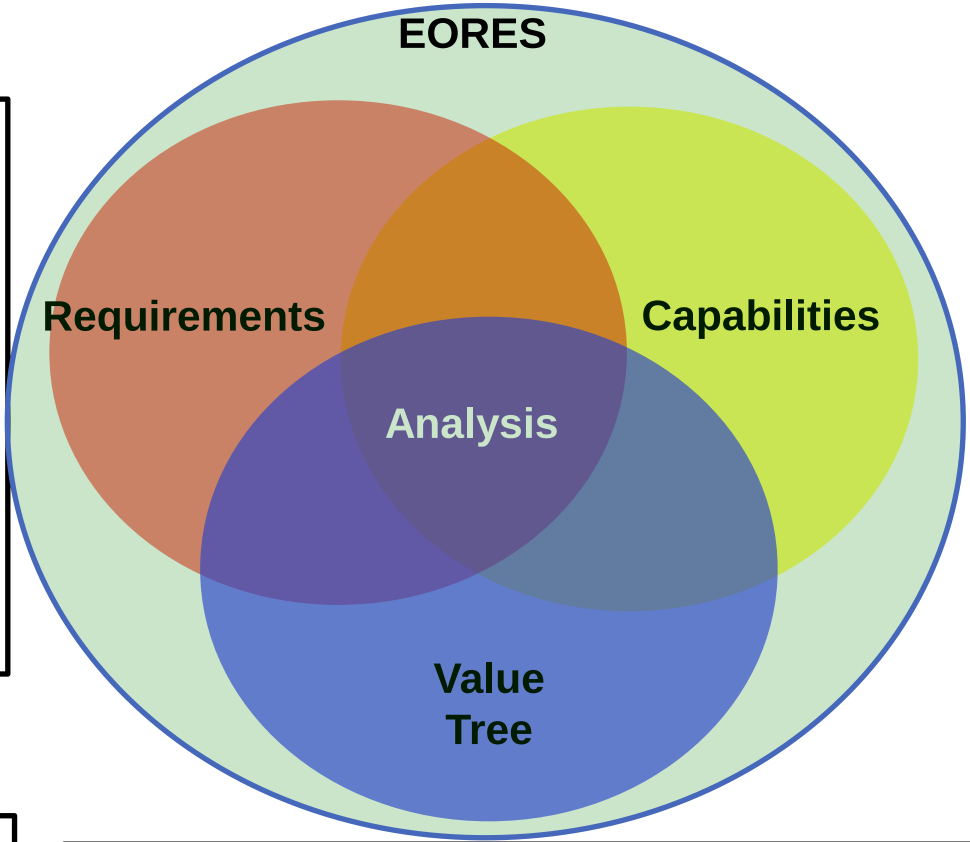
- **Propose global readjustment of the GLS using L8 data with sparse ties to Sentinel-2 GRI.**
  - Global scale version of what was done for the Australian AGRI during the phase 2 GCP improvement.
  - Block areas of up to ~1000 scenes are practical.
- **Blocks can be designed and run unconstrained (based 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

National Earth Observation Assessment

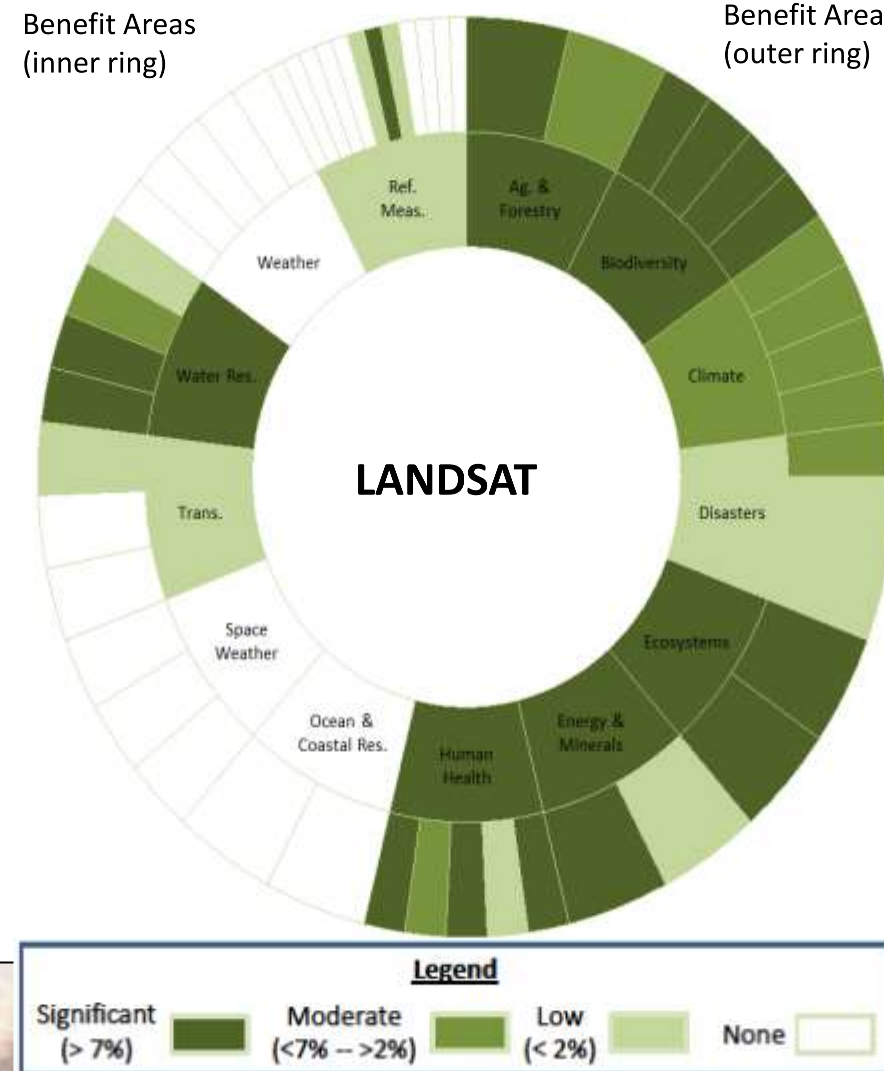
- **National Earth Observation Assessment (EOA 2012)**
  - http://www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/national_plan_for_civil_earth_observations_-_july_2014.pdf
  - Conducted to inform the National Plan for Civil Earth Observations
  - Identified a portfolio of observing systems 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

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

Societal Benefit Areas (inner ring)

Sub-Societal Benefit Areas (outer ring)



NOAA/USGS Land Product Characterization System

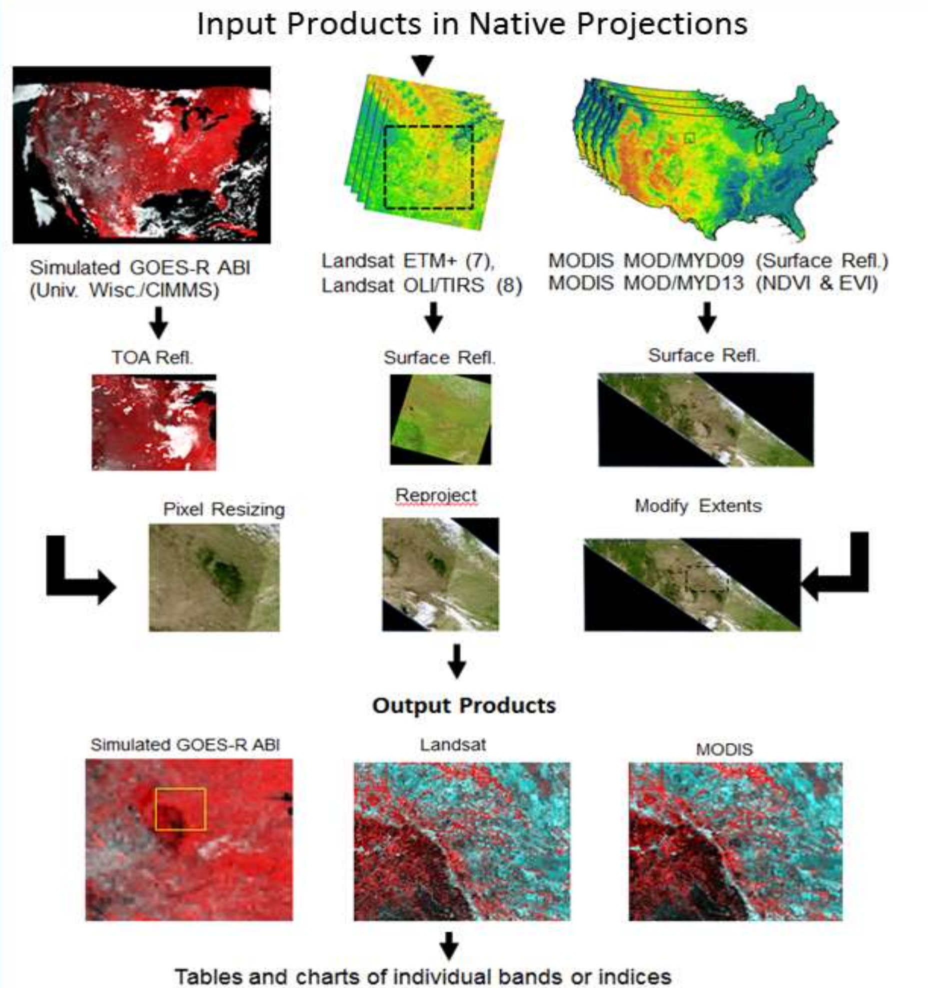
A web-based system that is designed to use moderate- to high-resolution satellite data for the characterization and validation of CEOS-endorsed time series products, including GOES-R ABI, Landsat-8/Sentinel-2, and the Land Science products from MODIS and VIIRS.

The LPCS includes:

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

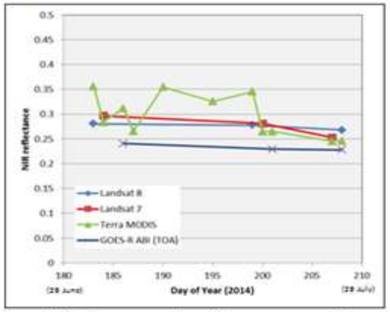
that will permit selection of data to be easily identified, retrieved, co-registered, and compared statistically through a single interface.

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



	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							

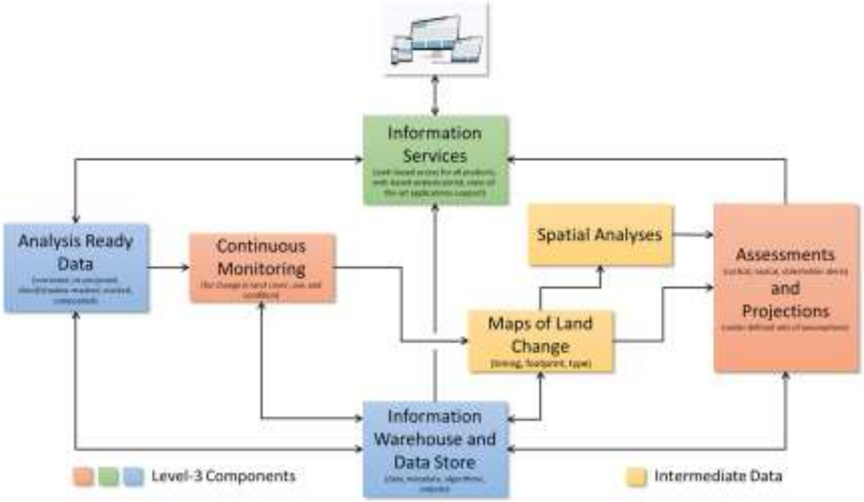
Mean, minimum, maximum, standard deviation

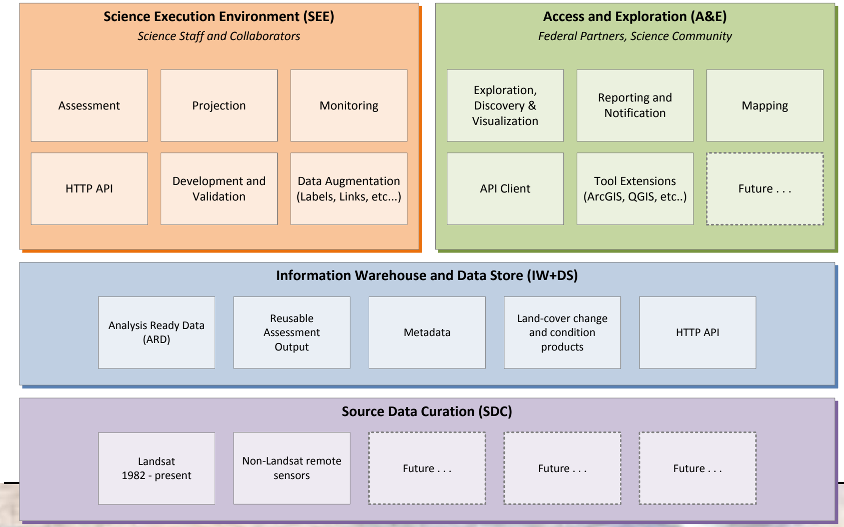


Near-IR time series inter-comparisons

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.

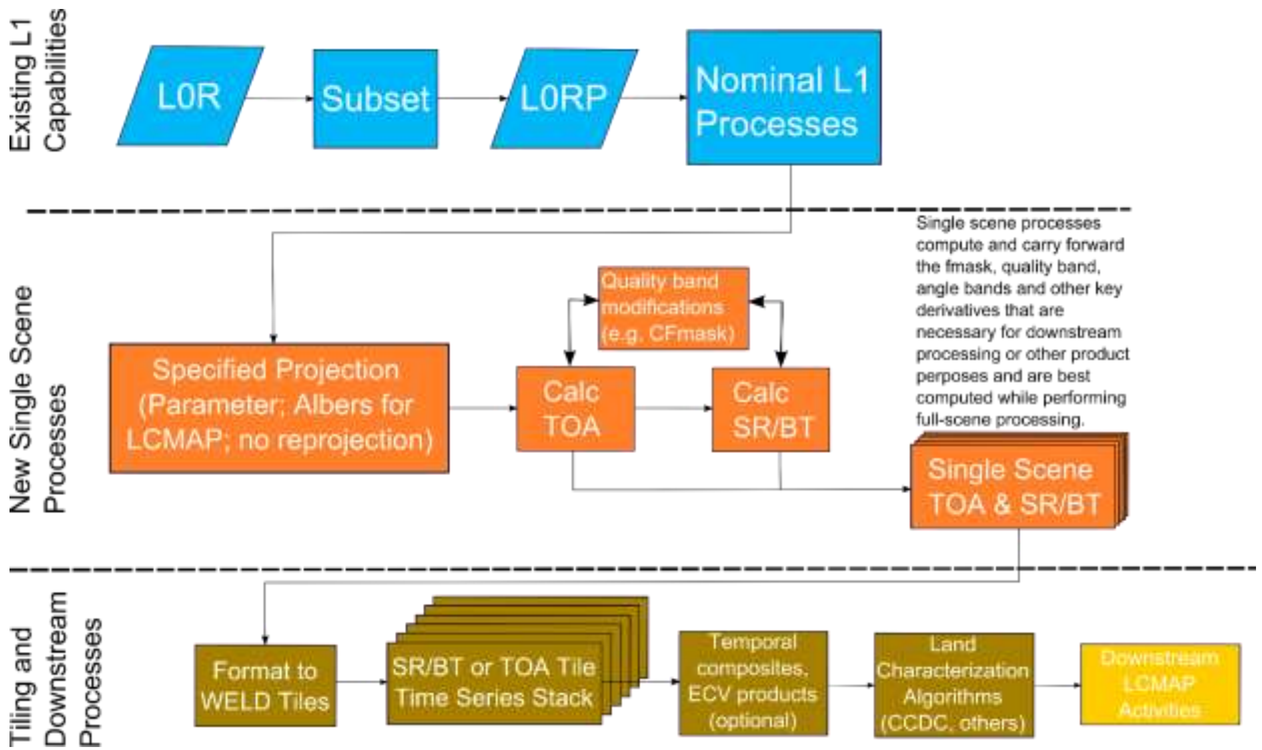


Figure 3 Summary of ARD product flow for LCMAP

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

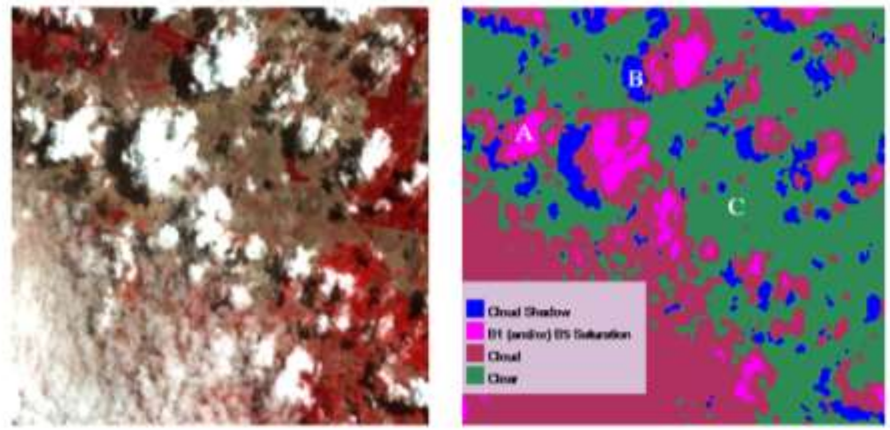
16-bit PQ band

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