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

CALCON 2017 – Logan, UT
August 22-25, 2017

Esad Micijevic\textsuperscript{a}, Nischal Mishra\textsuperscript{b}, Md. Obaidul Haque\textsuperscript{a} and Dennis Helder\textsuperscript{c}

\textsuperscript{a}SGT, Inc., contractor to the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD
\textsuperscript{b}SSAI, NASA Langley Research Center, Hampton, VA
\textsuperscript{c}South Dakota State University, Brookings, SD

esad.micijevic.ctr@usgs.gov, +1 (605) 594-2801
Outline

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

\[ Y = -8.48 \times 10^{-4} X + 0.252 \]

% Drift per year = -0.34% ± 0.1 (2-sigma)

Temporal Uncertainty = 1.74%

L5 TM TOA Reflectance, Blue Band, Libya 4

Pre-Collection

L5 TM TOA Reflectance, Blue Band, Libya 4

Collection 1

\[ Y = -3.71 \times 10^{-4} X + 0.252 \]

% Drift per year = -0.15% ± 0.1 (2-sigma)

Temporal Uncertainty = 1.32%
PICS Trending for L5 TM, Red Band

L5 TM TOA Reflectance, Red Band, Libya 4

Pre-Collection

Collection 1

Y = -8.57E-04*X + 0.449

% Drift per year = -0.19\% \pm 0.06 (2-sigma)

Temporal Uncertainty = 0.98\%

Y = -3.01E-04*X + 0.463

% Drift per year = -0.07\% \pm 0.06 (2-sigma)

Temporal Uncertainty = 0.84\%
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

<table>
<thead>
<tr>
<th>LANDSAT 5 TM</th>
<th>% CHANGE/YEAR ±2-SIGMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLUE</td>
<td>-0.15±0.10</td>
</tr>
<tr>
<td>GREEN</td>
<td>0.03±0.08</td>
</tr>
<tr>
<td>RED</td>
<td>-0.07±0.06</td>
</tr>
<tr>
<td>NIR</td>
<td>-0.13±0.11</td>
</tr>
<tr>
<td>SWIR-1</td>
<td>SATURATES</td>
</tr>
<tr>
<td>SWIR-2</td>
<td>-0.10±0.18</td>
</tr>
</tbody>
</table>

Estimate of TM Gain Change Over Libya4 PICS
(1/1/2000 - End of Mission, 2011)
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

Landsat-7 ETM+ Lamp, Diffuser And PICS Reponse (Blue Band)

Landsat-7 ETM+ Lamp, Diffuser And PICS Reponse (SWIR-1 Band)
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
Collection-1 processing indicates changes in the CA band PICS trends of \(~0.2\%\) per year, which is consistent with the desired update.
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

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

<table>
<thead>
<tr>
<th>Band</th>
<th>Temporal uncertainty (percents)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Landsat 8 OLI</td>
</tr>
<tr>
<td>Coastal Aerosol</td>
<td>0.07</td>
</tr>
<tr>
<td>Blue</td>
<td>0.11</td>
</tr>
<tr>
<td>Green</td>
<td>0.09</td>
</tr>
<tr>
<td>Red</td>
<td>0.07</td>
</tr>
<tr>
<td>NIR</td>
<td>0.05</td>
</tr>
<tr>
<td>SWIR 1</td>
<td>0.04</td>
</tr>
<tr>
<td>SWIR 2</td>
<td>0.07</td>
</tr>
</tbody>
</table>
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