meeting summaries

Landsat Science Team Meeting: First Landsat 8 Evaluations

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Introduction

The U.S. Geological Survey (USGS)-NASA Landsat Science Team (LST) met at the USGS' Earth Resources Observation and Science (EROS) Center near Sioux Falls, SD, from October 29-31, 2013. All meeting presentations can be downloaded from *landsat.usgs.gov/science_LST_October_29_31_2013.php*.

The meeting opened with a telephoned welcome from **Anne Castle** [Department of the Interior—*Associate Secretary for Water and Science*]. Castle thanked the LST members for their service to the Landsat missions and emphasized how important the team's efforts are to the success of the Landsat program. She summarized the discussions underway between NASA, USGS, and the White House Office of Management and Budget to transform Landsat into a sustained land-imaging program, with a series of continuous satellite deployments. —see discussion throughout, and especially the section on **Sustained Land Imaging Planning** on page 27.

Elizabeth Throndˆ [Augustana College], representing the Midwest Archive Conference (MAC), then presented the MAC President's Award to the 2006-2011 LST. The LST members were selected because of the team's significant efforts to expand the global Landsat archive, and for their advocacy for the Landsat free and open data policy. The impacts of such expansion and free access are manifold.

Tom Loveland [EROS—*Senior Scientist*] and **Jim Irons** [NASA's Goddard Space Flight Center (GSFC)—*Landsat 8 Project Scientist*], co-chairs of the LST, set the stage for the three-day meeting and discussed the primary meeting goals, which were to:

- Review the status of LST Landsat 8 investigations;
- discuss the status and requirements for Landsat 9 and beyond; and
- establish plans for improving Landsat science products.

Loveland and Irons stressed the importance of understanding the value of Landsat 8's new capabilities and whether they should be required for future Landsat missions. They also stressed the responsibility of the science team to contribute to the scientific and technical aspects of a sustainable land-imaging program by clearly representing the breadth of Landsat user requirements. Finally, they suggested that this is the most important LST meeting since 2006 and likely the most important

Group photo of Landsat Science Team Meeting attendees. **Image credit:** David Hair, USGS

of this current science team, owing to the combined NASA and USGS efforts to define sustained land imaging concepts by August 2014.

Landsat 8 Operations Status

Brian Markham [GSFC—*Landsat 8 Calibration Scientist*] initiated the technical meeting by providing a report on the radiometric performance of both the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). He said that OLI has been performing well since launch. The measured signal-to-noise ratio (SNR) characteristics exceed design requirements, and OLI outperforms the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) by factors of between 6 and 12. Measurement stability also exceeds requirements, and there is no evidence of significant contamination or degradation of the instrument or onboard calibration devices. Uniformity has been improving—with striping reduced by half—but there are still some discontinuities at focal plane module boundaries. Based on vicarious measurements, the absolute radiance and reflectance calibration generally agree within ±2%.

Regarding TIRS, Markham reported that the instrument is performing well in terms of SNR performance and radiometric stability, but radiometric accuracy of the thermal Band 11 (11.50–12.50 µm) has led to the advisory that at this time Band 11 should not be used for split-window calculations. Banding and streaking issues are a concern with TIRS; the instrument meets banding/streaking uniformity metrics for certain Earth scenes, but fails for others.

Based on the performance analysis, OLI and TIRS data recalibration is needed to increase the precision of OLI radiance-to-reflectance conversion coefficients and to adjust edge detector relative gains in overlap areas between sensor chip assemblies, and to improve the absolute calibration of thermal band 10.[1]

Jim Storey [USGS/Stinger Ghaffarian Technologies Inc.—*Landsat 8 Geospatial Imaging Scientist*] reviewed OLI and TIRS geometric performance, and reported that all geometry requirements are being met or exceeded. Band-to-band, worst-case registration is in the 3.28–4.07-m (~10–13-ft) range for OLI, and 8.7–10.5-m (~28–34-ft) range for TIRS. OLI-to-TIRS band registration is 18.8–20.8 m (~61–68 ft) [worst case], which is well below the 30-m (~98-ft) specification. Geodetic absolute accuracy was 37.0 m (~121 ft) circular error, well under the 65.0-m (~213-ft)specification. The geometric accuracy of the orthorectified Level-1T (L1T) datasets is 11.4 m (~37 ft) circular error, under the 12.0-m (~39 ft) specifications; no evidence of image jitter has been found. Landsat 8 geodetic accuracy in some areas is better than the current ground control observations used to orthorectify all Landsat images. As a result, Landsat 8 data may be used to improve the existing ground control data.

Storey also reported on an effort to develop an approach and tools for generating Landsat 8 scene pixel-level viewing angle and sun angle measurements. The approach is to provide enhanced metadata with each L1T product and a tool for users that would allow computation of scene viewing angles. The LST agreed to test the prototype angle-generation tool and to provide feedback to Storey on its viability as a permanent capability.

Gene Fosnight [USGS EROS—*Landsat Data Acquisition Manager*] summarized efforts to define a multimission acquisition strategy. With both Landsat 7 and 8 collecting data, mission operations staff are working on a new scheduling approach that maximizes the percentage of sunlit Earth imaged each day. Depending on the extent of the landmass associated with each day's orbits, Landsat 7 currently images between 350 and 450 of the 540–630 daily sunlit opportunities. By using Landsat 7 mainly for continental areas, the daily acquisition rate would be fixed at 470 images. Landsat 8 is acquiring approximately 550 images per day and covers almost all land masses, including continents, coastlines, islands, and special-interest areas, such as Antarctica. This approach results in a significant increase in daily science data while reducing instrument wear.

Jim Lacasse [USGS EROS—*Landsat Operations Team Leader*] closed the Landsat status session with a report on Landsat operations and the Landsat data archive. Landsat 8 operations are nominal for all systems, and the satellite has acquired as many as 732 images in a 24-hour period. While the latency design requirement is to be able to process 95% of the daily acquisitions to an L1T product within 24 hours, the system is currently generating nearly 100% of the L1Ts within 5 hours of the data being received at the EROS Center.

Landsat 7 has been operating for more than 14 years. While it has had scan-line corrector, gyro, and fuel-line thermostat problems, it continues to acquire more than 350 global images each day. At this point, it has sufficient fuel to continue operations through 2017. Lacasse mentioned that 1256 coincident Landsat 7 and 8 images were collected in late-March 2013 during the Landsat Data Continuity Mission (LDCM) commissioning phase. The images are available to anyone interested in addressing the differences and synergies between data from the two missions. They can be viewed using standard USGS query tools such as *Earth Explorer* (*earthexplorer.usgs.gov*) and *Glovis* (*glovis.usgs.gov*).

[1] **UPDATE**: A reprocessing took place in February 2014.

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The Landsat archive now includes more than five million images:

Landsat 8 OLI-TIRS: 149,273 scenes
Landsat 7 ETM+: 1,685,804 scenes
Landsat 4-5 Thematic Mapper (TM): 1,904,473 scenes
Landsat 1-5 Multispectral Scanner: 1,299,399 scenes

Archive statistics can be found at *landsat.usgs.gov/Landsat_Project_Statistics.php*.

There has been a substantial increase in archive holdings due to the success of the Landsat Global Archive Consolidation (LGAC) initiative conceived by the 2006–2011 LST. LGAC was established to repatriate international Landsat holdings not found in the USGS EROS Landsat archive. As of October 2013 2.55 million LGAC scenes have been added. The largest international collection, held by the European Space Agency, is now being delivered to the USGS. Lacasse concluded by mentioning that in Fiscal Year 2013, 4.36 million Landsat images were downloaded from EROS, substantially higher than the 2.73 million images downloaded the previous year.

Landsat 8 Science and Applications

Each of the LST members reported on their Landsat research, and where possible, their evaluation of Landsat 8 data. Collectively, the 20 research presentations showcased the:

- Excellent radiometric and geometric performance of the Landsat 8 instruments;
- opportunities resulting from the improved daily acquisition capacity;
- data quality improvements associated with the cirrus band;
- seamless integration of Landsat 8 data into many operational applications and scientific investigations; and
- potential new applications resulting from the additional spectral measurements.

The presenters, topics, and key findings from each presentation follow.

Kurt Thome [GSFC—*Terra Project Scientist*], with **Joel McCorkel** [GSFC] discussed *Absolute Radiometric and Climate Variable Intercalibration of Earth Observing Sensors*. Simultaneously acquired Landsat 7 and 8 data, when compared with other airborne and field measurements, show calibration results within ~4% absolute uncertainty, suggesting that Landsat provides a critical sampling resolution bridge between current and upcoming satellite, airborne, and ground-based observatories.

Eric Vermote [GSFC] discussed the *Development of Landsat Surface Reflectance Climate Data Records*. A preliminary Landsat 8 surface-reflectance product has been developed and is being validated; the addition of the Band 9 (the Landsat 8 cirrus band) should improve atmospheric corrections.

David Roy [South Dakota State University] described *Continuity of the Web Enabled Landsat Data (WELD) Product Record in the LDCM Era,* discussing the lack of Landsat 8 saturation over bright targets (as compared to Landsat 7) and how improved geolocation improves the quality of large-area products.

Yongwei Sheng's [University of California, Los Angeles] discussed *Developing Decadal High Resolution Global Lake Products from LDCM and Landsat*, describing how early results show that Landsat 8 radiometry is superior to that from Landsat 7 and will result in improved delineation of water bodies.

Crystal Schaaf [University of Massachusetts, Boston] presented *North American Land Surface Albedo and Nearshore Shallow Bottom Properties from Landsat and MODIS/VIIRS* [2], and said that a preliminary Landsat 8 albedo product has been generated and is being evaluated.

John Schott [Rochester Institute of Technology] discussed *The Use of LDCM for the Monitoring of Fresh and Coastal Water*, stating that Landsat 8 radiometric performance should increase the ability to characterize chlorophyll, suspended materials, and colored dissolved organic matter.

Ted Scambos [University of Colorado] discussed *Cryospheric Applications of the Landsat Data Continuity Mission (or Landsat 8),* describing how Landsat 8's improved acquisition capabilities offer significant opportunities for polar-region imaging campaigns. He stated that the improved geometry will lead to greater use in quantifying ice flows.

Ayse Kilic [University of Nebraska-Lincoln] and **Richard Allen** [University of Idaho] presented *Developing and Enhancing Landsat-Derived Evapotranspiration and Surface Energy Balance Product*, wherein they reported excellent correspondence in the comparison of surface albedo and evapotranspiration during the Landsat 8 underflight of Landsat 7, and that the addition of the cirrus band helps explain unexpected cool temperatures.

Feng Gao [U.S. Department of Agriculture, Agricultural Research Service] discussed *Mapping Vegetation Phenology, Water Use, and Drought at High Spatiotemporal Resolution Fusing Multiband and Multiplatform Satellite Imagery*, stating that Landsat 8's 30-m (~98.4-ft) thermal sharpening results are comparable

[2] MODIS is the Moderate Resolution Imaging Spectroradiometer; VIIRS is the Visible Infrared Imaging Radiometer Suite.

to those from Landsat 7; additional testing will require Landsat 8 surface temperature processing.

Jim Vogelmann [USGS] described *Ecological Disturbance Monitoring using Landsat Time Series Data,* and showed that there is a substantial improvement in the clarity of surface features in Landsat 8 imagery (over Landsat 7) due to the increased dynamic range and overall improved radiometry.

Alan Belward [European Commission Joint Research Centre] presented *Understanding the Global Land-Use Marketplace*, describing how Landsat continues to be the "gold standard" for global land-cover monitoring. The robust data acquisition strategy and distribution policy increases Landsat's importance for monitoring global land change.

Leo Lymburner [Geoscience Australia] described *Multitemporal Analysis of Biophysical Parameters Derived from the Landsat Series of Satellites*, stating that preliminary Landsat 8 results show the potential for retrieving shallow water bathymetry, improving vegetation characterization, and increasing the potential of nighttime imaging.

*Perhaps the best summary statement was **Alan Belward's** observation that while there are literally hundreds of Earth observation missions, Landsat stands out as the "gold standard" due to the systematic acquisition of global imagery, the consistent high data quality, and the accessibility of these data to anyone in the world.*

Patrick Griffith on behalf of **Patrick Hostert** [Humboldt University of Berlin—Germany] presented *Synergies Between Future Landsat and European Satellite Missions for Better Understanding Coupled Human-Environment Systems*. He stated that there is need for a Landsat 8 surface reflectance product, and recommended that efforts be undertaken to identify synergy between Landsat 8 and the European Space Agency's (ESA) Sentinel-2 platforms, the first of which is currently scheduled for launch in 2014.

Mike Wulder [Canadian Forest Service] focused on *Integrating the Past, Present, and Future of Landsat*, and discussed the integrity of the full Landsat production chain. He said that the confidence users have in Landsat data continues to enable operational applications and implementation of composited products.

Robert Kennedy [Boston University] discussed *Using Time-Series Approaches to Improve Landsat's Characterization of Land Surface Dynamics*. He described how Landsat 8 surface reflectance products are needed for long-term monitoring, and pointed out that a quick analysis of basic data products such as the normalized burn ratio shows consistency between Landsat 8 and previous missions.

Randolph Wynne [Virginia Tech] discussed *Integrating the Past, Present, and Future of Landsat*, explaining that preliminary results show slight improvements in Landsat 8 *versus* Landsat 7 correlations between leaf area index and the normalized difference wetness index.

Curtis Woodcock [Boston University] focused on *Better Use of the Landsat Temporal Domain: Monitoring Land Cover Type, Condition, and Change*. He explained that the Landsat 8 cirrus band significantly improves detection of clouds and cloud shadows. He also stated that image classification accuracies are improved using Landsat 8 *versus* 7 data, due to improved radiometric resolution, and that *variograms* show reduced noise and increased variance in Landsat 8 data.

Warren Cohen [USDA's Forest Service] presented *Ecological Applications of Landsat Data in the Context of U.S. Forest Service Science and Operational Needs*, showing that Landsat 8 potentially extends the Landsat record to 50 years, and offers the continuity of observation needed to understand changes in natural resources.

Jim Hipple [USDA's Risk Management Agency] discussed *Integrating Field-Level Biophysical Metrics Derived from Landsat Science Products into a National Agricultural Data Warehouse*, and described how growing condition variables derived from Landsat will be used to assess field-level conditions that relate to crop insurance issues.

David Johnson [USDA's National Agricultural Statistical Service] described *Operational Monitoring of U.S. Croplands with Landsat 8*, explaining that the USDA's annual crop type mapping used nearly 1000 Landsat 8 scenes in this year's cropland data layer generation

Sustained Land Imaging Planning

The Executive Branch of the U.S. government has initiated planning for a sustainable land imaging program. **Matt Larsen** [USGS—*Associate Director for Climate and Land Use Change*] gave an overview of the planning process that is to produce a solution for the next Landsat mission—and missions for the next 25 years. With Landsat 7's fuel-based end-of-life in 2017 and Landsat 8's five-year design life coming in 2018, there is considerable urgency to initiate development of the next Landsat. NASA is leading the planning process, with the USGS as a partner. **Brad Doorn** [NASA Headquarters—*Applied Sciences Program, Water Resources Program Manager*] emphasized that NASA's goal is to define a sustained, space-based, global land imaging capacity for the nation, that is driven by meeting user requirements. A Request for Information (RFI) was issued in September 2013 to identify concepts for future missions. NASA is required to provide an architecture plan to the White House by August 15, 2014.

Tim Newman [USGS's Land Remote Sensing Program—*Acting Program Coordinator*] provided additional details regarding the activities underway to define future Landsat capabilities. While the shape of the

future land imaging program is still being determined, it is certain that the strong cooperation between NASA and the USGS, established during Landsat, will continue, with NASA leading the architecture investigations and USGS working toward documenting user requirements. The USGS's National Land Imaging Requirements study has gone through a pilot phase in which requirements from federal users of moderate resolution imagery were collected. The NASA-led Architecture Study Team (AST) will use the results in their consideration of future mission concepts.

Newman also briefly summarized the recent National Research Council's (NRC) report, *Landsat and Beyond: Sustaining and Enhancing the Nation's Land Imaging Program* (*www.nap.edu/catalog.php?record_id=18420*). The report concludes that the U.S. Government should establish a "sustained and enhanced land imaging program" with sufficient funding to meet current and future needs. The NRC's report calls for the development of a plan for a program that capitalizes on NASA's and USGS's strengths; maintains current capabilities; enhances imaging capabilities and data products via emerging technologies; and establishes a research and development component for improved data products, new measurement methods, and approaches for meeting evolving requirements.

Del Jenstrom [GSFC—*AST Manager*] described the formation of a NASA–USGS AST, as mentioned earlier, that will assess architecture options for a long-term sustainable land-imaging program. The AST will analyze and prioritize user requirements, evaluate instrument and observatory designs, consider architecture technical concepts and business models, and conduct cost assessments. Recommended architectures must be delivered to NASA's Earth Science Division in May 2014.

Curtis Woodcock and **David Roy** [LST co-leaders] led a discussion of several scientific and technical issues associated with future Landsat plans. These included:

- Identifying critical characteristics and specifications (e.g., data consistency and accessibility, geographic coverage, temporal frequency, latency, spectral bands, spatial resolution, accuracy) for future missions, and their traceability to specific science and applications;
- defining data continuity approaches that ensure that long-term science investigations and operational program investments are preserved;
- determining the relative compatibility that ESA's Sentinel-2 mission offers the Landsat community in terms of science applications; and
- assessing required radiometric accuracy and stability needed for applications, and the science impact of temporal variability in radiometry.

Additional issues discussed included spectral precision advances (e.g., hyperspectral imaging), spectral band registration needs, coincident measurement issues (e.g. temporal separation of thermal imaging from the reflected bands), and the impacts of radiometric error. The LST established study teams that will prepare formal statements on each.

Landsat Science Products

The final meeting objective, to develop plans for improving Landsat science products, was discussed in general terms. **John Dwyer** [EROS—*Landsat Ground System Scientist*] led off the discussion with a brief update on USGS' plans to produce higher-level Landsat products. He reported on the availability of Landsat 4-7 TM and ETM+ surface reflectance products, the development status of the surface temperature product, and Essential Climate Variable (ECV) activities.

The LST then broadly discussed how the 2008 Landsat free-data policy changed data analysis approaches. Increasingly, users require access to data spanning longer periods and larger geographic areas. This suggests that, in the future, the on-demand model for L1T product downloads will become obsolete. Another important priority is generation of Landsat science datasets meeting international Climate Data Record and ECV standards. **David Roy** presented a philosophy for establishing a science information product program. The team agreed to prepare a *white paper* outlining a possible direction, given the uncertainties and constraints associated with the Landsat program.

Other Business

Darrel Williams [Global Science and Technology, Inc.—*Chief Scientist*] briefly reported on activities at the National Geospatial Advisory Committee's Landsat Advisory Group (LAG). The LAG is developing responses to several study questions related to Landsat. The questions address product opportunities, emerging computing and data management approaches, and an assessment of the NRC *Landsat and Beyond* report. The reports should be available by the end of 2014.

Conclusion

The meeting provided the first complete review of Landsat 8 experiences and capabilities. While the investigations into data quality, compatibility, and science and applications opportunities are still at an early stage, the initial results indicate that Landsat 8 is exceeding expectations. The team's findings are especially important as discussions on the strategies and characteristics of the next generation of land imaging satellites unfold. The next meeting will be scheduled during the summer, 2014. The specific dates and location are to be determined. ■