

USGS-NASA Landsat Science Team Statement on Landsat Continuity:
Priorities for a Future Land Imaging Architecture for Sustained Landsat Observations

January 27, 2014

Preface

At the October 29 – 31, 2014 Landsat Science Team (LST) meeting at USGS EROS Center, the LST received requests for input to the Future of Land Imaging Architecture Study Team from NASA and USGS representatives of the Future of Land Imaging Steering Committee. Specifically, the LST was asked to describe and prioritize the characteristics of the Landsat data record essential to data continuity. The LST considered the use of Landsat data in a wide range of scientific and operational applications, and in a follow-up meeting held January 7–8, 2014 at the U.S. Department of the Interior in Washington DC, the LST developed consensus comments and recommendations regarding Landsat continuity.

Landsat Continuity Definition

The USGS-NASA LST strongly endorses the goal of Landsat data continuity as the overriding driving requirement for a future Landsat land imaging architecture. The 1992 US Land Remote Sensing Policy Act stated “...it is in the best interest of the United States to maintain a permanent, comprehensive Government archive of global Landsat and other land remote sensing data for long-term monitoring and study of the changing global environment.” Landsat continuity is needed to:

- Ensure the scientific integrity and objectivity of global land and climate change research.
- Ensure the continued accrual of benefits from past Landsat investments by extending the long-term record.
- Protect the investments of agencies, organizations, and businesses that rely on Landsat data to meet their objectives.
- Deliver the benefits to society for which the Landsat program was established.
- Ensure our nation’s food and environmental security.

The LST defines Landsat data continuity as the collection, archival, and distribution of image data of the Earth’s continents and surrounding coastal regions with the content, quality and coverage needed to map, monitor and assess the Earth’s characteristics and its response to natural and human-induced change over time. To accomplish this, continuity includes:

- Long-term calibrated measurements that are consistent across the evolving instrument record.
- A continuous record since the initiation of observations in 1972 with no significant temporal or geographic data gaps.

- Measurements that enable backward and forward assessments of the conditions and changes in the Earth's surface. A period of overlap between missions is needed to ensure measurement consistency.
- Measurements with comparable spectral, spatial, temporal, and geographic properties that result in sufficiently consistent and accurate documentation of surface characteristic and dynamics.

The Landsat 1-8 mission goals have been unchanged with respect to the continuity purpose in support of science understanding of local to global land change and providing operational information to support natural resource and land management decision making. Consistent basic data characteristics are a hallmark of Landsat data since Landsat 1, and especially since Landsat 4 and the beginning of the Thematic Mapper (TM) era. Evolutionary advances in capabilities resulting from new technologies and ideas have improved applications without compromising continuity. Since 1972, incremental improvements in image acquisition capacity, measurement capabilities, and data quality, have led to expanded and improved Landsat science and applications. Now, both scientific and operational applications are based on the latest Landsat capabilities (e.g., Landsat 8), and those capabilities have been shown to meet design and operations aims and offer a *de facto* definition of minimum target specifications.

Recommended Continuity Specifications

The following specifications represent the synthesis of requirements by key societal benefit areas, experience with past and current Landsat data, and careful consideration of Landsat's storied history and mission goals. The recommendations are what the LST believes are the priorities for a future land imaging architecture that meets the needs of a broad Landsat science and applications user community.

Data Accessibility

Continuing the current USGS Landsat data policy of free and open access to data products is essential to the future of land imaging. The decision by USGS to provide free data, beginning in 2008, has engendered a revolution in the analyses and application of Landsat data, increasing the return on investment in the Landsat program by orders of magnitude. There is no going back to a fee-based distribution policy since this would jeopardize the increased utilization. Given continued free-access, the data distribution system maintained at USGS EROS must be scaled for not only the new Landsat imaging architecture, but for expanding use of Landsat 1 through 8 as applications of archive data continue to increase.

The revolution in Landsat use has changed user expectations for data accessibility and future Landsat missions and archive operations must rapidly evolve to provide calibrated and orthorectified pixel-based science data spanning large areas and long time periods. Future architectures must make Landsat image access and use easier,

and architectures that complicate data structure and make future images less compatible with the images from the earlier Landsat satellites should not be considered.

Geographic Coverage

Global coverage of the continental surfaces, ice sheets, coastal regions, islands, and coral reefs is essential and is consistent with the Long Term Acquisition Plans used to schedule the collection of Landsat 7 and Landsat 8 images. Complete global coverage every period (e.g., 16 days) should be a goal. There is a need to image the entire sunlit land surface in view on each orbit, as well as extensive areas of coastal and polar oceans.

With land and ice cover changing rapidly across the globe with profound consequences to society, the Landsat goal of monitoring and detecting changes in land and ice cover requires the continuation of sun-synchronous orbits and image acquisition plans.

Temporal Frequency

The LST considers eight-day coverage of the global land surface to be the standard for continuity. Two Landsat satellites have been in operation for the majority of the nearly 42-year Landsat era. Two Landsat satellites have provided the opportunity to collect an image anywhere over the globe once every eight or nine days.

Many applications and studies would be enhanced or enabled by more frequent coverage. Prominent amongst such applications and studies are those observing intra-annual vegetation phenology such as crop monitoring and yield forecasting. Other applications, such as tracking glacier extent changes, tropical forest mapping, and water rights monitoring benefit greatly from more frequent coverage. In addition, increased observation frequency will help all applications set in regions with significant cloud coverage (e.g., tropics, high latitudes). The LST encourages the consideration of land imaging architectures, operations concepts, international collaboration opportunities, and other strategies leading to more frequent global coverage at Landsat-like spatial and spectral resolutions. Four-day coverage is viewed as an appropriate long-term goal.

An example of the benefit of increased temporal frequency is in evapotranspiration (ET) retrievals, especially those at spatial scales associated with human activity. Ideally, higher frequency collections of reflected and thermal data will improve monitoring substantial variations in day-to-day ET rates caused by rapid vegetation growth, abrupt harvests, damaging weather events, and random irrigation wetting events. In summer months, vegetation amounts and ET rates can double over a ten-day period. Statistical analyses by Morton et al. (2014) have shown that four-day revisit time is necessary to produce a consistent and continuous series of monthly cloud-free views for much of the US, where a monthly time series is considered to be a minimum requirement for producing ET information for water resources management.

Swath width is related to temporal frequency as well as other continuity performance issues. While a wider swath enables more frequent acquisitions over the globe, increased angular views also result in larger footprints – as large as 75 m for AWiFS (Goward et al., 2012) and increased surface reflectance anisotropy effects. The bidirectional reflectance distribution function (BRDF) effects capture the varying amount of intrinsic shadowing displayed by vegetation surface structure under a range of viewing and solar illumination angles. These BRDF effects are evident even in the current near-nadir Landsat observations and can result in variations of 10% between true nadir and edge of scan (Gao et al., 2014) especially at higher solar zenith angles. These variations increase rapidly as sensors exceed view zenith angles of greater than 15° (as for AWiFs and HuanJing). While corrections are possible, *a priori* information of the surface anisotropy is then required, complicating processing and use of the data.

Latency

The performance of Landsat 8 with respect to data latency exceeds specifications and expectations. Currently, Landsat 8 images are typically available for downloading within five hours of collection by the spacecraft in comparison to the 24-hour specification. The LST finds the 24-hour specification suitable for most land imaging studies and applications with the notable exception of emergency response where near real time availability could be of benefit. For emergency response purposes, data availability within one hour of acquisition is considered optimal and data availability within 6 hours is considered workable. The LST suggests that operations flexibility can be used to meet emergency requirements.

Spectral Bands

The LST views the full set of 11 Landsat 8 spectral bands (OLI and TIRS) as the standard for data continuity. The LST priorities for spectral bands are from greatest priority to least priority:

- The eight heritage Enhanced Thematic Mapper-Plus (ETM+) spectral bands (Landsat 8 OLI bands 2 to 8, and TIRS band 10; three visible, one near infrared, two shortwave infrared, and one thermal infrared band).
- The cirrus band (OLI band 9)
- 15m panchromatic, or alternatively, a 15m pair at red and NIR
- The new blue band (OLI band 1)
- The second TIRS thermal band (band 12)

Including a few additional spectral bands in the future could advance Landsat applications and research. Options include a mid-wave infrared band (3 or 4 microns) for fire detection and high surface temperature measurement (e.g., fires and lava), red-edge and yellow bands comparable to Sentinel-2 Multispectral Imager (MSI) bands for vegetation observations, and two water vapor bands comparable to the MODIS bands around 940 nanometers for atmospheric correction. These additions are a lower priority than the Landsat 8 spectral bands for continuity.

Near simultaneous (i.e., within a few seconds) data collection for the reflective spectral bands (visible, near infrared, and shortwave infrared) is essential for land image analyses and applications. Some separation of time between the collection of reflective band data and thermal band data is tolerable. The collection must be within seconds to use thermal data for cloud detection and clearing for reflective band images, within minutes for observations of hydrodynamics in coastal waters and lakes, and can be within hours for measurements of evapotranspiration. Separation in time presents concerns with respect to band-to-band image registration and cloud cover obscuration of sequential observations. Because there is no record of integrated but time-separated measurements in operational applications, there is need for a significant research investment to first determine the utility of data not collected simultaneously. Therefore, at this time, the LST does not recommend measurement separation.

Spatial Resolution

The heritage 30 m spatial resolution of the reflective TM, ETM+, and OLI spectral bands has proven eminently suitable for the applications of Landsat data and the scientific objectives of the Landsat program. The LST considers continuation of the 30 m resolution for reflective bands as one of the highest priorities for future land missions. The LST views 30 m resolution for reflected spectral bands as the maximum ground sample distance and resolution for all future land imagers.

Likewise, the heritage 15 m spatial resolution of the ETM+ and OLI panchromatic bands is considered an optimal ground sample distance for future imaging for the Landsat system where enhanced spatial resolution is needed to meet application goals. A 15 m resolution red band, or red and near-infrared bands (e.g., enhanced NDVI resolution) is considered to be a useful alternative to a panchromatic band. In the latter case, the 15 m red and NIR pair would support vegetation and crop analysis, and glacier surface type and snow grain size studies, and improve any application where repeated mapping is the primary goal.

As the land imaging strategy evolves over time, it should be noted that there are a number of application areas that would benefit from routine collection of multispectral data at finer spatial resolutions than 30 meters. Examples of these application areas include agricultural mapping, monitoring of forest degradation in support of international Reducing Emissions from Deforestation and Forest Degradation Plus (REDD+) initiative, mapping and monitoring of urban areas, estimation of lake and glacier areas, and improved detail to support disaster assessment and response.

The LST considers the specified 120 m spatial resolution for the TIRS thermal bands as a maximum ground sample distance for future thermal images. The LST places a priority on improving the spatial resolution of future thermal images to at least the 60 m thermal band resolution provided by the ETM+. This return to the ETM+ heritage resolution would allow the measurement of water consumption within many irrigated agriculture fields that are not currently resolved by the 100 m Landsat 8 TIRS images,

and would support better mapping of coastal water temperatures in estuaries, bays, and fjords.

Radiometric Calibration and Accuracy

Radiometric accuracy and stability are essential to monitoring change over time and are therefore a critical element of Landsat continuity. Continuity requires either an uncertainty of less than 5% with respect to absolute spectral radiance or less than 3% with respect to top-of-atmosphere reflectance in the case of images for reflective spectral bands. Continuity requires an uncertainty less than 2% with respect to at-sensor spectral radiance in the case of thermal bands. These requirements have emerged as standards for other U.S. Earth observations by optical sensors, and are central to international science standards for long-term climate monitoring. Thus, the LST considers the retention of these requirements a high priority for future land imaging.

Long term consistency for many applications is as important as radiometric accuracy. Ideally, data overlap between missions is needed for maximum data integrity, an important issue for assuring the temporal consistency of measurements needed for detection of subtle ecosystem changes.

Radiometric Performance

The radiometric performance requirements of the Landsat 8 OLI and TIRS were stringently specified in terms of signal-to-noise ratios (SNR's), cross-track radiometric and spectral response uniformity, coherent noise, stray light, and a number of additional characteristics. The result is the collection of high-quality images by the Landsat 8 sensors with performance exceeding specifications in many respects, particularly SNR. The LST considers the OLI and TIRS specifications to be a high priority for future US land imaging sensors.

Early science results are showing significant improvements in detecting, characterizing, and mapping surface conditions and changes. These improvements will enhance the accuracy and acceptance of Landsat products, which should increase the role of Landsat in decision support. Therefore, deviating from the OLI specifications is not acceptable. Based on evidence from Landsat 7 and Landsat 8 applications results comparisons, the LST has identified significant applications improvements and sees benefit in achieving the actual OLI performance in the future. Ideally, the LST recommends SNR performance specifications located between the OLI specifications and the delivered performance.

Geometric and Geodetic Accuracy and Stability

As with radiometric accuracy and stability, geometric/geodetic accuracy and stability are critical to observing change over time and other land image analyses. The LST considers Landsat 8-level performance with respect to geometric accuracy and orthorectification (registration to a cartographic projection with ground control and digital

elevation models for Level 1T products), geodetic accuracy (registration to the Earth geoid without ground control), orthorectification, band-to-band registration, and multi-temporal image-to-image registration to be a high priority for the future of land imaging. Landsat 8 specifications and on-orbit performance are shown in the table below.

Table 1: Summary of Landsat 8 Specifications and Performance with Respect to Image Geometry and Registration Accuracy.

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)	3.98	<4.5	meters (LE90)	11.6%
OLI Band Registration Accuracy (no cirrus)	3.33	<4.5	meters (LE90)	26.1%
Absolute Geodetic Accuracy	36.9	<65	meters (CE90)	43.2%
Relative Geodetic Accuracy	19.9	<25	meters (CE90)	20.4%
Geometric (L1T) Accuracy	11.4	<12	meters (CE90)	5.0%
OLI Edge Slope	0.03054	>0.027	1/meters	13.1%
TIRS Swath	186.2	>185	kilometers	0.6%
TIRS Ground Sample Distance	103.424	<120	meters	13.8%
TIRS Band Registration Accuracy	10.5	<18	meters (LE90)	41.7%
TIRS-to-OLI Registration Accuracy	22.1	<30	meters (LE90)	26.2%

Inherent band-to-band registration (i.e., near-perfect band-to-band registration without resampling) is viewed as a long-term goal of advanced technology infusion and is not considered a priority by the LST for the near future. The current band-to-band registration of OLI and TIRS data is adequate for the vast majority of current analyses, applications, and studies.

References

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