Department of the Interior
U.S. Geological Survey

LANDSAT
COLLECTION 1 LEVEL 1
PRODUCT DEFINITION

Version 2.0

April 2019

science for a changing world

LANDSAT
COLLECTION 1 LEVEL 1
PRODUCT DEFINITION

April 2019

Approved By:

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Executive Summary

To support analysis of the Landsat long-term data record that began in 1972, the USGS Landsat data archive was reorganized into a formal tiered data collection structure. This structure ensures all Landsat Level 1 products provide a consistent archive of known data quality to support time-series analysis and data "stacking", while controlling continuous improvement of the archive, and access to all data as they are acquired.

Collection 1 Level 1 processing began in August 2016 and continued until all archived data was processed, completing May 2018. Newly-acquired Landsat 8 and Landsat 7 data continue to be processed into Collection 1 shortly after data is downlinked to USGS EROS.

Document History

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Section 1 Summary

To support analysis of the Landsat long-term data record that began in 1972, the Landsat data archive was reorganized into a formal tiered data collection structure. This structure ensures all Landsat Level 1 products provide a consistent archive of known data quality to support time-series analysis and data "stacking", while controlling continuous improvement of the archive, and access to all data as they are acquired.

The collection definition consists of three categories: Tier 1, Tier 2, and Real-Time. Data in Tier 1 meet formal geometric and radiometric quality criteria. Data in Tier 2 do not meet the Tier 1 criteria. The Real-Time tier contains data captured immediately after acquisition and uses estimated calibration parameters. Real-Time data are then reprocessed and assessed for inclusion into Tier 1 or Tier 2 as soon as final calibration parameters are available.

The radiometric performance of each Landsat sensor is characterized and quantified at the instrument level in terms of absolute radiometric uncertainty and temporal uncertainty (stability). Radiometric stability is critical to time-series analysis. However, occasional corrections may be needed that introduce discontinuities into the time-series observations. These corrections accumulate until the collection archive can be reprocessed, resulting in the release of a new collection. If individual bands fail to meet specifications, the collection definitions are updated accordingly.

The geometric quality of Landsat Level 1 data products can be quantified on a per-scene basis for each instrument in terms of geodetic accuracy relative to Ground Control Points (GCPs). The geodetic accuracy of the Level 1 products is the initial discriminating factor in determining whether they satisfy the criteria for being in the Tier 1 collection (i.e., the data are "stackable" to enable multispectral time-series analysis). It is anticipated that other quality conditions (no payload correction data, drop lines, excessive saturation, derivatives of data processed at ground stations) are identified, causing scenes to be assigned to Tier 2 even though they may meet the geodetic criterion.

For scenes to be eligible for data "stacking" for time-series analysis, an image-to-image registration accuracy of ≤12-meter Root Mean Square Error (RMSE) must be met. This threshold is tied to the Global Land Survey (GLS) reference database and was established specifically for Collection 1. The threshold can be met by the current processing system and ground reference database. The RMSE is stored in the Level 1 metadata to accommodate user requirements to either remove data in Tier 1 or add data in Tier 2 to satisfy specific user applications.

Section 2 Introduction

Most analyses of the Landsat Earth observation data record require the radiometry and geometry of the data record to be consistent and accurate. Consistency ensures that measured changes are due to Earth surface changes and not due to sensor changes (either radiometric response or geometric location). Absolute accuracy ensures a well-established relationship between the product digital number (DN) values and measured radiometric response in physical units, as well as ensuring that the measurements representing what is on the Earth's surface are in the correct location. Absolute accuracy also allows comparisons of Landsat measurements to other satellite and ground sampled measurements. This document describes the Landsat Collection structure, the criteria for Collection 1 and how they relate to the science requirements, the characterization of the Landsat archive.

Landsat Collection 1 consists of Level 1 products generated from the Landsat 8 Operational Land Imager (OLI) / Thermal Infrared Sensor (TIRS), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), Landsat 4-5 Thematic Mapper (TM), and Landsat 1-5 Multispectral Scanner (MSS) instruments. The implementation of collections ensures consistent and known radiometric and geometric quality through time and across instruments and improves control in the calibration and processing parameters.

Landsat Collection 1 Level 1 products are assigned to one of three Landsat collection tiers:

- Real-Time (RT) – OLI / TIRS and ETM+ data processed immediately upon downlink but use predicted ephemeris, initial bumper mode parameters, or initial TIRS Line of Sight (LOS) model parameters. Once the data have been reprocessed with Definitive Ephemeris (DE), updated bumper mode parameters, or refined TIRS parameters, the products transition to either Tier 1 or Tier 2.
- Tier 1 – OLI / TIRS, ETM+, TM, and MSS data processed to Level 1 Precision and Terrain corrected products (L1TP) with image-to-image registration to the GLS control of ≤12-meter Radial Root Mean Square Error (RMSE).
- Tier 2 – OLI / TIRS and ETM+ data processed to Level 1 Systematic and Terrain Corrected products (L1GT), TM and MSS data processed to Level 1 Systematically corrected (L1GS) products, and Level 1 Precision and Terrain Corrected products (L1TP) with image-to-image registration to the GLS control of >12-meter RMSE.

The Processing Level designations for Landsat Collection 1 are shown in Table 2-1. Precision (ground control) and terrain corrected products are labeled with the L1TP designation. Terrain and systematic corrected products are labeled as L1GT. Systematically corrected products are labeled as L1GS. OLI / TIRS products are either L1TP or L1GT and ETM+, TM, and MSS products are L1TP, L1GT, or L1GS.

Landsat Level-1 Processing Levels	
Processing Level	**Description**
Standard Terrain Correction L1TP	Radiometrically calibrated and orthorectified using ground control points and digital elevation model (DEM) data to correct for relief displacement. These are the highest quality Level-1 products suitable for pixel-level time series analysis.
Systematic Terrain Correction L1GT	Radiometrically calibrated and with systematic geometric corrections applied using the spacecraft ephemeris data and DEM data to correct for relief displacement.
Systematic Correction L1GS	Radiometrically calibrated and with only systematic geometric corrections applied using the spacecraft ephemeris data.

Table 2-1. Landsat Collection Level 1 Processing Levels

Radiometric and geometric data quality characteristics are available in sensor-, scene-, and pixel-level metadata. Specific details of how the radiometric and geometric accuracy is calculated are described in Section 3 and Section 4, respectively.

- Per-sensor metadata provide radiometric accuracy at the instrument level (see Section 3)
- Per-scene metadata include measures of geometric accuracy expressed as RMSE based on an analysis of the fit of the precision model to the ground control, the number and version of GCPs used in the fit, solar azimuth and elevation, coefficients for converting scaled Digital Numbers (DNs) to Top of Atmosphere (TOA) radiance or reflectance, the level of geometric processing, etc., (see Section 4)
- Per-pixel metadata are provided for Collection 1 Level 1 products. Two pixel-level metadata files are provided; a Quality Assessment (QA) band file and a Solar and View Angle Coefficient file (see Section 5)

The RMSE, calculated for each scene, is stored in the Landsat scene metadata. This statistic is used to characterize the geometric accuracy of each scene. The distributions of RMSE by sensor were analyzed to determine thresholds to satisfy science objectives. Over 90 percent of Level 1 precision and terrain corrected TM, ETM+, and OLI / TIRS L1TP data meet the Tier 1 RMSE requirement of ≤12-meter, which provides satisfactory image-to-image registration for time-series analysis. The median RMSEs for OLI / TIRS, ETM+, and TM are < 10 meters for each sensor. The median RMSE for MSS is 24.6 meters.

However, the spatial distribution of error is not even. Areas with persistently cloudy scenes are more likely to have fewer visible GCPs due to clouds and the quality of the control may be poor due to less contrast. As a result, many cloudy scenes fall back to L1GT and those that do not fall back to L1GT have higher RMSE estimates.

The RMSE stored in the Landsat metadata and the EarthExplorer database can be used to further filter either the Tier 1 or Tier 2 datasets to loosen or tighten the RMSE threshold to meet application specific requirements. Section 4 discusses the characterization of the archive and the selection of the Collection 1 threshold.

Time-series signals have three general sources of variability: noise or trends in the radiometric signal; spectral band differences between the sensors; and spatial mis-registration. Radiometric variability is minimized through careful trending and calibration of the instruments (see Section 3). Spatial mis-registration increases the variability of the signal through time in proportion to the amount of mis-registration, and the size and contrast of the object. The Tier 1 spatial threshold is established to find a balance between what is achievable and what is required to meet science objectives (see Section 4). Spectral band differences among sensors (see Figure 2-1) contribute to the uncertainty of the signal through time that is band and ground feature dependent. Signal differences that can be discriminated by the OLI sensor, due to its higher Signal-to-Nosie Ratio (SNR) or finer spectral resolution, may not be separable by ETM+ or earlier sensors. MSS data, even with their unique radiometric and geometric challenges, extend the Landsat environmental record ten additional years into the past. A well-calibrated and geo-registered instrument minimizes variability associated with the TOA product. The focus then becomes managing the error budget for higher-level products and interoperability with other data sources.

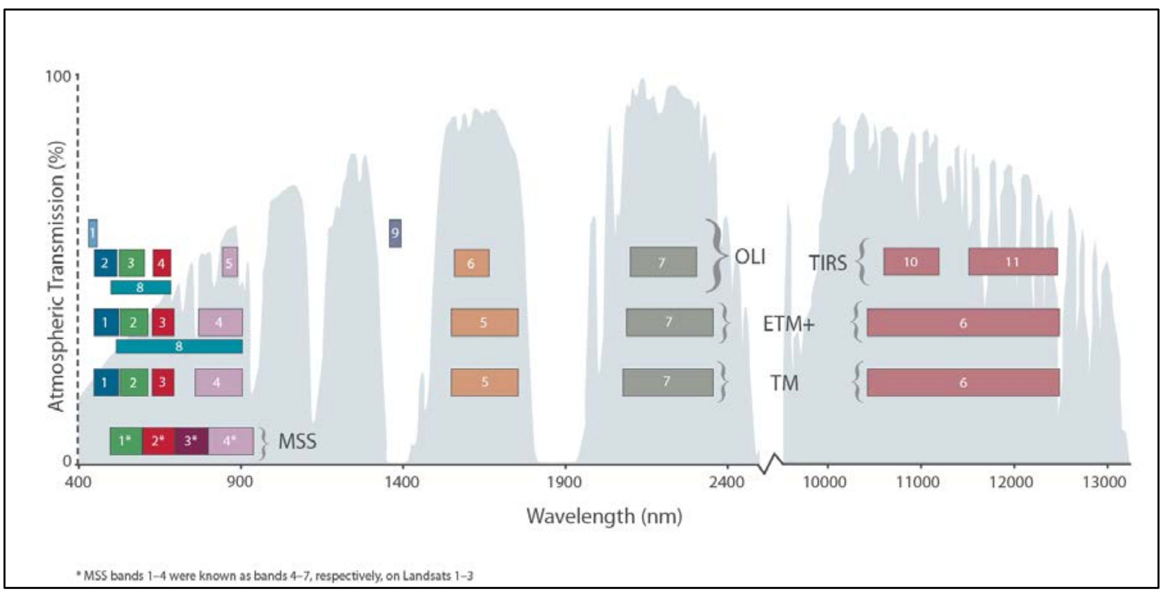

Figure 2-1. Comparison of Landsat Spectral Bands

The transition to a collection management strategy required new product naming conventions, modified processing flows, and improved the product data and metadata. Section 5 discusses this information in more detail.

Section 3 Radiometric Characterization

Continuous monitoring of radiometric stability and instrument performance ensures consistent radiometric response of Landsat data through time and prevents introduction of long-term artifacts. The USGS characterizes radiometric performance of the Landsat sensors with respect to absolute radiometric accuracy, relative gains of detectors, SNR, detection, characterization, and correction of artifacts, as well as a variety of additional measures. Calibration updates, due to changes in sensor responsivity, are incorporated into ground processing when necessary to ensure that user applications derived from the data, especially those multi-temporal applications that use data from multiple sensors, are not impacted by calibration errors.

Instrument providers and the National Aeronautics and Space Administration (NASA) characterize the absolute accuracy of each sensor prior to launch and transfer this calibration to orbit (B. Markham et al., 2014). After launch, a combination of onboard calibration methods in conjunction with vicarious calibration methods provide the means for ensuring calibration accuracy. Currently, only Landsat 8 uses onboard calibrators for long-term stability monitoring (B. Markham et al., 2014). Vicarious methods, which can be used for all Landsat sensors, include field campaigns for estimating TOA radiance at the time of overpass, Pseudo Invariant Calibration Site (PICS) methods, and lunar observations (Czapla-Myers et al., 2015; Thome et al., 2004). Use of all these calibration approaches has allowed improved understanding of the overall absolute radiometric accuracy of the Landsat archive resulting in uncertainties, shown in Table 3-1 (Helder, 2017, Pinto *et.al*., 2019). These values are based on well-known uncertainties for Landsat 7 and Landsat 8 that are then propagated backwards to the earlier sensors. The MSS series of sensors have the largest uncertainties, reaching up to about 10 percent with an exception of the near infrared band 2 in Landsat 1-3 MSS. This band is greatly affected by the atmosphere and, as a result, has much larger uncertainties.

	Landsat 8 OLI	**Landsat 7 ETM+**	**Landsat 5 TM**	**Landsat 4 TM**	**Landsat 5 MSS**	**Landsat 4 MSS**	**Landsat 3 MSS**	**Landsat 2 MSS**	**Landsat 1 MSS**
Coastal Aerosol	3								
Blue	3	4	5	7					
Green	3	4	5	7	6	7	8	8	9
Red	3	4	5	7	6	6	7	7	8
NIR-1					6	7	8	9	10
NIR-2	3	4	5	7	7	10	13	16	18
SWIR 1	3	4	5	7					
SWIR 2	3	4	5	7					
Pan	3	4							

Table 3-1. Landsat Sensor Absolute Radiometric Uncertainty in Percent (Helder, 2017, Pinto* et.al.*, 2019)

Sensor response to PICS should be very constant over time. Figure 3-1 provides an example where the calibrated Landsat archive response over the Algodones Dunes in Southern California shows a consistent measurement since the early 1970s. Users can be confident that the relative calibration, especially between consecutive sensors, is within the order of four percent or better, except for MSS NIR-2 band, that could be as high as 6 percent.

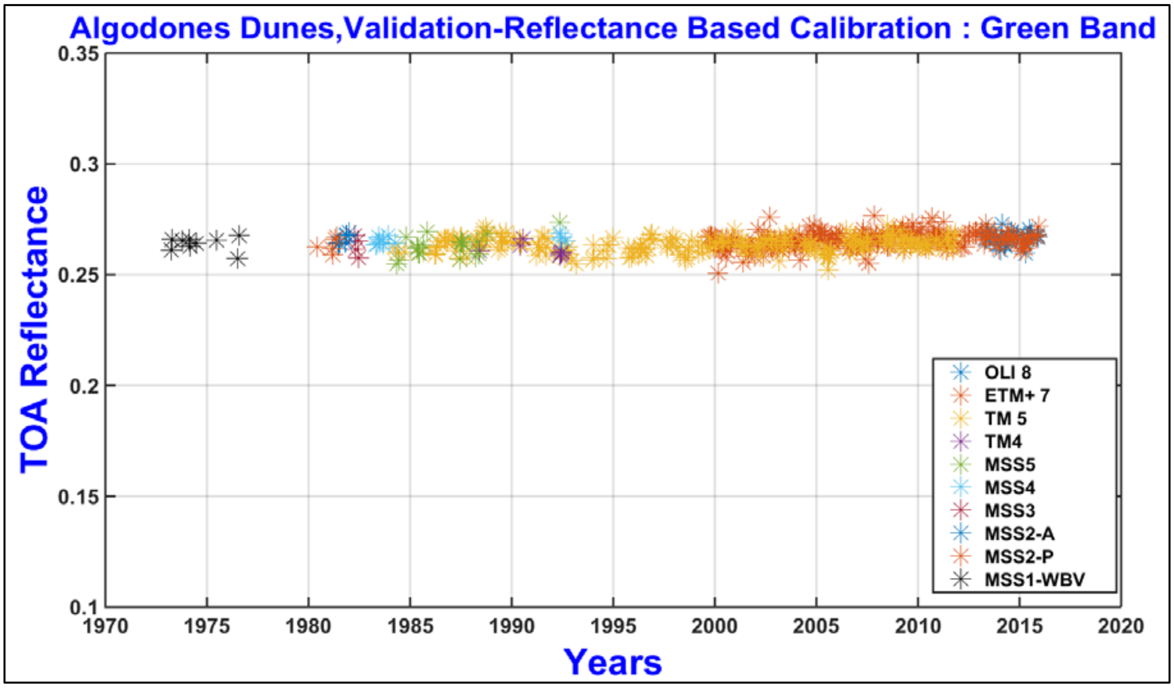

Figure 3-1. Cross-Calibration of Landsat Sensors

Figure 3-1 displays the cross-calibrated Landsat sensors for the green band over the life of the Landsat mission at the Algodones Dunes PICS. The earlier sensors are normalized to OLI / TIRS reflectance values using information from PICS and vicarious calibration sites (Helder *et al.,* 2016; Pinto *et al.,* 2019).

For Landsat 8 OLI data, the responses to the onboard calibrators, including lamps and diffusers, provide an estimate of the temporal uncertainty, expressed as the coefficient of variation (standard deviation of the response divided by mean response). Figure 3-2 shows the trends observed during the first 4 ½ years on orbit for the Coastal Aerosol band. Markham (Markham et al., 2014) reported the temporal uncertainty of OLI as 0.3 percent in 2014. After the removal of temporal trends and the inclusion of additional characterization data, the three-year estimate of the temporal uncertainty reported in 2016 is less than 0.11 percent across all OLI bands (see Table 3-2). While the Landsat 7 ETM+ housed a solar diffuser, its response has degraded over time in such a way that it cannot be trusted as a measure of temporal uncertainty. Therefore, Landsat 7 ETM+ and Landsat 5 TM TOA reflectance trended over PICS form the basis of the temporal uncertainty estimate for these sensors, and is better than two percent, with the exception of the Shortwave Infrared (SWIR) 2 band, over their respective lifetimes (Helder et al., 2013).

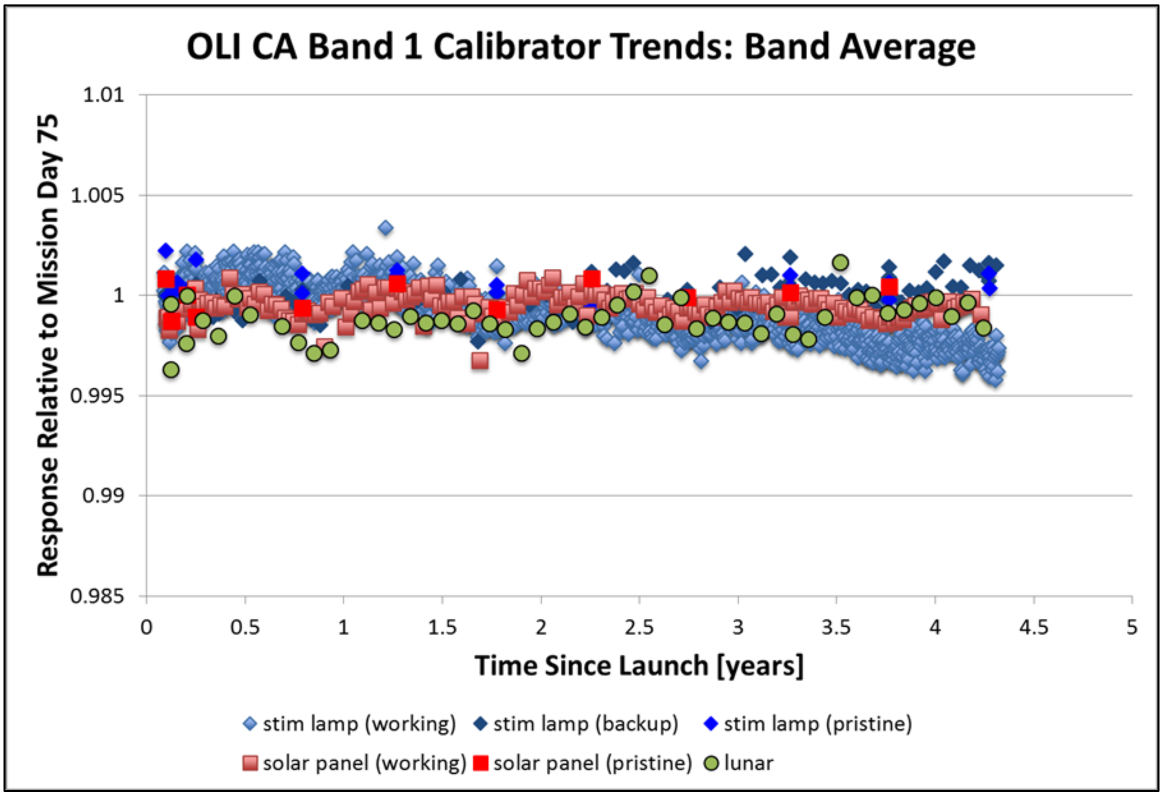

Figure 3-2. Typical Radiometric Response Corrected for Temporal Trends in OLI Instrument Response

Figure 3-2 displays the typical radiometric response to radiometric calibration sources for Landsat 8 OLI after correcting for temporal trends in instrument response.

Table 3-2 displays the temporal uncertainty in percent for Landsat 8 OLI, Landsat 7 ETM+, and Landsat 5 TM sensors after correcting for temporal trends in instrument response. (Calculations for other sensors have not been determined.)

Bands	Landsat 8 OLI	Landsat 7 ETM+	Landsat 5 TM
Coastal Aerosol	0.07		
Blue	0.11	0.8	0.8
Green	0.09	0.6	0.3
Red	0.07	0.4	0.2
NIR	0.05	1.8	1.7
SWIR 1	0.04	1.1	-
SWIR 2	0.07	2.0	2.7

Table 3-2. Temporal Uncertainty in Percent

Evaluations of large uniform areas such as desert, water, and snow / ice provide a qualitative measure of spatial uniformity. Small differences (>0.2 percent for an 8-bit sensor) in the radiometric calibration of neighboring detectors can produce clearly visible striping or banding, which only affects the visible quality of the imagery. OLI uniformity (Morfitt et al., 2015) is less than 0.3 percent for banding and less than 0.05 percent for striping. The ETM+ striping and banding characteristics are not visible, therefore have been difficult to quantify due to lower precision. An artifact known as Memory Effect can cause up to two percent radiometric error in the TM instruments (Helder et al., 1997), but after the artifact corrections, residual banding in images is much less than that. Striping is typically better than 0.2 percent and is not visible in TM imagery (Markham et al., 2012; Markham & Helder, 2012). There is no systematic striping or banding in regular MSS images; however, striping and banding can be observed in MSS data, due to various formats and anomalies in the data (i.e., missing scans, late start anomaly).

Thermal sensors are included aboard Landsat 4-8 (TM, ETM+, and TIRS). These sensors have been absolutely calibrated using vicarious buoys on large water bodies (Barsi et al., 2010; Barsi et al., 2014). The TM and ETM+ sensors are calibrated to within +/-0.7°K and the TIRS sensor's calibration is improved to +/- 0.5°K following the implementation of the stray light correction in Landsat Collection 1 (Montanaro et al., 2015).

Landsat products contain integer data numbers (DNs) that are scaled and quantized to reflectance or radiance. For Landsat 8 OLI data, the original 12-bit data downlinked from the instrument are scaled to the 16-bit range during Level 1 processing, without any loss of precision. Landsat ETM+ and TM original sensor data, as well as TOA product data, are 8-bit. Landsat MSS original sensor data are 6-bit and 7-bit but scaled to 8-bit in TOA products. Users convert the product data DNs to TOA radiance or TOA reflectance without solar angle correction using scaling factors contained in the metadata file distributed with Landsat Collection 1 products. Users can also correct for the scene-center solar angle or a per-pixel solar angle derived from the angle coefficient file distributed with Landsat Collection 1 products.

Features that can be discriminated with higher fidelity OLI data may fall beneath the detection level for ETM+, TM, or MSS. For some applications, the degree that trends and change can be quantified and detected depends on the sensitivity of the instrument.

Radiometric calibration is monitored continuously. Changes in the radiometric performance of the instrument that are large enough to affect user application results serve as the trigger to update the calibration coefficients and to reprocess that data up to the point in time when the radiometric change occurred. The user community will be notified if such reprocessing of a Landsat collection is needed. Currently, both Landsat 7 and Landsat 8 spacecraft are stable with only very slight long-term calibration trends, although it is possible that an abrupt calibration change could occur at any moment.

Section 4 Geometric Characterization

The objective of geometric characterization is to identify a reasonable accuracy criterion that can be met for the Landsat sensors, and also to meet the requirements for analysis of the archive through time. The RMSE threshold for Tier 1 data needs to be minimal and attainable. Figure 4-1 shows an idealized representation of the view through time of different RMSE threshold errors. In ideal circumstances, one would know exactly where the pixel falls on the Earth with zero locational error; however, the data are not perfect. Through an evaluation of the archive, it is possible to determine how close the accuracy can approach the ideal. The RMSE threshold selected to define Tier 1 is a compromise between the ideal and the achievable. The larger the RMSE threshold, the larger and more homogeneous a feature must be for analysis through time to be effective.

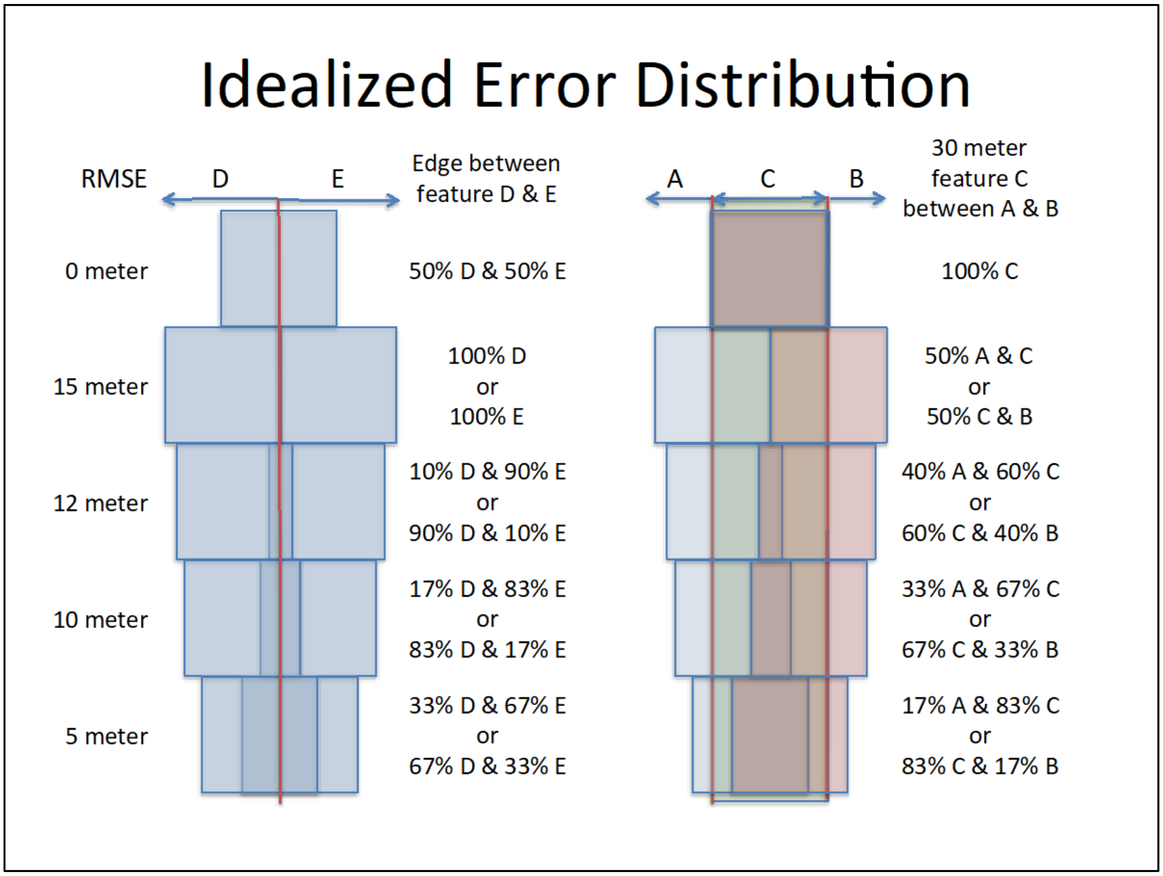

Figure 4-1. Error Distribution for Idealized Pixel and Ground Feature

Figure 4-1 displays error distribution for idealized pixel and ground feature. Pixels are offset to left and right of ideal by the RMSE. The effects of the point spread function and contrast are not represented.

For each sensor, a distribution of RMSE exists. Circular Error (CE) can be used to characterize the accuracy of the archive. Circular Error 90 (CE90) is the RMSE error of the 90^{th} percentile of RMSE distribution. CE90, CE95, and CE99 are calculated for each sensor archived and measures of the overall accuracy. Figure 4-3, Figure 4-4, Figure 4-6, and Figure 4-7 illustrate the distribution of L1TP data with CE90, CE95, and CE99 levels shown. To encompass 90 percent of the L1TP data, an RMSE threshold of 12-meters is appropriate. To increase this to 95 percent of the L1TP data, an RMSE threshold of 15-meters is required. As represented in Figure 4-1, with a 15-meter RMSE threshold, pixels viewing an idealized point may not have any overlap. A 12-meter RMSE threshold is considered the lowest threshold attainable with an acceptable percent rejection.

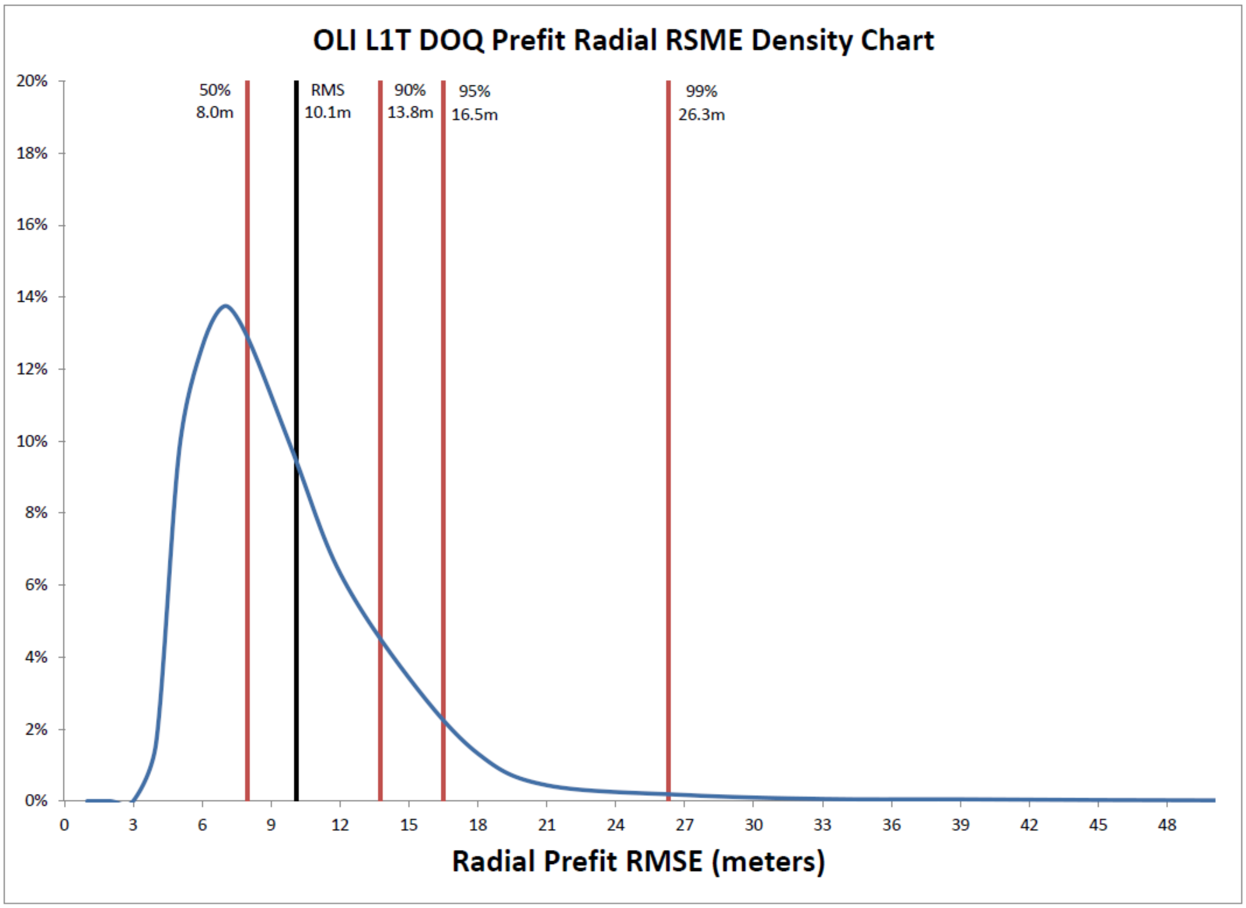

Figure 4-2. OLI Prefit RMSE Values

Figure 4-2 displays the distribution of RMSE for Landsat 8 OLI when processed to an L1TP using Digital Orthophoto Quadrangle (DOQ) mosaics, which have a resolution of 1 meter to estimate the accuracy of Landsat 8 L1TP products.

The performance of the Landsat 4 through Landsat 5 TM, Landsat 7 ETM+, and the Landsat 8 OLI / TIRS sensors exceeds a CE90 criteria with a 12-meter RMSE threshold; therefore, at least 90 percent of the L1TP data from each sensor would be included in Tier 1. Landsat 1 through Landsat 5 MSS data performance is yet to be determined. Based on an analysis of the Level 1 data relative to the GLS ground control, approximately 60 percent of all OLI (92 percent of L1TP), 70 percent of all ETM+ (96 percent of L1TP), 58 percent of all TM (~95 percent of L1TP), and 0.6 percent of all MSS (1.2 percent of L1TP) scenes can be processed to Tier 1. (see Table 4-1).

Table 4-1 lists data category versus percent of archive and percent of OLI / TIRS, ETM+, TM, and MSS L1TP data given a 12-meter Tier 1 threshold as of February 20, 2019.

Sensor	**OLI / TIRS**		**ETM+**		**TM**		**MSS**	
Product	%	%L1TP	%	%L1TP	%	%L1TP	%	%L1TP
L1TP ≤ 12m (T1)	59.63	92.21	70.04	96.34	57.65	95.42	0.61	1.23
L1TP > 12m (T2)	5.03		2.66		2.77		48.65	
L1GT/L1GS Fallback (T2)	15.08		16.96		26.93		36.72	
L1GT/L1GS (T2)	20.26		10.34		12.65		14.03	

Table 4-1. Data Category vs Percent of Archive

Data that fall back to L1GT are placed in Tier 2 (15 percent, 17 percent, 27 percent, and 37 percent for OLI / TIRS, ETM+, TM, and MSS, respectively) during image-to-image registration usually due to excessive cloud cover (see Table 4-1). TM and MSS data fall back to L1GS because the geolocation of the systematic model for TM and MSS is not sufficiently accurate to permit terrain correction. If no ground control is available, such as data over Antarctica and over water, data are automatically generated as L1GT for OLI / TIRS and ETM+ and as L1GS for TM and MSS.

For scenes to be eligible for “stacking” for time-series analysis, an image-to-image accuracy threshold of ≤12-meter RMSE was established for Collection 1, Tier 1. The greater the RMSE, the more variability is introduced into the temporal signal. The 12-meter RMSE threshold is a pragmatic heuristic. How much noise is acceptable depends on the nature of the analysis. The 12-meter threshold can be met by the current processing system and ground reference database without excessive rejection of L1TP data. However, as a result, 8 percent of the OLI / TIRS L1TP archive will be placed in Tier 2. An inspection of the distributions in Figure 4-3, Figure 4-4, Figure 4-6, and Figure 4-7 show the median RMSE values to be 8.0 meters for OLI / TIRS, 4.7 meters for ETM+, and 4.7 meters for TM. Hence, 50 percent of the Level 1 data approach or exceed the 5 meters example in Figure 4-1. The RMSE distribution of OLI / TIRS continues to improve as the absolute accuracy of the ground reference database improves, and OLI reference data become available.

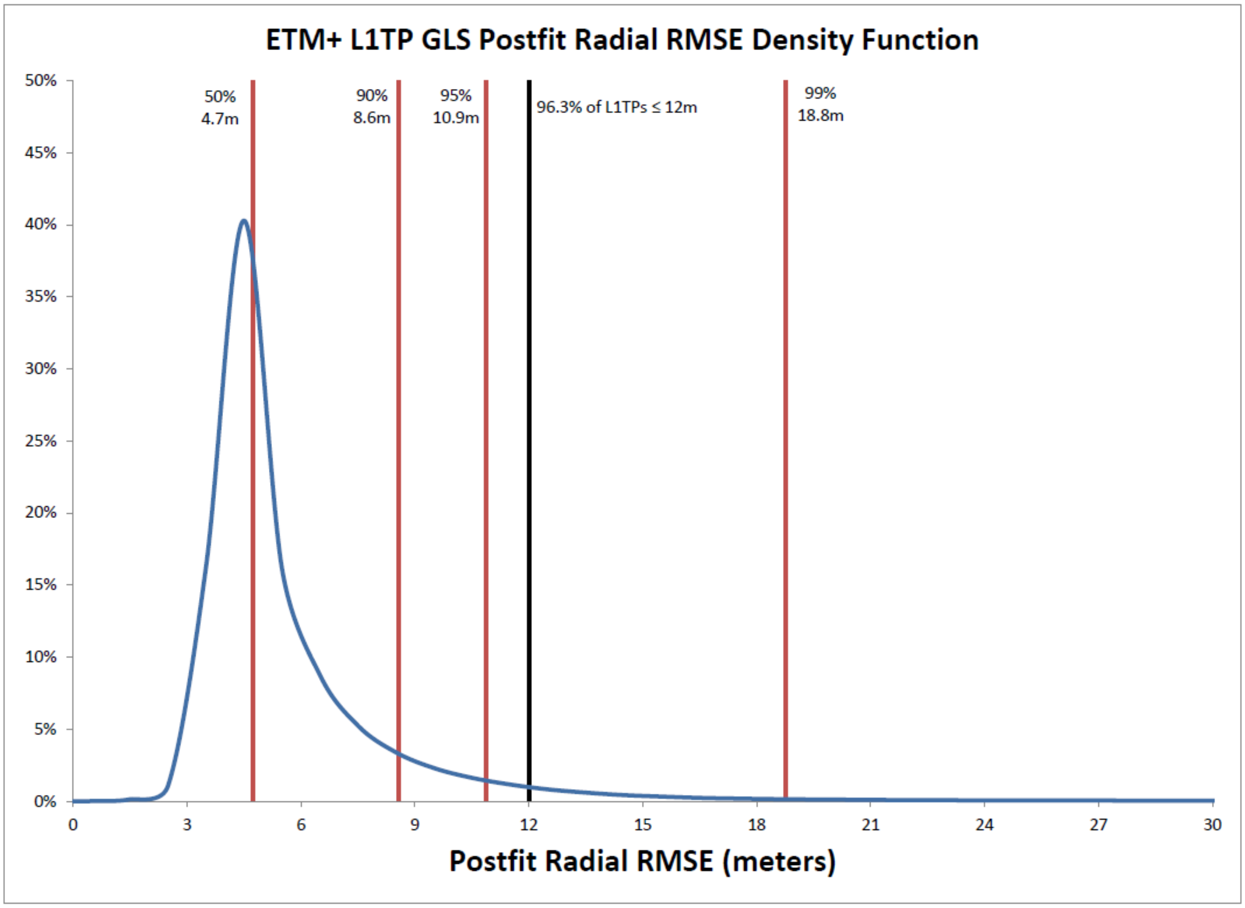

Figure 4-3. Distribution of RMSE for ETM+

Figure 4-3 displays the distribution of RMSE for Landsat 7 ETM+ with CE50, CE90, CE95, and CE99 lines in red and 12-meter line in black.

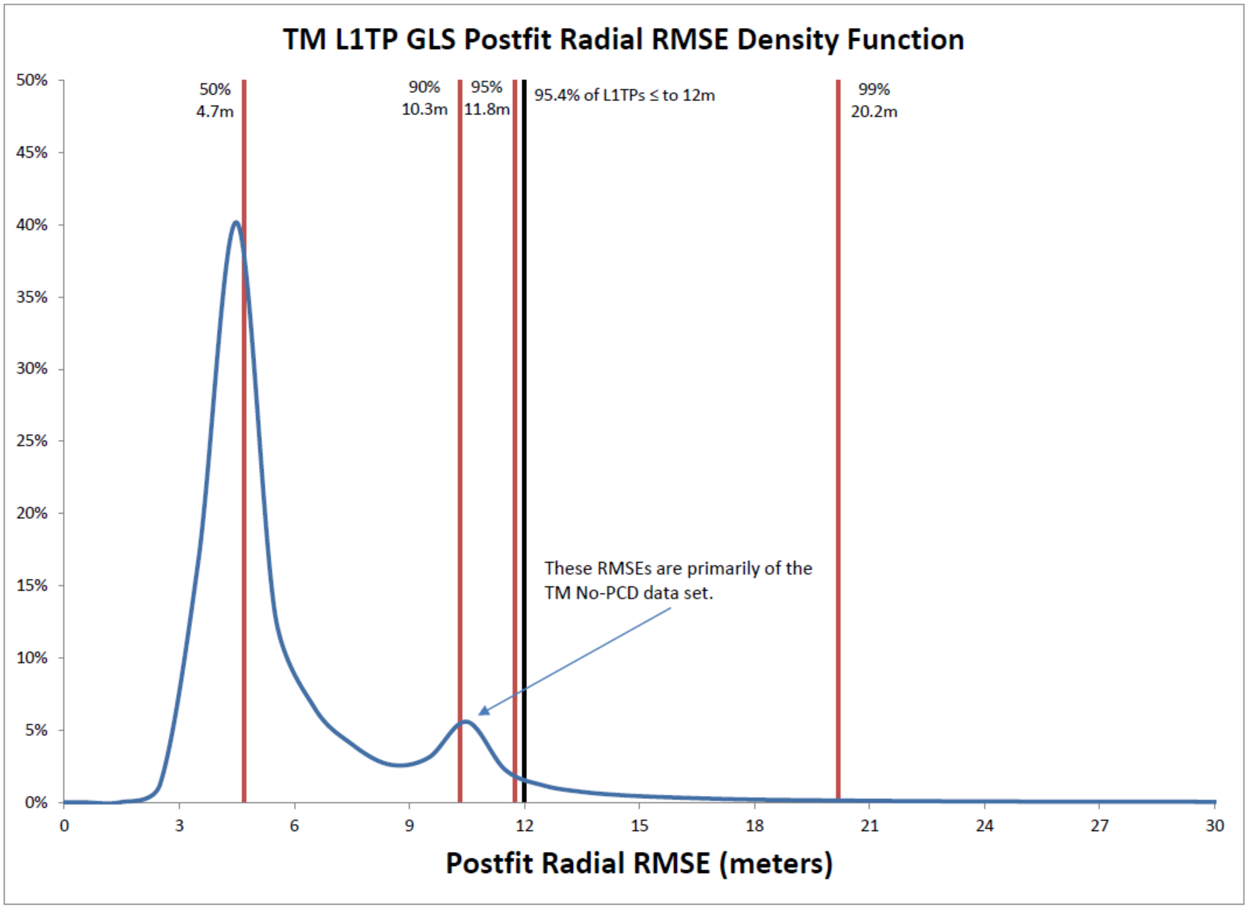

Figure 4-4. Distribution of RMSE for TM

Figure 4-4 displays the distribution of RMSE for Landsat 4-5 TM with CE50, CE90, CE95, and CE99 lines in red and 12-meter line in black.

The geodetic accuracy of the Landsat Level 1 products varies by sensor, the source data type, the quality of the Payload Correction Data (PCD), and the level to which the data have been processed for Collection 1: L1TP, L1GT, and L1GS. In addition, the older Thematic Mapper - Archive Format (TM-A) PCD are of lower quality, and for some of the TM data being repatriated from International Ground Stations (IGS) through the Landsat Global Archive Consolidation (LGAC) activity, the PCD are incomplete or missing (Wulder et al., 2015). The consequence of either lower quality, incomplete, or even missing PCD can be difficult to quantify. Although processing checks are in place to avoid having data that is adversely affected by these conditions end up within a Tier 1 collection bin, on rare occasions, this may occur.

The geometric accuracy of Landsat Level 1 products has been characterized relative to the GCPs used in developing the GLS L1TP dataset (Gutman *et al.,* 2013). This tends to mask any errors in the positional accuracy of the GLS data and the elevation height accuracy of the Digital Elevation Model (DEM) used to generate the L1TP products; this is reasonable for a measure of product consistency because these errors are mostly repeatable for a given scene. The L1TP product accuracy relative to the GLS control used to make the products is routinely measured during product generation and by the geometric accuracy characterization process.

The Landsat 8 geolocation accuracy analysis has identified areas where the GLS-derived global GCP library is deficient. Regions of poor accuracy were re-triangulated using Landsat 8 data, with new OLI GCPs added where needed. Triangulation updates proceeded in three phases: Phase 1 high-priority area; Phase 2 low-latitude areas, and Phase 3 arctic areas. These updates were applied to Landsat data before Collection 1 processing began. Figure 4-5 illustrates the distribution of GCP errors in the GLS GCP database that will be used in Collection 1 estimated using Landsat 8 OLI. The Australia triangulation completed in Phase 2 demonstrates the improved accuracy expected for the global triangulation planned for following phases.

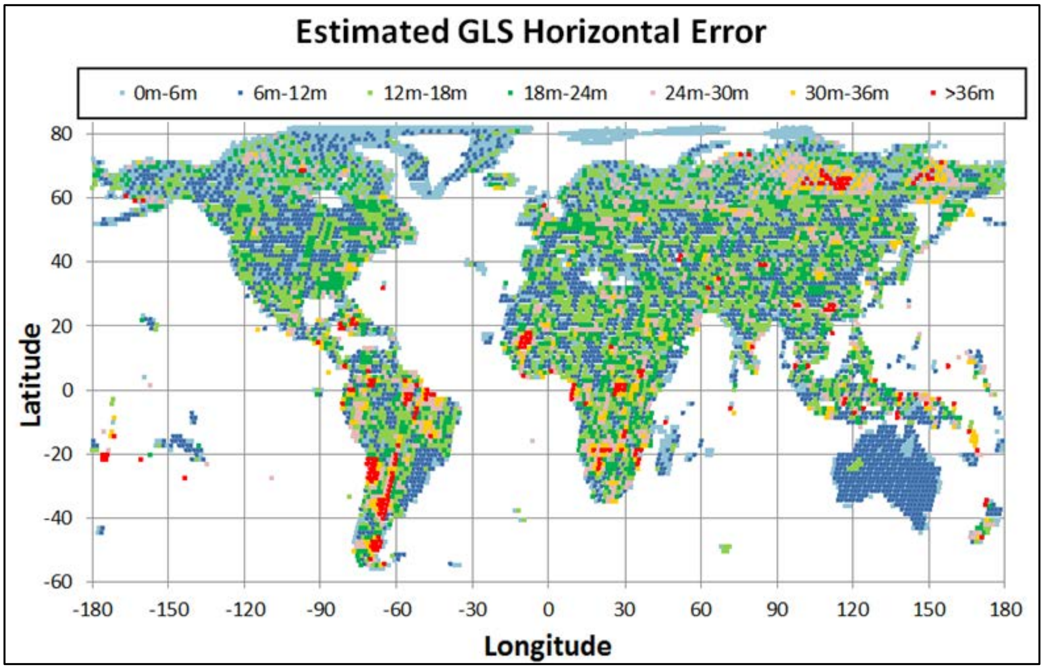

Figure 4-5. Assessment of Distribution Error through GLS

Figure 4-5 displays the assessment of distribution error through GLS. Assessment of the distribution of error through the GLS reference database using OLI L1GT data provides an independent estimate of absolute geometric accuracy. The accuracy of the OLI L1GT data was assessed using independent high-resolution data.

One of the next phases of the GCP update includes the creation of an OLI GCP reference database tied to the Sentinel 2 Global Reference Image (GRI) Storey *et al*., 2016. . This new reference database is a major component of a future Landsat collection release, which is anticipated in 2019. The absolute accuracy of the new reference database should increase the accuracy of the OLI / TIRS L1TP data to equal or better than that of the ETM+ and TM L1TP data. The goal for geometric improvement is always to increase the yield and accuracy of the L1TP data.

The absolute accuracy of the OLI / TIRS L1GT data can be estimated using the prefit residual statistics for GCPs extracted from USGS DOQ data (see Figure 4-2). The data may be stackable if used with caution, with Tier 1 data in regions where the current GLS reference grid is accurate (see Figure 4-5). Current OLI / TIRS L1GT scenes may be stackable, even though they are not stackable with L1TP data. This has been demonstrated to be true by the cryosphere community for estimating the rates of ice movement in Antarctica (Fahnestock et al., 2016). The ETM+ and TM systematic corrections are estimated to be accurate to 112-meters and 659-meters RMSE respectively and do not meet the criteria for stackability, demonstrating the dramatically improved geometry of OLI / TIRS L1GT data (Lee et al., 2004). The ephemeris data for ETM+ support the production of a terrain corrected L1GT product whereas terrain correction cannot be applied to the TM systematic product (Storey, 2003).

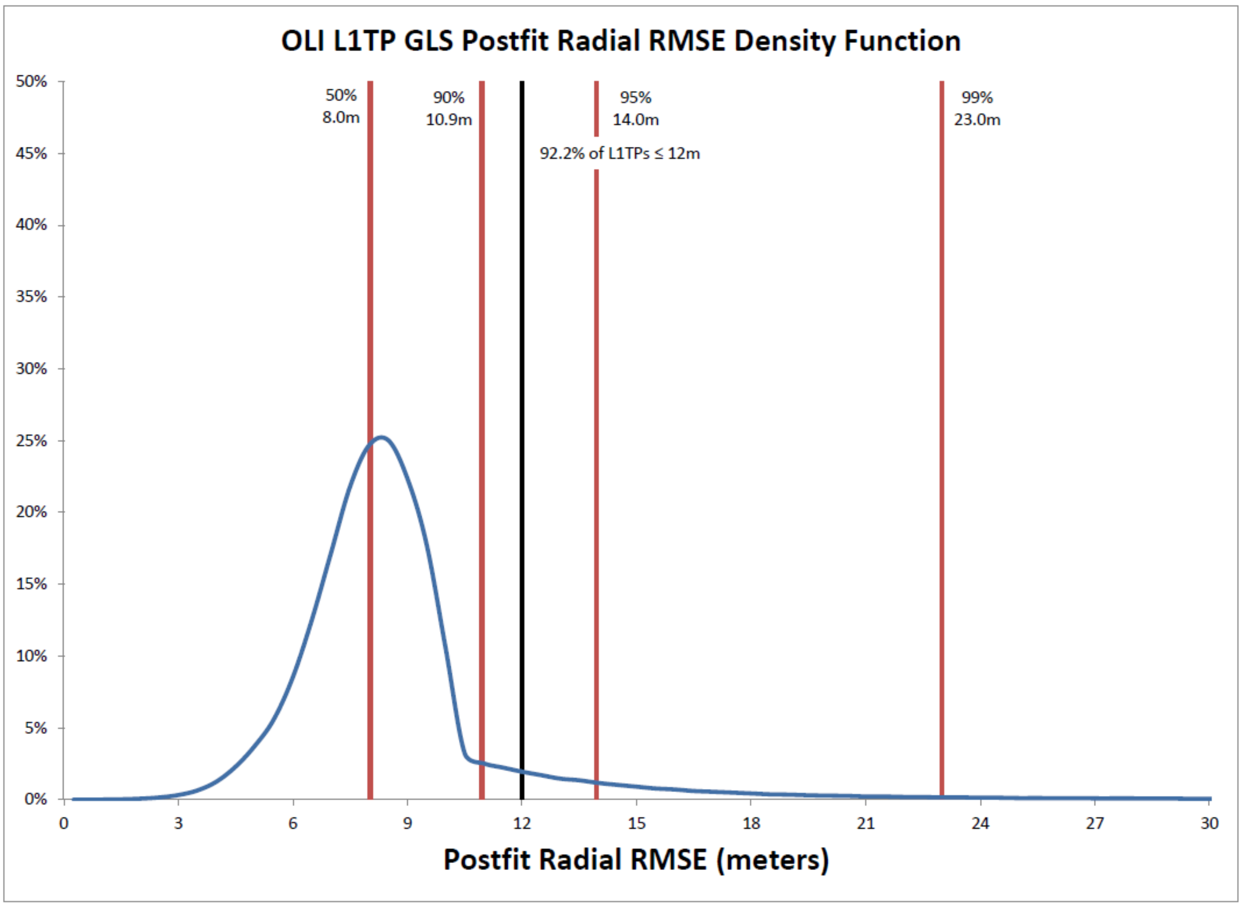

Figure 4-6. Distribution of RMSE for OLI

Figure 4-6 displays the distribution of RMSE for Landsat 8 OLI with CE50, CE90, CE95, and CE99 lines in red and 12-meter line in black.

The relatively lower OLI L1TP performance (90 percent) is a reflection of the current GLS ground control consisting of TM data with residual errors of up to 50 meters (see

Figure 4-5) and improves once registration shifts to the Sentinel 2 GRI and a reference database that includes OLI reference chips. The overall yield of OLI / TIRS L1TP (63 percent) always remains low, because over 17 percent of Landsat OLI / TIRS acquisitions are for night, Antarctic, and ocean scenes where no ground control exists, and significantly more snow / ice and cloudy data are acquired where GCPs may not be visible.

OLI and ETM+ may register with as few as 7 GCPs, where at least 30 GCPs are needed for TM. As a result, more OLI L1TP scenes with low RMSE may be created for islands and other small land mass scenes, particularly when these scenes tend to have clouds, than are created for TM or ETM+ data. It is possible to create L1TP data for OLI with fewer GCPs because the internal geometry is very good. Similar TM and ETM+ scenes would automatically fall back to L1GS or L1GT data, respectively, because of too few GCPs.

The first 10 years of the Landsat record were imaged with the MSS sensor. MSS was a unique sensor that anchors the long-term environmental record of Earth observing sensors. Unfortunately, both the radiometry and geometry of MSS are of lower quality than subsequent Landsat sensors. Much was learned about sensor design from MSS that significantly improved future Landsat sensors' geometric accuracy, radiometric sensitivity, and stability. The CE90 criteria for MSS Level 1 Precision and Terrain (L1TP) data falls at 39 meters (see Figure 4-7), which is less than one MSS pixel but greater than the pixel size of subsequent sensors. MSS data should only be used in full-record time-series studies following either additional geometric improvements or with methods that compensate for the lower-quality image registration.

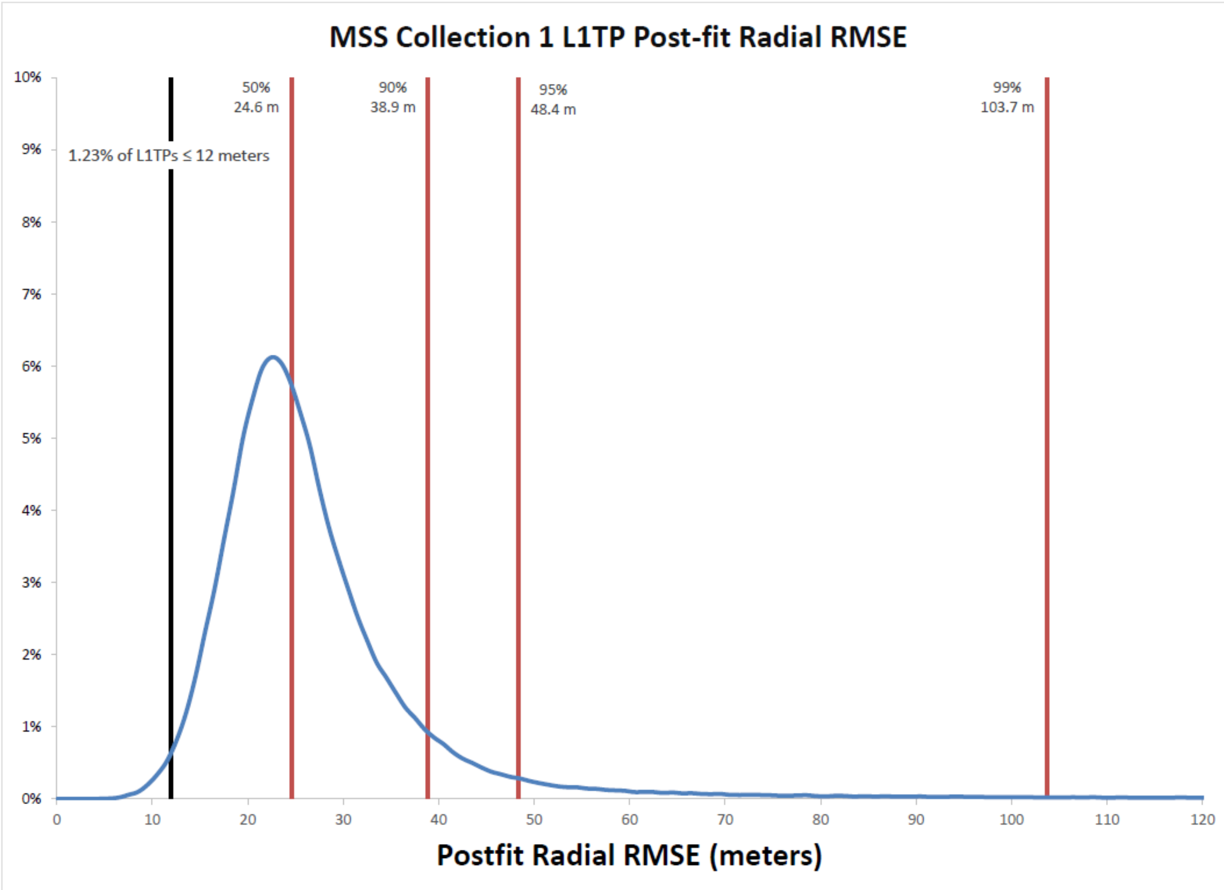

Figure 4-7. Distribution of RMSE for MSS

Figure 4-7 displays the RMSE for Landsat 1-5 MSS L1TP data with CE50, CE90, CE95, and CE99 lines in red and 12-meter line in black.

The spatial distribution of RMSE estimates is not even (see Figure 4-8). Areas with persistently cloudy scenes are more likely to have L1TP data with high RMSE estimates and L1GT or L1GS data. For some applications, the densification of the time series may be more important than image-to-image registration. The spatial distribution of high RMSE values is highly correlated with clouds and snow / ice. Because the season of most interest for many applications may be cloudy, each user needs to consider the consequences of low RMSE versus the density of the time-series. For persistently cloudy or snow / ice covered areas, it may be necessary to relax the RMSE constraints and accept L1TP data from Tier 2 to populate the phenological curve.

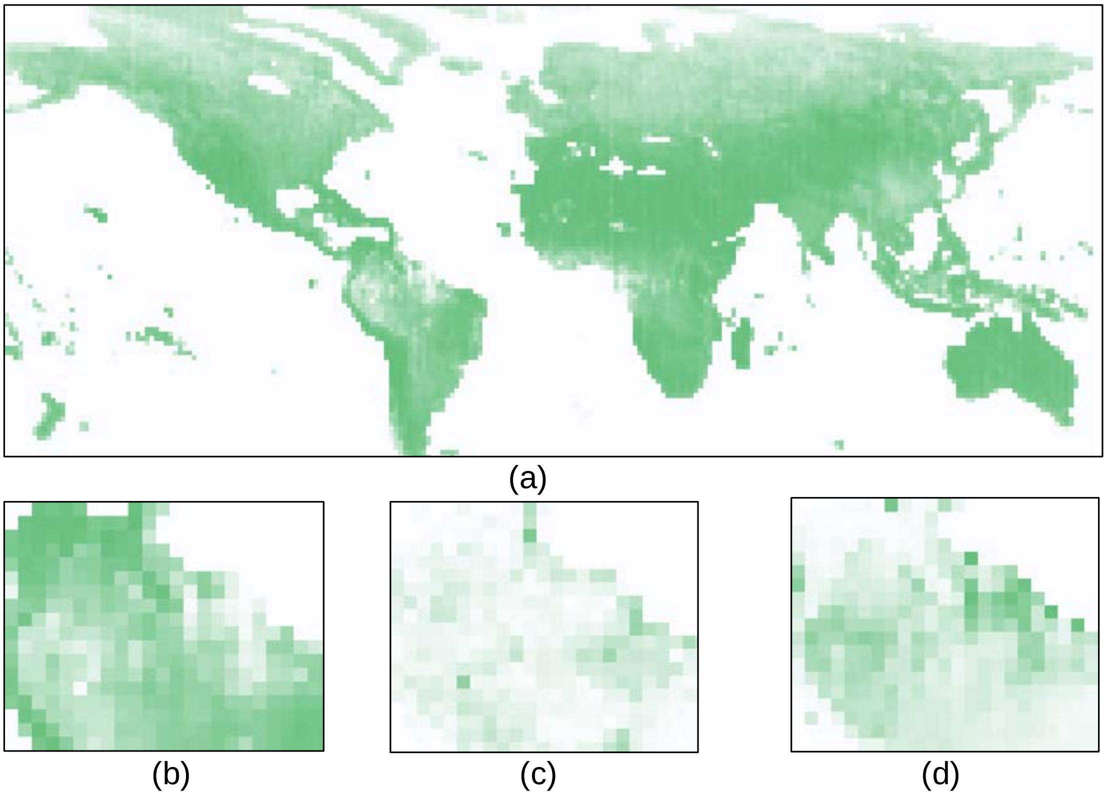

Figure 4-8. Global Map

Figure 4-8 displays the global map of the spatial distribution of (a) OLI / TIRS Tier 1 scenes (RMSE ≤12-meters), (b) with detailed maps for the Amazon Basin for Tier 1, (c) Tier 2 L1TP, and (d) Tier 2 L1GT as of March 1, 2019.

The number of L1TP images varies from 1 to over 137 images for the life of Landsat 8. The relationship between clouds, snow / ice, and low yields of Tier 1 L1TP also holds for TM and ETM+. This trend holds for all sensors, but is more obvious for Landsat 8, because the OLI / TIRS image archive better represents the entire population of images through the lifetime of the sensor, where previous sensor image archives are highly biased toward low cloud and snow cover images.

Section 5 Landsat Collection Generation, Format, and Organization

Collection 1 Level 1 processing began in August 2016 and continued until all archived data was processed, completing May 2018. Newly acquired Landsat 8 and Landsat 7 data continue to be processed into Collection 1 shortly after data is downlinked to USGS EROS.

The Landsat LPGS has the capability to generate the following products:

1. L1TP products – generated by applying the GLS GCPs and elevation data for geometric correction of Landsat OLI / TIRS, ETM+, TM, and MSS data.
2. L1GT products – generated for Landsat OLI / TIRS and ETM+, for which there is insufficient GCPs for precision correction, but for which the PCD is sufficient for co-registration with the DEM to enable systematic geometric and terrain correction.
3. L1GS products – generated for all Landsat ETM+, TM, or MSS scenes that cannot be correlated with GCPs, or no GCP is present.

All Landsat acquisitions are assigned to one of three collection tiers (Real-Time, Tier 1, or Tier 2) when they are processed. All new Landsat 8 OLI / TIRS and Landsat 7 ETM+ acquisitions are assigned to the Real-Time tier as they wait for additional calibration parameter information. All acquisitions are assigned to either Tier 1 or Tier 2 depending on data quality when moved out of the preliminary Real-Time tier. Tier 1 contains the highest quality Landsat data and should support most time-series analysis applications. Users need to evaluate Tier 2 data to determine whether the characteristics meet their specific application needs. All L1GT and L1GS products are assigned Tier 2. All L1TP products are placed into either Tier 1 or Tier 2 based on quality criteria. Only RMSE is currently used, but it is anticipated that other quality criteria may be used to determine tier designation assignment in future collections. These criteria are documented and communicated to the user community before they are implemented.

Three modes of Real-Time data collection and processing exist that may not immediately satisfy the collection definition criteria, two of which apply to Landsat 7 ETM+ data and the other applies to Landsat 8 OLI / TIRS.

- ETM+ Level 1 products of sufficient geometric accuracy may be delayed due to the need to update the bumper mode calibration coefficients
- ETM+ products generated using predicted ephemeris data may not satisfy geometric accuracy criteria
- TIRS initially uses a preliminary LOS model based on an “estimated” position of the Scene Select Mirror (SSM). The TIRS LOS model is updated periodically, nominally twice per month, after sufficient telemetry and ground calibration data have been collected.

When data processing falls within one of these three Real-Time modes, the data are temporarily categorized as Real-Time. When a Level 1 Real-Time data product generated by the LPGS is processed, a determination is made as to whether the product meets Collection 1 specifications for Tier 1 or Tier 2. In the case of Landsat 7 ETM+, data are initially processed using predicted ephemeris and preliminary bumper mode correction coefficients. Once the DE and updated bumper mode coefficients are available, the data are automatically reprocessed and placed into either Tier 1 or Tier 2. All data in the current Landsat distributable archive are included in Collection 1.

The Landsat Level 1 products are distributed as .gzip compressed tar files (*.tar.gz) that contain the image files for each of the spectral bands and the quality band in Geographic Tagged Image File Format (GeoTIFF) format, and the associated metadata, solar and sensor view angle coefficients, and checksum in generic text (.txt) files. (USGS EROS, 2015a, 2015b, 2015c, 2015d).

To better identify which collection category the product is associated with (Real-Time, Tier 1, or Tier 2), the Collection 1 Level 1 product is named in accordance with the following convention for the scene identifier:

LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CC_TX

L = Landsat (constant)
X = Sensor (C = OLI / TIRS, O = OLI-only, T= TIRS-only, E = ETM+, T = TM, M= MSS)
SS = Satellite (e.g., 04 for Landsat 4, 05 for Landsat 5, 07 for Landsat 7, etc.)
LLLL = Processing level (L1TP, L1GT, L1GS)
PPP = WRS path
RRR = WRS row
YYYYMMDD = Acquisition Year (YYYY) / Month (MM) / Day (DD)
yyyymmdd = Processing Year (yyyy) / Month (mm) / Day (dd)
CC = Collection number (e.g., 01, 02, etc.)
TX= RT for Real-Time, T1 for Tier 1 (highest quality), and T2 for Tier 2

For the processing level (LLLL), L1TP is precision and terrain correction; L1GT is used for systematic and terrain correction; and L1GS is for systematic correction.

For example:

LC08_L1TP_032034_20140927_20140928_01_RT
LE07_L1TP_032034_20140919_20140920_01_T1

The Collection 1 Level 1 product includes a QA image file, a Solar and Viewing Angle Coefficient file, land cloud cover assessment, TIRS stray light correction, and additional radiometric calibration updates. Collection 1 data are processed using the GCP improvements discussed in Section 4.

The QA band evolves as the Landsat collection structure evolves. Pixel-level radiometric degradation due to saturation, no data, fill data, cloud, etc. are identified in the quality band for each scene (USGS EROS, 2016a). The QA band can be used to filter pixels in order to meet application-specific requirements. When processing data, the QA band can be used to account for pixels experiencing radiometric degradation. With ever-changing conditions (clouds, aerosols, solar angle, viewing geometry, etc.) between the sensor and the surface of the Earth, the pixels experiencing radiometric variability varies over time, although the radiometric accuracy of the sensor remains relatively constant. The QA band can also be used to assess localized cloud cover and identify pixels where uncertainty may exist.

The Angle Coefficient file provides sensor viewing angle model coefficients that can be used to compute the solar and sensor viewing angles for every pixel. Angle bands allow users to better understand how the sensor viewing geometry and solar illumination geometry affect the object being sensed by the imaging instrument. Angle bands can also be used in science algorithms to produce more accurate results over the current practice of using the solar illumination and sensor viewing angles at the Landsat scene center. The solar zenith angle can be used in combination with rescaling factors from the Level 1 metadata to calculate per-pixel TOA reflectance. This can be important for analyzing effects such as the Bidirectional Reflectance Distribution Function (BRDF).

Section 6 Summary

The formal tiered data collection structure ensures that Landsat Level 1 products provide a consistent archive of known data quality to support time-series analysis and data “stacking”, while controlling continuous improvement of the archive and access to all data as they are acquired. The Landsat Collection 1 inventory structure creates a cross-calibrated time-series of satellite data that helps in better understand the changing planet.

Future Landsat collection releases will be carefully planned and paced to bring timely improvements without imposing changes onto the Landsat user community too frequently. For instance, two main components in Landsat Collection 2 will be improved geodetic accuracy using updated Landsat 8 Operational Land Imager (OLI) ground control points and/or the Sentinel 2 Global Reference Image (GRI).

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