Remote Sensing of Environment 185 (2016) 1–6

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Landsat 8: The plans, the reality, and the legacy

Thomas R. Loveland [a,*], James R. Irons [b]

[a] U.S. Geological Survey, EROS Center, Sioux Falls, SD 57198, United States
[b] Earth Sciences Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, United States

ARTICLE INFO

Article history:
Received 25 March 2016
Received in revised form 15 July 2016
Accepted 22 July 2016
Available online 8 August 2016

ABSTRACT

Landsat 8, originally known as the Landsat Data Continuity Mission (LDCM), is a National Aeronautics and Space Administration (NASA)-U.S. Geological Survey (USGS) partnership that continues the legacy of continuous moderate resolution observations started in 1972. The conception of LDCM to the reality of Landsat 8 followed an arduous path extending over nearly 13 years, but the successful launch on February 11, 2013 ensures the continuity of the unparalleled Landsat record. The USGS took over mission operations on May 30, 2013 and renamed LCDM to Landsat 8. Access to Landsat 8 data was opened to users worldwide. Three years following launch we evaluate the science and applications impact of Landsat 8. With a mission objective to enable the detection and characterization of global land changes at a scale where differentiation between natural and human-induced causes of change is possible, LDCM promised incremental technical improvements in capabilities needed for Landsat scientific and applications investigations. Results show that with Landsat 8, we are acquiring more data than ever before, the radiometric and geometric quality of data are generally technically superior to data acquired by past Landsat missions, and the new measurements, e.g., the coastal aerosol and cirrus bands, are opening new opportunities. Collectively, these improvements are sparking the growth of science and applications opportunities. Equally important, with Landsat 7 still operational, we have returned to global imaging on an 8-day cycle, a capability that ended when Landsat 5 ceased operational Earth imaging in November 2011. As a result, the Landsat program is on secure footings and planning is underway to extend the record for another 20 or more years.

Published by Elsevier Inc.

1. Introduction

The NASA-USGS Landsat Data Continuity Mission (LDCM) was successfully launched on February 11, 2013 ensuring the continuity of the unparalleled Landsat record. Following 3 months of on-orbit verification of LDCM's capabilities by NASA and LCDM partners, the USGS took over mission operations on May 30, 2013, renamed LCDM to Landsat 8, and opened access to Landsat 8 data to users worldwide.

True to the continuity name, LDCM was to add to the longest, continuous, and unprecedented space-based global land survey (NASA, 2013). "The LDCM is the successor mission to Landsat 7. Landsat satellites have continuously acquired multispectral images of the global land surface since the launch of Landsat 1 in 1972. The Landsat data archive constitutes the longest continuous moderate-resolution record of the global land surface as viewed from space. The LDCM mission objective is to extend the ability to detect and quantitatively characterize changes on the global land surface at a scale where natural and human-induced causes of change can be detected and differentiated."

The conception of LDCM to the reality of Landsat 8 followed a winding path extending over nearly 13 years. Initially, LCDM was to be a Federal data purchase activity involving a privately-owned and commercially operated system. This system was to provide 250 scenes daily that were consistent with previous Landsat collections but would include two new bands, blue and cirrus, and would not have a thermal imaging capability (Irons et al., 2003). That plan gave way to a new approach to include Landsat imaging capabilities on the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) with an instrument named the Operational Land Imager (OLI) that would be launched in 2009 (Irons and Ochs, 2004). Finally, in 2005, when a third strategy was defined for a free-flying satellite (Fig. 1), the development of what became Landsat 8 started in earnest (Irons and Masek, 2006). Irons et al. (2012) provide a detailed summary of the free-flying LDCM requirements and capabilities, including the plans for OLI and the addition of the Thermal Infrared Sensor (TIRS). The LDCM development was a partnership between NASA and the USGS, with NASA responsible for the space segment including instruments, spacecraft, and launch, and the USGS responsible for the ground system development and operational activities following launch.

Now 3 years past the successful launch, with this special issue, we present the science and applications lessons learned so far. We

* Corresponding author.
E-mail address: Loveland@usgs.gov (T.R. Loveland).

http://dx.doi.org/10.1016/j.rse.2016.07.033
0034-4257/Published by Elsevier Inc.

Fig. 1. Artist's depiction of the Landsat 8 in orbit.

summarize major Landsat 8 characteristics, lessons learned, and we review whether the expectations for the mission are being met.

2. LDCM/Landsat 8 mission requirements

As the follow-on to Landsat 7, the LDCM mission objective was to "extend the ability to detect and quantitatively characterize changes on the global land surface at a scale where natural and human-induced causes of change can be detected and differentiated" (NASA, 2013). The major mission objectives were to:

- *Collect and archive moderate-resolution, reflective multispectral image data affording seasonal coverage of the global landmass for a period of no less than 5 years.* This objective led to inclusion of the OLI instrument.
- *Collect and archive moderate-resolution, thermal multispectral image data affording seasonal coverage of the global landmass for a period of no less than 3 years.* This objective led to the inclusion of the TIRS instrument.
- *Ensure that LDCM data are sufficiently consistent with data from the earlier Landsat missions, in terms of acquisition geometry, calibration, coverage characteristics, spectral and spatial characteristics, output product quality, and data availability to permit studies of land cover and land use change over multi-decadal periods.* This resulted in the continued use of the World Reference System-2 that allows a 16-day repeat cycle using a 185-km-wide swath consistent with Landsat 4–7 as well as OLI and TIRS spectral bands covering the range afforded by the Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors.
- *Distribute standard LDCM data products to users on a nondiscriminatory basis and at no cost to the users.*

Consistent with the Landsat legacy, LDCM promised significant evolutionary technical improvements in capabilities needed for Landsat scientific and applications investigations. Major improvements included:

- Collecting 11 bands of multispectral imagery with OLI and TIRS with 30 m and 100 m spatial resolution respectively (see Table 1).
- Changing instrument technology that provided improved (1) onboard radiometric calibration, (2) significant improvements in each band's signal to noise ratio (SNR), and (3) the quantization of observations at 12-bit radiometric resolution. Geolocation capabilities were also improved.
- Improving the daily acquisition capacity. The Landsat 8 requirement was 400 images per day as compared to the Landsat 7 requirement to collect 250 images per day.
- Improving the ground network so that all data imaged each day are relayed to the USGS EROS for immediate processing and distribution to Landsat users.

Table 1
Spectral bands of the Operational Land Imager (bands 1–9) and Thermal Infrared Sensor (bands 11–12). Observations are quantized over a 12-bit dynamic range and provided to users as 16-bit numbers. Note that the 100 m thermal bands are resampled to 30 m in the Landsat 8 data product.

Bands	Wavelength (micrometers)	Spatial resolution (meters)
Band 1 – coastal aerosol	0.43–0.45	30
Band 2 - blue	0.45–0.51	30
Band 3 - green	0.53–0.59	30
Band 4 - red	0.64–0.67	30
Band 5 - near infrared (NIR)	0.85–0.88	30
Band 6 - SWIR 1	1.57–1.65	30
Band 7 - SWIR 2	2.11–2.29	30
Band 8 - panchromatic	0.50–0.68	15
Band 9 - cirrus	1.36–1.38	30
Band 10 - Thermal Infrared 1	10.60–11.19	100
Band 11 - Thermal Infrared 2	11.50–12.51	100

- Standardizing the primary Landsat 8 WRS-2 scene-based Level 1 products, in both terrain-corrected orthorectified formats (L1T) or systematically corrected (L1G) – see Irons et al. (2012) for specifications.

Detailed discussions of the requirements, specifications, design considerations, and pre- and post-launch instrument performance of LDCM/Landsat 8 have been summarized in many publications. For example, prior to the February 2013 LCDM launch, Irons et al. (2012) published an overall mission description, and Markham et al. (2012) and Reuter et al. (2010) published details on OLI and TIRS technologies and capabilities respectively. Following launch, Markham et al. (2014) organized a special issue of *Remote Sensing* on "Landsat-8 Sensor Characterization and Calibration" that provided design, pre-launch, and on-orbit spectral and geometric characterizations of the OLI and TIRS instruments.

In the special issue collection, Knight and Kvaran (2014) provided a detailed description of OLI design and performance. Markham et al. (2014) summarized both pre-launch and on-orbit OLI radiometric calibration and stability and reported, except for the coastal aerosol band, OLI stability has been better than 0.3%. Morfitt et al. (2015) concluded that OLI radiometric performance met or exceeded expectations due to pre-launch calibration efforts, and that since launch, calibration updates have improved image quality even more. Finally, Storey et al. (2014) summarize on-orbit geometric performance and concluded that all geometry requirements are being met or exceeded.

In more recent journal publications, Pahlevan et al. (2014) provided an on-orbit radiometric assessment of OLI and concluded that that for aquatic applications, the absolute radiometric performance of visible and near-infrared channels (except for the new 443-nm coastal aerosol band - band 1) over water agrees with top-of-atmosphere (TOA) radiances estimated by ocean color satellites. In addition, Czapla-Myers et al. (2015) conducted OLI TOA spectral reflectance and radiance comparisons with ground-based measurement and conclude that except for band 7 (shortwave), reflectance is within ±3% and radiance is within ±5% of the OLI design specifications. They also report that Landsat 7 ETM+ and OLI TOA radiance and reflectance obtained during the March 2013 tandem acquisitions are within ±2% and 4% respectively.

Regarding TIRS performance, in the *Remote Sensing* special issue, Reuter et al. (2015) provide an overview of the TIRS instrument design, pre-launch calibration, and initial on-orbit performance. More details on TIRS performance was provided by Barsi et al. (2014), including their comparison of TIRS observations with buoy in situ measurements that showed that TIRS data in both thermal bands resulted in TOA brightness temperatures that were too warm (+2.1 K for band 10 and +4.4 K at 300 K for band 11) when compared to buoy-measured