[DC-03-032] Landsat

Abstract

The Landsat series of satellites have collected the longest and continuous earth observation data. Earth surface data collected since 1972 are providing invaluable data for managing natural resources, monitoring changes, and disaster response. After the US Geological Survey (USGS) opened the entire archive to users, the number of monitoring and mapping applications have increased several folds. Currently, Landsat data can be obtained from the USGS and other private entities. The sensors onboard these Landsat satellites have improved over time resulting in changes to the spatial, spectral, radiometric, and temporal resolutions of the images they have collected. Data recorded by the sensors in the form of pixels can be converted to reflectance values. Recently, USGS has reprocessed the entire Landsat data archive and is releasing them as collections. This section provides an overview of the Landsat program and remotely sensed data characteristics, followed by the description of various sensors onboard and data collected by the past and current sensors.

Keywords: Earth observation, Landsat, multispectral, passive sensors, satellites, scanning instruments

Author & citation

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Explanation

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1. Definitions

Reflected and emitted light: When light interacts with objects it can be a) transmitted, b) absorbed, or c) reflected. Objects that absorb light will emit the energy later. The reflected and emitted light forms the basis of remote sensing.

Passive sensor: An electronic device or instrument that records the intensity of light reflected or emitted from objects. The source of the incident light is external to the sensor (e.g., the sun).

Pixel: Stands for picture-element and is the smallest spatial unit of measurement recorded by the sensor.

Multispectral data: Spectral data acquired in more than three wavelength bands of the electromagnetic spectrum. Data recorded in each region is referred as a spectral band or channel.

Polar orbiting satellites: Satellites that orbit the earth along a path goes over, or close to, both poles.

Sun synchronous satellites: A class of polar orbiting satellites where each repeat orbit of the satellite passes a particular ground location at the same local time of the day. Data collected by these satellites are well suited for analyzing changes over time.

Scene: As satellites orbit along a path, the sensors scan the terrain below and collect data. These data are divided into individual frames called scenes. Each scene is identified by its unique path (North-South) and row (East-West) numbers.

2. History & Significance of Landsat in GIS&T

Remotely sensed data acquired by NASA/USGS Landsat series of satellites constitute the longest collection of Earth Observation (EO) imagery data. The first satellite was built and launched by the US Department of Interior, NASA, and the US Department of Agriculture in 1972 as Earth Resources Technology Satellite (ERTS-1) and was later renamed as Landsat 1 (Figure 1). Seven satellites have been launched since then, however Landsat 6 failed to reach its orbit. Landsat 5, launched in 1984, collected data for 28 years and 10 months, and made an entry in the Guinness World Book as the “Longest Operating Earth Observation Satellite”. Landsat 7 and 8 are currently operational and together they collect more than 1500 scenes every day. However, there are gaps in the images collected by Landsat 7 since May 2003, due to a mechanical failure (For more details, see Section 4.4). The next satellite in the sequence, Landsat 9, is scheduled for launch in 2021.

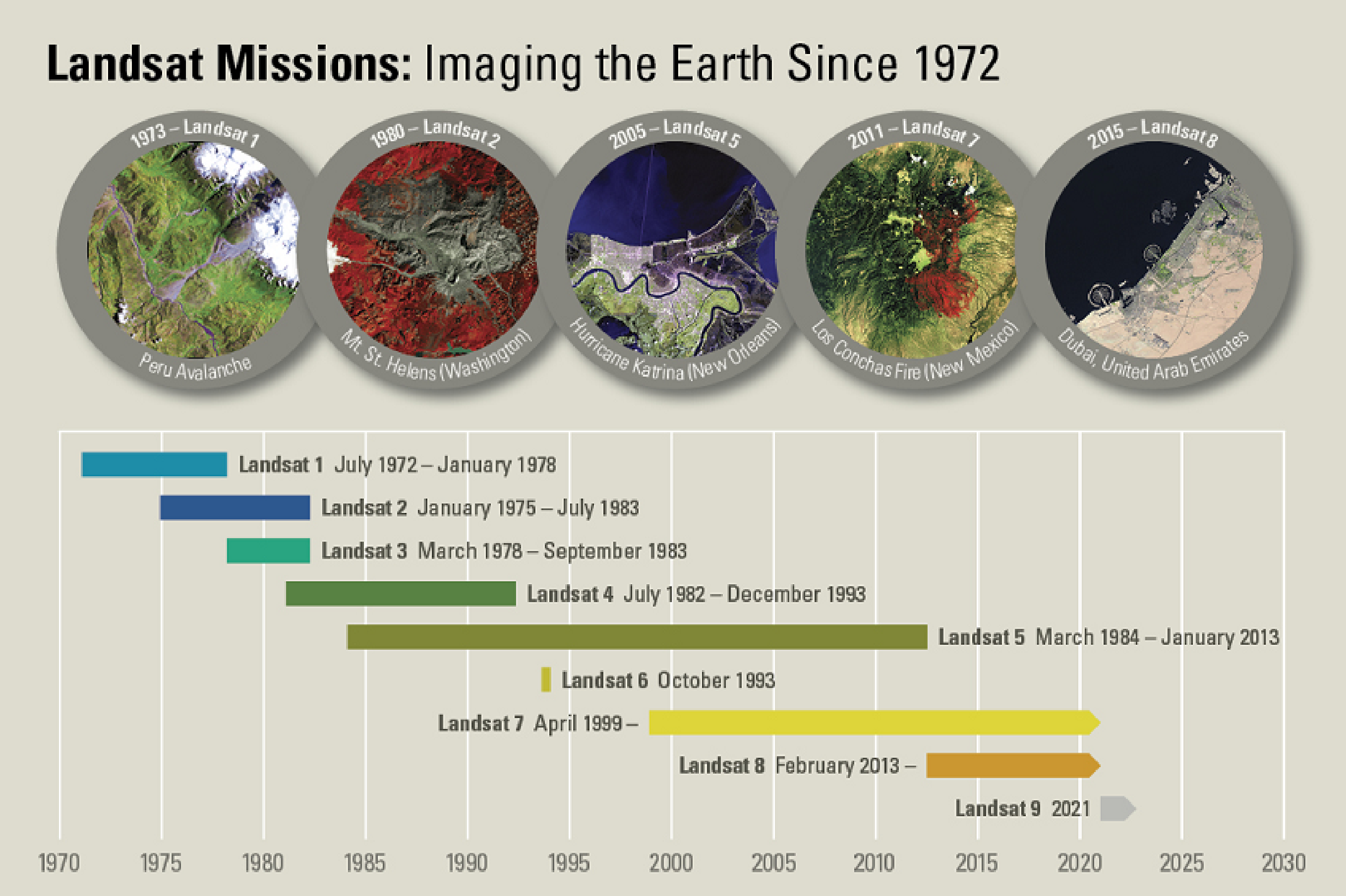

Figure 1. A timeline history of Landsat satellite missions. Source: US Geological Survey.

After the United States Geological Survey (USGS) opened the entire Landsat archive for no-cost use, interest in these EO data have increased several folds (Zhu et al., 2019). Numerous studies have combined images acquired by one or more Landsat satellites to characterize earth surface features and their changes from local (Cai et al., 2018) to global (Hansen et al., 2013) scales. Landsat data are used for countless number of applications in agriculture, forestry, grassland, rangeland, disaster response, hydrology, and land cover/use and change analyses (Sivanpillai, Jones & Lamp 2017; Young et al., 2017). Landsat images are also used as a visual backdrop in many GIS applications. Information derived by manual interpretation or digitally processed images are integrated with existing data in geospatial modeling applications.

3. Remotely Sensed Data Characteristics

Landsat images collected over the decades have varied due to differences in the onboard sensors (section 3) used for collecting them. Landsat imagery data are characterized by the following four resolutions: a) spatial, b) spectral, c) radiometric, and d) temporal. Spatial resolution corresponds to the size of the pixel on the ground (e.g., 15 x 15 m). Spectral resolution refers to width of the regions in the electromagnetic spectrum in which data are acquired. Radiometric resolution corresponds to the range of values between minimum and maximum, which are used for distinguishing the brightness values. Since these values are digitally stored, radiometric resolution is denoted as 2n, where n corresponds to the number of bits. For example, when n = 6 bits, 64 levels of brightness values that can be stored that range from 0 (minimum) to 63 (maximum). As n increases more subtle differences in brightness values can be distinguished and stored. Temporal resolution refers to the time lapsed between any two consecutive acquisitions. This is also referred as the revisit time of the satellite. For more information on this topic, see Nature of Multispectral Image Data.

4. Sensors Onboard Landsat 1-8 Satellites

Over the decades, the passive sensors onboard the Landsat satellites have evolved by capitalizing on advances in optics, electronics, and communication technology. Owing to these advances, the type and capabilities of sensors have also changed in newer Landsat missions.

4.1 Return Beam Vidicon

The return bean vidicon (RBV) was similar to a TV camera and was designed as the primary instrument for acquiring photogrammetric quality images from space. Initially, it was assumed that these space-based images would be similar to the aerial film-based cameras that were widely used in photogrammetric applications. The RBV on Landsat 1 and 2 had three independent cameras that acquired in images in green, red, and near infrared regions. Shutters in each camera simultaneously opened and recorded the spectral data for a geographic region. These three independent images that were slightly offset because they were acquired by independent cameras were ‘co-registered’ to generate a false-color Landsat scene. However, the images acquired by RBV had high spatial distortions, and the sensor experienced some technical difficulties. Therefore, the focus shifted to the Multi-Spectral Scanner (section 4.2) system.

The RBV sensor on Landsat 2 was identical to the one in the first satellite but was seldom used. Landsat 3 carried a RBV with two cameras capable of acquiring data in broad spectral regions (green to near infrared), and like its predecessors, its data was also rarely used. Additional details about RBV data can be found in the USGS RBV - Film only page (USGS).

4.2 Multi-Spectral Scanner

Multi-Spectral Scanner (MSS) was an **across-track** sensor that acquired spectral data for one pixel at a time unlike RBV that performed like cameras. **Across-track** or whisk broom sensors consist of a mirror that scan the earth surface perpendicular to the movement of the satellite. Each scan would result in row(s) of pixels and as the satellite moved forward the sensor would collect the next rows.

A numeric value was assigned to the pixel based on the intensity of incoming radiation for a given wavelength (Campbell, 2007). Scanners build a line of pixels for the width of 185 km referred as the swath of the MSS image. MSS had 24 separate detectors that were capable of scanning six lines at a time in four spectral (green, red, and two infrared) bands.

Spectral data collected by scanning devices produce an image in an electronic device by displaying one pixel at a time. MSS sensors on Landsat 1-3 had a revisit time of 18 days.

When the orbital height of Landsat 4 and 5 was lowered to 705 km, the revisit time reduced to 16 days. Other characteristics of MSS data are summarized in Table 1.

4.3 Thematic Mapper

Thematic Mapper (TM) was similar to the earlier MSS but collected data in seven spectral regions and also at relatively higher spatial resolution (30 m). These improvements were aimed at collecting higher quality data for better differentiating the earth surface features. The radiometric resolution of TM was also higher (8 bits) which means the incoming spectral radiation can be separated to 256 brightness levels. Other characteristics of TM data are summarized in Table (1). The swath of each TM scene was set at 185 km matching the earlier MSS scenes. TM instruments were part of Landsat 4 and 5 missions.

4.4 Enhanced Thematic Mapper Plus

Enhanced Thematic Mapper Plus (ETM+) scanning instrument on Landsat 7 is similar to TM in terms of its radiometric and temporal resolutions. The spatial resolution of the thermal infrared band was increased to 60 m. A new panchromatic band with 15 m was added to the ETM+ (Table 1). The swath of each ETM+ scene was kept at 185 km to match the earlier Landsat MSS and TM scenes. Other hallmarks of ETM+ was its improved radiometric calibration, better filter and detector technology which increased the performance and accuracy.

ETM+ suffered a setback on May 31, 2003 when the Scan Line Corrector (SLC) failed. The SLC compensated for the satellite’s forward motion of the across-track scanner and its failure resulted in gaps in the scene. The middle 20% of each scene (in the north-south direction) was not impacted by SLC failure and gaps of missing scan lines appear on either side of the scene (in the east-west direction).

4.5 Operational Land Imager

Operational Land Imager (OLI) onboard Landsat 8 is similar to TM and ETM+ in terms of the orbital characteristics, swath (185 km), and spatial resolution. The radiometric resolution was improved to 12 bits in order to capture finer details in brightness values and to improve the signal-to-noise ratio. Two new bands, coastal blue (0.43 - 0.45 µm) and cirrus (1.36 - 1.38 µm), were added. Data collected in cirrus band are used for automatic cloud cover assessments. Unlike, TM and ETM+, OLI does not collect thermal data since a separate instrument was added to Landsat 8 mission (section 4.6). Other characteristics of OLI sensor are summarized in Table (1).

OLI is an along track or push broom scanner where the scan lines are parallel to the movement of the satellite. This was a major change made to the newest sensor compared to its predecessors.

4.6 Thermal Infrared Sensor

Thermal Infrared Sensor (TIRS) onboard Landsat 8 is a standalone, along track or push broom scanning instrument, which collects data in two longwave thermal infrared wavebands (Table 1). In contrast the TM and ETM+ sensors recorded a single measurement in the same region. Two bands of thermal data provide the potential for improved estimates of surface temperature, compared to a single band. However, ghosting in the TRS second band reduced the effectiveness of this approach. TIRS and OLI (section 4.6) simultaneously collect data.

Table 1. Characteristics of the Data Collected by Landsat Satellites 1-5, 7, and 8.

		Resolution			
Sensor	**Satellite #**	**Spatial (m)**	**Radiometric**	**Temporal**	**Spectral**
MSS	L01-05	80a	6 bits	18/16 daysb	• Green (0.5 to 0.6 µm) • Red (0.6 to 0.7 µm) • Infrared (0.7 to 0.8 µm) • Infrared (0.8 to 1.1 µm)
TM	L04-05	30c/120d	8 bits	16 days	• Blue (0.45 to 0.54 µm) • Green (0.52 to 0.60 µm) • Red (0.63 to 0.69 µm) • Near Infrared (0.76 to 0.90 µm) • Near Infrared (1.55 to 1.75 µm) • Mid infrared (2.08 to 2.35 µm) • Thermal IR (10.4 to 12.5 µm)
ETM+	L06e-07	30c/60f/15g	12 bits	16 days	• Blue (0.45 - 0.52 µm) • Green (0.52 - 0.60 µm) • Red (0.63 - 0.69 µm) • Near infrared (0.77 - 0.90 µm) • Shortwave IR (1.55 - 1.75 µm) • Thermal IR (10.40 - 12.50 µm) • Mid infrared (2.08 - 2.35 µm) • Panchromatic (0.52 - 0.92 µm)
OLI	L08	30c/15g	12 bits	16 days	• Coastal blue (0.43 - 0.45 µm) • Blue (0.45 - 0.51 µm) • Green (0.53 - 0.59 µm) • Red (0.64 - 0.67 µm) • Near infrared (0.85 - 0.88 µm) • Shortwave IR1 (1.57 - 1.65 µm) • Shortwave IR2 (2.11 - 2.29 µm) • Panchromatic (0.50 - 0.68 µm) • Cirrus (1.36 - 1.38 µm)
TIRS	L08	100	12 bites	16 days	• TIRS 1 (10.6 - 11.19 µm) • TIRS-2 (11.5 - 12.51 µm)

Notes:
a Spatial resolution of MSS data were 80 m but they are distributed as 60 m pixels.
b Temporal resolution or revisit time of Landsat 1-3 was 18 days, and for Landsat 4-5 was 16 days.
c Spatial resolution of the Multispectral bands in Landsat 5, 7 and 8 is 30 m.
d Spatial resolution of the Thermal band in Landsat 4 and 5 was 120 meters.
e Landsat 6 failed to reach orbit.
f Spatial resolution of the Thermal band in Landsat 7 is 60 meters.
g Spatial resolution of the Panchromatic band in Landsat 7 and 8 is 15 meters.

Spectral data from MSS, TM, ETM+, and OLI are available as digital numbers, at sensor spectral radiance, at sensor reflectance, and surface reflectance (Young et al., 2017). The Landsat data archive can be queried and downloaded from the USGS EarthExplorer website (https://earthexplorer.usgs.gov) or from other private entities. These conversions are completed as part of data pre-processing. The USGS uses specific product information such as Level 0, Level 1G, and Level 1T to identify the type and level of pre-processing completed for a Landsat scene. Since USGS opened the archive at no-cost, Landsat data can be accessed from USGS and other sources as Google Earth Engine, and Amazon Web Services. If users download data from more than one source, it is imperative to pay close attention to the type of pre-processing completed to minimize erroneous results.

5. Landsat Data Format

Landsat images are available as scenes (Figure 2) and the swath width of each scene is 185 km (distance in the east-west direction). The distance in the along-track direction (north-south) ranges between 170 km and 180 km for different sensors. Landsat scenes are identified by their unique path/row numbers associated with the Worldwide Reference System (WRS). Scenes from Landsat 1-3 were part of the WRS-1, whereas the rest of the scenes starting from Landsat 4 are part of the WRS-2.

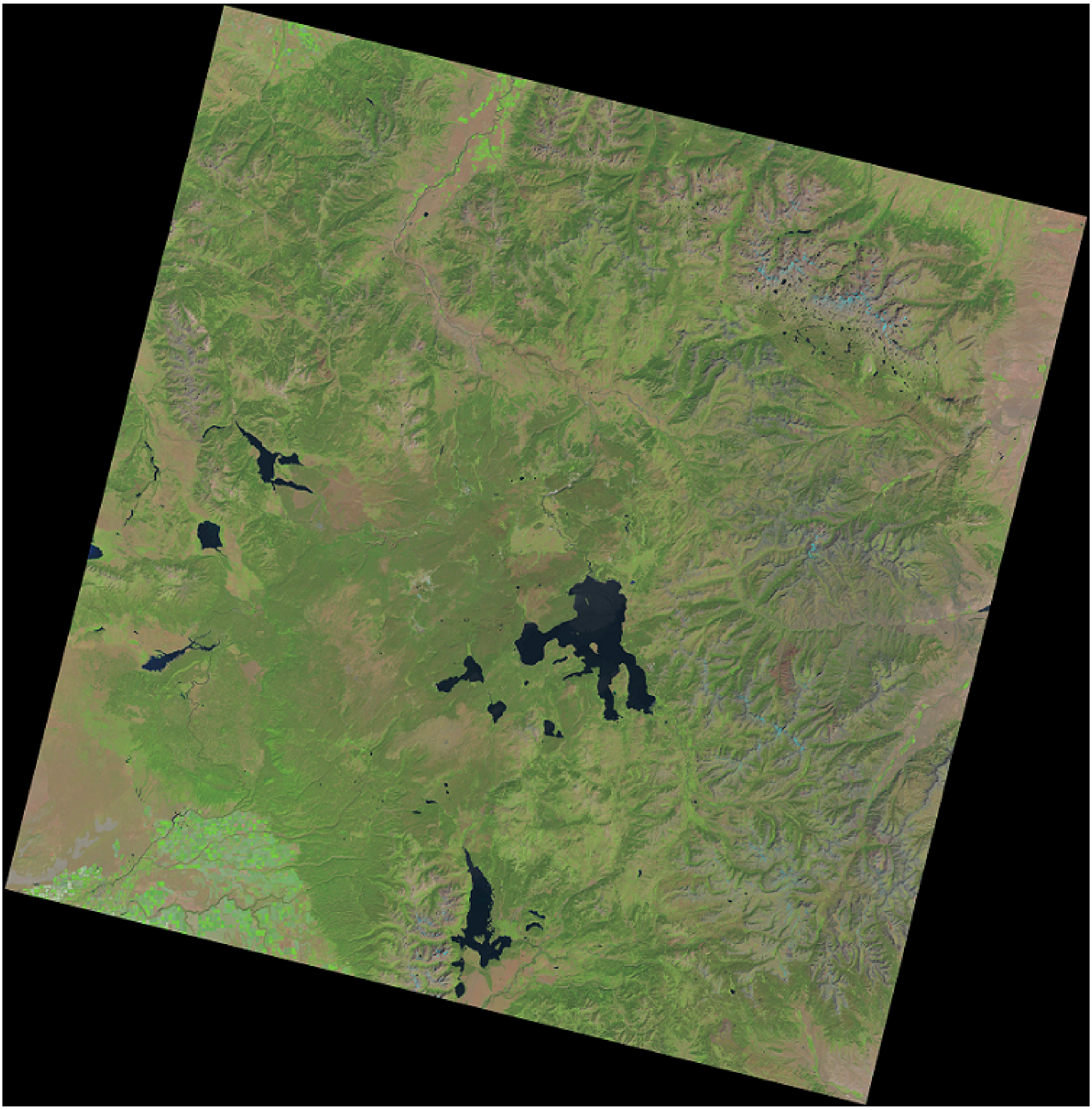

Figure 2. A Landsat scene (Worldwide Reference System-2 Path 38, Row 29) acquired on August 15, 2020 covering Yellowstone National Park (Wyo. USA). Yellowstone Lake is in the middle and Jackson Lake is directly south in the scene acquired by the Operational Land Imager onboard Landsat 8. Source: US Geological Survey.

5.1 Collections Level Data

Starting in 2016, USGS reprocessed the entire Landsat archive to common accuracy standards and organized them as Collection Level Data. Within a collection, Landsat scenes are assigned to Tiers based on quality and level of processing. Scenes that are minimally processed are placed in the tier named Real Time (RT). These scenes provide rapid information for applications such as disaster response. Next, scenes are processed for terrain effects and inter-calibrated with data from other Landsat sensors. Scenes with highest precision and terrain corrected data with ≤ 12-meter RMS error are placed in Tier 1 (T1). Scenes that do not meet this stringent quality are placed in Tier 2 (T2). Thus, users can determine the quality and analyze any number of scenes in the archive irrespective of the sensor that acquired a particular image. Users can obtain Landsat imagery that are part of Collection 1 as Digital Numbers (DNs), at sensor reflectance, and surface reflectance values.

In December 2020, USGS reprocessed and released Collection 2 Landsat data. Collection 2 scenes have increased geolocation accuracy which improves the interoperability of Landsat data over the entire archive. In Collection 2, only DNs and surface reflectance values are provided; at sensor reflectance, if needed, has to be calculated by users on their own. Each new collection comprises images with higher quality. Hence users should not combine Landsat scenes from different collections for any applications.

The level of processing completed for any Landsat scene can be derived from its ID. For example, based on the following ID, one can determine the following information:

LC08_L1TP_038029_20200815_20200919_02_T1

L: Landsat (Constant)

C: Sensor (C: OLI/TIRS)

08: Satellite number (08)

L1TP: Processing level (Level 1 Terrain Precession)

038029: WRS2 Path 38; Row 29

20200815: Acquisition date (YYYYMMDD)

20200919: Processing date (YYYYMMDD)

02: Collection number

T1: Tier level (T1 highest quality)

NOTES:

- Options for sensor: C: OLI/TRIS O: OLI; T: TIRS; E: ETM+; T: TM; M: MSS
- Options for satellite number: 01, 02, 03, 04, 05, 07, 08, etc.
- Options for Processing level: L1TP, L1GT, L1GS
- Options for Collection number: 01, 02
- Options for Tier: RT, T1, T2

Within a collection, if any Landsat scene is reprocessed it will be reflected with a new Processing date. Users should check the archive for any updates prior to using Landsat scene(s) downloaded at an earlier date.

5.2 Analysis Ready Data

In 2018, USGS released Analysis Ready Data (ARD) for the US based on a tiled grid reference system instead of path/row format. Each Landsat tile consists of 5000 x 5000 pixels and is smaller than a scene (Figure 3) and are identified by a unique horizontal-vertical number.

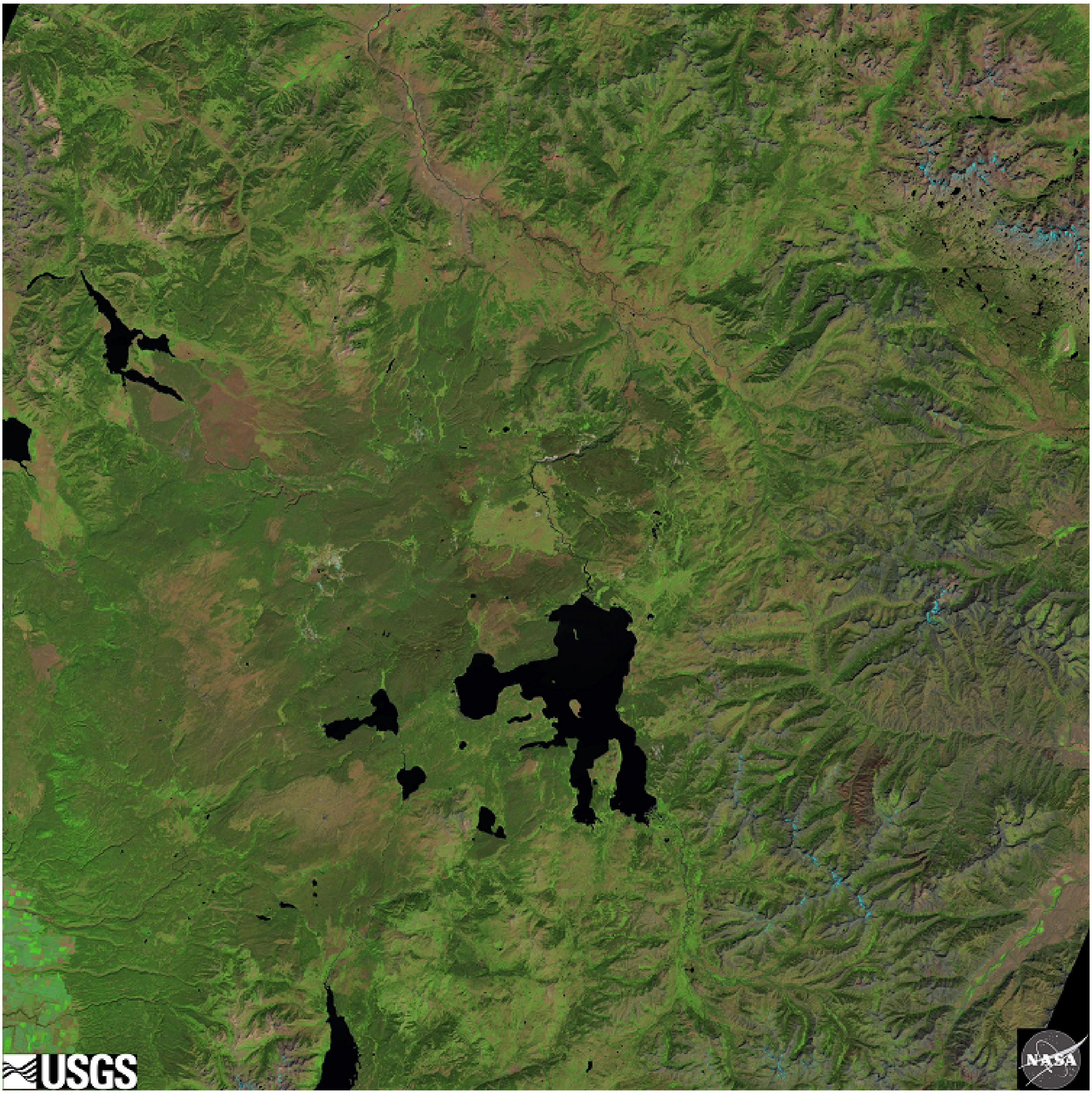

Figure 3. A Landsat tile grid (Horizontal 9; Vertical 5) generated from the scene acquired on August 15, 2020 covering the Yellowstone National Park (Wyo. USA). There are 5000 x 5000 pixels in each tile grid. Source: US Geological Survey.

Landsat ARD tiles for the US contain Top of Atmosphere (TA) reflectance, top of atmosphere Brightness Temperature (BT), Surface Reflectance (SR), and quality assessment data. ARD tiles can be directly used for time-series analyses thus reducing the time to download and pre-process large number of Landsat scenes.

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