40 Years of Landsat Thermal Infrared Earth Observations with a Look Ahead

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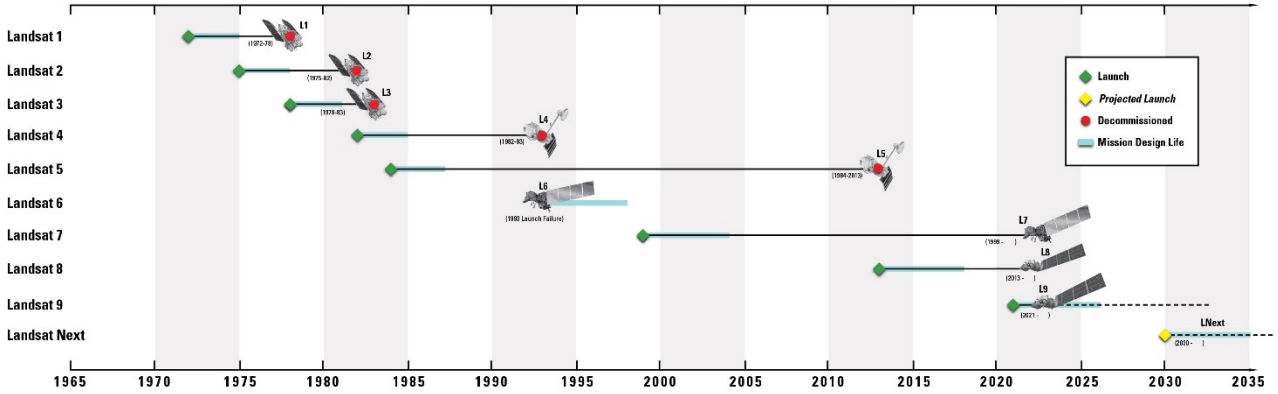
Outline

- Landsat Thermal Infrared (TIR) Observation
- Landsat Collection 2 Surface Temperature Product
- Landsat Collection 3 Improvement Plans
- Landsat Next science mission concept

Landsat TIR Observation since 1982

- Landsat Thermal Infrared (TIR) observation began with Landsat 4 Thematic Mapper (TM) in 1982
- The Landsat 4 and 5 TM had a single 120-m TIR spectral band centered at around 11.4 µm
- Landsat 7 Enhanced Thematic Mapper Plus (ETM+) had the spectrally similar single TIR spectral band but with 60-m ground sampling distance and low and high gain settings
- Landsat 8 and Landsat 9 Thermal Infrared Sensor (TIRS) have two 100-m TIR spectral bands centered at 10.8 µm and 12.0 µm.
- With five TIR spectral bands, the Landsat Next observatory constellation will measure emitted radiance between 8.05 to 9.45 µm, and between 10.75 to 12.55 µm spectral regions



Landsat TIR Calibration

- ***On-orbit Calibration***
  - Instrument responsivity and stability are measured using an onboard blackbody along with deep space per orbit calibration sequences

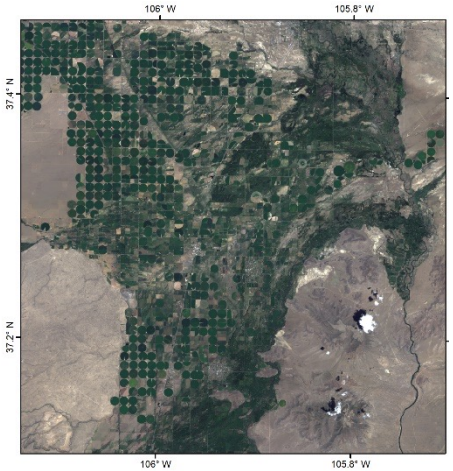
- ***Vicarious Calibration***
  - Buoy measurements: water has been used as the primary target for vicarious calibration of the Landsat TIR spectral bands given its uniform composition, emissive properties, and
    low frequency spatial variation over large areas

  - Inter-Satellite Top-of-Atmosphere comparison; under-flight opportunities, coincident to near-coincident acquisitions, and radiative transfer modeling

NOAA buoys and JPL instruments used for Landsat TIR vicarious calibration

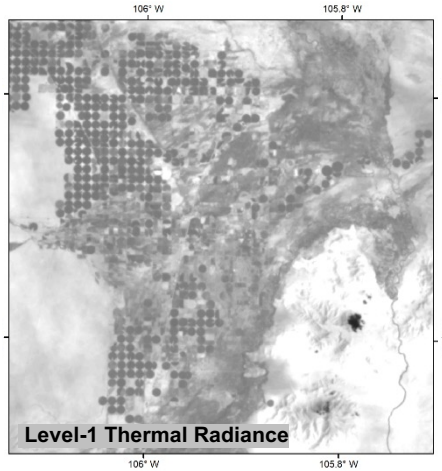
Barsi et al. "Landsat-8 thermal infrared sensor (TIRS) vicarious radiometric calibration." *Remote Sensing* 6.11 (2014): 11607-11626.

Landsat Collection 2 (C2) TIR Product Offerings



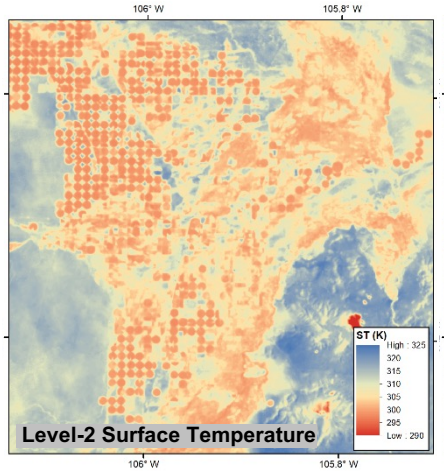
True Color Red/Green/Blue
Top-of-Atmosphere Reflectance
LC80330342017200LGN00

Radiometrically calibrated and orthorectified Level-1 thermal radiance ($Wm^{-2}\,sr^{-1}\,\mu m$)



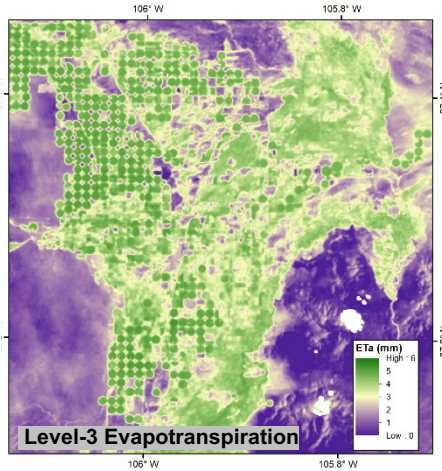
https://www.usgs.gov/landsat-missions/landsat-collection-2-level-1-data

Atmospherically corrected Level 2 surface temperature (Kelvins)



https://www.usgs.gov/landsat-missions/landsat-collection-2-surface-temperature

On-demand Level 3 provisional actual evapotranspiration (mm)

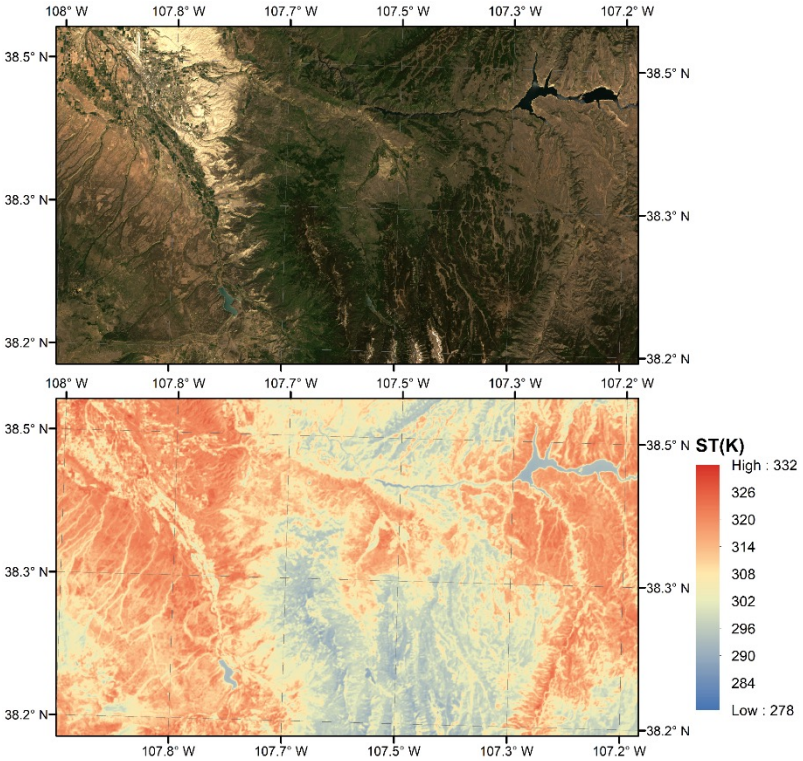


https://www.usgs.gov/landsat-missions/landsat-collection-2-provisional-actual-evapotranspiration-science-product

Landsat C2 Surface Temperature

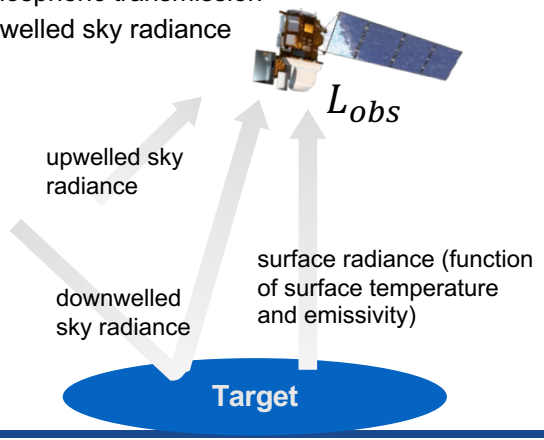
- Represents the temperature of the Earth's surface in Kelvin (K) and is available globally for Landsat 4-9 (1982 to present)
- Essential product for estimating evapotranspiration, heat islands, phenological studies, agricultural management, energy balance, aquatic environments, and cold regions
- Notably, a per-pixel measure of surface temperature uncertainty (Kelvin) is provided to enable downstream analysis of information retrieval sensitivitv

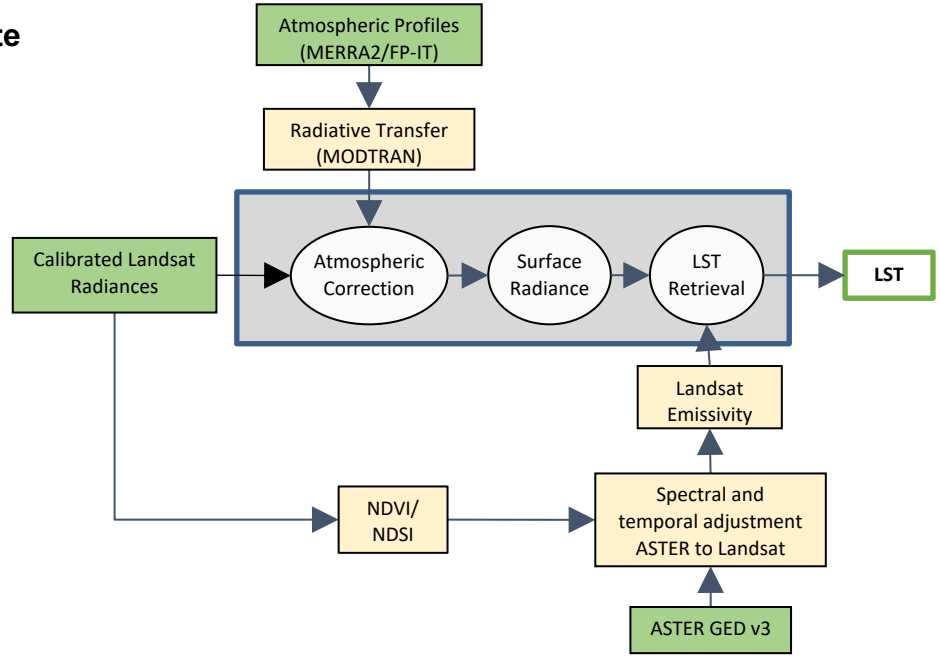
The Landsat C2 Level-2 products are endorsed by the Committee on Earth Observation Satellites (CEOS) to be Analysis Ready Data for Land (CARD4L)-compliant.



Landsat C2 Surface Temperature Algorithm

- **Single-Channel Radiative Transfer based on MODerate resolution atmospheric TRANsmission (MODTRAN)**
  - $L_{obs} = (L_T\varepsilon + (1-\varepsilon)L_d)\tau + L_u$
    - L_{obs}: sensor-reaching radiance
    - L_T: blackbody radiance emitting from a surface with temperature T
    - ε: emissivity of surface
    - L_d: downwelled sky radiance
    - τ : atmospheric transmission
    - L_u: upwelled sky radiance

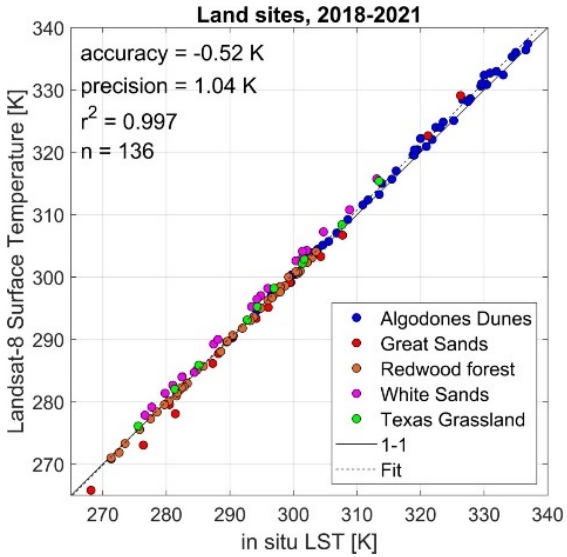


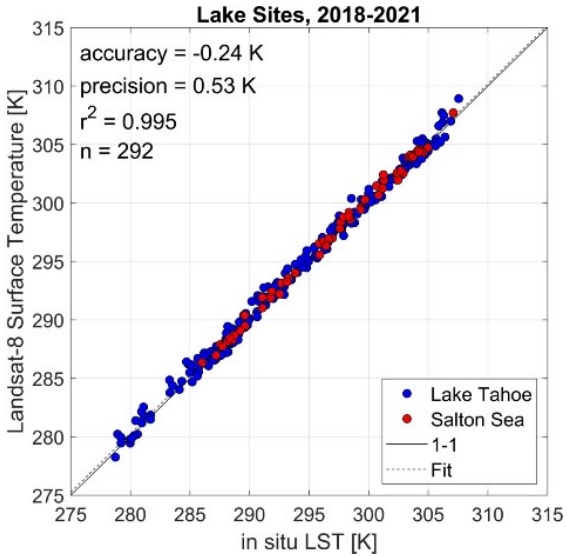


Source: Malakar et al. "An operational land surface temperature product for Landsat thermal data: Methodology and validation." *IEEE Transactions on Geoscience and Remote Sensing* 56.10 (2018): 5717-5735.

Validation of C2 Surface Temperature Product

- The C2 Landsat 8 surface temperature product has been validated over a variety of land sites with ~0.5 K accuracy and ~1K precision, and over lake sites with approximately 50% better performance
- Lower accuracy and precision over land sites is expected due to the larger variability in surface emissivity compared to water bodies
- Encourage more validation activity by TIR community





Crawford et al. 2023 (in preparation)

Landsat Collection 3 Surface Temperature Scope

- **Improve Emissivity Inputs**
  - Gaps in ASTER GED
  - Incorporate CAMEL / ECOSTRESS for emissivity
  - Improve interpolation method for Landsat emissivity
  - Improve temporal adjustment procedure
- **Algorithm Enhancements**
  - Alternative radiative transfer model (order of magnitude speed increase from MODTRAN to RTTOV without compromising accuracy)
  - Single-channel surface temperature improvements (e.g. uncertainty band, resampling method of atmospheric bands)
- **Product Offering and Architecture**
  - Decouple Level-2 surface temperature from surface reflectance processing (better latency)
  - Generate a surface temperature-only product for polar regions
  - Incorporate split window surface temperature for Landsat 8/9
- **Landsat Next Inclusion post-launch**
  - Emerging science products and algorithms

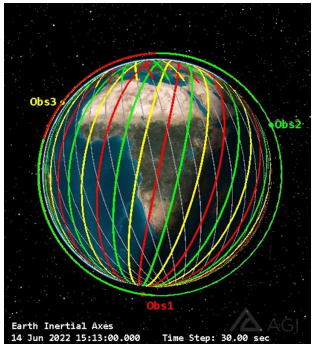
Landsat Collection 3 release timeline is no earlier than 2028.

Proposed Change	Collection 2	Collection 3
Emissivity source	ASTER GED	ASTER GED CAMEL ECOSTRESS
Interpolation of ancillary data	Nearest-neighbor	Bicubic
Radiative Transfer model	MODTRAN	RTTOV v13
Atmospheric correction source	MERRA-2/GEOS5 FP-IT	MERRA-2/GEOS IT
Algorithm	Single Channel	Single Channel (All sensors) Split Window (L8, L9)

Landsat Next Mission Overview

- Landsat Next Mission is a coincident VSWIR/TIR constellation of three identical “triplets” observatories with equal orbit spacing
  - Each observatory images the full swath required to achieve global coverage; three satellites used to improve revisit
- Launch Readiness Date: ~November 2030
- Provides measurement advancements and new capabilities for the next generation of Landsat users
  - **Improved spectral resolution** to support new and evolving applications, including surface water quality, cryospheric science, geology, and agricultural applications including crop management and water consumption - Improved spectral resolution for thermal will improve surface temperature accuracy.
  - **Improved temporal revisit** for monitoring dynamic land and water surfaces such as vegetation crop phenology, burn severity, water use and quality, coastal and wetland change, glacier and ice sheet dynamics
  - **Improved spatial resolution** for agricultural monitoring, ecological monitoring, urban studies, water resources management and other applications
  - **Synergy with European Sentinel-2** spectral bands allowing easier merging of information products

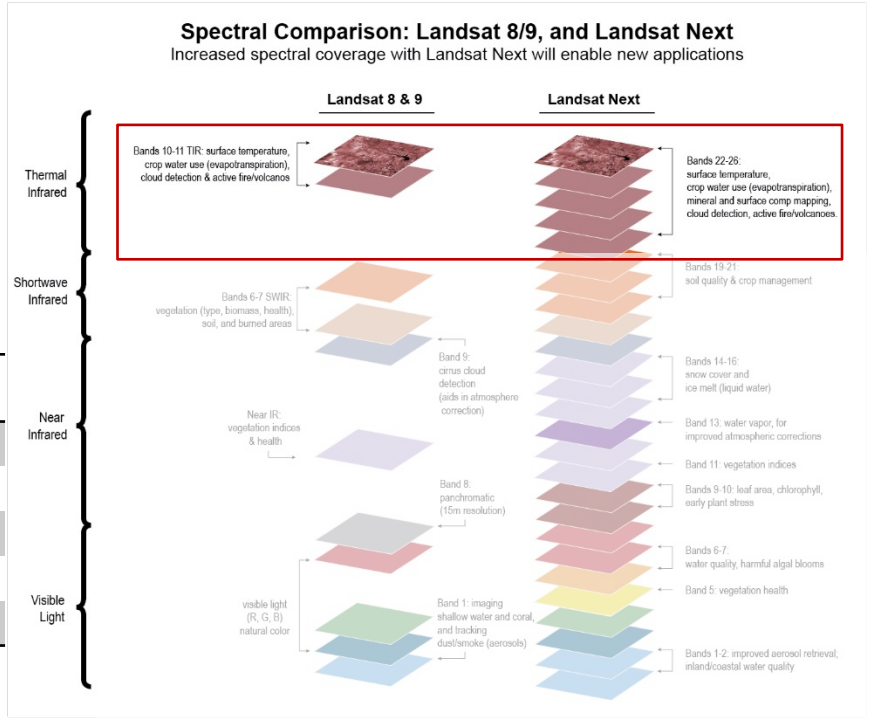
Parameter	Value
Mission Category	Category 2, Class B
Mission Life	5-Years
Altitude	653 km Sun-synchronous
Inclination	~98-degrees
Orbital Separation	120-degrees
Mean Local Time (MLT)	10:10 AM +/- 5-min
Repeating Ground Track	18-day
Constellation Aggregate	6-day
Swath Width	164 km
Half Angle FOV	7.2-degrees



Landsat Next TIR observation

- With five TIR spectral bands, the Landsat Next observatory constellation will measure emitted radiance between 8.05 to 9.45 µm, and between 10.75 to 12.55 µm spectral regions

Band Number	Band Name	Ground Sampling Distance (m)	Center Wavelength (nm)	Band Width (nm)	Rationale
22	TIR 1	60	8300	250	Mineral and surface composition mapping (ASTER)
23	TIR 2	60	8600	350	Emissivity separation, volcanos (SO2) (MODIS/ASTER)
24	TIR 3	60	9100	350	Mineral and surface composition mapping (ASTER)
25	TIR 4	60	11300	550	Surface temperature (Landsat), carbonates
26	TIR 5	60	12000	550	Surface temperature (Landsat), snow grain size



Landsat Next TIR Science Data Products

- **LNext science mission products will include the following geophysical quantities for TIR measurements:**
  - Level 2 Surface Temperature
  - Level 2 Surface Emissivity
- **LNext science algorithms (i.e., atmospheric compensation) for product generation will require evolution and advances:**
  - Leverage new TIR spectral bands targeted for emissivity
  - TIR algorithms will combine Temperature Emissivity Separation (TES) and generalized split window techniques
- **LNext science mission products will be processed into the existing Landsat Collection at time of operations (i.e. Collection 3)**