

Comprehensive Land Surface Temperature (LST) Mapping Tutorial in ArcGIS Pro

A Detailed, Step-by-Step Academic Workflow

Prepared by Dr. Aran
GIS Manager, Geospatial Campus, Nagercoil
Research Coordinator, ICWM, Kochi
draran.online | arancastro17@gmail.com

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Part 1: Theoretical Foundation

1.1 What is Land Surface Temperature (LST)?

Land Surface Temperature (LST) refers to the radiative skin temperature of the Earth's surface as derived from satellite-based thermal infrared (TIR) sensors. It is a critical parameter in environmental science, urban climatology, agriculture, hydrology, and public health research. Unlike air temperature measured at meteorological stations, LST captures the spatial heterogeneity of surface thermal conditions at the pixel level, making it valuable for spatially explicit analyses such as Urban Heat Island (UHI) studies, drought monitoring, and evapotranspiration estimation.

1.2 Why Landsat Data?

The Landsat programme, operated jointly by NASA and the USGS, provides the longest continuous archive of moderate-resolution (30 m multispectral, 100 m thermal resampled to 30 m) satellite imagery. Landsat 8 carries two key instruments: the Operational Land Imager (OLI) for visible/NIR/SWIR bands and the Thermal Infrared Sensor (TIRS) for thermal bands (Band 10 at 10.6–11.19 μm and Band 11 at 11.5–12.51 μm). The USGS recommends using **Band 10 only** for LST retrieval due to calibration uncertainties associated with Band 11 (USGS, 2019).

1.3 The General LST Retrieval Workflow

The standard mono-window/single-channel approach involves the following sequential processes:

Raw DN → TOA Spectral Radiance → Brightness Temperature → NDVI → Proportion of
Vegetation → Emissivity → LST

Part 2: Data Acquisition

2.1 Downloading Landsat Imagery

Step 2.1.1: Navigate to USGS EarthExplorer (<https://earthexplorer.usgs.gov/>).

Step 2.1.2: Create a free USGS account if one does not already exist. Click **Register** in the top-right corner, fill in the required credentials, and verify the email address.

Step 2.1.3: Define the Area of Interest (AOI) under the **Search Criteria** tab using one of the following methods: Address/Place, Coordinates, Shapefile/KML Upload, or the Interactive Map interface.

Step 2.1.4: Set the **Date Range** relevant to the study (e.g., summer months for UHI analysis). Set the **Cloud Cover** filter to less than 10% to ensure minimal atmospheric interference.

Step 2.1.5: Select the Dataset: Navigate to the **Data Sets** tab. Expand Landsat → Landsat Collection 2 Level-1 → Check Landsat 8-9 OLI/TIRS C2 L1.

Note: Use Level-1 (L1) data, not Level-2, because Level-2 products have already been atmospherically corrected and the standard LST workflow requires raw DN or TOA radiance as input.

Step 2.1.6: Click **Results** to view available scenes.

Step 2.1.7: Preview each scene by clicking the footprint or thumbnail icons. Select a scene with minimal cloud cover over the study area.

Step 2.1.8: Click the **Download** button and select Product Options. Download the following individual bands: Band 4 (Red), Band 5 (NIR), Band 10 (TIR), and the MTL.txt metadata file.

2.2 Understanding the Metadata (MTL) File

Open the MTL.txt file in any text editor. Locate and record the following parameters:

```
RADIANCE_MULT_BAND_10 = 3.3420E-04      → ML
RADIANCE_ADD_BAND_10   = 0.10000        → AL
K1_CONSTANT_BAND_10    = 774.8853       → K1
K2_CONSTANT_BAND_10    = 1321.0789      → K2
```

Parameter	Symbol	Typical Value (Band 10)	Purpose
Radiance Multiplicative Factor	ML	3.3420E-04	Converts DN to Radiance
Radiance Additive Factor	AL	0.10000	Converts DN to Radiance

Thermal Constant 1	K1	774.8853	Planck function constant
Thermal Constant 2	K2	1321.0789	Planck function constant

Table 1. Radiometric calibration parameters from the Landsat 8 MTL metadata file.

Part 3: Setting Up ArcGIS Pro

3.1 Creating a New Project

Step 3.1.1: Launch **ArcGIS Pro**.

Step 3.1.2: Click **New Project** → Select **Map** template.

Step 3.1.3: Name the project (e.g., LST_Analysis_StudyArea) and choose a folder location.

Step 3.1.4: Click **OK**. A new map view will open.

3.2 Setting the Coordinate System

Step 3.2.1: In the **Contents** pane, right-click the **Map** → **Properties**.

Step 3.2.2: Navigate to **Coordinate Systems**.

Step 3.2.3: Set the coordinate system to match the Landsat data. Landsat imagery is typically delivered in **WGS 1984 UTM Zone XX** (where XX corresponds to the study area's UTM zone).

Step 3.2.4: Click **OK**.

3.3 Adding Raster Data

Step 3.3.1: Go to **Map** tab → **Add Data** → **Add Data**.

Step 3.3.2: Navigate to the folder containing the downloaded Landsat bands.

Step 3.3.3: Add the following: B4.TIF (Red Band), B5.TIF (NIR Band), B10.TIF (Thermal Band).

Step 3.3.4: All three raster layers should now appear in the **Contents** pane and be displayed on the map canvas.

3.4 Clipping to the Study Area (Optional but Recommended)

Step 3.4.1: Go to **Analysis** tab → **Tools** → Search for **Clip Raster** (or **Extract by Mask** under Spatial Analyst).

Step 3.4.2: Set Input Raster to Band 10 (repeat for Band 4 and Band 5), Feature Mask Data to the study area shapefile, and provide descriptive output names (e.g., B10_clipped.tif).

Step 3.4.3: Click **Run**. Repeat for all three bands.

Note: This step reduces processing time and focuses the analysis on the area of interest.

Part 4: Computing TOA Spectral Radiance

4.1 Theory

The Digital Numbers (DN) stored in the raw Landsat Band 10 raster must first be converted to Top-of-Atmosphere (TOA) spectral radiance using the radiometric calibration coefficients from the metadata file. The formula is:

$$L\lambda = ML \times Q_{cal} + AL$$

Where $L\lambda$ is the TOA spectral radiance ($W/(m^2 \cdot sr \cdot \mu m)$), ML is the radiance multiplicative scaling factor for Band 10, Q_{cal} is the quantised calibrated pixel value (DN) of Band 10, and AL is the radiance additive scaling factor for Band 10.

4.2 Implementation in ArcGIS Pro

Step 4.2.1: Navigate to **Analysis** tab → **Tools** → Search for **Raster Calculator**.

Note: The Spatial Analyst Extension must be enabled. Go to Project → Licensing → Ensure Spatial Analyst is checked.

Step 4.2.2: In the Raster Calculator expression box, type:

```
0.0003342 * "B10_clipped.tif" + 0.1
```

Step 4.2.3: Set the Output raster to a meaningful name, e.g., TOA_Radiance.tif.

Step 4.2.4: Click **Run**.

Step 4.2.5: Verify the output using the **Identify** tool. Typical values range from approximately 4 to 15 $W/(m^2 \cdot sr \cdot \mu m)$.

Part 5: Conversion to Brightness Temperature (BT)

5.1 Theory

Brightness temperature is derived by inverting the Planck radiance function. It represents the temperature a blackbody would need to have in order to emit the same amount of radiance at the given wavelength. The formula is:

$$BT = K2 / \ln(K1 / L\lambda + 1) - 273.15$$

Where BT is the brightness temperature in degrees Celsius, K1 = 774.8853, K2 = 1321.0789 (for Landsat 8 Band 10), $L\lambda$ is the TOA spectral radiance, and subtracting 273.15 converts from Kelvin to Celsius.

5.2 Implementation in ArcGIS Pro

Step 5.2.1: Open **Raster Calculator** again.

Step 5.2.2: Enter the following expression:

```
(1321.0789 / Ln((774.8853 / "TOA_Radiance.tif") + 1)) - 273.15
```

Step 5.2.3: Set the Output raster to **Brightness_Temp.tif**.

Step 5.2.4: Click **Run**.

Step 5.2.5: Verify the output. Brightness temperature values typically range from 15°C to 50°C depending on the climate zone, season, and land cover.

Part 6: Computing NDVI

6.1 Theory

The Normalised Difference Vegetation Index (NDVI) quantifies the density and health of vegetation. It is computed from the red and near-infrared reflectance values and ranges from -1 to $+1$, where higher values indicate denser vegetation. In the context of LST retrieval, NDVI is used as an intermediate variable to estimate the proportion of vegetation and subsequently the land surface emissivity.

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red}) = (\text{Band 5} - \text{Band 4}) / (\text{Band 5} + \text{Band 4})$$

6.2 Implementation in ArcGIS Pro

Step 6.2.1: Open **Raster Calculator**.

Step 6.2.2: Enter the following expression:

```
Float("B5_clipped.tif" - "B4_clipped.tif") / Float("B5_clipped.tif" +  
"B4_clipped.tif")
```

Note: The Float() function ensures floating-point division rather than integer division, which would truncate decimal values.

Step 6.2.3: Set the Output raster to NDVI.tif.

Step 6.2.4: Click **Run**.

Step 6.2.5: Verify the output: Water bodies (NDVI < 0 , typically around -0.1 to -0.3), Bare soil/Built-up (NDVI ≈ 0.0 to 0.2), Sparse vegetation (NDVI ≈ 0.2 to 0.4), Dense vegetation (NDVI ≈ 0.4 to $0.8+$).

Part 7: Proportion of Vegetation (Pv)

7.1 Theory

The proportion of vegetation (Pv) quantifies the fractional vegetation cover within each pixel. It is derived from NDVI using the following equation:

$$Pv = ((NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}))^2$$

Where NDVI_{min} = 0.2 (representing bare soil) and NDVI_{max} = 0.5 (representing full vegetation). These threshold values can be adjusted based on the histogram of the NDVI raster.

7.2 Implementation in ArcGIS Pro

Step 7.2.1: Open **Raster Calculator**.

Step 7.2.2: Enter the following expression:

```
Square(("NDVI.tif" - 0.2) / (0.5 - 0.2))
```

Step 7.2.3: Set the Output raster to Pv.tif.

Step 7.2.4: Click **Run**.

Step 7.2.5: Output values should range from 0 (bare soil) to 1 (full vegetation). Values slightly below 0 or above 1 may occur at the extremes; these can be reclassified if necessary.

Part 8: Land Surface Emissivity (ϵ)

8.1 Theory

Emissivity (ϵ) describes the efficiency of a surface in emitting thermal radiation relative to a blackbody. It is a dimensionless quantity ranging from 0 to 1 and varies by surface type: water (~0.99), vegetation (~0.98), bare soil (~0.97), built-up surfaces (~0.95), and metals (~0.88–0.93).

The NDVI-based emissivity estimation method (Sobrino et al., 2004) uses the following equation:

$$\epsilon = 0.004 \times P_v + 0.986$$

This equation assumes emissivity of vegetation (ϵ_v) \approx 0.990, emissivity of soil (ϵ_s) \approx 0.986, and a geometric distribution factor (F) \approx 0.55.

8.2 Implementation in ArcGIS Pro

Step 8.2.1: Open **Raster Calculator**.

Step 8.2.2: Enter the following expression:

```
0.004 * "Pv.tif" + 0.986
```

Step 8.2.3: Set the Output raster to Emissivity.tif.

Step 8.2.4: Click **Run**.

Step 8.2.5: Verify the output. Emissivity values should range approximately from 0.986 (bare soil) to 0.990 (dense vegetation).

Part 9: Land Surface Temperature (LST)

9.1 Theory

The final LST is derived by correcting the brightness temperature for surface emissivity effects. The equation is:

$$\text{LST} = \text{BT} / (1 + (\lambda \times \text{BT} / \rho) \times \ln(\epsilon))$$

Where BT is the brightness temperature (°C), $\lambda = 10.8 \mu\text{m}$ (wavelength of emitted radiance), $\rho = h \times c / \sigma = 1.4388 \times 10^{-2} \text{ m}\cdot\text{K}$ (h = Planck's constant, c = speed of light, σ = Boltzmann constant), and ϵ = land surface emissivity. The simplified constant used in the formula is $\lambda/\rho = 0.00115/1.4388$.

9.2 Implementation in ArcGIS Pro

Step 9.2.1: Open **Raster Calculator**.

Step 9.2.2: Enter the following expression:

```
"Brightness_Temp.tif" / (1 + (0.00115 * "Brightness_Temp.tif" / 1.4388) * Ln("Emissivity.tif"))
```

Step 9.2.3: Set the Output raster to LST.tif.

Step 9.2.4: Click **Run**.

Step 9.2.5: Verify the output. LST values should be physically realistic: cool surfaces (water, dense forests) at 18–25°C, moderate surfaces (agricultural land) at 25–35°C, and hot surfaces (bare soil, asphalt, built-up areas) at 35–50°C+.

Note: If values appear unreasonably high or low, double-check the MTL constants and ensure all intermediate rasters are correct.

Part 10: Symbology and Classification

10.1 Applying a Colour Scheme

Step 10.1.1: In the **Contents** pane, right-click the LST.tif layer → **Symbology**.

Step 10.1.2: The Symbology pane will open on the right side.

Step 10.1.3: Under **Primary Symbology**, select **Classify** (for discrete classes) or **Stretched** (for a continuous gradient).

Option A: Stretched Symbology (Continuous)

Set Colour Scheme to a diverging ramp such as Blue-Yellow-Red or Cyan-to-Red. Under Stretch Type, select Minimum-Maximum or Standard Deviation. This provides a smooth, continuous gradient from cool to hot zones.

Option B: Classified Symbology (Discrete)

Set the Method to Manual or Natural Breaks (Jenks). Set the Number of Classes (e.g., 5 or 7). Define the class breaks manually:

Class	Temperature Range	Colour	Interpretation	LULC Association
1	< 20°C	Dark Blue	Very Cool	Water bodies, Dense forests
2	20–25°C	Light Blue	Cool	Wetlands, Irrigated fields
3	25–30°C	Yellow	Moderate	Agricultural land
4	30–35°C	Orange	Warm	Sparse vegetation, Fallow
5	35–40°C	Red	Hot	Built-up, Bare soil
6	> 40°C	Dark Red	Very Hot	Industrial, Impervious

Table 2. Suggested LST classification scheme with land use/land cover associations.

10.2 Adding Contour Lines (Optional)

Step 10.2.1: Go to **Analysis** → **Tools** → Search for **Contour**.

Step 10.2.2: Set Input Raster to LST.tif, Contour Interval to 2 (degrees Celsius), and Output Feature Class to LST_Contours.

Step 10.2.3: Click **Run**.

Part 11: Map Layout and Cartographic Design

11.1 Creating a Layout

Step 11.1.1: Go to **Insert** tab → **New Layout**.

Step 11.1.2: Select an appropriate page size: A4 (210 × 297 mm) for standard academic submissions, A3 for poster presentations, or Letter (8.5 × 11 inches) for US-standard publications.

11.2 Inserting the Map Frame

Step 11.2.1: In Layout view, go to **Insert** tab → **Map Frame** → Select the map.

Step 11.2.2: Draw a rectangle on the layout where the map should appear.

Step 11.2.3: Adjust the extent by right-clicking the map frame → **Activate** → Pan/zoom to the desired view → Click outside the frame to deactivate.

11.3 Adding Cartographic Elements

Title

Insert → Text → Rectangle → Type the map title. Use Times New Roman, Bold, 16 pt for academic publications.

Legend

Insert → Legend → Click on the map frame. Double-click the legend to edit: remove unnecessary layers, rename items (e.g., LST (°C)), and adjust font size and spacing.

Scale Bar

Insert → Scale Bar → Select Alternating Scale Bar style. Place it at the bottom of the map. Set Division units to Kilometres with 4–5 divisions.

North Arrow

Insert → North Arrow → Select a style and place it in the upper-right corner.

Grid/Graticule

Right-click the Map Frame → Properties → Grids → Add Grid. Choose Measured Grid (for projected coordinates) or Graticule (for geographic coordinates). Configure interval, label format, and line style.

Data Source and Credits

Data Source: Landsat 8 OLI/TIRS, USGS EarthExplorer. Acquired: [Date]. Projection: WGS 1984 UTM Zone XX. Processed in ArcGIS Pro [Version].

11.4 Exporting the Final Map

Step 11.4.1: Go to **Share** tab → **Export Layout**.

Step 11.4.2: Choose the format: PDF (best for publications), TIFF (best for high-resolution raster images), or JPEG/PNG (best for web or presentations).

Step 11.4.3: Set resolution to 300 DPI minimum for journal publications, 150 DPI for presentations and reports.

Step 11.4.4: Click **Export**.

Part 12: Validation and Accuracy Assessment

12.1 Validation Methods

Ground Truth Comparison

Compare derived LST values with in-situ temperature measurements from weather stations within the study area. Extract pixel values at station locations using the Extract Values to Points tool in ArcGIS Pro.

Cross-Validation with MODIS LST Products

Compare Landsat-derived LST with MODIS LST products (MOD11A1/MYD11A1) at corresponding dates. While MODIS has coarser spatial resolution (1 km), it serves as a useful benchmark.

Statistical Metrics

Calculate RMSE (Root Mean Square Error), MAE (Mean Absolute Error), and correlation coefficient (R^2) between derived LST and reference data.

12.2 Extract Values to Points

Step 12.2.1: Prepare a point shapefile of weather station locations with recorded temperatures.

Step 12.2.2: Go to **Analysis** → **Tools** → Search for **Extract Values to Points**.

Step 12.2.3: Set Input Point Features to the weather stations shapefile, Input Raster to LST.tif, and Output Point Features to LST_Validation_Points.

Step 12.2.4: Click **Run**.

Step 12.2.5: Open the attribute table. A new field RASTERVALU will contain the extracted LST values. Compare these with the recorded ground truth temperatures.

Part 13: Common Errors and Troubleshooting

Problem	Cause	Solution
LST values are unrealistically high (>70°C)	Incorrect ML/AL or K1/K2 values	Re-check the MTL file and ensure correct values
LST values are all negative	BT was not converted from Kelvin to Celsius	Ensure -273.15 is included in the BT formula
NDVI values are all 0	Integer division instead of float	Use Float() function in the NDVI formula
Raster Calculator gives an error	Spaces in file path or name	Move data to a path with no spaces
Black pixels in output	NoData values from clipping	Use Set Null or check the extent of the clip boundary
Emissivity values > 1 or < 0.9	Incorrect Pv values	Re-check NDVImin and NDVImax thresholds

Table 3. Common errors encountered during LST retrieval and their solutions.

Part 14: Complete Formula Reference Sheet

Step	Formula	Output
TOA Radiance	$L\lambda = ML \times \text{Band10} + AL$	$W/(m^2 \cdot sr \cdot \mu m)$
Brightness Temp	$BT = (K2 / \ln(K1/L\lambda + 1)) - 273.15$	$^{\circ}C$
NDVI	$(\text{Band5} - \text{Band4}) / (\text{Band5} + \text{Band4})$	-1 to +1
Proportion of Vegetation	$Pv = ((NDVI - NDVImin) / (NDVImax - NDVImin))^2$	0 to 1
Emissivity	$\epsilon = 0.004 \times Pv + 0.986$	0.986 to 0.990
LST	$BT / (1 + (0.00115 \times BT / 1.4388) \times \ln(\epsilon))$	$^{\circ}C$

Table 4. Complete formula reference for LST retrieval from Landsat 8 Band 10.

Part 15: Key Academic References

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