

5th ECMWF-ESA Machine Learning Workshop

Bologna, Italy | 13-17 April 2026



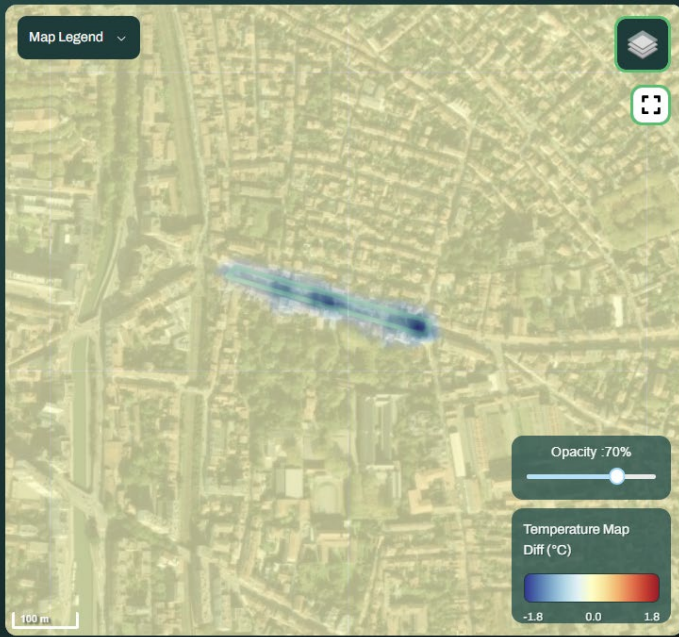
WI-HEAT-INSIGHTS-DEMO-TOULOUSE

Project Information: Trees_CamPujol

The project is saved at the following URL:

<https://services.murmureo.com/wi-heat-insig...>

EVOLUTION BEFORE AFTER



Simulated Heat Impact

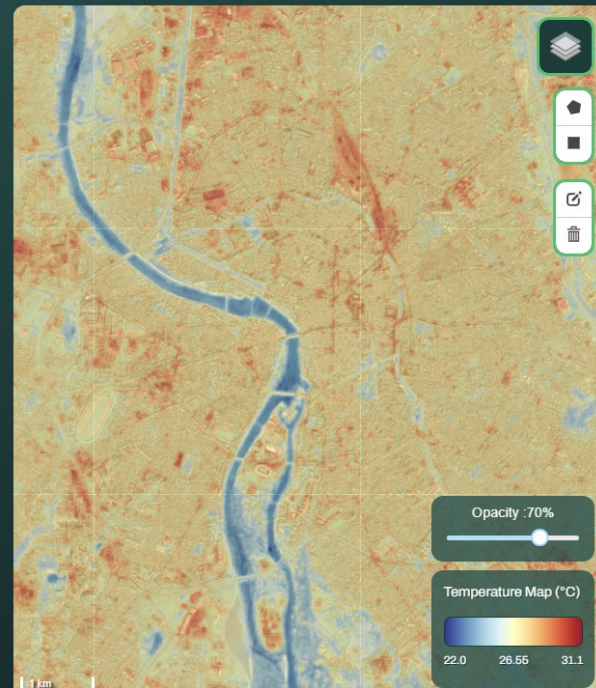
Temperature difference between the current situation and the simulated scenario

-0.8°C

Landcover Surface Mean diff

Trees

Temperat



High - Resolution Thermal Mapping for Land Cover Intervention Planning

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PROBLEM DEFINITION

Current state

Future state
Vegetated areas being implemented

Cities concentrate heat through sealed surfaces, scarce vegetation, and dense built-up areas. As climate change accelerates and urbanization expands, local authorities face growing pressure to integrate thermal mitigation into every new development.

But quantifying the cooling effect of a planned intervention remains a major challenge.

An urban planning agency in Montpellier came to us with a deceptively simple question:

"What will the surface temperature be after we redevelop this area?"

To answer it operationally, we needed a method that is:

- **Fine-grained** —to resolve trees and street features
- **Out-of-the-box** —runs on any AOI without on-site measurement or 3D model
- **Open-data based** —to keep deployment cost minimal
- **Visual** —to support direct dialogue with stakeholders

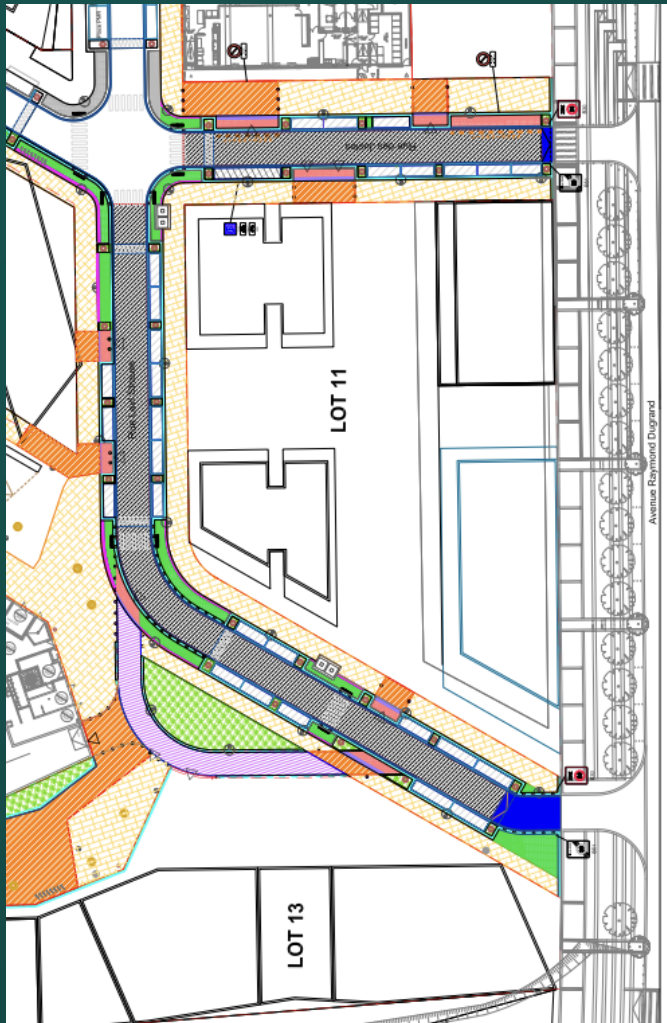


Fig. 1: Urban redesign scheme

→ EXISTING SOLUTIONS

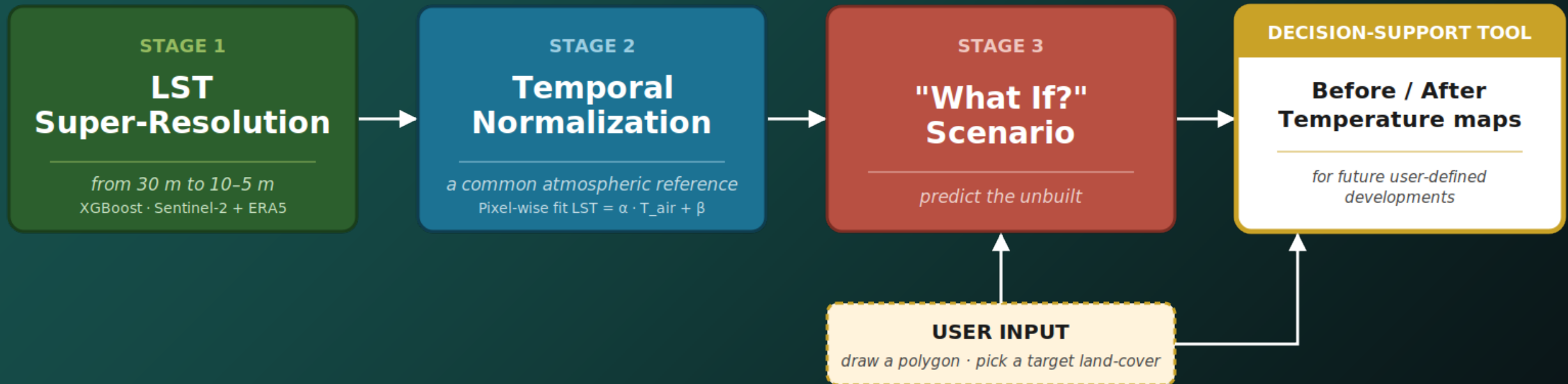
Solution	Can estimate temperature impact of a planned (not - yet - built) development?	Resolution	Scale	Key limitation
ENVI-met	✓ Yes	~1-5 m	Few blocks	Requires detailed 3D design, very slow (hours – days), not scalable
UMEP / SOLWEIG	⚠ No	~1-5 m	Neighborhood	Focus on radiation/comfort, indirect proxy for temperature
CFD (ANSYS Fluent / OpenFOAM)	✓ Yes	<1 m	Street canyon	Extremely complex, expert -only, impractical for planning workflows
SOLENE-Microclimat	⚠ No	~1 m	Single block	Not operational for large - scale urban projects

Tab. 1: Comparison of urban microclimate modeling tools.

A 3-STAGE FRAMEWORK

OUR FRAMEWORK FOCUSED ON USING REMOTE-SENSING DATA (MURMURATION'S EXPERTISE) :

Re-trained from scratch on every new AOI. No cross city transfer.



Case Study: Toulouse, France

1- LST SUPER-RESOLUTION - METHODOLOGY

The need: Street-level thermal information.

The constraint: Landsat thermal native resolution is 100 m resampled to 30m → Doesn't grasp fine details.

The approach: Increase LST resolution by modeling the spectral-thermal relationship from Landsat LST using Sentinel-2 and ERA5 through an XGBoost regressor, then apply it at native Sentinel-2 resolution → LST at 10 m, or 5 m via cascaded Sentinel -2 SR

ERA5 = *when & how hot*

→ sets the thermal level at date level.

Sentinel -2 = *where*

→ disaggregates heat spatially within the scene.

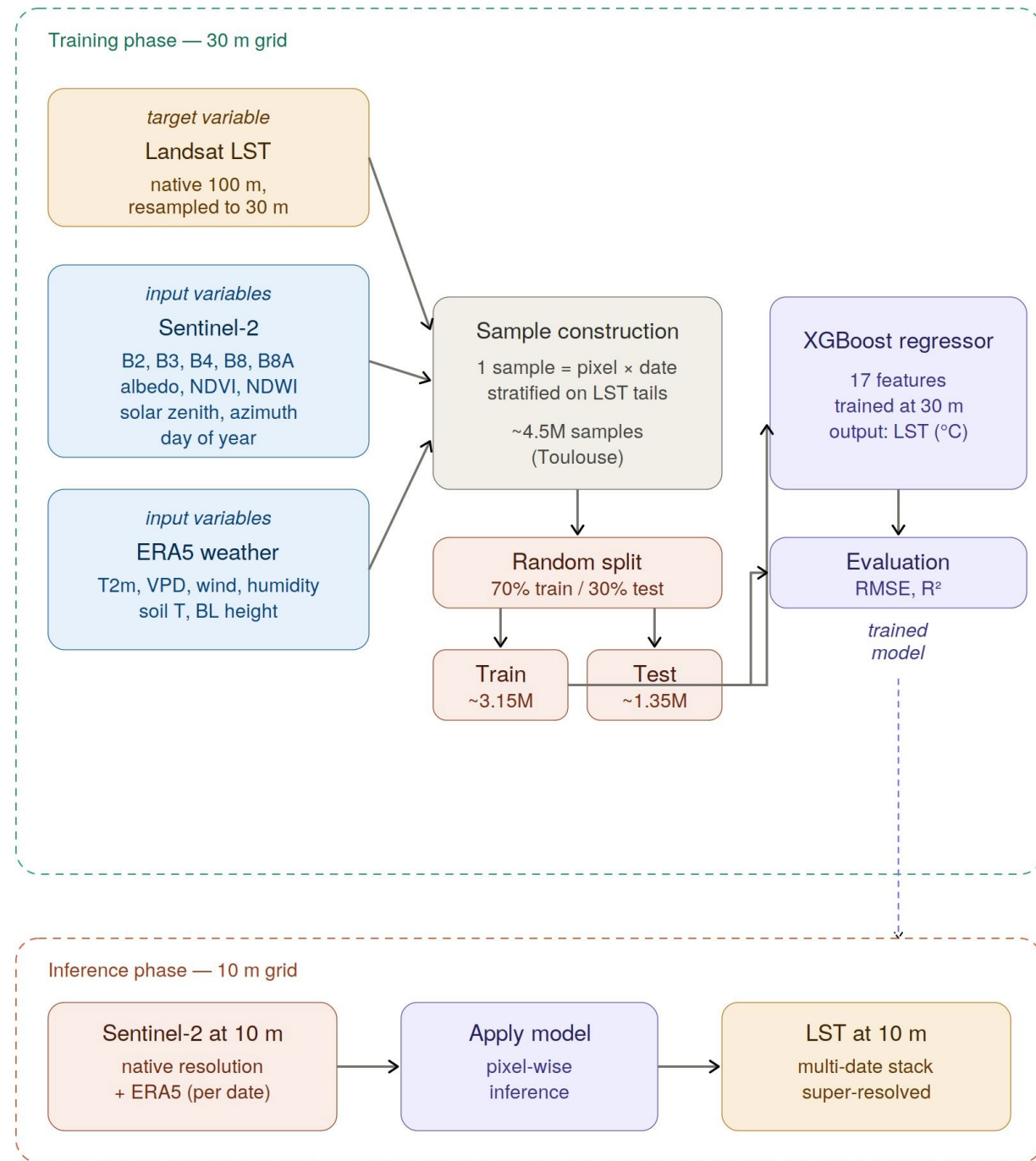


Fig. 2: XGBoost super-resolution pipeline.

1- LST SUPER-RESOLUTION - RESULTS

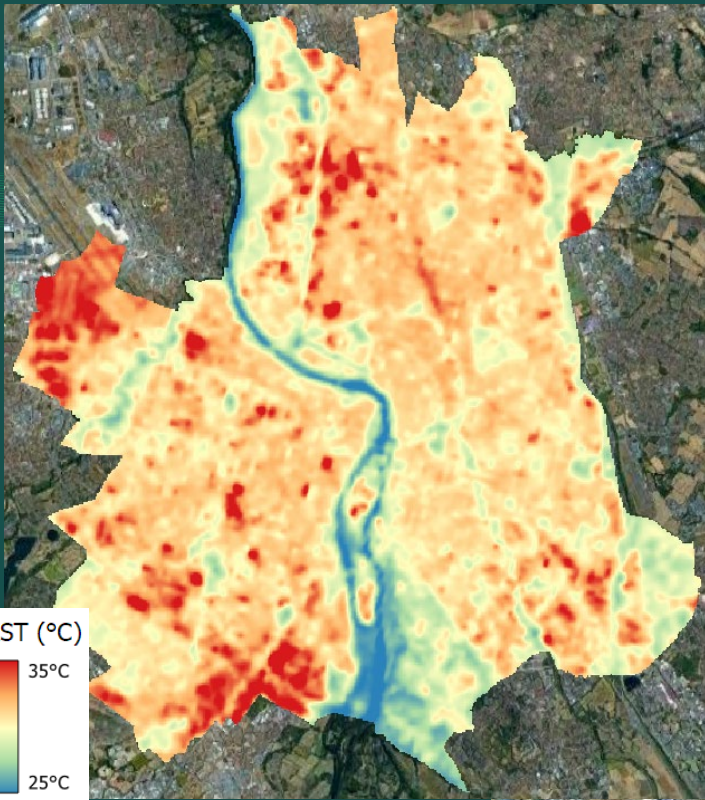
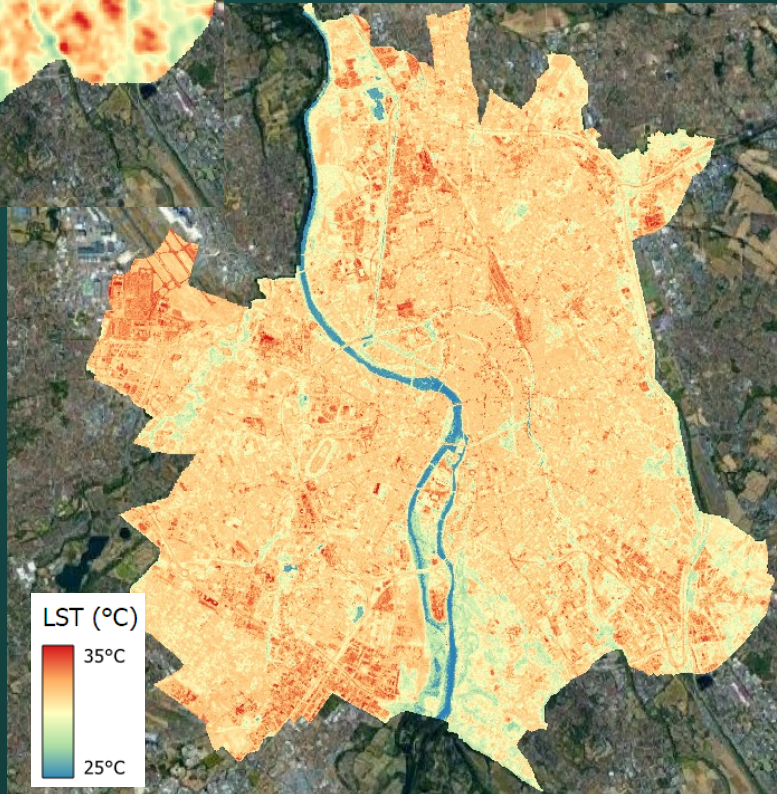


Fig. 3a: LST observation from *Landsat* (30m – top) and SR from *Sentinel2* & *ERA5* (10m– right)



Observation date :
2025-08-14



Fig. 3b: High-Resolution Satellite View over Toulouse

1- LST SUPER-RESOLUTION - RESULTS

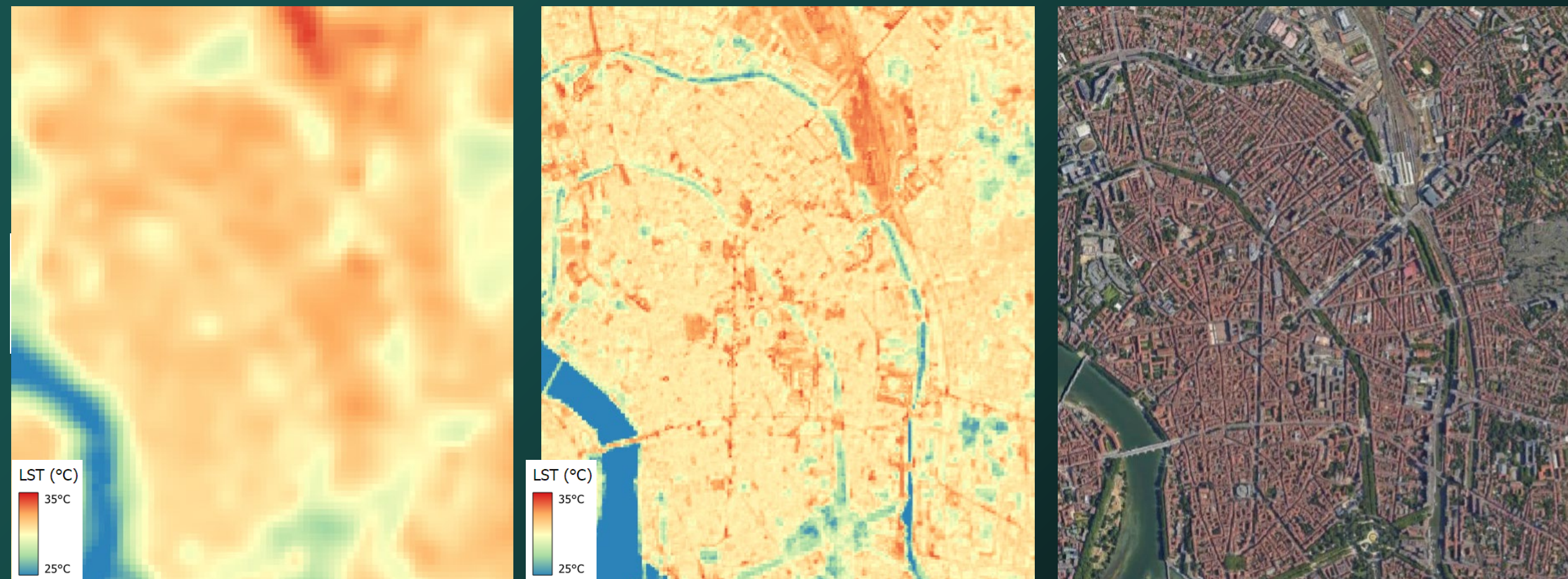


Fig. 3c: LST observation from *Landsat* (30m - left), *SR Sentinel2 & ERA5* (10m - Middle) and *high-resolution satellite view* (right) over *Toulouse City Center*

1- LST SUPER-RESOLUTION - EVALUATION

Step by Step validation approach :

1. Found matching dates between Landsat and SR LST scenes (5 held-out dates).
2. Resample all observations from the SR LST (10m) to the Landsat 30 m grid (linear).
3. Compute pixel-by-pixel differences against native Landsat LST.
4. Aggregate metrics overall, per land cover class.

	RMSE	Bias	R²
Trees	1.62	+0.19	0.80
Grassland	1.75	-0.24	0.70
Cropland	1.84	+0.02	0.64
Built-up	1.52	+0.01	0.84
OVERALL	1,59	+0,03	0,83

Tab. 2: Model metrics.

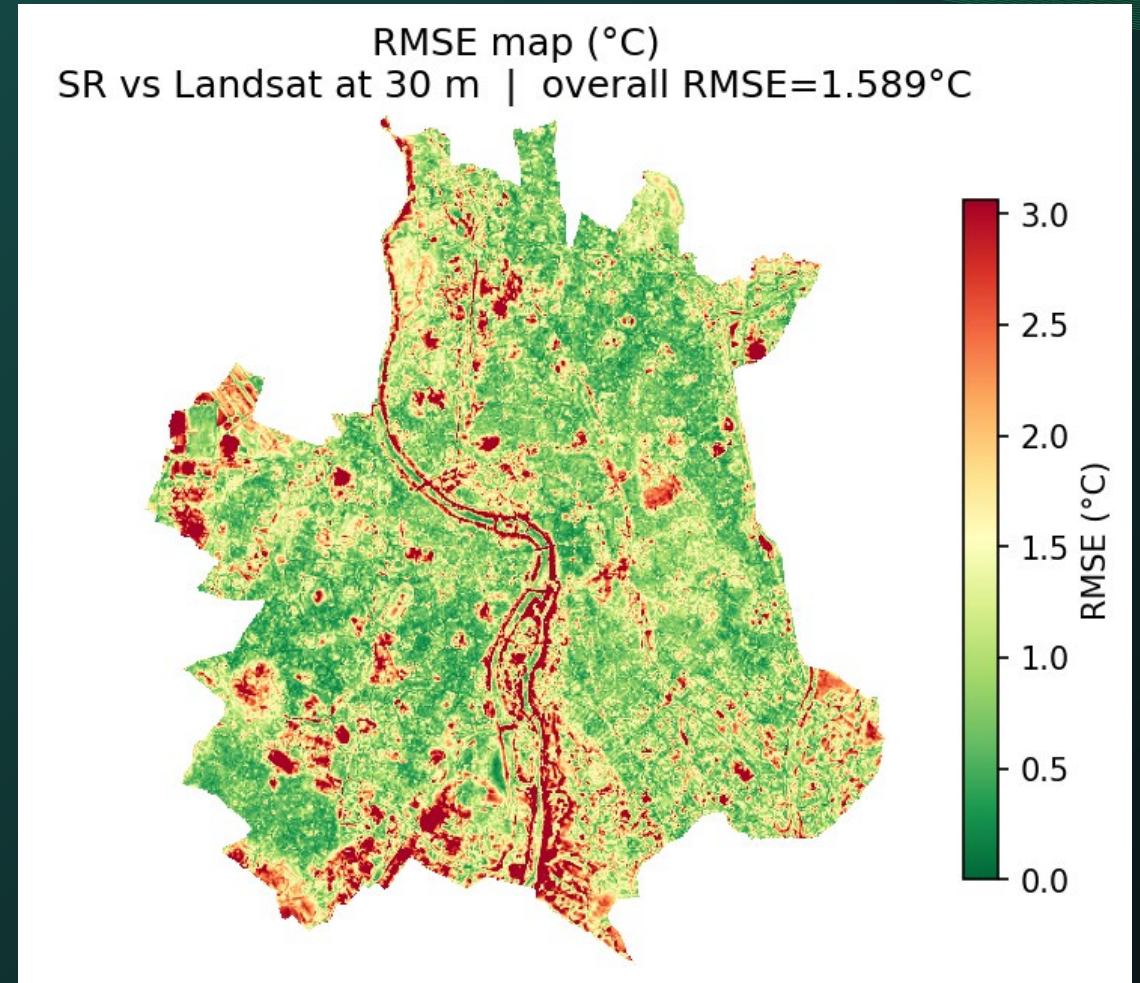


Fig. 4: RMSE map of SR LST vs. Landsat LST at 30 m.

1- LST SUPER-RESOLUTION - EVALUATION

SR validation by land cover | RMSE=1.589 °C R²=0.8342

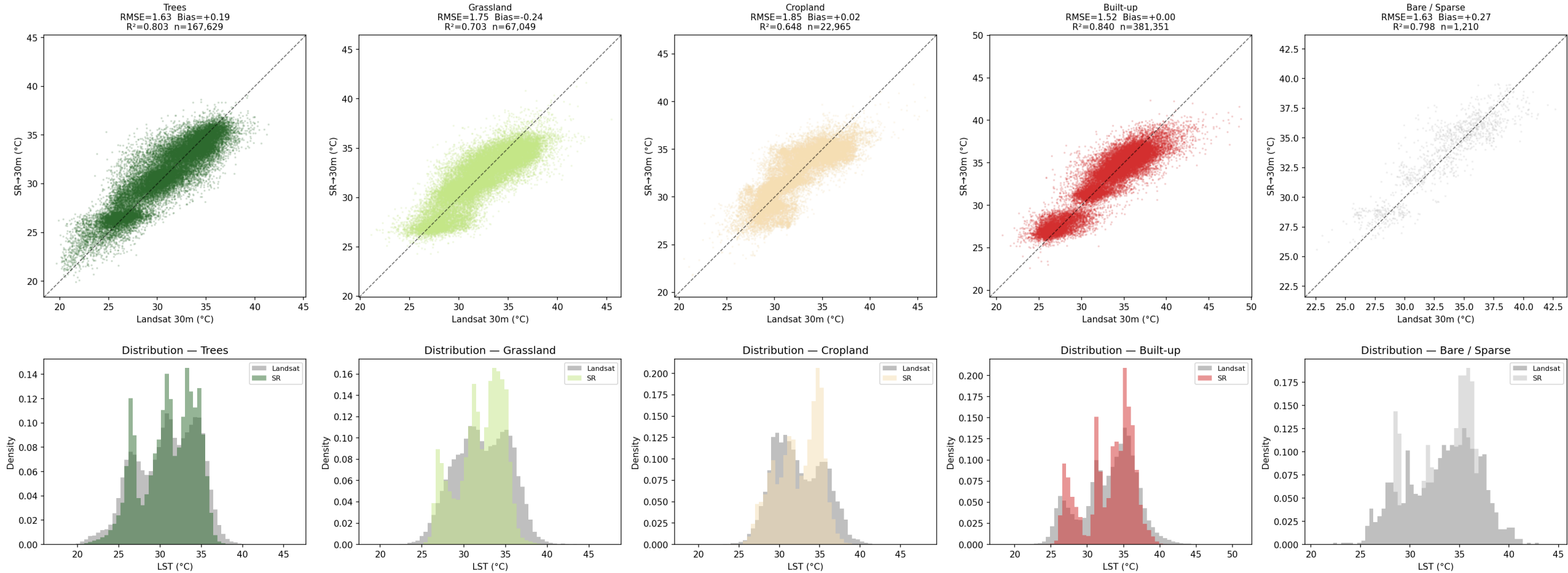


Fig. 5: Per-class validation of SR LST vs. Landsat LST at 30 m for five land cover types.

Top: scatter plots with RMSE, bias, R² and n. *Bottom:* LST density distributions (Landsat in grey, SR in color).

2- LST NORMALIZATION

The need: Facilitating LST comprehension for the user: fixing a scenario (e.g. $T_{\text{air}} = 25\text{ }^{\circ}\text{C}$) provides a generic, comparable baseline—every pixel, every date, every neighborhood expressed under the same atmospheric reference.

The obstacle: Each Landsat acquisition is a snapshot under one specific weather state. Two scenes from two different dates mix the surface response with the atmospheric state. We can't compare them, and we can't extrapolate them to a target T_{air} .

The opportunity: For most pixels, LST and ERA5 T_{air} are strongly correlated across dates—and the relationship is approximately linear over the $[15^{\circ}\text{C} - 35^{\circ}\text{C}]$ range we observe.

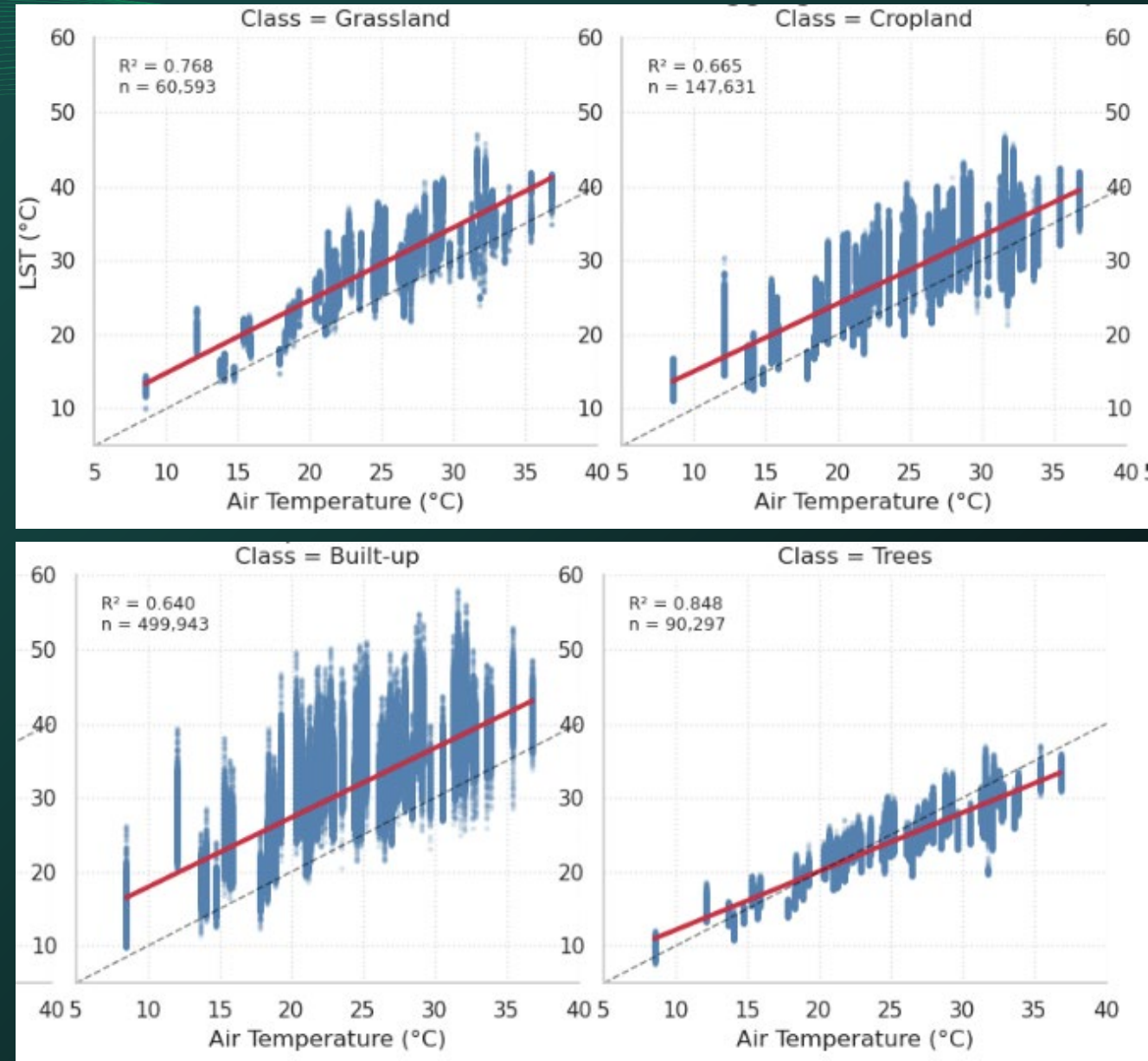


Fig. 6: LST vs. air temperature by land cover (linear fit = red line, 1:1 ref = dashed)

2- LST NORMALIZATION – LST PIXEL-WISE LINEAR REGRESSION

One regression per pixel — LST vs air temperature across dates

Each date provides one LST raster and one scalar T_{air} (uniform over the scene) — paired by date

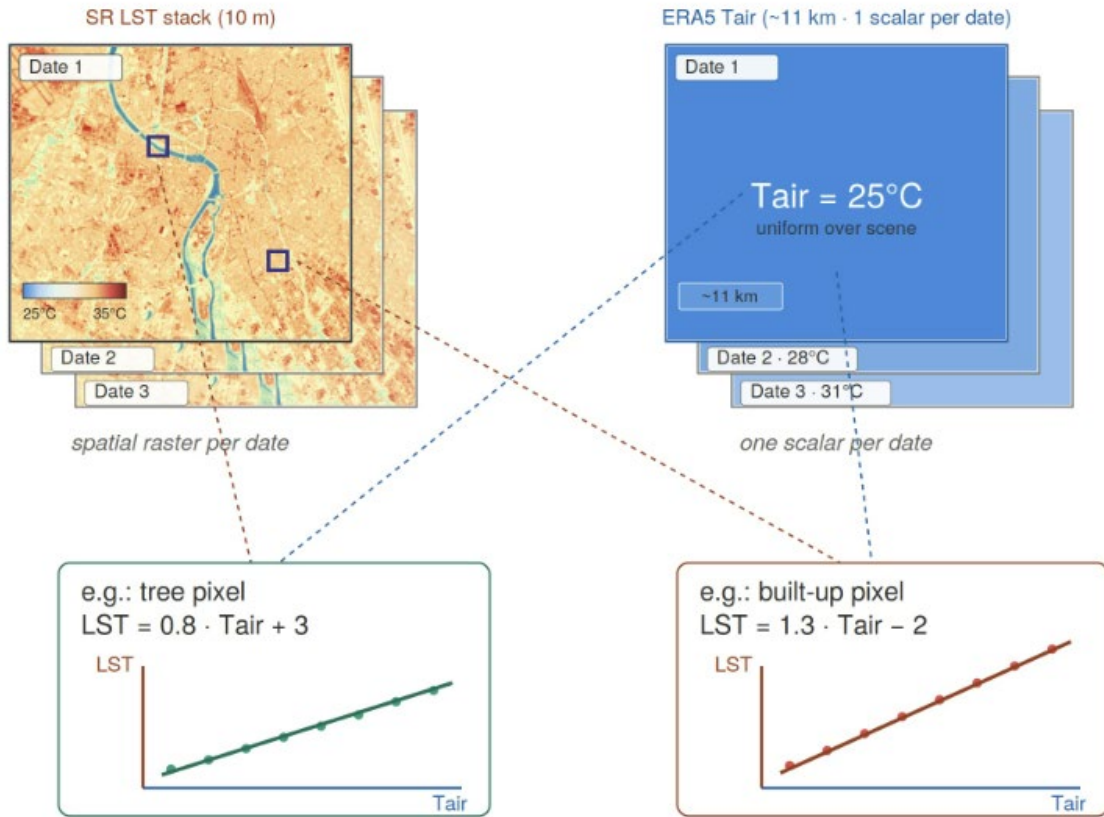


Fig. 7a: Pixel-wise regression of LST against air temperature across dates.

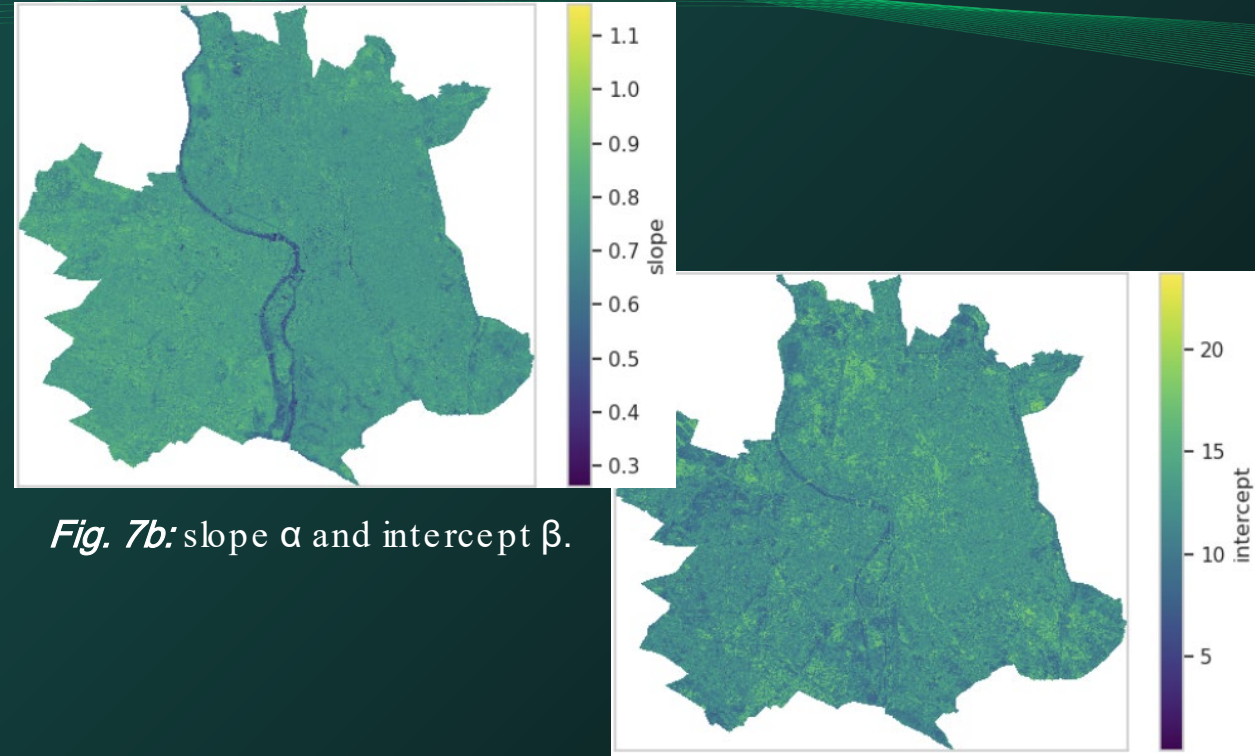


Fig. 7b: slope α and intercept β .

For every pixel, fit $LST = \alpha \cdot T_{air} + \beta$ across all available dates.

→ 2 maps : **slope α** (sensitivity to T_{air}) and **intercept β** (offset).

→ Reconstruct LST at any target temperature by simple substitution.

2- LST NORMALIZATION - RESULTS

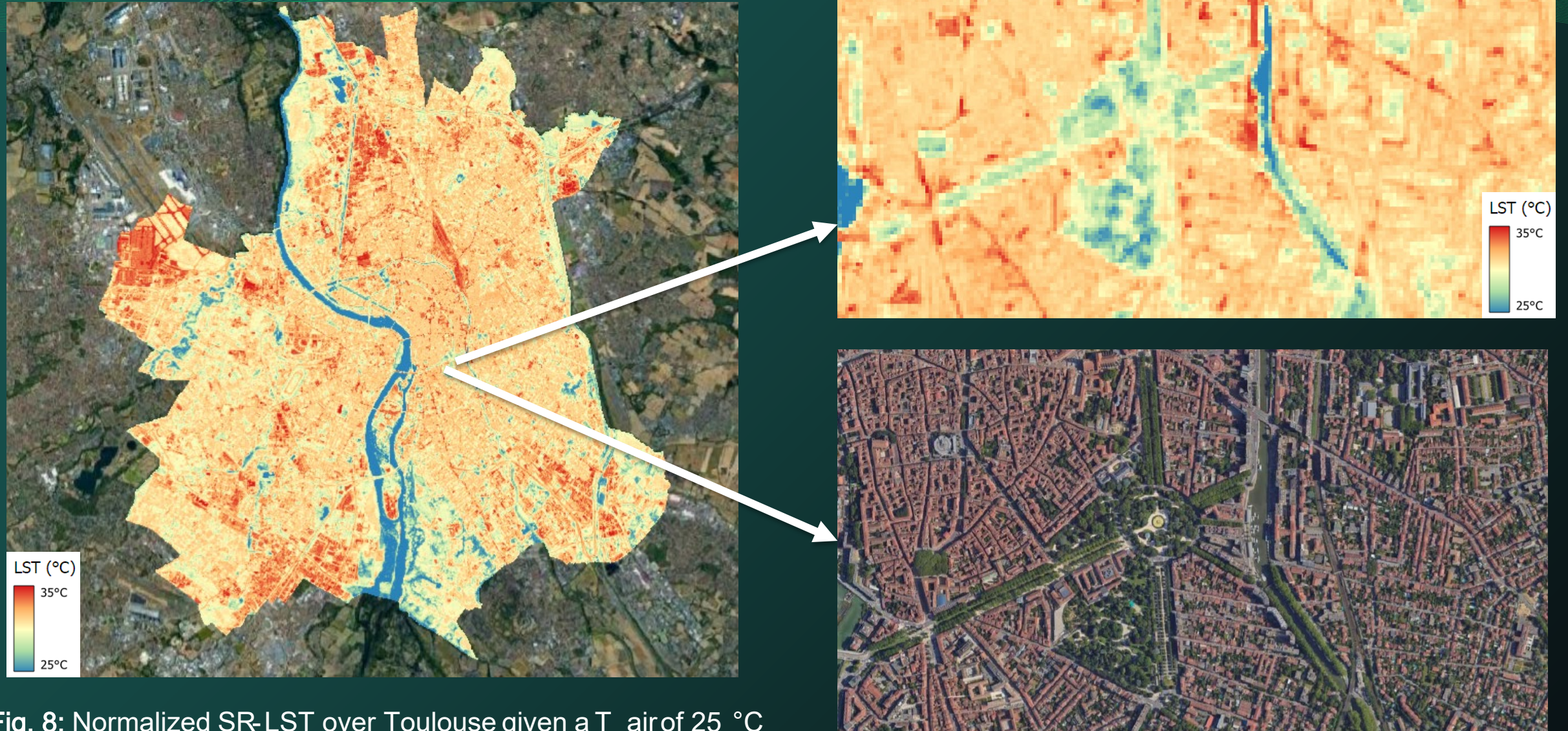


Fig. 8: Normalized SR-LST over Toulouse given a T_{air} of 25 °C (normal summer day) built from 2025 observations.

3 - THERMAL SIMULATION — "WHAT IF?"

The needs: An urban planner draws a polygon and says: *"here I'll plant trees."* What surface temperature should that area take once built?

The approach: Build a **thermal lookup table** from the normalized base map substitute pixels inside the user polygon with the LUT value of the target class

What it means in practice: The framework doesn't simulate physics, it says *"based on how Toulouse trees actually behave thermally at 25°C Tair, here's what your new planted trees (expected fully grown) will look like at 25°C Tair."*

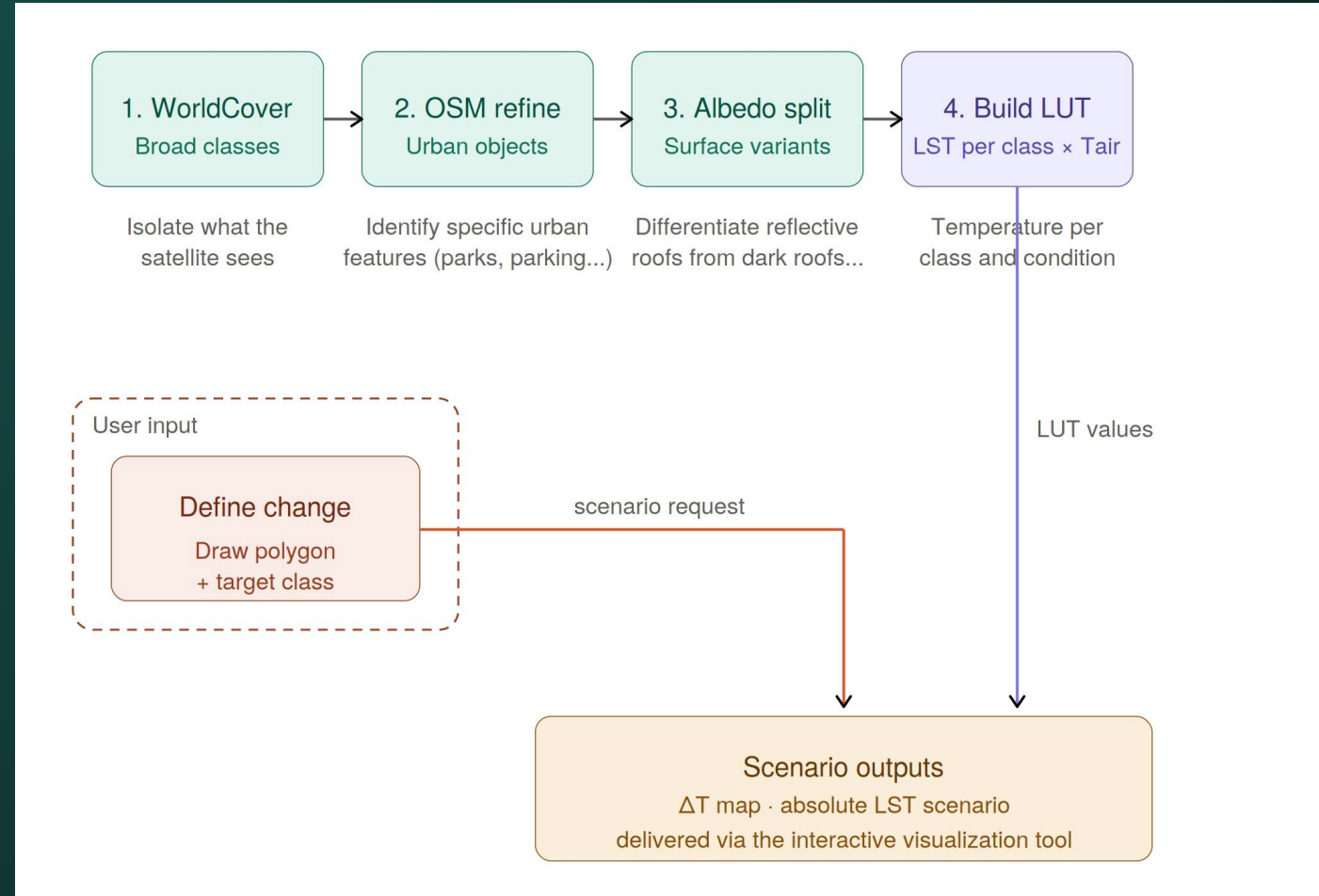


Fig. 9: Workflow of the LUT-based what-if scenario module.

3 - THERMAL SIMULATION — "WHAT IF?"

Each surface class gets one representative LST at a chosen T_{air} , learned from real pixels of that class across the city.

When the planner draws a polygon and picks a target class, the framework substitutes its pixels with the matching LUT value and returns the ΔT .

Class	LST @ $T_{air} = 25 \text{ }^\circ\text{C}$
Standard roofs	30.1 $^\circ\text{C}$
Asphalt roads	29.2 $^\circ\text{C}$
Mitigation surfaces (<i>green roofs, permeable pavement</i>)	28.0 $^\circ\text{C}$
Grassland	28.1 $^\circ\text{C}$
Trees & urban parks	27.2 $^\circ\text{C}$
Water & wetlands	23.9 $^\circ\text{C}$

Tab. 3: Class wise LST lookup table at $T_{air} = 25 \text{ }^\circ\text{C}$ for Toulouse

4 - DECISION SUPPORT TOOL

Diagnose → User can spot overheating areas at a glance, on the SR baseline LST map.

The screenshot displays the 'WI-HEAT-INSIGHTS-DEMO-TOULOUSE' web application. The interface is divided into several sections:

- Header:** Features the 'MURMURATION' logo and the title 'WI-HEAT-INSIGHTS-DEMO-TOULOUSE' with the subtitle 'Simulate & Mitigate Heat'.
- Map Area:** A central satellite-style map of Toulouse, France, overlaid with a color-coded heat map. The heat map uses a color scale from blue (cooler) to red (warmer). A 1 km scale bar is located in the bottom left of the map.
- Map Controls:** On the right side of the map, there are icons for layers, a drawing tool, a trash icon, and a refresh icon. Below these is an 'Opacity :70%' slider and a 'Temperature Map (°C)' legend with a color gradient from 22.0 to 31.1.
- Left Sidebar:** Contains the text 'Simulate & Mitigate Heat' and 'History'.
- Right Panel:** A dark-themed sidebar with three main steps:
 - 1. Select future development areas:** Includes the instruction 'Select areas on the map to be modified using the drawing tools. (📍 📐)'. Below this is a text input field labeled 'Enter project name here'.
 - 2. Choose Project Name:** This section is currently empty.
 - 3. Choose land cover changes:** This section is currently empty. To its right is a link for 'Simulated Heat Impact' with an information icon.At the bottom of the right panel is a large 'Validate →' button.
- Footer:** In the bottom left corner, it reads '© 2026 Copyright: Murmuration'.

4 - DECISION SUPPORT TOOL

Design → User can freely draw planned development areas and assign their target land cover.

The screenshot displays the 'WI-HEAT-INSIGHTS-DEMO-TOULOUSE' web application. The interface is divided into several sections:

- Header:** Features the 'MURMURATION' logo and the title 'WI-HEAT-INSIGHTS-DEMO-TOULOUSE' with the subtitle 'Simulate & Mitigate Heat'.
- Map:** A central aerial view of a city street grid with a blue highlighted area. A '100 m' scale bar is located in the bottom-left corner of the map.
- Left Sidebar:** Contains the text 'Simulate & Mitigate Heat' and 'History'.
- Right Panel:** A control interface with three main steps:
 - 1. Select future development areas:** Includes a sub-instruction 'Select areas on the map to be modified using the drawing tools. (●■)' and a drawing tool icon.
 - 2. Choose Project Name:** A text input field containing 'Camille_pujol'.
 - 3. Choose land cover changes:** Includes a 'Simulated Heat Impact' indicator and a dropdown menu for land cover selection, currently set to 'Trees'. A small thumbnail map shows the selected area.
- Bottom Right:** A large 'Validate →' button.
- Map Controls:** A vertical toolbar on the right side of the map contains icons for layers, home, and drawing tools. Below the map, there is an 'Opacity : 0%' slider and a 'Temperature Map (°C)' color scale ranging from 22.0 to 31.1.

4 - DECISION SUPPORT TOOL

WI-HEAT-INSIGHTS-DEMO-TOULOUSE
Project Information: Trees_CamPujol

EVOLUTION **BEFORE** AFTER

Map Legend
Land Cover Modifications
Trees

The project is saved at the following URL:
<https://services.murmureo.com/wi-heat-insig...>

Simulated Heat Impact
Temperature difference between the current situation and the simulated scenario
-0.8 °C

Landcover	Surface (ha)	Mean diff (°C)
Trees	0.01	-0.8

Temperature at clicked point: 0.00 °C

Project Information

Results

RETURN TO THE PORTAL

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Impact of planting trees in warmstreet.

Quantify → User can extract Before / After maps and per-polygon KPIs in one click.

WI-HEAT-INSIGHTS-DEMO-TOULOUSE
Project Information: Trees_CamPujol

EVOLUTION BEFORE **AFTER**

Map Legend
Land Cover Modifications
Trees

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Simulated Heat Impact
Temperature difference between the current situation and the simulated scenario
-0.8 °C

Landcover	Surface (ha)	Mean diff (°C)
Trees	0.01	-0.8

Temperature at clicked point: 0.00 °C

Project Information

Results

RETURN TO THE PORTAL

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Opacity: 50%

Temperature Map After (°C)
24.4 26.9 29.4

4 - DECISION SUPPORT TOOL

WI-HEAT-INSIGHTS-DEMO-TOULOUSE

Simulate & Mitigate Heat



1. Select future development areas

Select areas on the map to be modified using the drawing tools. (📐)

2. Choose Project Name

buildings

3. Choose land cover changes

Simulated Heat Impact



Choose the land cover :

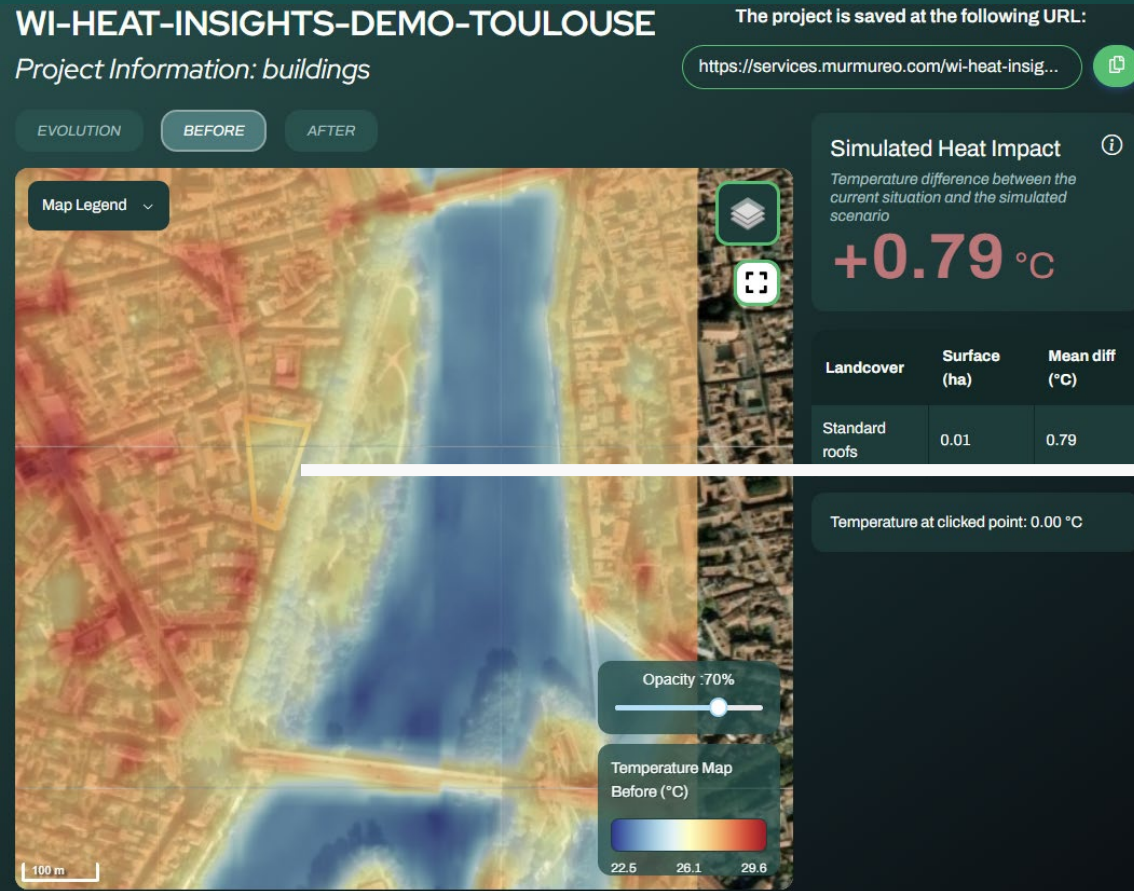
Standard roofs



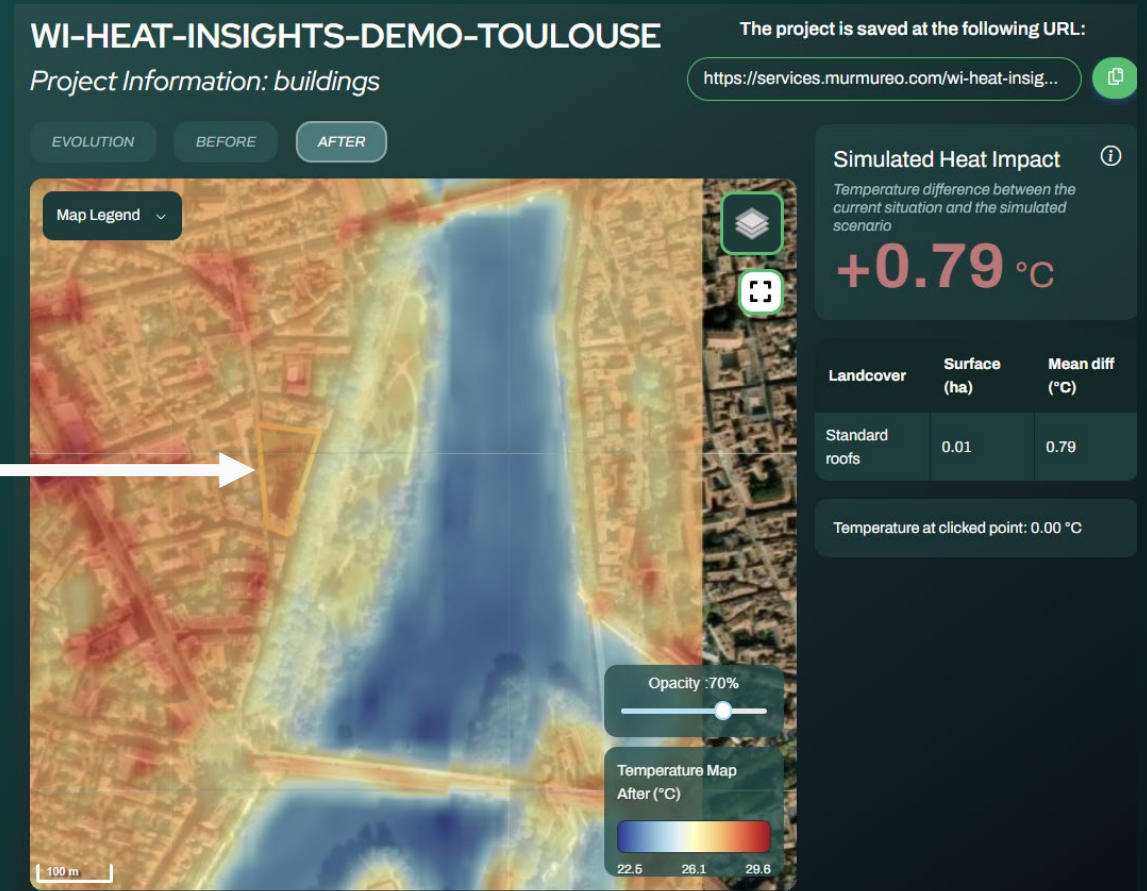
Validate →

Impact of replacing vegetated areas by buildings (standard roofs).

4 - DECISION SUPPORT TOOL



Before



After

Impact of replacing vegetated areas by buildings (standard roofs).

4 - DECISION SUPPORT TOOL



WI-HEAT-INSIGHTS-DEMO-TOULOUSE
History

[Refresh history](#)

Project name	Project ID	Created at	Dashboard	Delete
parks_carmes	02734453eed4c22baea0594fb592755	13/04/2026 12:19:07	Open	Delete
buildings	e15c151777004948ae4c69434ed469ec	13/04/2026 12:17:25	Open	Delete
Capitole_trees	15b87b1fd29e4360a8afd80406296049	03/04/2026 13:45:52	Open	Delete
arbre	7938d65aadca4267a99343a3955c7862	25/03/2026 14:25:02	Open	Delete
Trees_CamPujol	35de409d5d2749e78efc2985d74bb64a	23/03/2026 16:04:16	Open	Delete

Simulate & Mitigate Heat

History

Manage → User can reopen and iterate on past simulations

LIMITATIONS AND FUTURE WORK

Current limitations

- **LST \neq thermal comfort:** Surface temperature is a proxy for thermal comfort but not truly what an individual feels.
- **Temporal coverage:** Landsat overpass at 10-11 AM only; no afternoon peak, no nighttime cooling.
- **Ground truth at 10 m:** No in-situ thermal network at this resolution.
- **Linear Tair –LST fit:** Works on stable surfaces (built); flattens drought on grass, harvest on croplands.
- **Statistical, not physical:** LUT substitutes by class average; no wind, shading, or thermal diffusion from neighbors.

Future work

- **LST \rightarrow thermal comfort:** Couple with UMEP/SOLWEIG to derive thermal comfort at street level (but requires DSM at high resolution).
- **Denser temporal and spatial sampling:** ECOSTRESS to extend beyond the 10-11AM window / OroraTech, SatVu, Constellar for higher spatial resolution / validation.
- **Cross-city generalization:** Move from per-AOI training toward leave-one-city-out validation.
- **Implement more Tair scenarios:** Complement the current LST at Tair 25 °C (summer baseline) with heatwave and off-peak references for operational use.