



UTCIcast: A Scalable Urban Thermal Stress Forecasting System Powered by GLIDE-SOL

Building-scale forecasts using global static and meteorological data

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Aim of the work

Develop a tool for building-scale UTCI forecasting

Develop a tool to forecast UTCI at the **building scale**, resolving thermal exposure around buildings, trees and open spaces.

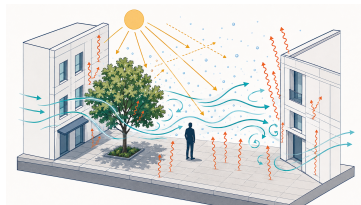
What UTCI represents

UTCI is the equivalent temperature of a reference environment that produces the same physiological response as the actual outdoor conditions.

Four environmental drivers

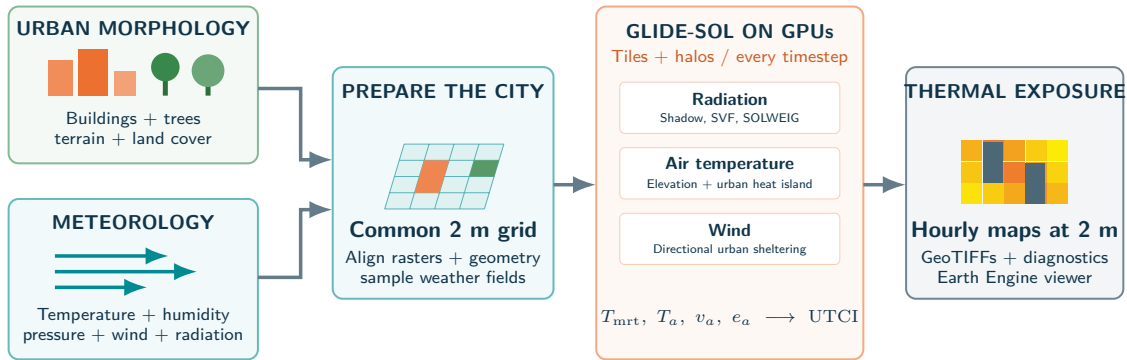
$$UTCI = F(T_a, T_{mrt}, v_a, e_a)$$

T_a	air temperature
T_{mrt}	mean radiant temperature
v_a	wind speed at the person
e_a	water-vapour pressure



Local conditions determine pedestrian exposure

From global inputs to 2 m UTCI maps



From global data to building-scale thermal exposure.

Static geometry is prepared once and reused; meteorology and thermal diagnostics evolve at every timestep.

The input sources

Buildings

Footprints: Microsoft Global Building Footprints; Overture Maps; Global Building Atlas; OpenBuildingMap; EUBUCCO; OpenStreetMap.

Heights: Google Open Buildings 2.5D; Global Building Atlas; GHS-OBAT; OpenBuildingMap; EUBUCCO.

Configurable priority and de-duplication combine the available sources.

Trees and canopy height

Meta Forest Monitoring / Canopy Height (1 m);

ETH Global Canopy Height 2020 (10 m);

GEDI Canopy Height Mapper (30 m).

The best available product supplies vegetation extent and height.

Land cover and terrain

ESA WorldCover 2020 v2 (10 m) provides the global land-cover baseline.

OpenStreetMap refines vegetation, water, impervious surfaces and streets where available.

MERIT DEM (3 arc-sec, about 90 m) provides the global elevation baseline.

Meteorological forcing

ERA5: ECMWF global atmospheric reanalysis.

ERA5-Land: ECMWF global land-surface reanalysis.

ICON: global or regional numerical weather prediction.

WRF: regional numerical weather prediction; the operational UTCIcast forcing over Italy.

One workflow, different data backbones: all sources converge on the same 2 m GLIDE-SOL grid.

Urban radiation: mean radiant temperature

- SOLWEIG resolves shortwave and longwave exchanges around a pedestrian in a 3-D urban canopy.
- Buildings, trees, terrain and surface properties determine shadow, sky-view factor and radiative load.
- The resulting mean radiant temperature carries the dominant 2 m spatial contrast on clear warm days.

Radiative exposure

SOLWEIG combines direct, diffuse and reflected shortwave radiation with longwave emission from the sky and surrounding surfaces.

Human-body angular factors convert the directional fluxes into a single radiative exposure, expressed as T_{mrt} .

Mean radiant temperature

$$T_{\text{mrt}} = \left[\frac{K_{\downarrow} + K_{\uparrow} + L_{\downarrow} + L_{\uparrow}}{\sigma \varepsilon_p} \right]^{1/4} - 273.15$$

Role in UTCIcast

Geometry-dependent radiation supplies the local T_{mrt} field used in the UTCI calculation at every pixel and timestep.

Air temperature: elevation and UHI

Elevation correction

$$\Delta H(x, y) = H_{\text{met}} - H_{\text{DEM}}(x, y)$$

$$T_{a,\text{corr}} = T_a + \Gamma_d \Delta H, \quad \Gamma_d = \frac{g}{c_p}$$

Dry adiabatic displacement applies below the lifting condensation level. Above it, the code integrates a saturated pseudo-adiabatic profile. Temperature, relative humidity and pressure diagnose the LCL.

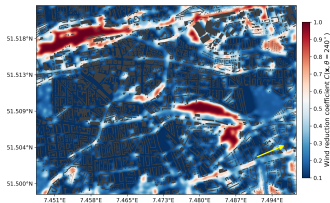
Source: UHI amplitude: Theeuwes et al. (2016), *A diagnostic equation for the daily maximum urban heat island effect for cities in northwestern Europe*. doi:10.1002/joc.4717.

Nocturnal UHI perturbation

$$\Delta T_{\text{UHI}} = (2 - \text{SVF} - f_{\text{veg}}) \text{UHI}_{\text{max}} S_{\text{night}}(t)$$

Following **Theeuwes et al. (2016)**, radiation, daily temperature range and background wind set the daily UHI amplitude. Local sky exposure and vegetation modulate the perturbation during the diagnosed night window.

Wind: from background flow to local exposure



A directional wind field at 2 m

Urban roughness, buildings and vegetation shape pedestrian wind exposure.

$$v_a(x, y, t) = \underbrace{R_z}_{\text{background}} \underbrace{|\mathbf{V}_{10}^{\text{met}}|}_{\text{local sheltering}} C_b C_t$$

Map: local attenuation coefficient for 240° inflow.

1 / Background wind

Neutral vertical profile:
meteorological z_0 to urban z_0 .

Sets the background speed.

2 / Local wind



Upwind deceleration and leeward sheltering, for 12 wind sectors.

3 / Trees

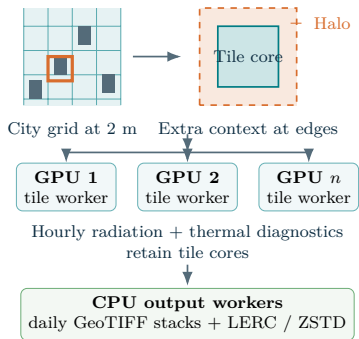
Porous-canopy drag depends on LAI and tree height.

Canopy profile uses displacement height d and roughness $z_{0,t}$.

Source: Röckle (1990); Bernard et al. (2023), *URock 2023a*, doi:10.5194/gmd-16-5703-2023. Simplified diagnostic zones; no mass balancing. Canopy displacement height differs from the upwind displacement zone.

Efficient computation at 2 m

One city, many GPU-sized tiles



Dortmund 24 h benchmark	CPU	A100 GPU
Grid	3129 × 3113, 2 m	
Runtime	1285 s	254 s
Speed-up	–	about 5×

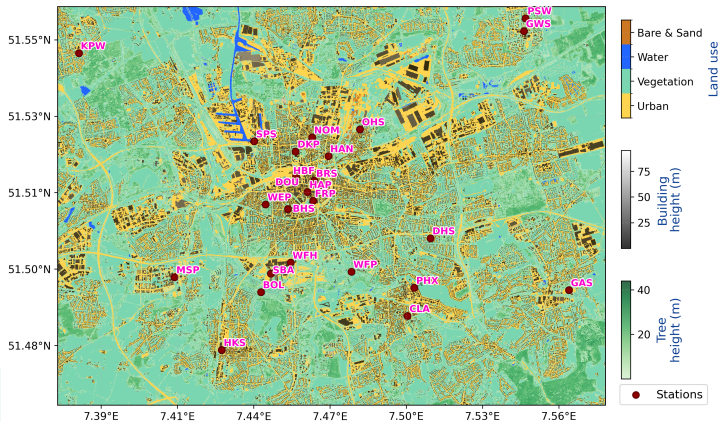
Daily UTCI stack	Size
Uncompressed	3.3 GB
LERC + ZSTD	251 MB
Reduction	about 92%

Controlled-loss compression. LERC + ZSTD limits the maximum absolute UTCI error to 0.15°C.

Compute locally, scale across the city.

Cached geometry is reused while meteorology and thermal exposure evolve hour by hour.

Validation in Dortmund



Experiment

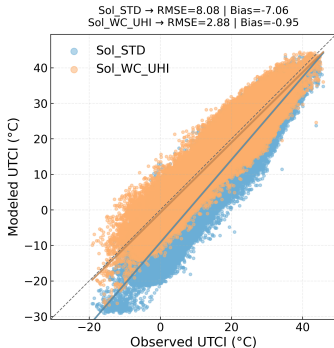
- 25 urban and peri-urban stations
- 2 m model grid
- August 2024 to December 2025
- more than 250,000 station-hours

Comparison

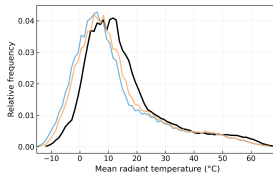
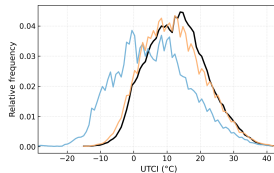
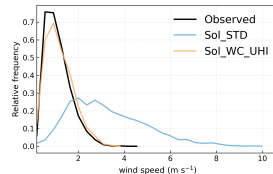
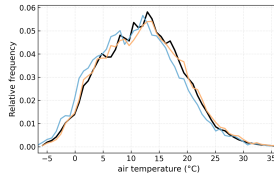
So1_STD: direct ERA5 forcing.

So1_WC_UHI: wind attenuation plus elevation and UHI temperature diagnostics.

Validation: reduced UTCI error



Observed versus modelled UTCI



Error distributions across thermal drivers

UTCI RMSE

8.09 → **2.84** °C **-65%**

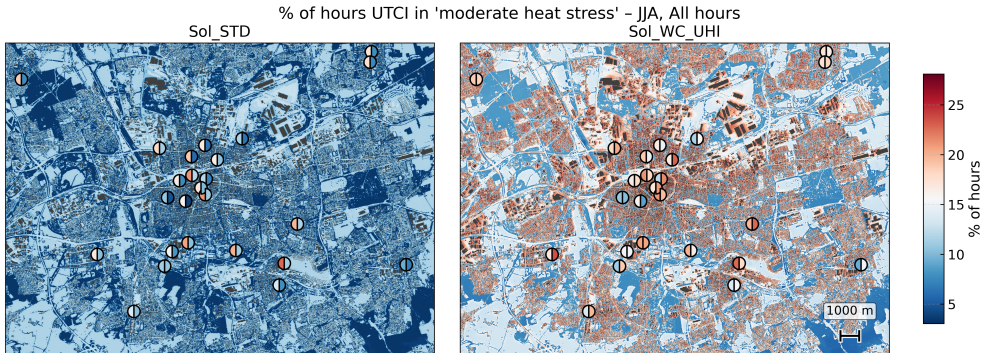
UTCI mean bias

-7.07 → **-0.85** °C

Wind mean bias

2.18 → **0.03** m s⁻¹

Validation: heat-stress patterns at 2 m



Sol_STD: no physical modifications

Direct coarse forcing leaves canopy wind too strong and air temperature too cold. Moderate heat-stress frequency becomes weak and spatially flat.

Sol_WC_UHI: modified forcing

Terrain correction, nocturnal UHI and directional wind attenuation restore the contrast between compact fabric, green areas and ventilated outskirts.

From LAM forecasts to urban UTCI at 2 m



Bring the weather into the city

Extract the limited-area model (LAM) cells covering each urban domain.

Bilinear interpolation at every hour preserves the large-scale weather gradients on the 2 m grid.

Resolve local thermal exposure

Reuse buildings, trees, terrain and precomputed geometry.

Radiation, wind sheltering and temperature adjustments turn the weather forecast into local UTCI.

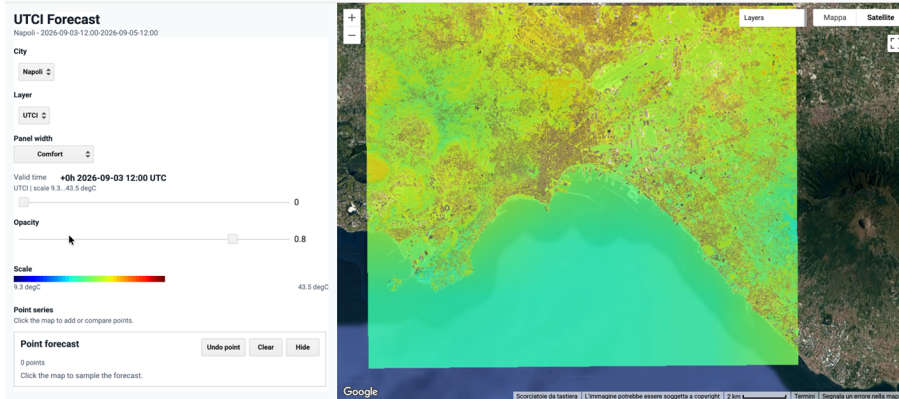
Make the forecast accessible

Publish a time-stamped sequence of hourly UTCI maps.

Users select a city and forecast hour, or inspect the evolution at a location.

Regional weather sets the conditions; urban form determines where people experience heat.

UTCIcast live over Italy at 2 m



Open the live Google Earth Engine map

Conclusions

Global inputs and code

Any city

Open-source code, global urban datasets and globally available meteorology make the complete workflow portable.

Lightweight model

No CFD runs

Diagnostic terrain, UHI and wind corrections reduce Dortmund UTCI RMSE from **8.09** to **2.84°C**.

Operational forecasts

0–48 h at 2 m

Multi-cell meteorological forcing drives hourly city forecasts published through Earth Engine.

Next: GLIDE-SOL AI

We are training a U-Net surrogate on GLIDE-SOL outputs to predict T_{mrt} from urban morphology and weather forcing and reduce forecast time.

Paper

GLIDE-SOL: A GPU-accelerated Global Lightweight Infrastructure for Diagnostic Environmental Modeling with SOLWEIG

Zonato et al. (2026), GMD

Code release

<https://doi.org/10.5281/zenodo.18671813>

Live forecast

<https://forecast-utci.projects.earthengine.app/view/utciforecast>