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Validation of Grid-Based UTCI Derived from ERA5 Reanalysis in Slovakia (2002–2022)

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Introduction

The Universal Thermal Climate Index (UTCI) is a widely used biometeorological index designed to quantify human thermal stress in outdoor environments. It incorporates air temperature, wind speed, humidity, and mean radiant temperature (Tmrt), and expresses thermal conditions as an equivalent temperature. Gridded UTCI datasets, such as those derived from the ERA5 reanalysis, are increasingly used in large-scale climate assessments, health risk modelling, and decision support systems. However, the accuracy and applicability of these datasets under different geographical and climatic conditions remains insufficiently validated – especially in complex terrains like Slovakia. This study aims to evaluate the spatial and seasonal accuracy of ERA5-derived UTCI grids against station-based UTCI values calculated from in-situ meteorological observations.

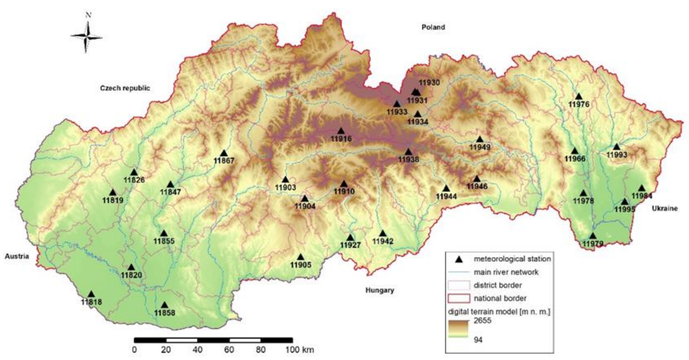

Figure1: Location of selected climatological stations

Results

Results confirm that gridded ERA5 UTCI provides a reliable representation of thermal stress conditions, showing strong agreement with station observations, especially in lowland regions and during summer ($r > 0.9$, WAPE < 20%). The seasonal cycle is captured consistently across the entire year, with only minor differences in monthly mean UTCI categories (Figure 3), which highlights the stability of the dataset. This makes ERA5 a valuable and practical source for spatial analyses and regional assessments of human thermal comfort, while larger deviations mainly reflect local topographic effects in mountainous areas and the smoothing of rare extremes.

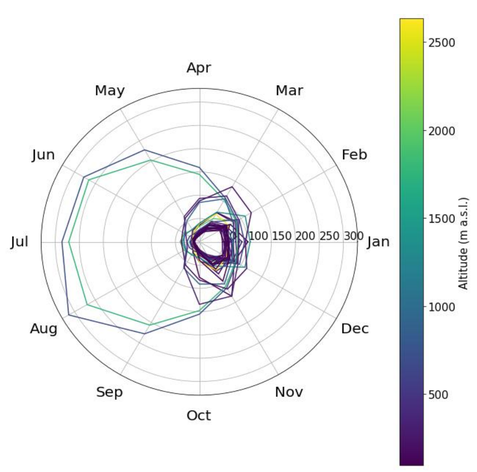

Figure 2: Monthly WAPE between UTCIGRID and UTCIMEA across individual stations, accounting for station elevation

Methods

The analysis covers a 21-year period (2002–2022) using data from 30 meteorological stations across Slovakia, provided by the Slovak Hydrometeorological Institute (SHMÚ). Station-based UTCI values were calculated hourly using the MASH model, which estimates mean radiant temperature (Tmrt) based on observed air temperature, humidity, wind, and global solar radiation. Gridded UTCI data were obtained from the ERA5 reanalysis (Copernicus Climate Data Store) with 0.25° × 0.25° spatial resolution. For each station, the nearest ERA5 grid cell was used for comparison. Several validation metrics were applied:

Correlation coefficient (r) – to assess linear consistency;

BIAS – average deviation;

WAPE (Weighted Absolute Percentage Error) – to evaluate relative accuracy;

Category agreement – comparing thermal stress classes;

Frequency of extreme days, defined as UTCI ≥ 32 °C (sultry) and UTCI ≤ -27 °C (very cold).

Table 1: Categories of UTCI index

UTCI [°C]	UTCI Category	Category number
below -40	Extreme cold stress	1
-40 to -27	Very strong cold stress	2
-27 to -13	Strong cold stress	3
-13 to 0	Moderate cold stress	4
0 to 9	Slight cold stress	5
9 to 26	No thermal stress	6
26 to 32	Moderate heat stress	7
32 to 38	Strong heat stress	8
38 to 46	Very strong heat stress	9
above 46	Extreme heat stress	10

Conclusions

ERA5-derived UTCI grids can be considered reliable for spatial analysis and long-term trend studies in flat regions. However, their direct application in complex or high-altitude areas should be approached with caution due to observed underestimation of extremes and category mismatches.

Gridded UTCI products are not suitable for local-level decision-making (e.g. urban health warnings) without proper validation or bias correction.

Future directions include:

using higher-resolution datasets (e.g. ERA5-Land), implementing local calibration techniques, improving Tmrt estimation methods, and integrating gridded UTCI with impact-based modelling and risk communication systems.

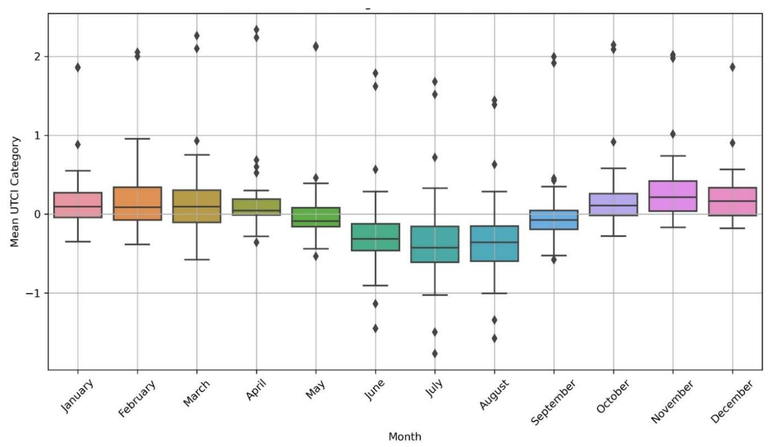

Figure 3: Average station bias between UTCIGRID and UTCIMEA (UTCIGRID − UTCIMEA) across categories for each month.

References

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Di Napoli, C., Pappenberger, F., & Cloke, H. L. (2020). Assessing heat stress across Europe: an evaluation of the Universal Thermal Climate Index (UTCI) using the ERA5 reanalysis. Geoscientific Model Development, 13(2), 1237–1256.