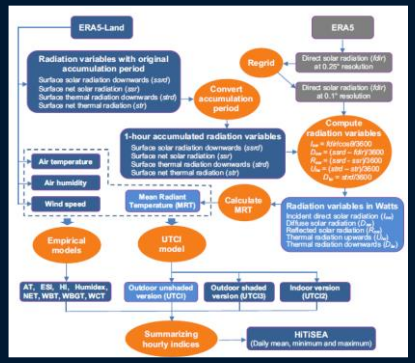
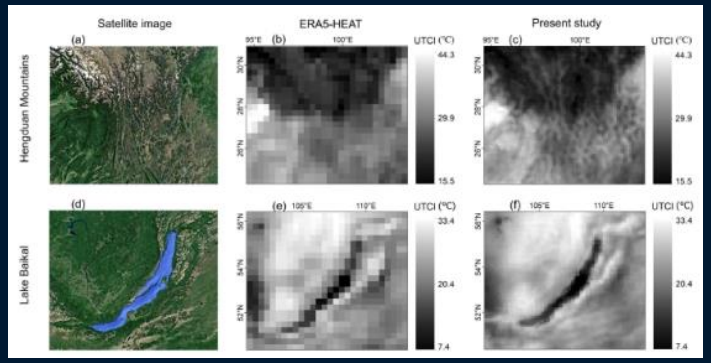
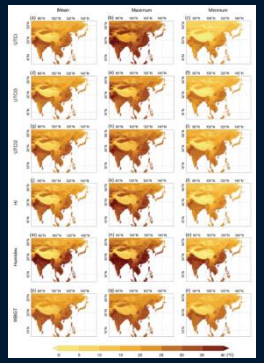
Published Work

Yan, Y., Xu, Y. & Yue, S. A high-spatial-resolution dataset of human thermal stress indices over South and East Asia. *Scientific Data* **8,** 229 (2021). Available at: https://www.nature.com/articles/s41597-021-01010-w







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Outline

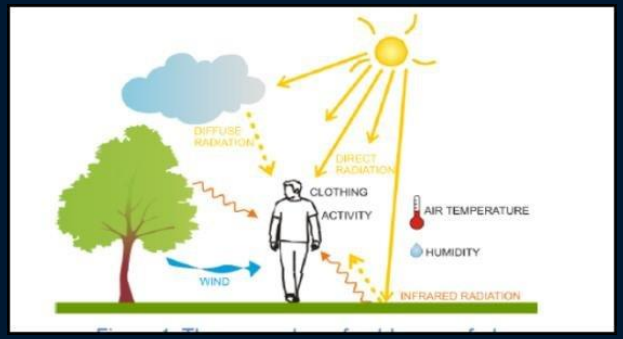
1. Background
2. Methods
3. Data Records
4. Technical Validation
5. Usage Notes
6. Code availability

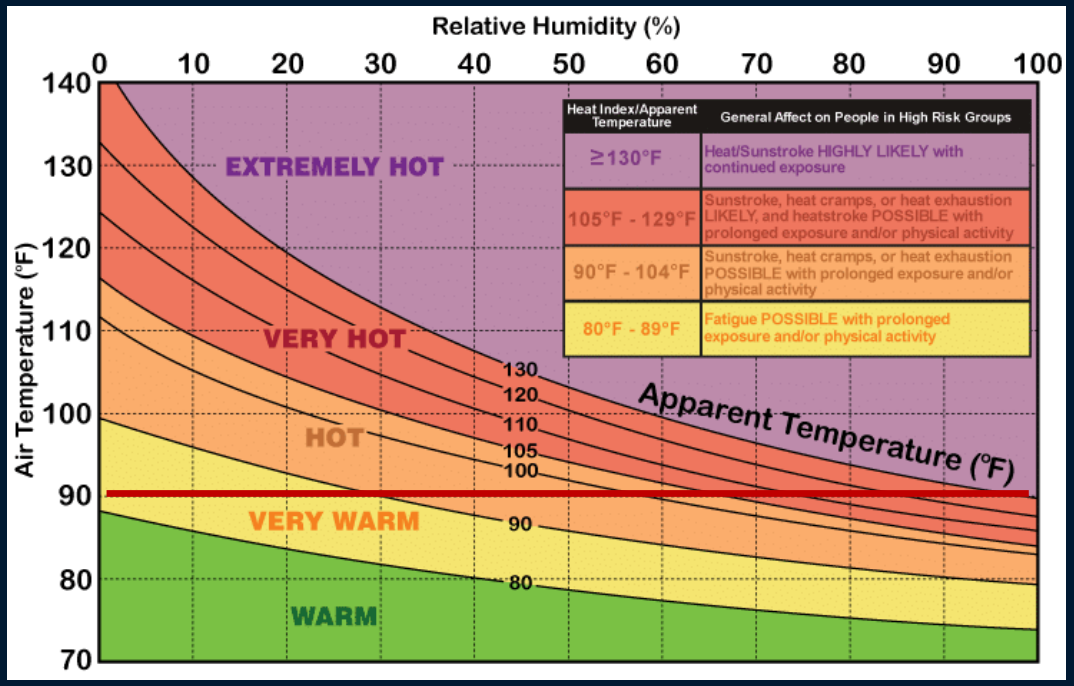
Background

Why do we need thermal-stress indices?

Besides air temperature, other factors also matter

- Air temperature
- Air humidity
- Wind speed
- Radiations





Wet Bulb Globe Temperature (WBGT)

Why do we need thermal-stress indices?

Human-thermal-stress indices

- **Empirical indices**
  - Empirical models
  - E.g., NET, HI, Humidex, WBGT, WBT, WCT, ESI, etc.
- **Rational indices**
  - Models based on human heat balance considerations
  - E.g., UTCI, PET, SET, etc.

Existing Work

- **Di Napoli, C., Barnard, C. & Prudhomme, C., et al.**
  - ERA5-HEAT: a global gridded historical dataset of human thermal comfort indices from climate reanalysis. Geosci. Data J. https://doi.org/10.1002/gdj3.102 (2020)
  - Data source: ERA5
  - 0.25º×0.25º , hourly values (UTCI, MRT)

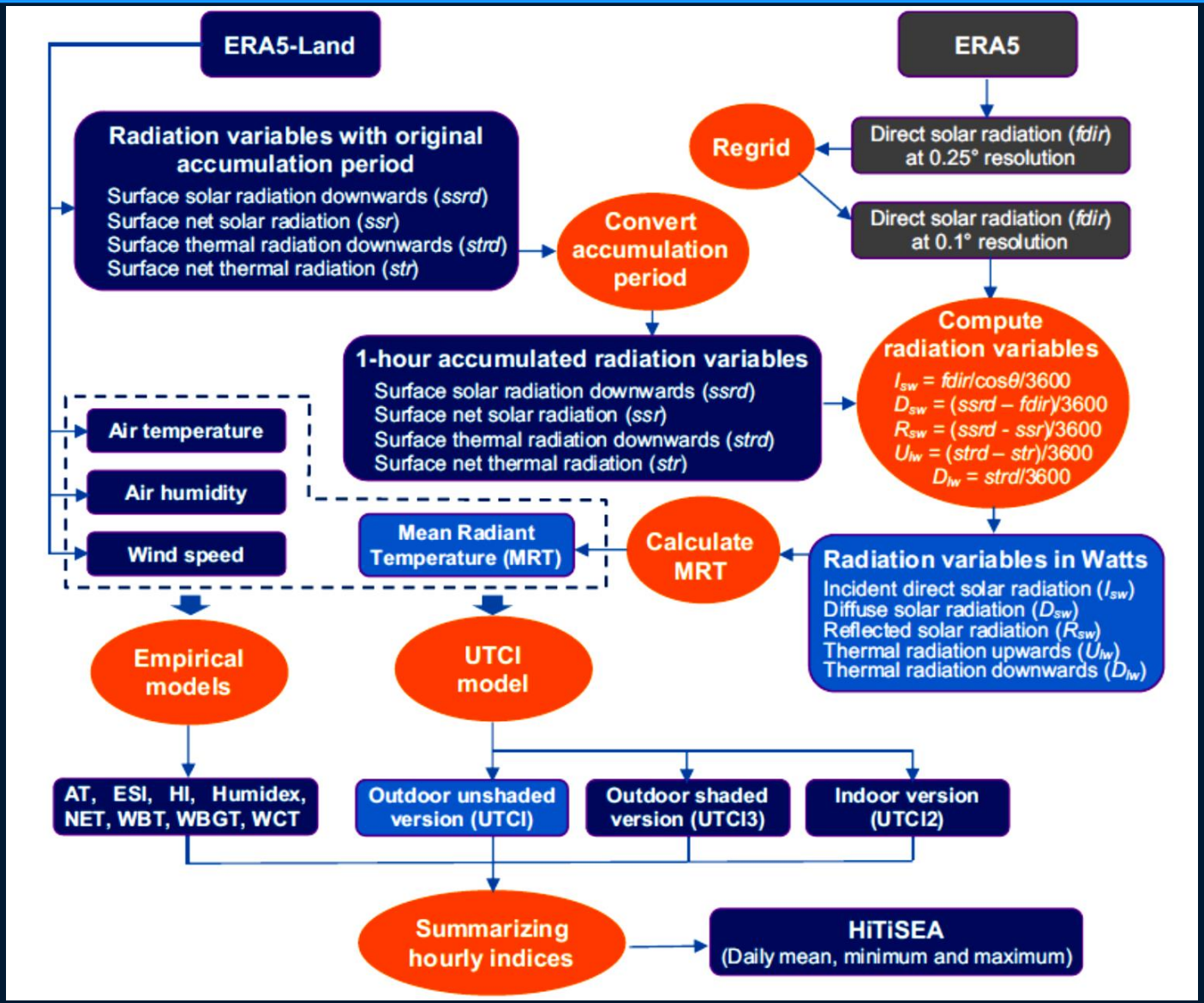
- **Mistry, M.N.**
  - A high spatiotemporal resolution global gridded dataset of historical human discomfort indices. Atmosphere https://doi.org/10.3390/atmos11080835 (2020)
  - Data source: GLDAS
  - 0.25º×0.25º , daily values (eight empirical indices)

Highlights

- **Higher spatial resolution**
  - 0.1°×0.1°
- **More indices**
  - 12 indices (rational and empirical)
  - UTCI and its variants (indoor, outdoor shaded & outdoor unshaded)
- **Comprehensive validation**
  - based on thousands of weather stations
- **Open-source code**
  - freely available python source code

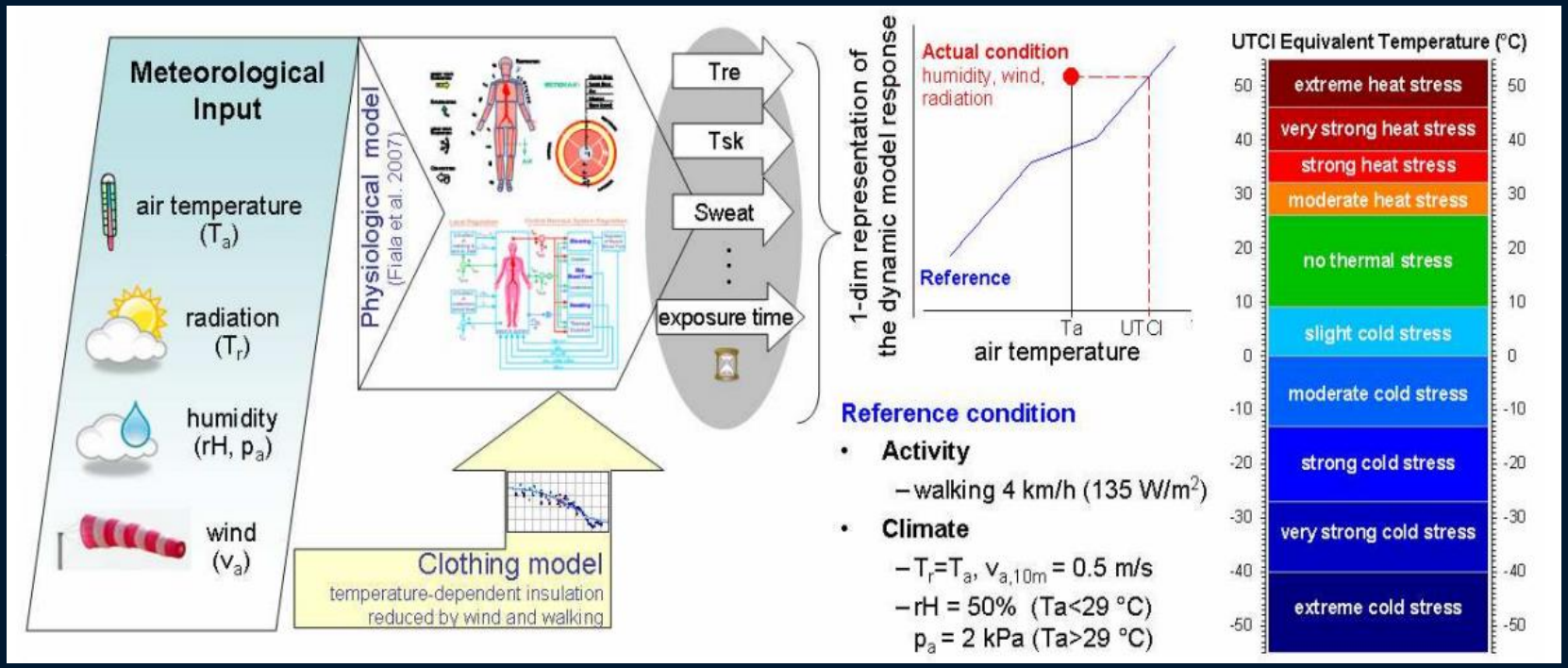
Methods

Schematic of the workflow



What is UTCI?

- *The Universal Thermal Climate Index is defined as an equivalent ambient temperature (in °C) of a reference environment that produces the same physiological response of a typical person as in the actual environment.*



What is UTCI?

Approximated by:

$$UTCI = T_a + f(T_a,\ V_a,\ e,\ MRT - T_a)$$

A 6th-order polynomial regression function given by Bröde et al. (2012)

MRT for outdoor environment (*Weihs et al., 2012*)

$$MRT = \left\{ \frac{1}{\sigma} \left[\frac{\alpha_k}{\varepsilon_p} (f_p \cdot I_{sw} + f_a \cdot D_{sw} + f_a \cdot R_{sw}) + f_a \cdot (D_{lw} + U_{lw}) \right] \right\}^{0.25} - 273.5$$

What is UTCI?

Projected area factor (f_p)

$$f_p = 0.308 \cdot \cos\left\{\left(\frac{\pi}{2} - \theta\right) \cdot \left[1 - \frac{\left(90 - \frac{180}{\pi}\theta\right)^2}{48402}\right]\right\}$$

Solar zenith angle (θ, in radians)

$$\cos\theta = \sin\delta \sin\varphi + \cos\delta \cos\varphi \cos h$$

Empirical indices

- ***Apparent Temperature (AT)***

$$AT = T_a + 0.33 \times e - 0.7V_a - 4$$

- ***Environment Stress Index (ESI)***

$$ESI = 0.63T - 0.03RH + 0.002SR + 0.0054 \times T \times RH - \frac{0.073}{0.1 + SR}$$

- ***Humidex***

$$Humidex = T_a + 0.5555 \times (e - 10)$$

Empirical indices

- ***Heat Index (HI)***

$$
\begin{aligned}
HI \;=\; & -42.379 + 2.04901523 \times T_a + 10.14333127 \times RH \\
& -0.22475541 \times T_a \times RH - 0.00683783 \times T_a^2 - 0.05481717 \times RH^2 \\
& +0.00122874 \times T_a^2 \times RH + 0.00085282 \times T_a \times RH^2 \\
& -0.00000199 \times T_a^2 \times RH^2
\end{aligned}
$$

Note: Adjustment should be made in case of much lower or higher RH. For more information, please go to NOAA's website or see our article.

- ***Wet Bulb Temperature (WBT)***

$$
\begin{aligned}
WBT \;=\; & T_a \times \operatorname{atan}\left[0.151977(RH + 8.313659)^{0.5}\right] + \operatorname{atan}(T_a + RH) - \operatorname{atan}(RH - 1.676331) \\
& +0.00391838(RH)^{1.5}\operatorname{atan}(0.023101 \times RH) - 4.686035
\end{aligned}
$$

Empirical indices

- ***Wet-Bulb Globe Temperature (WBGT)***

  Original form:

$$WBGT = 0.7 \times T_w + 0.2 \times T_g + 0.1 \times T_d$$

  Simplified equation:

$$WBGT = 0.567 \times T_a + 0.393 \times e + 3.94$$

- ***Wind Chill Temperature (WCT)***

$$WCT = 13.12 + 0.6215 \times T_a - 11.37 \times V_a^{0.16} + 0.3965 \times T_a \times V_a^{0.16}$$

Empirical indices

- ***Net Effective Temperature (NET)***

$$NET = 37 - \frac{37 - T_a}{0.68 - 0.0014 \times RH + \frac{1}{1.76 + 1.4 \times V_a^{0.75}}} - 0.29 \times T_a \times (1 - 0.01 \times RH)$$

$$V_a = V_{Z_r} \frac{\log(Z/Z_0)}{\log(Z_r/Z_0)}$$

Note: V_a is the wind speed (m/s) at a height of 1.2 m.

Data Records

Data Records

Title	**High-spatial-resolution Thermal-stress Indices over South and East Asia (HiTiSEA)**
Data type	**Gridded**
Projection	**Regular latitude-longitude grid**
Horizontal coverage	**South and East Asia (65°E–155°E; 3°N–58°N)**
Horizontal resolution	**0.1° x 0.1°**
Vertical resolution	**Surface level**
Temporal coverage	**1981-01-03 to 2019-12-31**
Temporal resolution	**Daily (mean, maximum and minimum)**
File format	**NetCDF**
NoData Value	**-32767**
Name convention	**HiTiSEA_YYYY-mm-dd.nc**

Total volume: 450 GB
Daily NetCDF files are archived by year and compressed into tar.gz files to save storage space.

Data Records

Table 1. Thermal indices and their input variables

Thermal Indices	Full Name of the Indices	Air Temperature	Air Humidity	Wind Speed	Radiation
UTCI	universal thermal climate index	T_a	e	V_a	R
indoor UTCI	UTCI for indoor environment	T_a	e		
outdoor shaded UTCI	UTCI for outdoor shaded space	T_a	e	V_a	
MRT	mean radiant temperature				R
ESI	environment stress index	T_a	RH		SR
HI	heat index	T_a	RH		
Humidex	humidity index	T_a	e		
WBGT	wet-bulb globe temperature	T_a	e		
WBT	wet bulb temperature	T_a	RH		
WCT	wind chill temperature	T_a		V_a	
AT	apparent temperature	T_a	e	V_a	
NET	net effective temperature	T_a	RH	V_a	

Note:

1) *R* stands for the radiation variables, including direct, diffuse, and reflected solar radiation, as well as upward and downward thermal radiation, while *SR* represents the solar radiation, which includes both the direct and diffuse solar radiation reaching the horizontal surface of the Earth.

2) All indices are with a unit expressed in °C.

Technical Validation

Technical Validation

Table 3. Summary table of accuracy, in terms of RMSE (°C) and bias (°C), obtained by comparing the indices computed from ERA5-Land reanalysis and weather station observations. This table only lists the indices that do not require radiation as data input.

Thermal Indices	Daily Mean		Daily Maximum		Daily Minimum	
	RMSE	Bias	RMSE	Bias	RMSE	Bias
indoor UTCI	1.6	-0.4	1.9	-0.7	2.2	-0.3
outdoor shaded UTCI	2.7	-0.9	3.1	-1.2	3.7	-0.7
HI	2.0	-0.6	2.4	-0.9	2.5	-0.4
Humidex	1.9	-0.6	2.3	-0.8	2.7	-0.5
WBGT	1.1	-0.4	1.3	-0.5	1.6	-0.3
WBT	1.3	-0.3	1.4	-0.4	1.9	-0.3
WCT	3.1	-1.7	4.8	-2.5	3.3	-1.3
AT	2.0	-0.7	2.3	-0.9	2.7	-0.7
NET	2.7	-0.3	3.3	-0.7	3.6	0.2

E.g., Indoor UTCI: 81% of the stations presenting an RMSE for daily mean lower than 2°C

Technical Validation

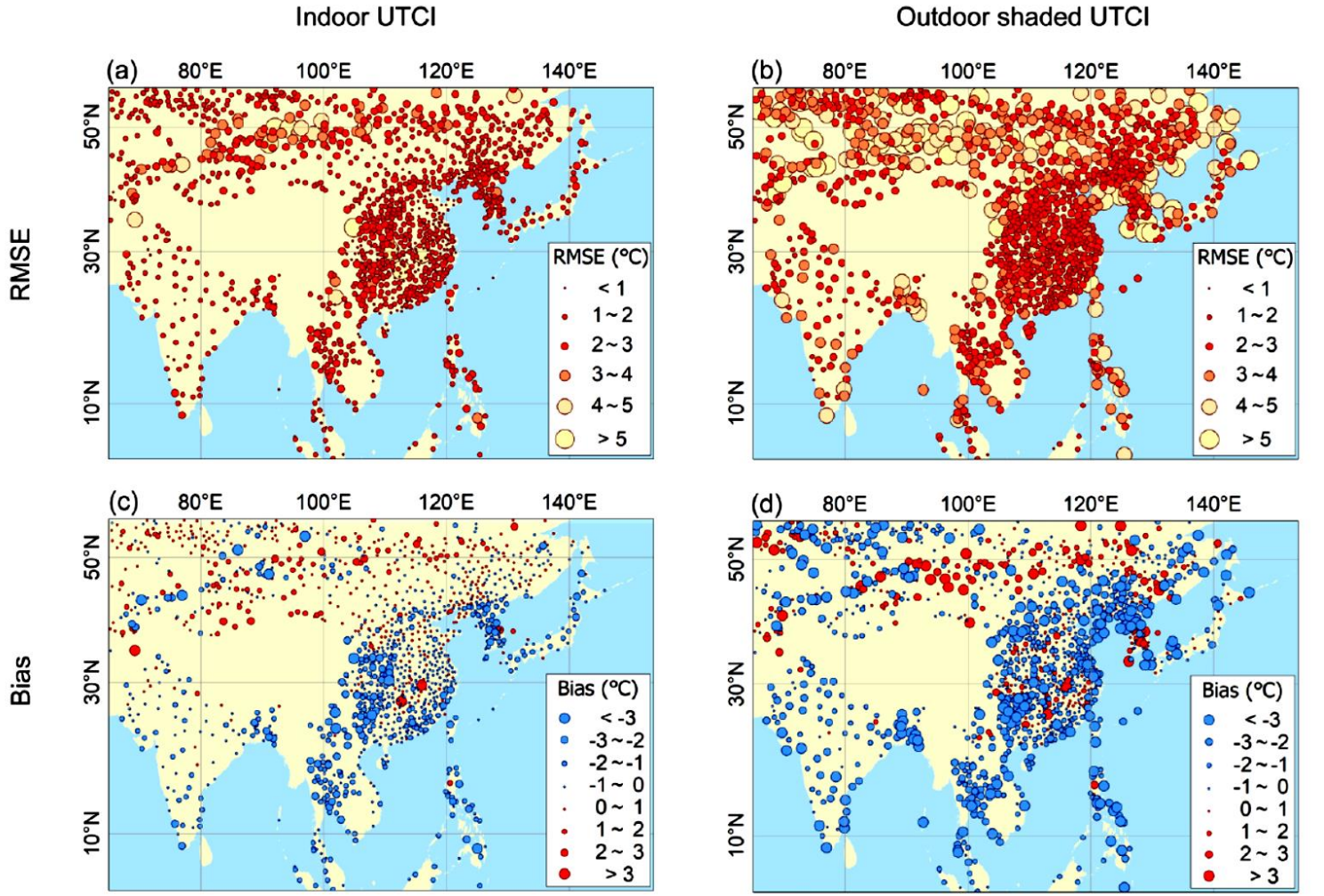


Fig. 2 Spatial distribution of values of RMSE and bias for daily mean indoor UTCI (left column) and outdoor shaded UTCI (right column) computed from ERA5-Land.

Technical Validation

Table 4. Average RMSE values (°C) and biases (°C) of the MRT, UTCI, and ESI for stations that have both radiation data and commonly observed meteorological data for 2018.

Station ID	Station Name	Longitude	Latitude	Number of Records	MRT		UTCI		ESI	
					RMSE	Bias	RMSE	Bias	RMSE	Bias
54511	Beijing	116.47	39.80	230	10.1	8.1	5.4	3.8	1.0	-0.1
54342	Shenyang	123.52	41.73	283	8.7	4.3	4.5	0.1	1.6	-0.2
50953	Harbin	126.57	45.93	282	11.1	8.0	5.5	2.9	1.5	-0.3
58362	Baoshan	121.45	31.40	289	7.4	3.3	3.2	-0.5	1.2	-0.7
57494	Wuhan	114.05	30.60	284	9.8	5.4	3.8	0.7	1.6	-0.4
59287	Guangzhou	113.48	23.22	288	7.1	3.6	2.9	0.5	1.5	-1.0
56187	Wenjiang	103.87	30.75	289	9.9	2.2	3.9	0.9	1.9	-1.3
51463	Urumqi	87.65	43.78	275	12.1	1.6	6.9	-0.8	3.2	-0.4

- Radiation observations are only available at 8 stations.
  - daily values of maximum global radiation flux
  - the time when maximum global radiation flux occurs
- Paired-up observations have a size of 2220 hourly records
- BioKlima 2.6 were used to calculate the MRT and the outdoor unshaded UTCI

Technical Validation

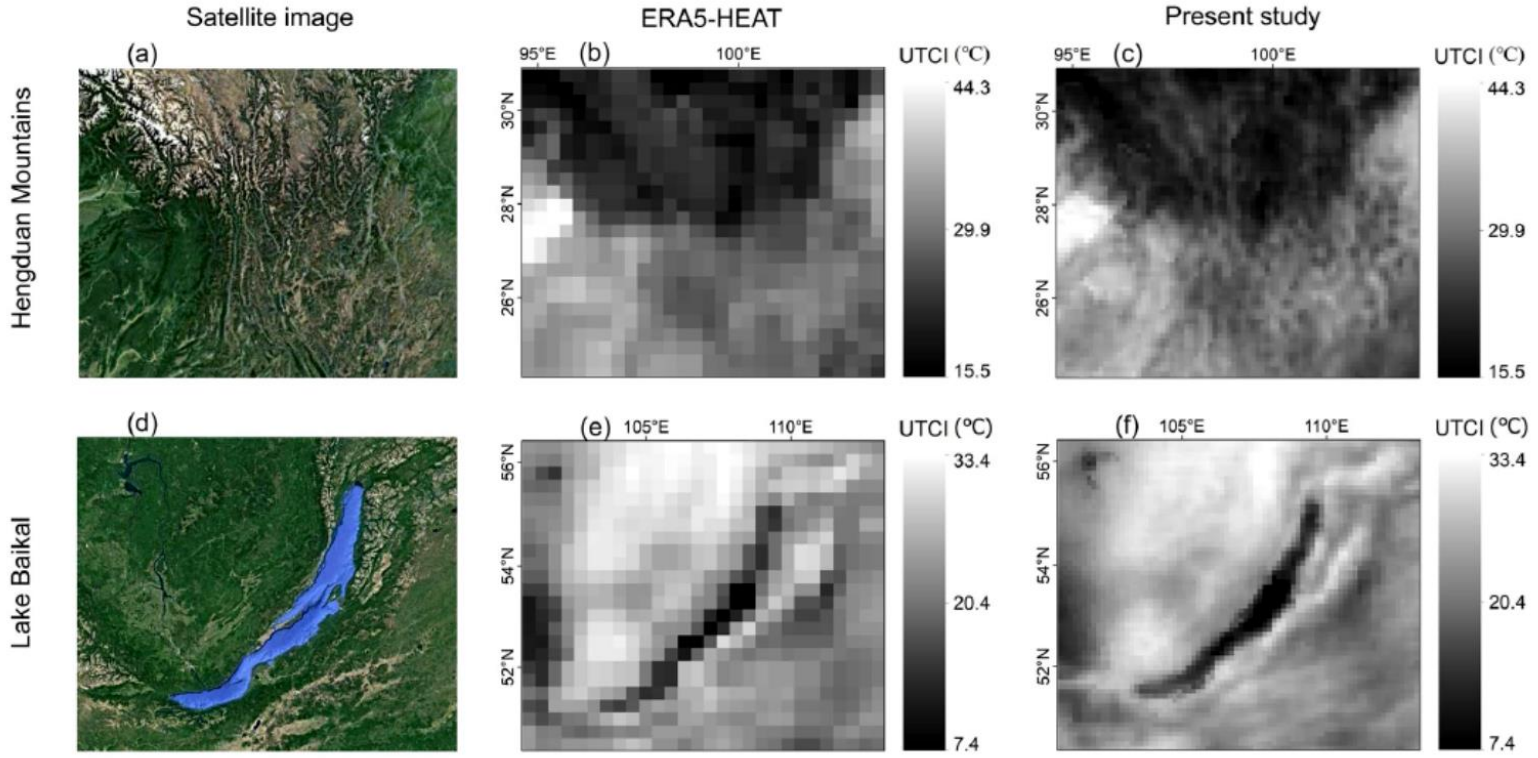


Fig. 6 The satellite images from Google Earth for the regions of Hengduan Mountains (upper left) and Lake Baikal (lower left), and the distributions of daily maximum UTCI from ERA5-HEAT (middle) and the present study (right) on 2018-07-20.

RMSE: **5.2±2.5℃** **4.5±2.4℃**

Technical Validation

Seasonal effects of the data accuracy

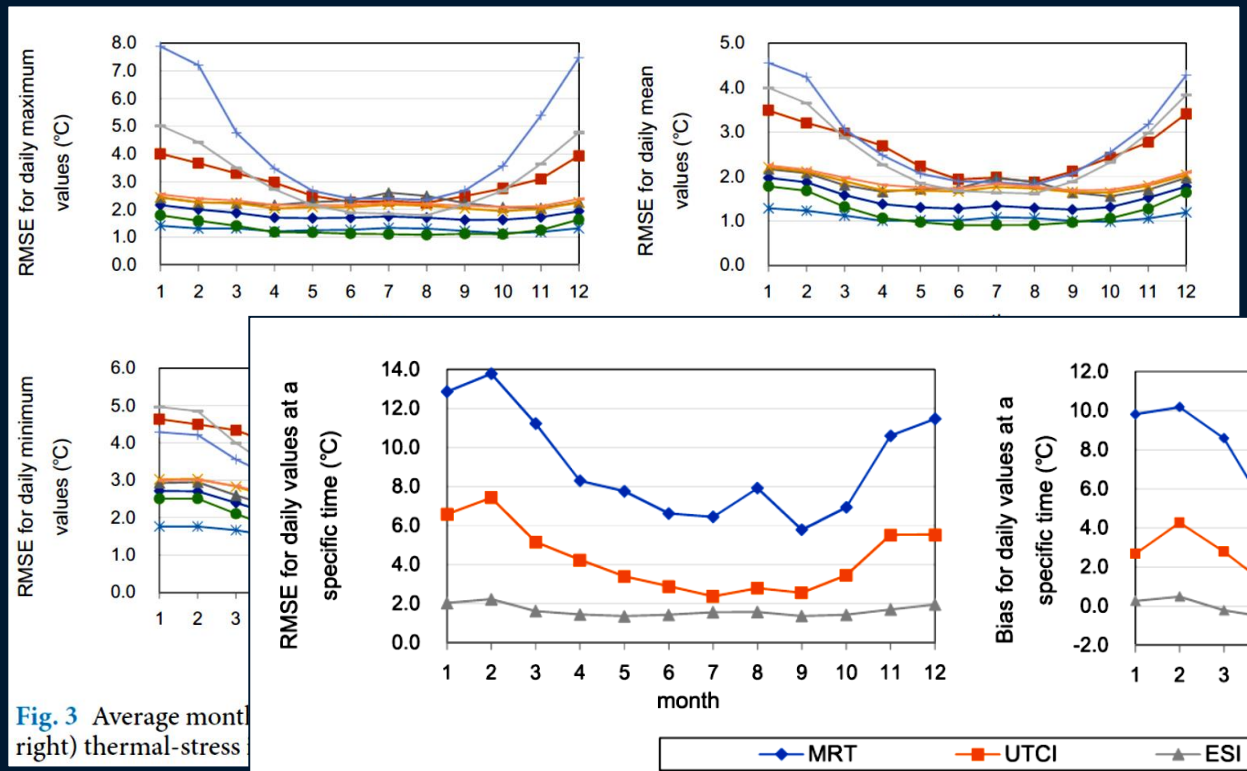


Fig. 3 Average montl
right) thermal-stress

Fig. 4 Average monthly RMSE values (left) and biases (right) for daily values of the MRT, UTCI, and ESI at specific time of the day when maximum global radiation flux occurs.

Usage Notes

Usage Notes

- **Assessment scale**
  - Each index is associated with a particular assessment scale
  - E.g., “strong heat stress”: UTCI (32-38°C), Humidex(40-45°C)
  - Can refer to Blazejczyk’s work published on Int. J. Biometeorol, 2012
- **Suitability**
  - Indoor UTCI, outdoor shaded and unshaded UTCI
  - Some can only be used in hot season, and some in cold season
- **Orographic effects**
  - higher accuracy in flat areas
  - accuracy degrades in mountainous areas and coastal zones (mixed-pixel problem)

Code availability

Code availability

- **All codes were written in Python (3.8)**
  - Using cdsapi (0.3.1), numpy (1.19.2), pandas (1.1.3), netCDF4 (1.5.4), and scipy (1.5.3) libraries
  - Users can use ‘pip install’ command to install the above libraries
- **Developed on Linux (CentOS 6.10)**
  - Can be easily adapted to Windows (if Anaconda is installed)
- **Published along with the dataset**
  - Freely available at the dataset repository

Thanks!

Article is available at:
https://www.nature.com/articles/s41597-021-01010-w

Dataset and python source code are available at：
https://doi.org/10.6084/m9.figshare.c.5196296