ERA5-CHI: Global High-Resolution ERA5-Comprehensive Heat Indices Dataset from 1950 to 2024

Overview

This dataset offers a globally complete, high-resolution (0.1° × 0.1°), hourly historical reconstruction of 13 comprehensive heat stress indices for the period 1950–2024. Known as ERA5-CHI (ERA5-Comprehensive Heat Indices), the dataset represents the most diverse and detailed heat stress climatology currently available, supporting studies of human thermal comfort, mortality risk, and climate adaptation across diverse environmental conditions.

The dataset is built around 13 key thermal comfort and stress indicators, including:

1. Mean Radiant Temperature (Tmrt)
2. Universal Thermal Climate Index (UTCI)
3. Wet-Bulb Globe Temperature (Twbg)
4. Natural Wet-Bulb Temperatures (Tnwb)
5. Indoor Wet-Bulb Temperature (Twb)
6. Natural Lethal Heat Stress Index (Lsin)
7. Indoor Lethal Heat Stress Index (Lsi)
8. Globe Temperature (Tg)
9. Heat Index (HI)
10. Apparent Temperature (AT)
11. Wind Chill (WC)
12. Humidex (Hu)
13. Normal Effective Temperature (NET)

These variables quantify how the human body experiences atmospheric conditions, incorporating the effects of air temperature, humidity, wind speed, solar radiation, and soil moisture—factors critical to assessing heat-related discomfort, workability, and mortality risk.

The dataset is derived from the ERA5 and ERA5-Land reanalyses from the European Centre for Medium-Range Weather Forecasts (ECMWF). ERA5 provides hourly atmospheric data at a global scale using advanced data assimilation techniques, while ERA5-Land refines this output over land with a higher spatial resolution. Together, they underpin ERA5-CHI's detailed global coverage (60°S to 75°N and 180°W to 180°E) and extended historical range.

ERA5-CHI improves upon earlier datasets by:

- Extended long-term coverage from 1950 to 2024
- Utilising 2 m wind speed instead of the standard 10 m, enhancing near-surface physiological relevance
- Computing solar zenith angles only during sunlit hours to avoid radiation-related index errors
- Providing both indoor and outdoor variants of key indices (e.g., Lsi, Tw)
- Offering the first global hourly dataset for the empirical, mortality-based lethal heat stress index (Ls)

The dataset is particularly relevant for applications in climate-health research, urban planning, occupational heat risk, and climate adaptation, especially in vulnerable regions such as the Middle East, South Asia, and sub-Saharan Africa.

The dataset currently covers 02/01/1950 to 31/12/2024. The dataset is produced by the Climate Change Center at King Abdullah University of Science and Technology (KAUST) in collaboration with international researchers. See Tables 1-5 for more information.

Data Record and File Name Convention

The ERA5-CHI dataset is provided in NetCDF format, with monthly files containing hourly data for each heat index. Each monthly file is approximately 6 GB in size, contributing to a total dataset volume of around 73 TB and 11,700 files. Files follow the naming convention: *ERA5-CHI_<IndexName>_YYYY-MM.nc*, where *<IndexName>* is the abbreviation of the specific index as listed in Table 5. For example, the file containing UTCI data for June 2015 would be named: *ERA5-CHI_UTCI_2024-12.nc* Figs. 1-2 provide further information about this and similar other data files.

```
netcdf ERA5-CHI_UTCI_2024-12 {
dimensions:
        time = 744 ;
        latitude = 1351 ;
        longitude = 3600 ;
variables:
        double UTCI(time, latitude, longitude) ;
                UTCI:_FillValue = -9999. ;
                UTCI:units = "K" ;
                UTCI:long_name = "Universal Thermal Climate Index" ;
                UTCI:standard_name = "UTCI" ;
        float longitude(longitude) ;
                longitude:_FillValue = NaNf ;
                longitude:standard_name = "longitude" ;
                longitude:long_name = "longitude" ;
                longitude:units = "degrees_east" ;
                longitude:axis = "X" ;
        float latitude(latitude) ;
                latitude:_FillValue = NaNf ;
                latitude:standard_name = "latitude" ;
                latitude:long_name = "latitude" ;
                latitude:units = "degrees_north" ;
                latitude:axis = "Y" ;
        int time(time) ;
                time:long_name = "time" ;
                time:units = "hours since 1900-01-01" ;
                time:calendar = "gregorian" ;
}
```

Figure1. NetCDF header metadata (via *ncdump -h*) for the *ERA5-CHI_UTCI_2024-12.nc* file. This output displays the structure of the NetCDF file, including its dimensions (time, latitude, longitude), variable definitions (e.g., UTCI), units (K for Kelvin), and attributes such as standard names and long names. It confirms that the Universal Thermal Climate Index (UTCI) is provided at hourly resolution on a global 0.1° × 0.1° grid, covering latitudes from 60°S to 75°N and longitudes from 180°W to 180°E.

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   File format : NetCDF4 zip
    -1 : Institut Source   T Steptype Levels Num    Points Num Dtype : Parameter name
     1 : unknown  unknown  v instant       1   1   4863600   1  F64z : UTCI
   Grid coordinates :
     1 : lonlat                   : points=4863600 (3600x1351)
                        longitude : -180 to 179.9 by 0.1 degrees_east  circular
                         latitude : 75 to -60 by -0.1 degrees_north
   Vertical coordinates :
     1 : surface                  : levels=1
   Time coordinate :
                             time : 744 steps
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Figure 2. Metadata summary using CDO (*cdo sinfov*) for *ERA5-CHI_UTCI_2024-12.nc.* This output details the time dimension (744 hourly steps in December 2024), spatial resolution (3600×1351 grid points at 0.1° spacing), and coordinate system (regular lon-lat grid). It confirms that the dataset contains one surface-level field (UTCI) at each hourly timestep. The sample timestamps show hourly intervals spanning December 1 to December 31, 2024, using the Gregorian calendar.

Tables

Table 1. Data description

Data type	Gridded
Projection	Regular latitude-longitude grid
Horizontal coverage	Global except for Arctic and Antarctica (75N-60S, 180W-180E)
Horizontal resolution	0.1° x 0.1°
Vertical resolution	Surface level
Temporal coverage	From January 1950 to December 2024.
Temporal resolution	Hourly data.
File format	NetCDF
Versions	v1
Update frequency	None

Table 2. Main Variables

Name	Units	Description
Mean Radiant Temperature (Tmrt)	K	Total radiant heat absorbed by a person from surroundings, including sunlight and surface radiation. Calculated using shortwave and longwave fluxes and adjusted solar angles per Di Napoli et al. (2020).
Universal Thermal Climate Index (UTCI)	K	Simulates thermal sensation based on air temperature, humidity, wind (2 m), and radiation (Tmrt). Uses a 6th-order polynomial fit (Bröde et al., 2012) for physiological heat balance modelling.
Wet-Bulb Globe Temperature (Twbg)	K	Outdoor heat stress index combining temperature, humidity, wind, and radiation. Computed as a weighted mean of Tnwb, globe temperature, and air temperature using the Liljegren et al. (2008) model with updated radiation input (Kong et al., 2022).
Natural Wet-Bulb Temperature (Tnwb)	K	Physical model of sweat-based body cooling under full environmental exposure. Computed using radiation, humidity, and wind following Liljegren et al. (2008), modified by Kong et al. (2022).
Indoor Wet-Bulb Temperature (Twb)	K	A simpler, shaded/indoor estimate of wet-bulb temperature. Calculated from temperature and relative humidity using Stull's (2011) empirical formula.
Natural Lethal Heat Stress Index (Lsin)	K	Mortality-linked index based on Tnwb and relative humidity. Sensitive to outdoor conditions. Thresholds (19 °C, 27 °C) mark onset and escalation of lethal heat risk (Wouters et al., 2022).
Indoor Lethal Heat Stress Index (Ls)	K	Variant of Lsn using indoor Twb instead of Tnwb. Used for assessing life-threatening indoor heat conditions in vulnerable environments.
Globe Temperature (Tg)	K	Simulated reading from a black globe thermometer, combining air temperature, radiation, and wind. Estimated using Tmrt and wind speed at 2 m (Brimicombe et al., 2023).
Humidex (Hu)	K	Canadian discomfort index combining air and dew point temperature. Indicates how hot it feels due to humidity (Masterson & Richardson, 1979).
Heat Index Adjusted (HI)	K	Enhanced US Heat Index combining temperature and

		humidity. Includes adjustments under extreme relative humidity or temperature conditions (Rothfusz, 1990; NOAA).
Apparent Temperature (AT)	K	Feels-like temperature accounting for humidity and wind at 1.2 m (converted from 10 m wind). Reflects evaporative and convective heat loss (Steadman, 1984).
Normal Effective Temperature (NET)	K	Combines temperature, humidity, and wind into a single comfort index for hot and cold conditions. Based on Li et al. (2000).

Table 3. Input variables from ERA5 and ERA5-Land used for calculating heat stress indices in the ERA5-CHI dataset. Variables include wind components, surface radiation fluxes, and near-surface meteorological parameters, with their units and data sources.

Variable	**Abbreviation**	**Units**	**Source Data**
Eastward component of 10 m wind	u10	m s^{-1}	ERA5-Land (Muñoz-Sabater 2019; Muñoz-Sabater et al., 2021)
Northward component of 10 m wind	v10	m s^{-1}	"
2 m temperature	T2m	K	"
2 m dewpoint temperature	Td2m	K	"
Surface pressure	sp	Pa	"
Surface net solar radiation	Snsr	J m^{-2}	"
Surface net thermal radiation	Sntr	J m^{-2}	"
Surface solar radiation downwards	Ssrd	J m^{-2}	"
Surface thermal radiation downwards	Strd	J m^{-2}	"
Total sky direct solar radiation at the surface	Tsdsrs	J m^{-2}	ERA5 (Copernicus Climate Change Service, 2023; Hersbach et al., 2023)

Table 4. Derived variables and radiation parameters computed for intermediate processing in the ERA5-CHI workflow. These variables are not directly available from ERA5 or ERA5-Land but are calculated using source code and methods cited.

Calculated Variable	**Abbreviation**	**Units**	**Source Code**	**Method**
Relative humidity	rh	%	thermofeel (Brimicombe et al., 2022)	$rh = (\frac{e}{es}) \times 100$ $e = vapor\ pressure = 6.11 \times 10^{(\frac{7.5\times(Td2m-273.15)}{237.3+(Td2m-273.15)})}$ $es = saturated\ vapor\ pressure = 6.11 \times 10^{(\frac{7.5\times(T2m-273.15)}{237.3+(T2m-273.15)})}$
Average cosine of the solar zenith angle during only the sunlit part of the interval	$\cos\theta$	unitless	Kong et al. (2022)	$\cos\theta = sin\delta sin\Phi + \frac{1}{h_{max}-h_{min}} cos\delta cos\Phi(\sin h_{max} - \sin h_{min})$ δ = solar declination angle Φ = geographic latitude h = hour angle See Di Napoli et al. (2020)
Wind speed at 10 m	ws10	m s^{-1}	Kong et al. (2022)	$\mathrm{ws10} = \sqrt{(u10)^2 + (v10)^2}$ (see Spangler et al., 2022)
Wind speed at 2 m	ws2	m s^{-1}	Kong et al. (2022)	$ws2 = max\left(ws10\left(\frac{zws2}{zws10}\right)^{urb\_exp[stab\_class-1]}, 0.13\right)$ $\frac{zws2}{zws10}$: ratio of the sensor heights urb_exp: urban exponent $stab\_class$: is atmospheric stability class and is a function of $\cos\theta$, ws10, and ssrd 0.13 is the minimum ws2 threshold See Liljegren et al. (2008)
Direct radiation from the sun	dsrp	W m^{-2}	Kong et al. (2022)	$dsrp = \frac{tsdsrs}{\cos\theta}\ for\ \cos\theta > 0$ Di Napoli et al. (2020)
Ratio of direct solar radiation	fdir	unitless	Kong et al. (2022)	$fdir = \frac{(ssrd - ssrdDif)}{ssrd} = \frac{tsdsrs}{ssrd};$ $fdir = \begin{cases} 0\ if\ \cos\theta \leq 0\ or\ fdir < 0 \\ 0.9\ if\ fdir > 0.9 \end{cases}$ $tsdsrs = (ssrd - ssrdDif)$ $ssrdDif$: Diffuse component of ssrd Di Napoli et al. (2020) and Yan et al. (2021)
Surface thermal radiation upwards	stru	W m^{-2}		$stru = strd - sntr$ Di Napoli et al. (2020)
Surface solar radiation upwards	ssru	W m^{-2}		$ssru = ssrd - snsr$ Di Napoli et al. (2020)
Diffuse solar radiation	ssrdDif	W m^{-2}		$ssrdDif = ssrd - tsdsrs$ Di Napoli et al. (2020)

Table 5. List of heat stress indices calculated in the ERA5-CHI dataset, including their abbreviations, units, required input variables, computation methods, and source code used.

Heat Stress Metric	Abbreviation	Units	Input Variables	Method	Source Code
Mean Radiant Temperature	Tmrt	K	ssrd, snsr, dsrp, strd, tsdsrs, sntr, cos θ	Di Napoli et. al. (2020)	thermofeel (Brimicombe et al. 2022)
Globe Temperature	Tg	K	T2m, Tmrt, ws2	Guo et al. (2018); de Dear (1987), Brimicombe et al. (2023)	thermofeel (Brimicombe et al. 2022)
Universal Thermal Climate Index	UTCI	K	T2m, ws2, Tmrt, svp	Bröde et al. (2012); Di Napoli et. al. (2020)	thermofeel (Brimicombe et al. 2022)
Natural Wet-bulb Temperature	Tnwb	K	T2m, rh, sp, ws2, ssrd, snsr, strd, sntr, fdir, cos θ	The Liljegren et al. (2008) method, as modified by Kong et al. (2022)	Kong et al. (2022)
Indoor Wet-Bulb Temperature	Twb	K	T2m, rh	Stull (2011)	thermofeel (Brimicombe et al. 2022)
Indoor Lethal Heat Stress Index	Lsi	K	Twb, rh	Wouters et al. (2022)	
Natural Lethal Heat Stress Index	Lsin	K	Tnwb, rh	Wouters et al. (2022)	
Wet-Bulb Globe Temperature	Twbg	K	T2m, Tmrt, ws2, Td2m	Liljegren et al. (2008); Minard (1961)	thermofeel (Brimicombe et al. 2022)
Humidex	Hu	K	T2m, Td2m	Masterson et al. (1979)	thermofeel (Brimicombe et al. 2022)
Normal / Net Effective Temperature	NET	K	T2m, ws2, rh	Li et al. (2000)	thermofeel (Brimicombe et al. 2022)
Apparent Temperature	AP	K	T2m, rh, ws2	Steadman (1984)	thermofeel (Brimicombe et al. 2022)
Wind Chill	WC	K	T2m, ws2	Coccolo et al. (2016)	thermofeel (Brimicombe et al. 2022)
Heat Index Adjusted	HI	K	T2m, Td2m	Rothfusz (1990); NOAA / National Weather Service	thermofeel (Brimicombe et al. 2022)

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