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REGIONAL WORKSHOP ON IMPACT-BASED FORECASTING:

Training-of-Trainers and National Demonstration Planning for Temperature-Related Hazards

SAHF IBF Working Group Implementation Plan Project

09-13 February 2026

Kathmandu, Nepal

Supported by:

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REGIONAL WORKSHOP ON IMPACT-BASED FORECASTING

Training-of-Trainers and National Demonstration Planning for Temperature-Related Hazards

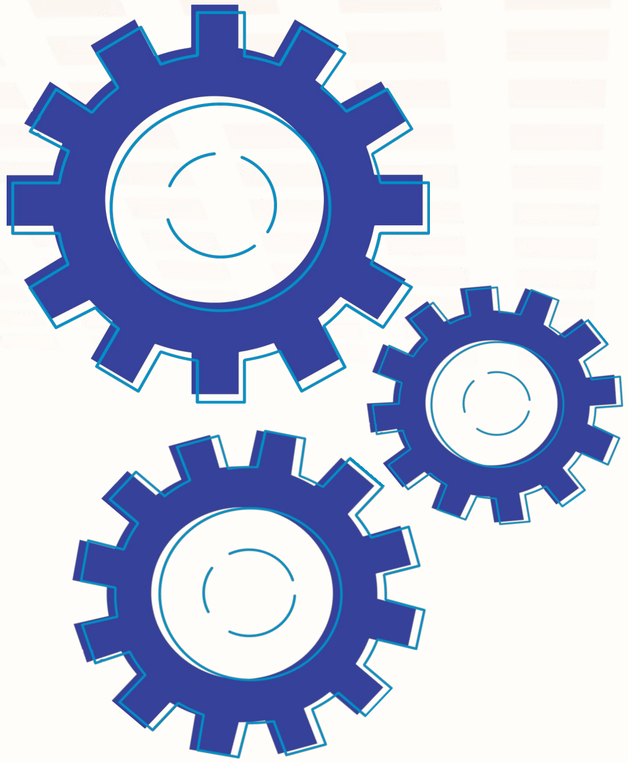
Session 3: Forecast Generation for Temperature Hazards

- Forecast types, lead times, and uncertainties
- Strengths and limitations of temperature forecasts for IBF

Shiromani Jayawardena

SAHF Advisor (Weather and Climate Services), RIMES

AGENDA



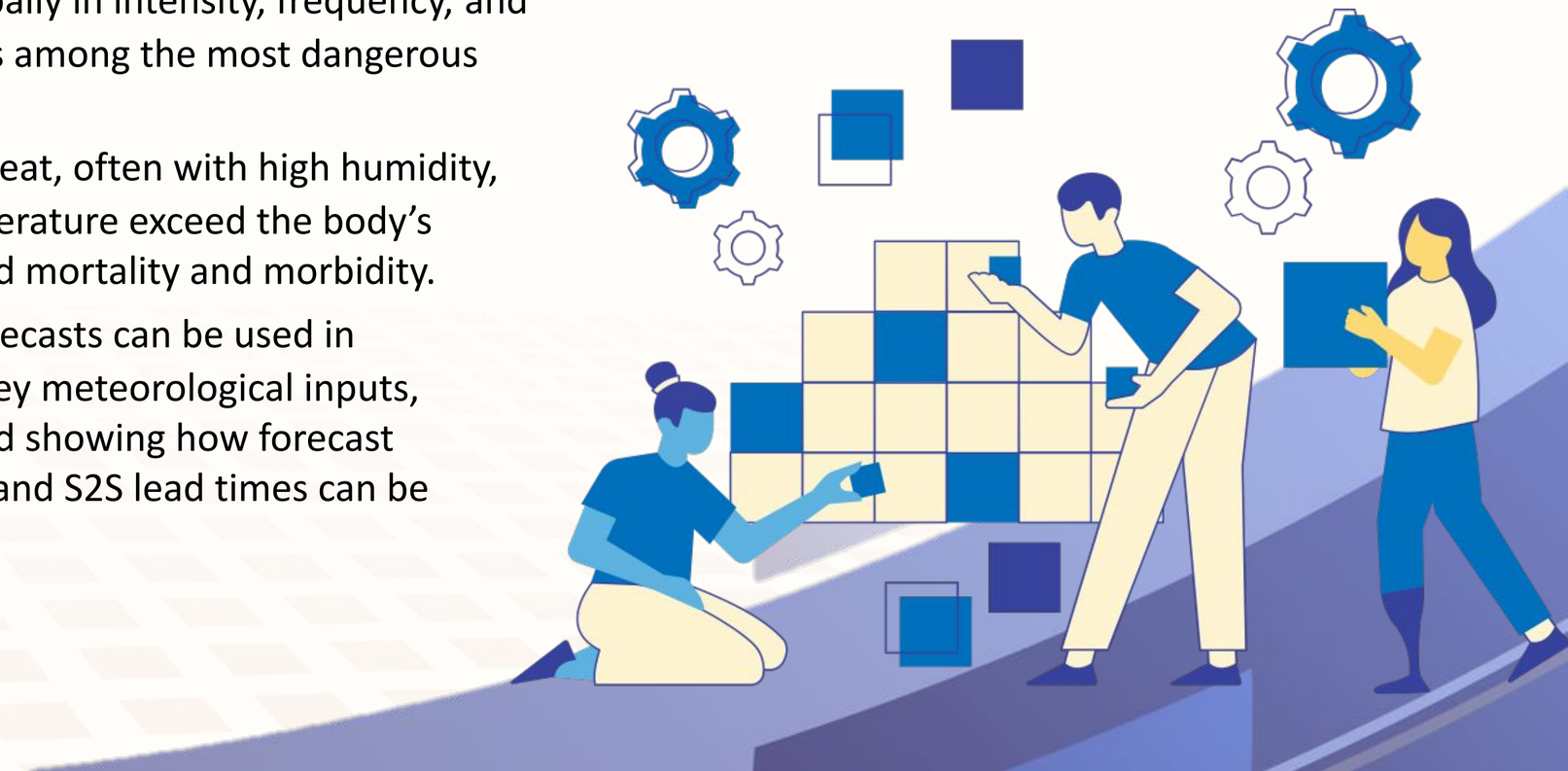
- Overview
- Forecast Types
- Lead Time
- Thermal comfort indices
- Extreme Forecast Index (EFI)
  Forecast Skill & Uncertainties
- Hands on Session-
- ECMWF Thermal comfort indices and EFI Forecast
- UTCI data from Copernicus Data store
  Questions

- Other Concerns

REGIONAL WORKSHOP ON IMPACT-BASED FORECASTING

Training-of-Trainers and National Demonstration Planning for Temperature-Related Hazards

- Extreme temperature events are increasing globally in intensity, frequency, and duration due to climate change, with heatwaves among the most dangerous yet under-recognised hazards.
- A heatwave is a prolonged period of excessive heat, often with high humidity, where consecutive days of above-average temperature exceed the body's ability to cope, causing heat stress and increased mortality and morbidity.
- This session demonstrates how temperature forecasts can be used in Impact-Based Forecasting (IBF) by introducing key meteorological inputs, thermal indices, ensemble forecasts and EFI, and showing how forecast information across short-range, medium-range and S2S lead times can be translated into early, impact-based actions.



- **Meteorological Parameters**
  - Near-surface air temperature (2 m)
  - Humidity (relative humidity / vapour pressure)
  - Wind speed (10 m, adjusted to body level)
  - Radiation (shortwave and longwave components, mean radiant temperature)
- **Forecast Products**
  - **Deterministic forecasts** (single NWP run; mainly short-range)
  - **Ensemble forecasts** (multiple realizations capturing uncertainty; short- to medium-range)
  - **S2S forecasts** (weekly to monthly outlooks supporting preparedness and planning)
- **Thermal Comfort Indices**
  - Universal Thermal Climate Index (UTCI)
  - WBGT
  - Heat Index
  - Humidex
  - Wind chill Factor

Forecast Types, Lead Times, and Uncertainties

- **Forecast types**
  - **Short range (Day 0–2):** High confidence, operational warnings
  - **Medium range (Day 3–7/10):** Preparedness, early action
  - **Extended range (>10 days):** Planning and awareness
- **Why ensembles matter**
  - Temperature forecasts are **probabilistic by nature**
  - Ensembles:
    - Represent forecast spread
    - Capture extreme tails
    - Enable probability-based thresholds for IBF
  - Probabilistic UTCI forecasts show **skill up to ~10 days**, outperforming deterministic forecasts
  - Ensemble mean generally has higher skill than single runs

Forecast Uncertainties

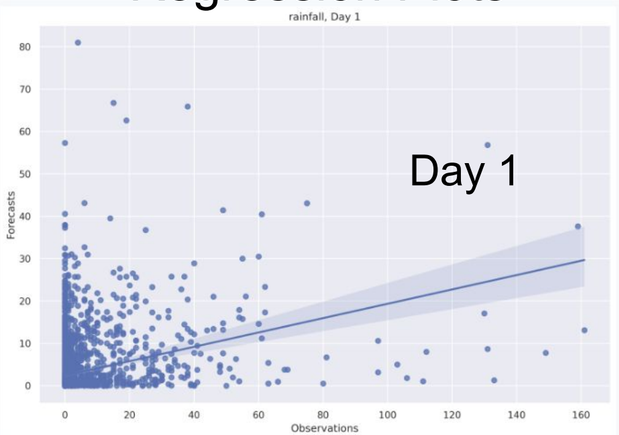
- **Why temperature forecasts are reliable**
  - **Temperature is among the most skillful NWP forecast variables**
  - Retains **useful skill from Day-1 through Day-10**
- **Main sources of uncertainty (temperature only)**
  - **Initial condition uncertainty** (errors in the analysed atmospheric state)
  - **Model physics uncertainty** (boundary-layer, radiation, surface processes)
  - **Land–surface representation** (soil moisture, urban effects, elevation)
- Verification comparison between **ECMWF HRES forecasts** and **station observations** using **regression plots** for two variables: **rainfall** and **minimum temperature**, at **Day-1 and Day-10 lead times.** Minimum temperature at Day-1 to day 10 shows a **strong correlation** between forecasts and observations indicating **high skill, low bias, and low uncertainty**
- Temperature forecasts provide a stable, high-confidence foundation for early warning and impact-based decision support, even at Day-7 to Day-10 lead times.

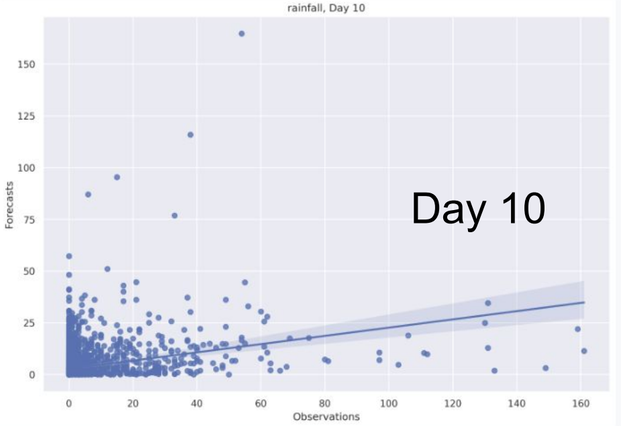
Data Exchange Platform

Forecast : ECMWF HRES Country-Myanmar, Station : Mandalay
Period : 1991-01-01 to 2020-12-31

Regression Plots

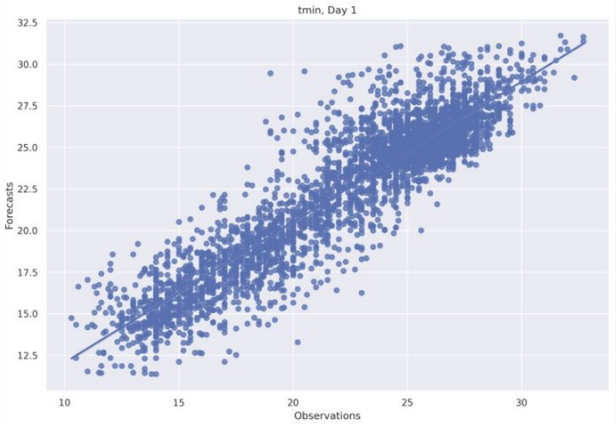
Parameter : Rainfall



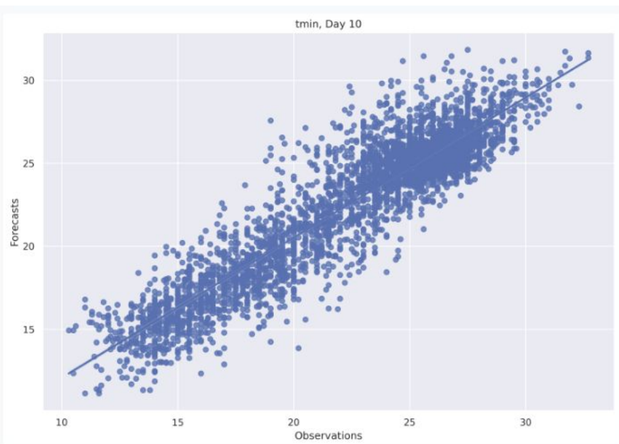


Parameter : Minimum Temperature

Day 1



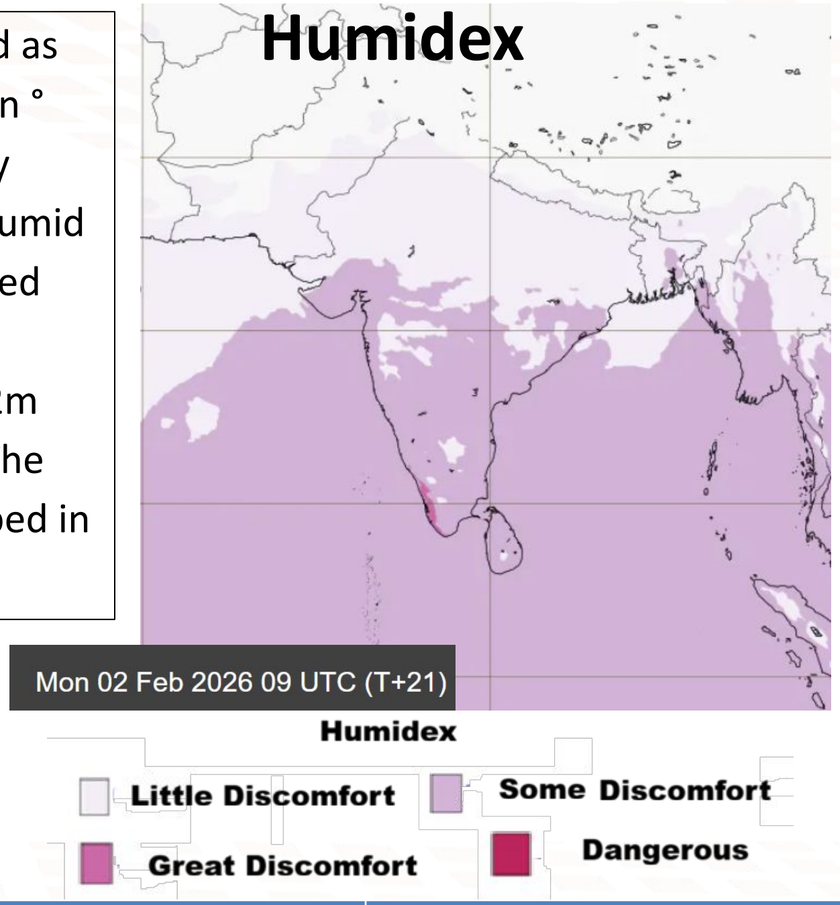
Day 10



Thermal Comfort Indices

Humidex

Humidex is defined as the temperature (in °C) the human body perceives in hot, humid weather. It is derived from 2m air temperature and 2m vapour pressure. The Humidex is described in terms of comfort.



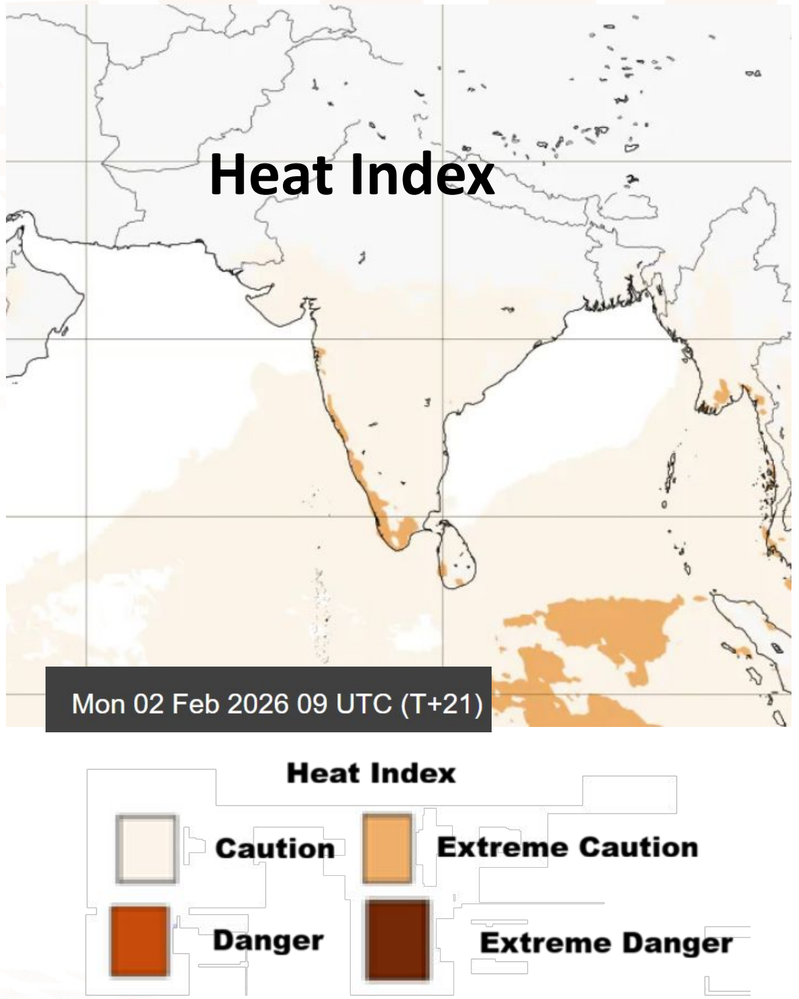
20 ≤ Humidex < 30	**Little discomfort**
30 ≤ Humidex < 40	Some discomfort
40 ≤ Humidex < 46	Great discomfort; avoid exertion
Humidex ≥ 46	Dangerous; possible heat stroke

Heat Index

Heat Index is defined as the temperature the human body perceives in shady conditions when perspiration is limited due to increased relative humidity.

It is derived from 2m air temperature and 2m relative humidity.

Heat index is described in terms of danger of heat-related illnesses.



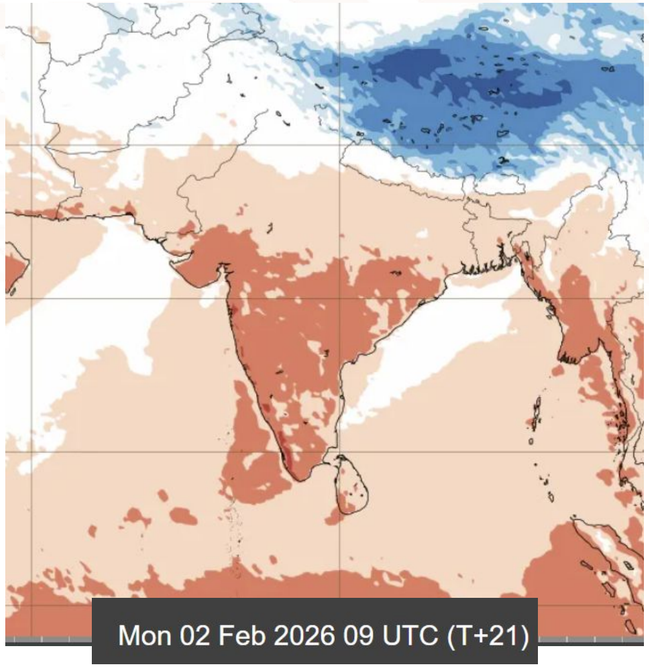
26.7 ≤ HI < 32.2	**Caution**
32.2 ≤ HI < 39.4	**Extreme caution**
39.4 ≤ HI < 51.1	**Danger**
HI ≥ 51.1	**Extreme danger**

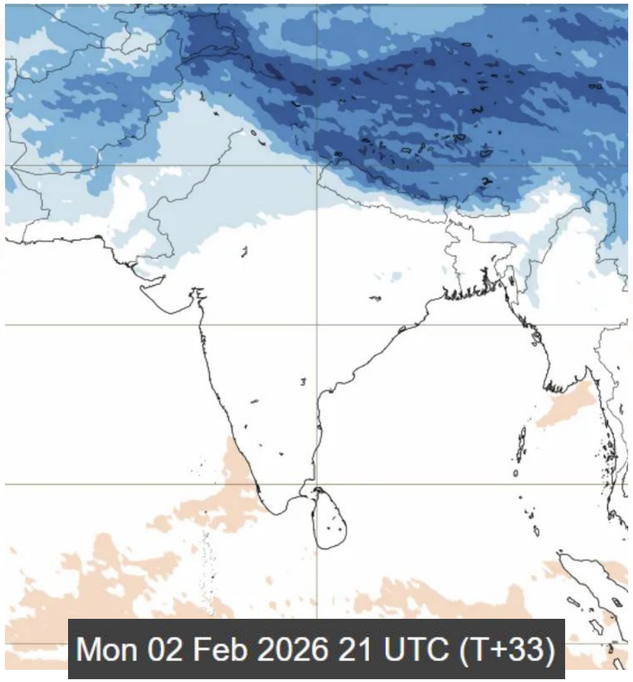
Universal Thermal Climate Index (UTCI)

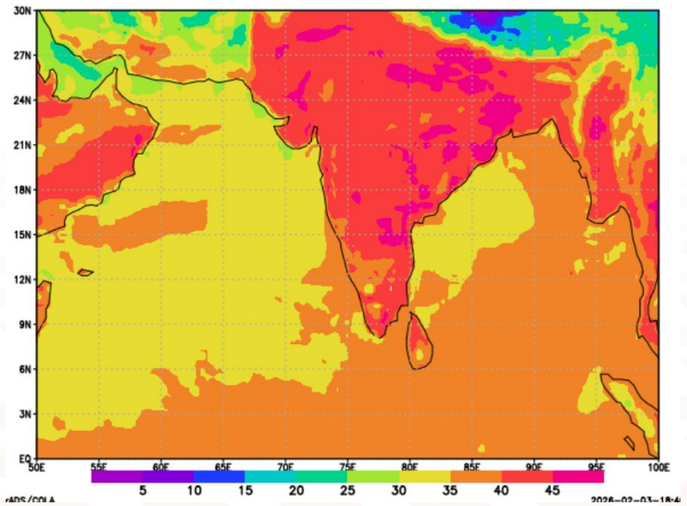
- Universal Thermal Climate Index is defined as the air temperature of a reference outdoor environment that would produce the same physiological response as the actual environment. The complex model combines a physiological model with temperature-adaptive clothing insulation.
- It is derived from 2m air temperature, 2m relative humidity, 10m wind speed, and Mean Radiant Temperature.
- The Universal Thermal Climate Index is described in terms of the human internal heat or cold stress experienced while trying to maintain a thermal equilibrium with the outdoor

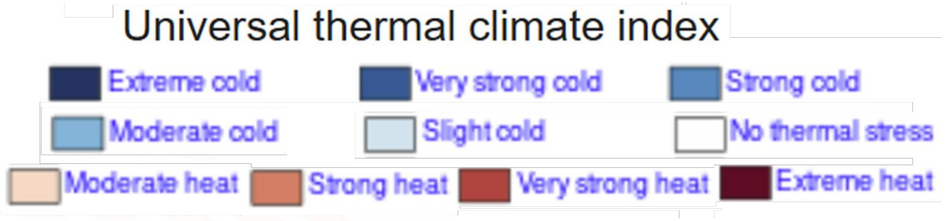
UTCI > 46	Extreme heat stress
38 < UTCI ≤ 46	Very strong heat stress
32 < UTCI ≤ 38	Strong heat stress
26 < UTCI ≤ 32	Moderate heat stress
9 < UTCI ≤ 26	No thermal stress
0 < UTCI ≤ 9	Slight cold stress
-13 < UTCI ≤ 0	Moderate cold stress
−27 < UTCI ≤ −13	Strong cold stress
−40 < UTCI ≤ −27	Very strong cold stress
UTCI < −40	Extreme cold stress

Thermal Comfort Indices









Maximum heat stress. The chart shows maximum heat stress as given by the UTCI in ERA5-HEAT on 25 May 2023

Wet Bulb Globe Temperature (WBGT)

- The Wet Bulb Globe Temperature represents the thermal environment to which an individual is exposed and its value gives a first approximation of the heat stress on a person. The Wet Bulb Globe Temperature is an International Organization for Standardization (ISO) screening method to establish the presence or absence of heat stress.
- Wet Bulb Globe Temperature (WBGT) is derived using the equation:

$$WBGT = 0.7 \cdot TNW + 0.2 \cdot Tg + 0.1 \cdot Ta$$

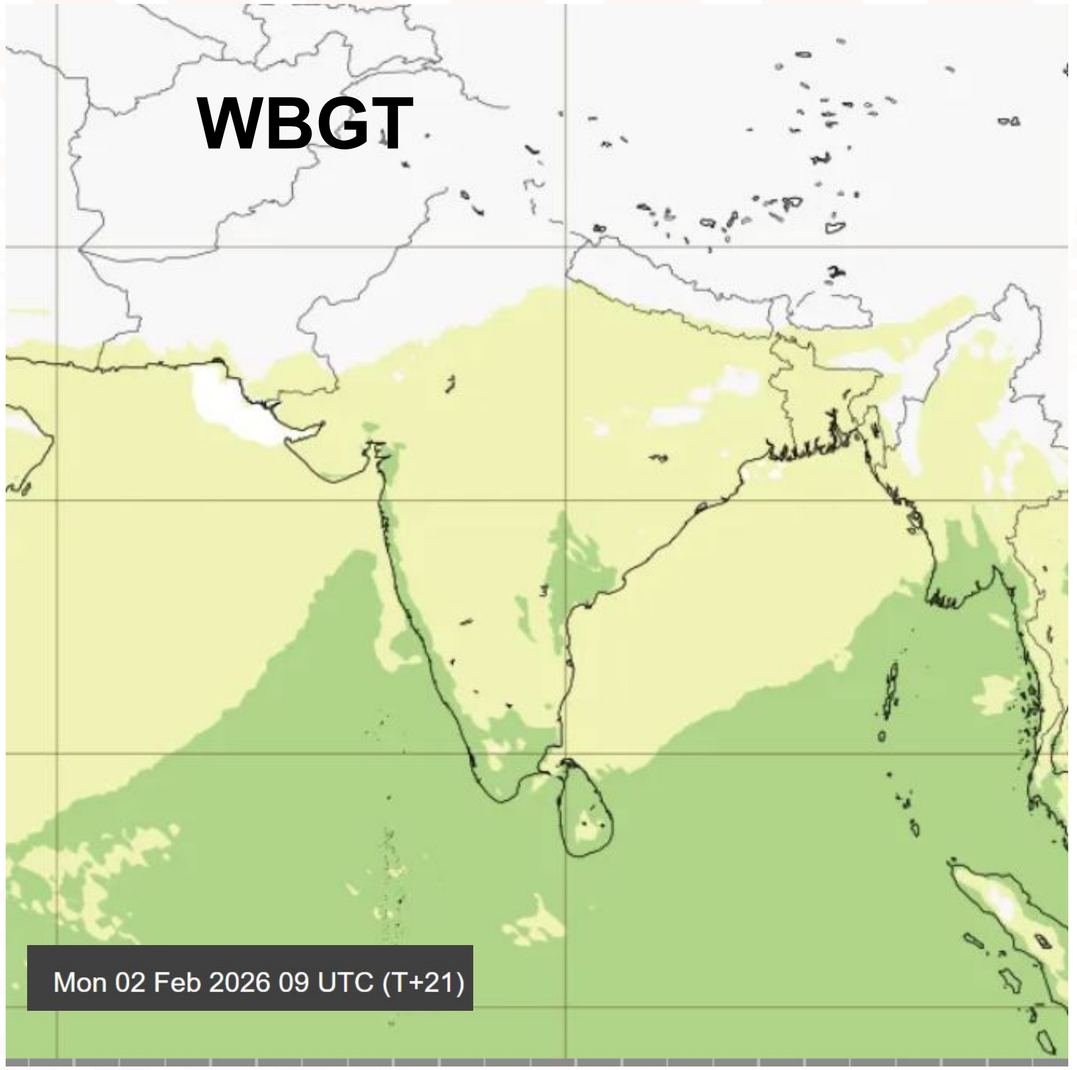
- Where:
  - Ta is the 2m air temperature (in °C)
  - Td is the 2m dew point temperature (in °C)
  - TNW is the the natural wet bulb temperature (in °C)
  - Tg is the globe temperature (in °C)

- The Wet Bulb Globe Temperature is described in terms of the heat-related risk to human health. Scales are generally tailored to

Global scale is:

20 ≤ WBGT < 25	**Low Risk**
25 ≤ WBGT < 31	Moderate risk
WBGT ≥ 31	High risk

Thermal Comfort Indices



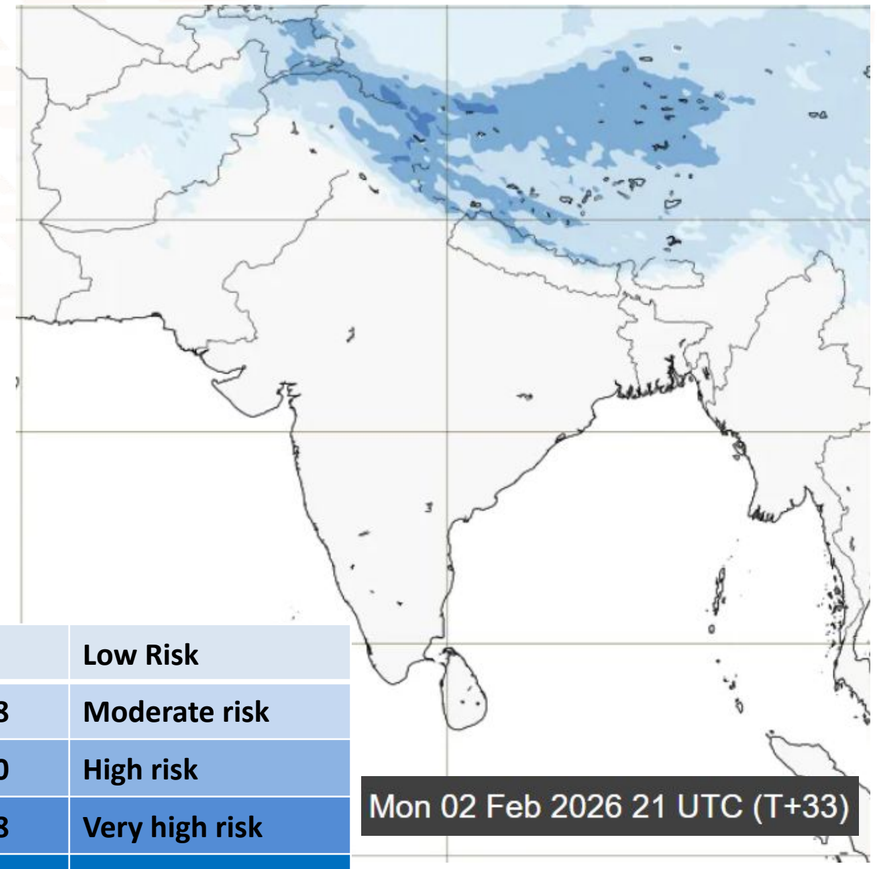
Wind Chill Factor (WCF)

- The Wind Chill Factor is defined as the air temperature of an equivalent environment that, under calm wind conditions, would entail the same skin surface heat loss to the environment as in the actual, windy, environment. It takes into account the assumptions of convective and radiative heat loss described in modern heat transfer theory, and assumes no impact from the sun. The equivalent environment considers a still airspeed of 1.34 ms^{-1} (average walking speed) and a wind speed at face level (i.e., it assumes that the adult is walking into the wind).
- Wind Chill Factor (in °C) is derived via the equation:

$$WCF = 13.12 + 0.6215 \cdot Ta - 11.37 \cdot va \cdot 0.16 + 0.3965 \cdot Ta \cdot 0.16 \cdot va$$

- Where:
- Ta is the 2m air temperature Ta (in °C).
- va is the 10m wind speed (in m/s).

- The Wind Chill Factor is described in terms of the risk incurred by human skin, based on the rate of heat loss caused by exposure to wind and low temperatures.



0 ≥ WCF > -10	Low Risk
-10 ≥ WCF > -28	Moderate risk
-28 ≥ WCF > -40	High risk
-40 ≥ WCF > -48	Very high risk
-48 ≥ WCF > -55	Severe risk
WCF ≤ -55	Extreme risk

Extreme Forecast Index (EFI)
2 m temperature

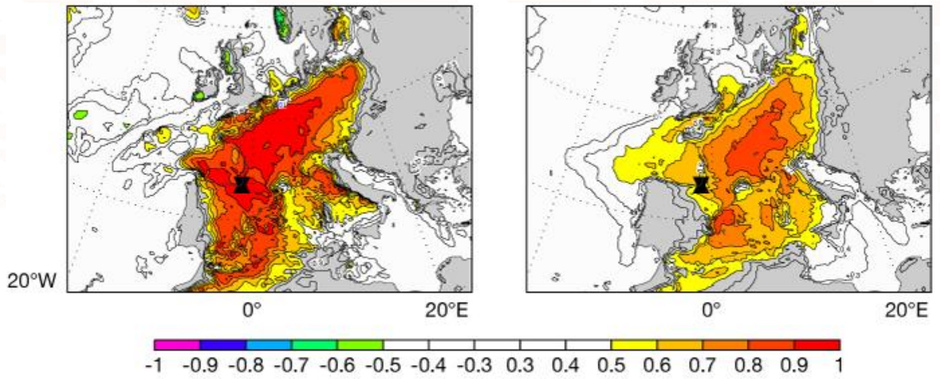
- The Extreme Forecast Index (EFI) is used to indicate the potential for hot weather. EFI values from 0.5 to 1 can be regarded as signifying that unusual weather is likely.
- Experience suggests :
  - EFI values between 0.5 to 0.8 (irrespective of sign) can be generally regarded as signifying that □“unusual□” weather is likely,
  - EFI values above 0.8 (irrespective of sign) as usually signifying that □very unusual□ or extreme weather is likely.

- **Positive EFI (0 → +1): unusually warm / hot**
  - **+0.6 to +0.8**: **Strong heat anomaly** (high confidence of unusual warmth)
  - **> +0.8**: **Very extreme heat** relative to climatology (rare event)
- **Negative EFI (0 → −1): unusually cool / cold**
  - **−0.6 to −0.8**: **Strong cold anomaly**
  - **< −0.8**: **Very extreme cold**

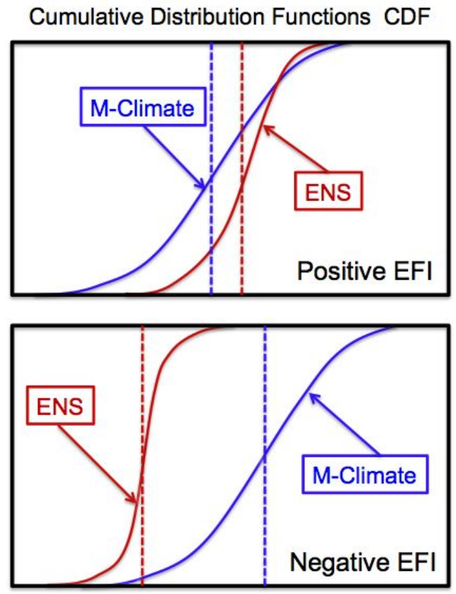
European heatwaves in June 2022

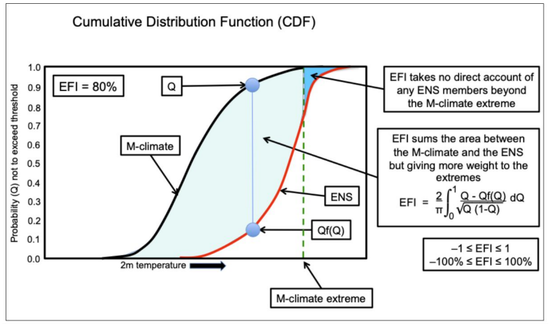
18 June 2022 in forecasts (00 UTC on 18 June initial condition)

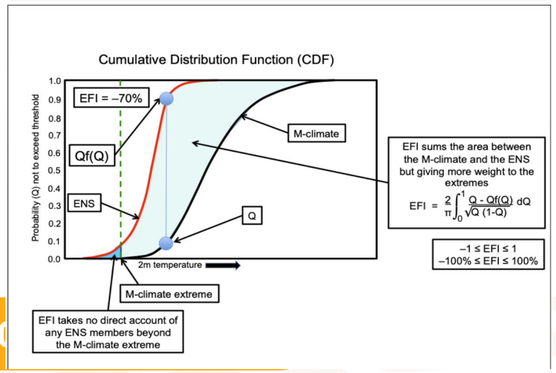
18 June 2022 in forecasts (00 UTC on 12 June initial condition)



The hot area was already indicated fairly accurately six days in advance.







UTCI Forecast Skill

- **UTCI forecasts are skilful up to ~10 days** when driven by ECMWF ensemble predictions
- **Probabilistic UTCI forecasts outperform deterministic forecasts**, particularly for extreme heat and cold stress
- **Useful deterministic skill (Anomaly Correlation Coefficient (ACC) > 0.6)** is typically maintained up to **Day-4 to Day-6**, depending on region
- **Probabilistic skill (Continuous Ranked Probability Skill Score (CRPSS), Brier Skill Score (BSS))** remains **positive up to Day-8 to Day-10**, supporting preparedness decisions
- **Extreme stress thresholds** (e.g. UTCI > 32 °C, UTCI < −13 °C) are **well captured by ensemble forecasts**
- **Ensemble-mean UTCI** shows **higher predictability** than single deterministic runs
- UTCI skill **inherits high temperature forecast skill**, with additional uncertainty from **wind and radiation**
- Main uncertainty sources: **wind speed**, **radiation/clouds**, and **non-linear error propagation**
- Overall, UTCI provides a **strong basis for medium-range heat- and cold-health early warning**

Pappenberger, at al., 2015. Global forecasting of thermal health hazards: the skill of probabilistic predictions of the Universal Thermal Climate Index (UTCI). *International journal of biometeorology*, *59*(3), pp.311-323.

WBGT Forecast Skill

- **WBGT forecasts show good short-range accuracy**, particularly for **Day-1 to Day-3**, supporting operational decision-making
- **Typical WBGT forecast error is ~0.6–1.0 °C**, which is **comparable to measurement uncertainty** of WBGT instruments
- **Highest skill occurs during dangerous heat conditions** (WBGT > 31–32 °C), when health impacts are most critical
- WBGT forecasts are **more reliable for categorical thresholds** (flag levels) than for exact values
- **Ensemble-based WBGT forecasts** improve detection of extreme heat stress compared to single deterministic methods
- **Wind speed and radiation are the dominant uncertainty sources**; small wind errors can shift WBGT by **one or more risk categories**
- Accounting for **surface roughness and local wind reduction** significantly improves WBGT forecast accuracy
- WBGT forecasts provide a **useful planning tool**, but **on-site observations remain essential** in complex microclimates

Clark et al., 2024: ***The Development and Accuracy Assessment of Wet Bulb Globe Temperature Forecasts*****, Weather and Forecasting, 39, 403–414**

EFI Forecast Skill for Extreme Temperature

- **Ensemble probability information** provides a strong basis for forecasting **extreme high and low temperature events**
- **EFI warning signals for extreme high (summer) and extreme low (winter) temperatures** showed **good agreement with automatic station observations**
- **Optimal EFI thresholds** identified as:
  - **+0.7 to +0.8** for extreme high temperatures
  - **−0.8** for extreme low temperatures
- **Strong forecast skill is observed at 2-day lead time**, demonstrating effective early warning capability
- Strong EFI forecast skill, measured by Relative Operating Characteristic (ROC) and Threat Score (TS), is evident at short- to medium-range lead times (1–10 days), with optimal warning thresholds identified through analysis.
- Forecast performance varies by region and lead time, reflecting differences in 2-m temperature predictability and ensemble forecast quality
- **Forecast accuracy decreases with increasing lead time**, consistent with ensemble predictability limits
- **High-resolution ensemble-based EFI outperforms global ensemble-based EFI**, providing:
  - Stronger warning signals
  - More detailed and realistic spatial distributions of extreme temperature risk

Zhang et al., 2025. Development of an Extreme Temperature Forecast Index from Convection Permitting Ensemble Forecasts. *Journal of Meteorological Research*, *39*(5), pp.1316-1329.

Strengths of Temperature Forecasts for IBF

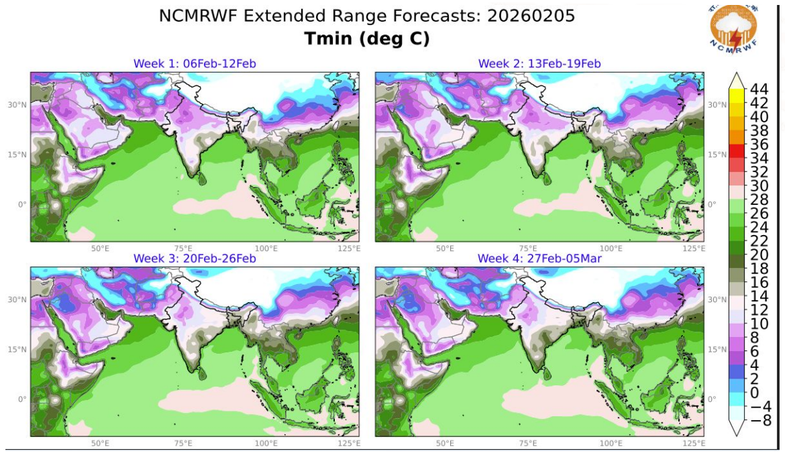
✔ Higher inherent predictability than rainfall
✔ Lower spatial variability
✔ Consistent ensemble skill across regions
✔Temperature-based IBF retains useful skill at medium to extended lead times (≈5–10 days), supporting early warning and preparedness.

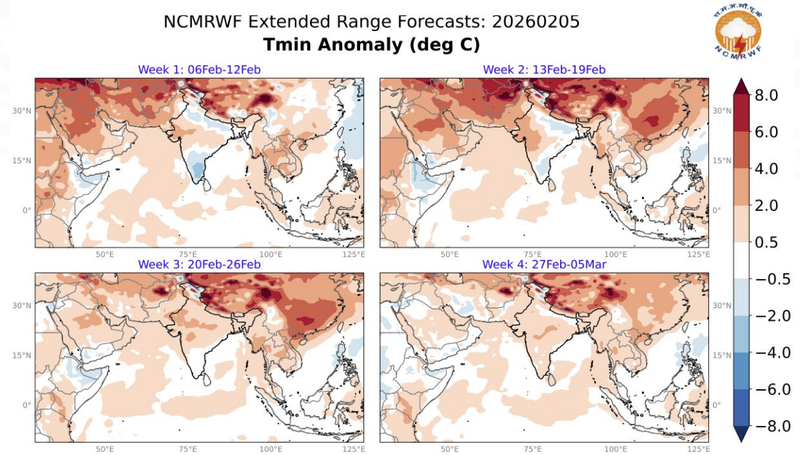
For IBF

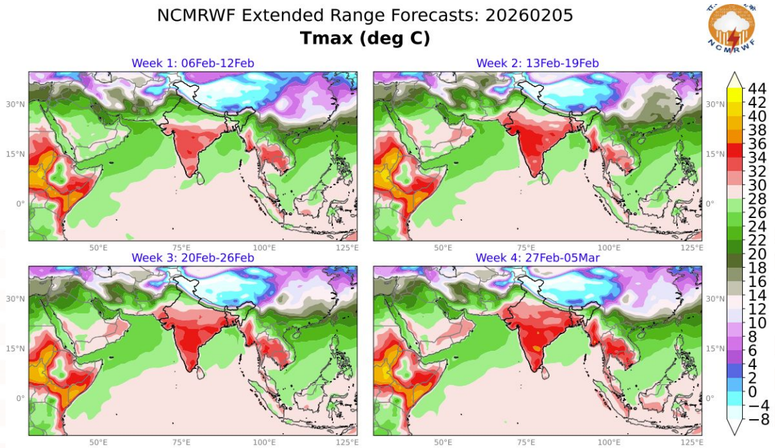
- Enables:
  - Heat–health early warning
  - Worker safety advisories
  - Energy demand alerts
  - Urban heat risk communication

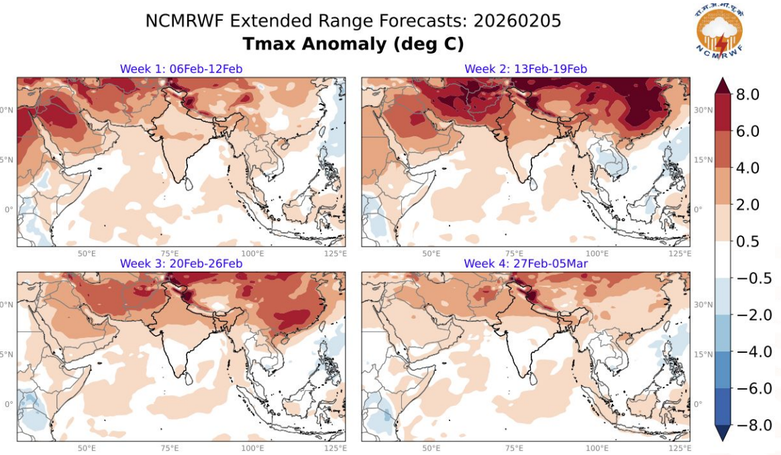
NCMRWF/BCWC Extended Range FC
Tmin /Tmax

Extended range



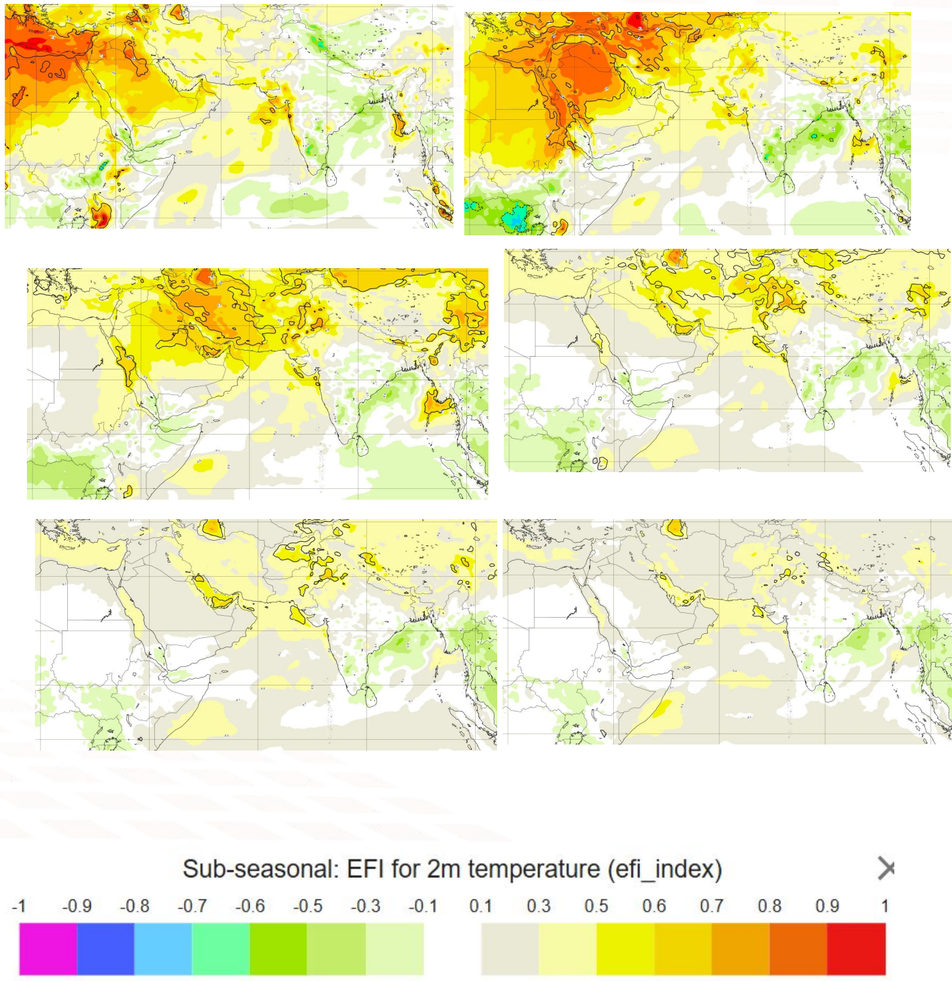






Weekly mean:
https://nwp.ncmrwf.gov.in/region/bimstec-region/weeklymean

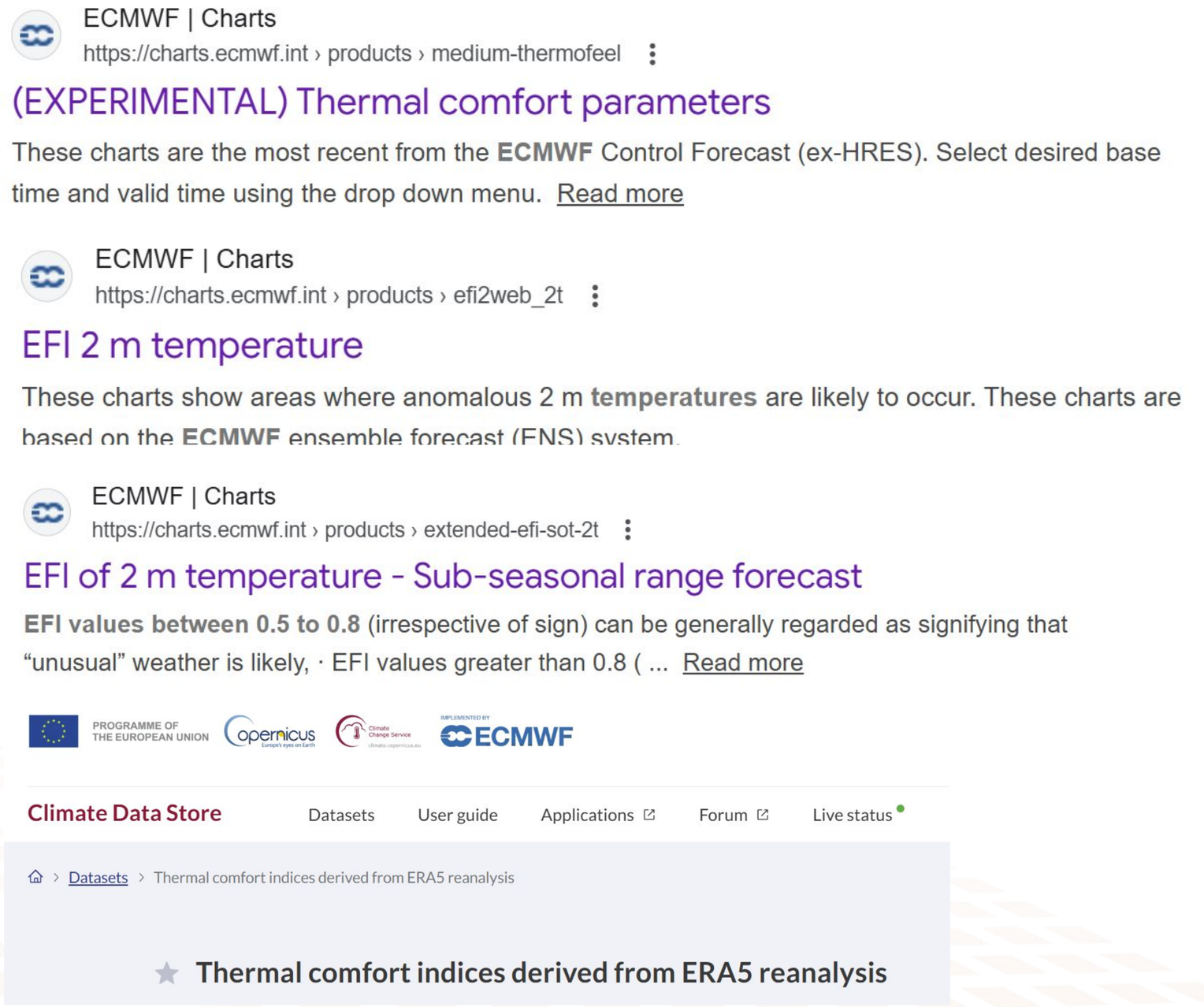
ECMWF s2s EFI
2m Temperature FC



Hand on Session

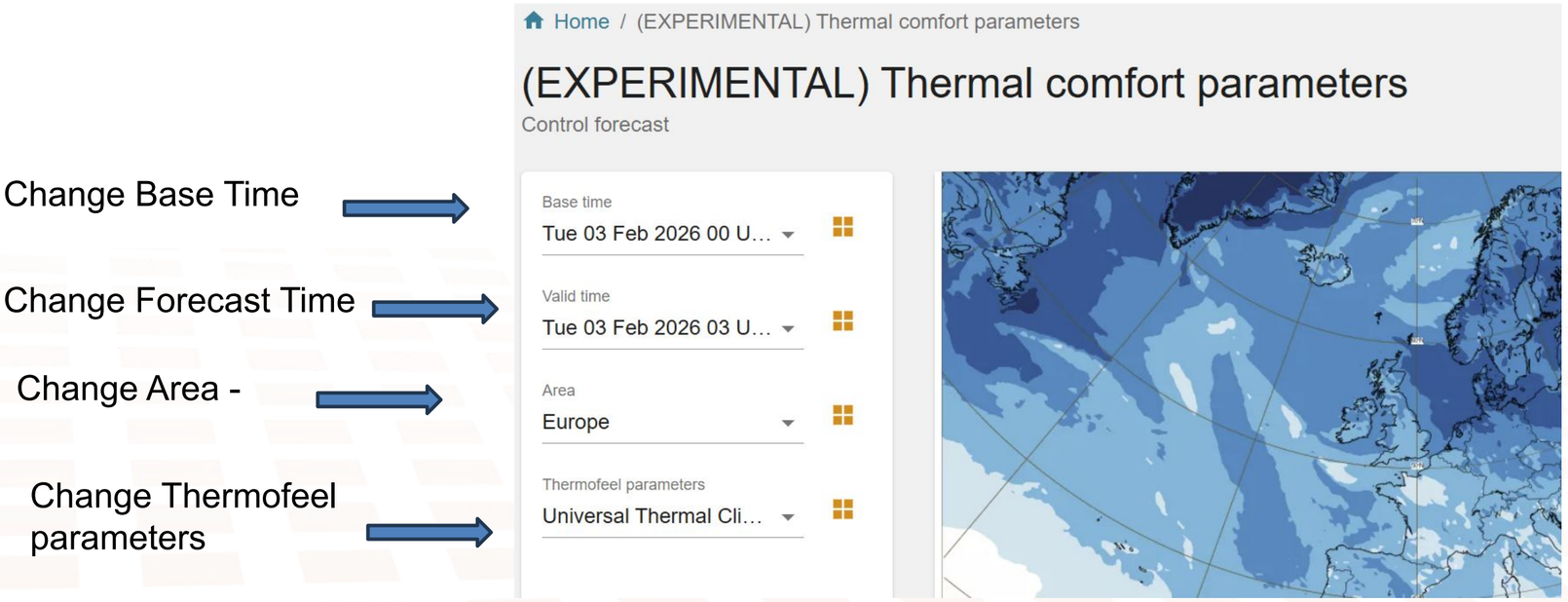
- ECMWF Thermal comfort indices and EFI Forecast

- UTCI data from Copernicus Data store



ECMWF Thermal comfort parameters

- In Google – type ECMWF thermal comfort parameters



Home / (EXPERIMENTAL) Thermal comfort parameters

(EXPERIMENTAL) Thermal comfort parameters

Control forecast

Tue 03 Feb 2026 00 UTC
Mon 02 Feb 2026 12 UTC
Mon 02 Feb 2026 00 UTC
Sun 01 Feb 2026 12 UTC
Sun 01 Feb 2026 00 UTC
Sat 31 Jan 2026 12 UTC
Sat 31 Jan 2026 00 UTC
Fri 30 Jan 2026 12 UTC
Fri 30 Jan 2026 00 UTC
Thu 29 Jan 2026 12 UTC
Thu 29 Jan 2026 00 UTC

Change Base Time

(EXPERIMENTAL) Thermal comfort parameters

Mon 02 Feb 2026 15 UTC (T+3)
Mon 02 Feb 2026 18 UTC (T+6)
Mon 02 Feb 2026 21 UTC (T+9)
Tue 03 Feb 2026 00 UTC (T+12)
Tue 03 Feb 2026 03 UTC (T+15)
Tue 03 Feb 2026 06 UTC (T+18)
Tue 03 Feb 2026 09 UTC (T+21)
Tue 03 Feb 2026 12 UTC (T+24)
Tue 03 Feb 2026 15 UTC (T+27)
Tue 03 Feb 2026 18 UTC (T+30)
Tue 03 Feb 2026 21 UTC (T+33)
Wed 04 Feb 2026 00 UTC (T+36)

Change Forecast Time

Home / (EXPERIMENTAL) Thermal comfort parameters

(EXPERIMENTAL) Thermal comfort parameters

Central America
South America
Eurasia
Southern Asia
Western Asia
Eastern Asia
South East Asia & Indonesia
Middle East & India
Africa
Southern Africa
Australasia
West Tropic

Change Area –Choose South Asia or Middle East & India

Change Thermofeel parameters

UTCI
WBGT
HI
Humidex
Wind chill Factor

Home / (EXPERIMENTAL) Thermal comfort parameters

(EXPERIMENTAL) Thermal comfort parame

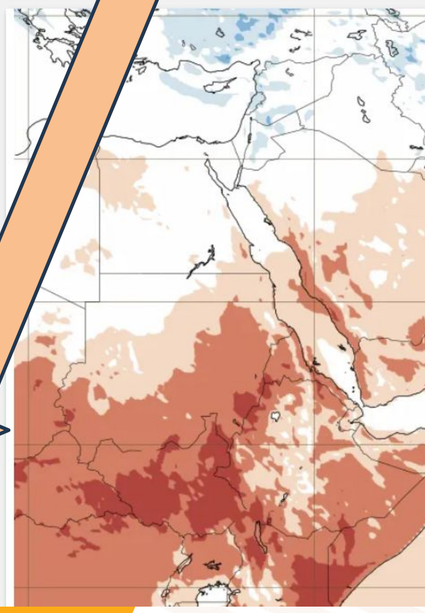
Control forecast

Base time
Mon 02 Feb 2026 00 …

Valid time
Tue 03 Feb 2026 09 U…

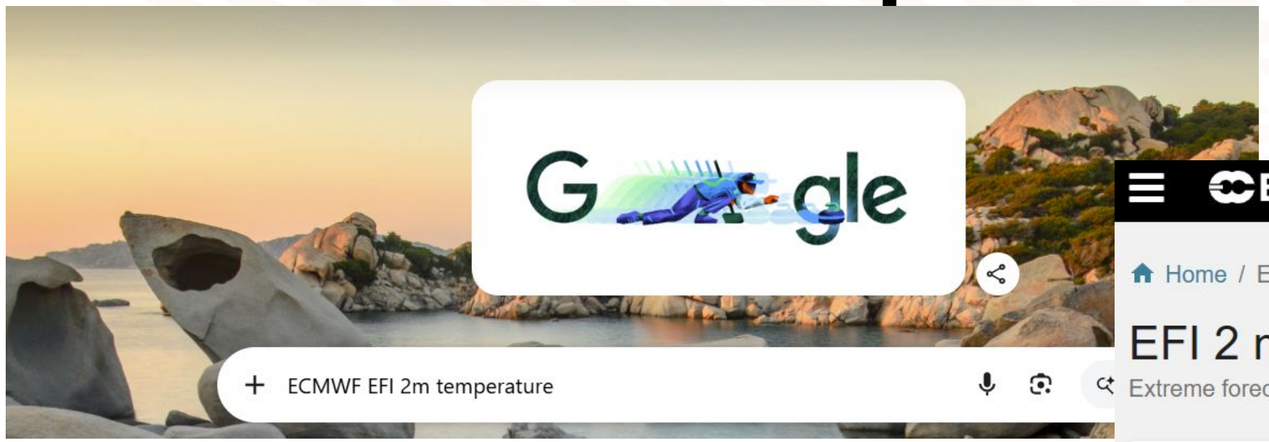
Area
Middle East & India

Universal Thermal Climate Index
Wet Bulb Global Temperatur
Heat index
Humidex
Wind Chill Factor

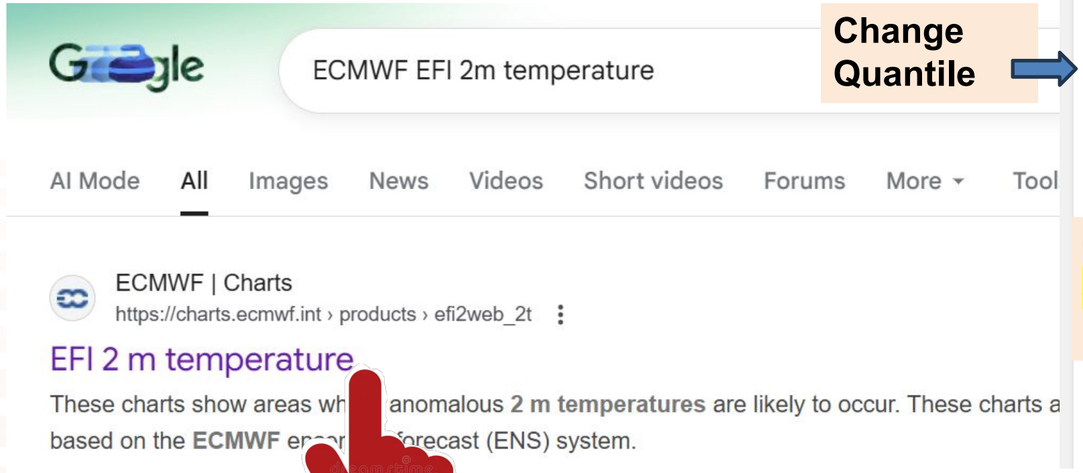


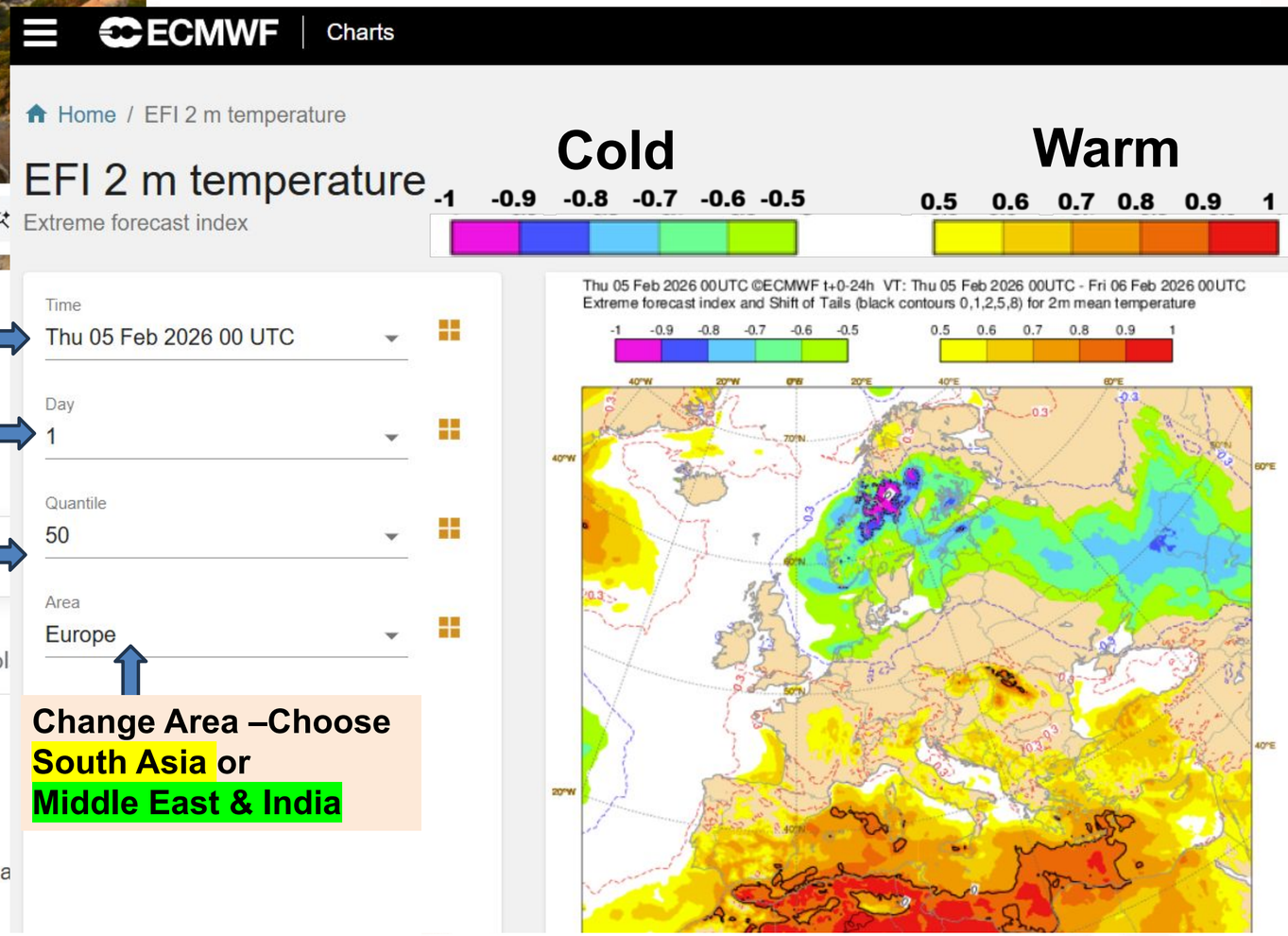
ECMWF EFI 2m Temperature

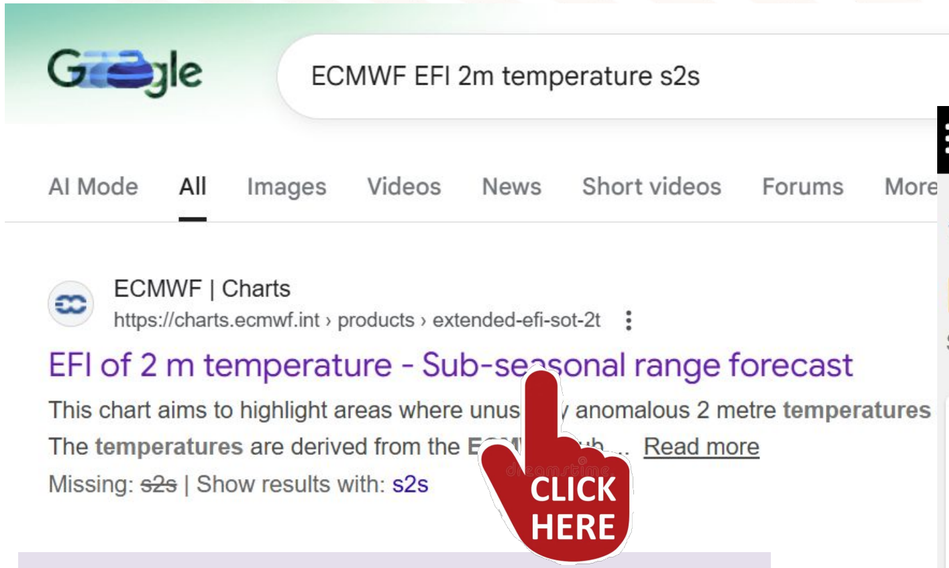
EFI values between 0.5 to 0.8 (irrespective of sign) can be generally regarded as signifying that "unusual" weather is likely,
EFI values greater than 0.8 (irrespective of sign) usually signifies that "very unusual" or extreme weather is likely.



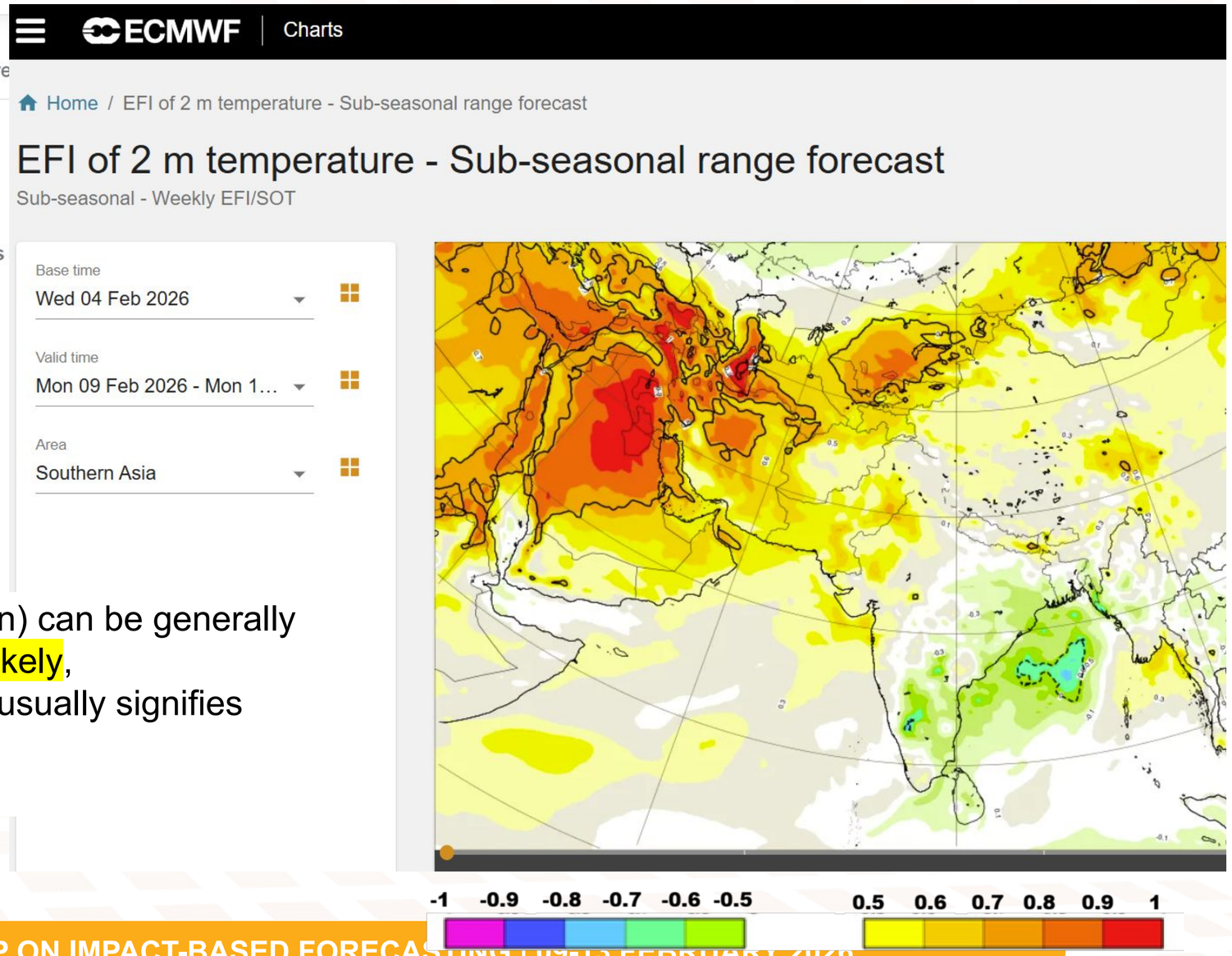
In Google – type ECMWF EFI 2m Temperature







In Google – type ECMWF EFI 2m Temperature s2s



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Home / EFI 2 m temperature

EFI 2 m temperature

Extreme forecast index

Time

Thu 05 Feb 2026 00 UTC

Day

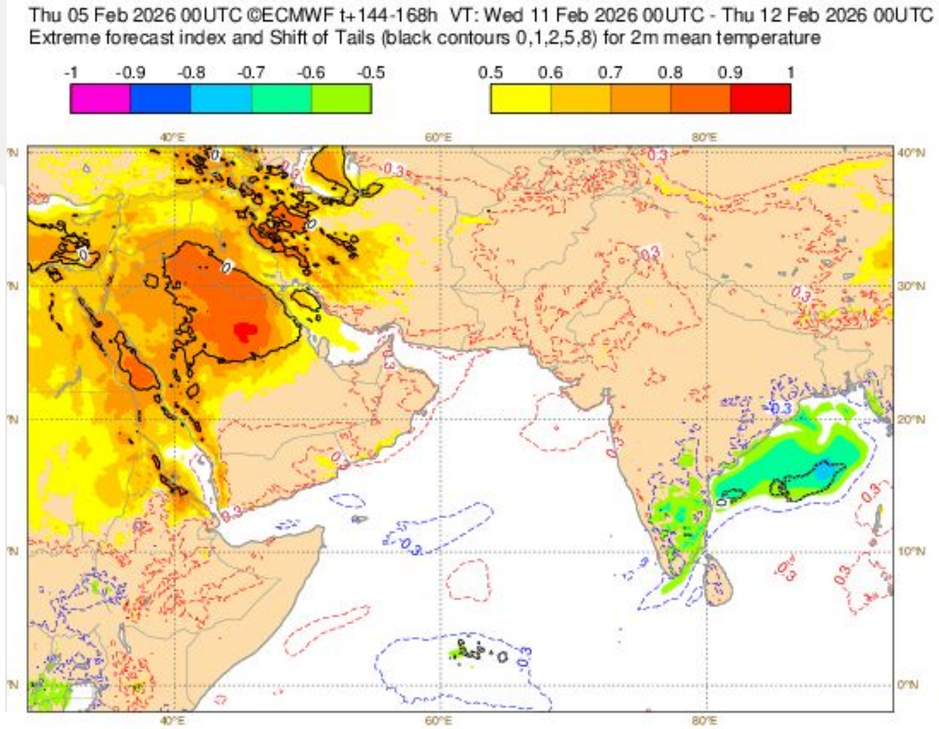
7

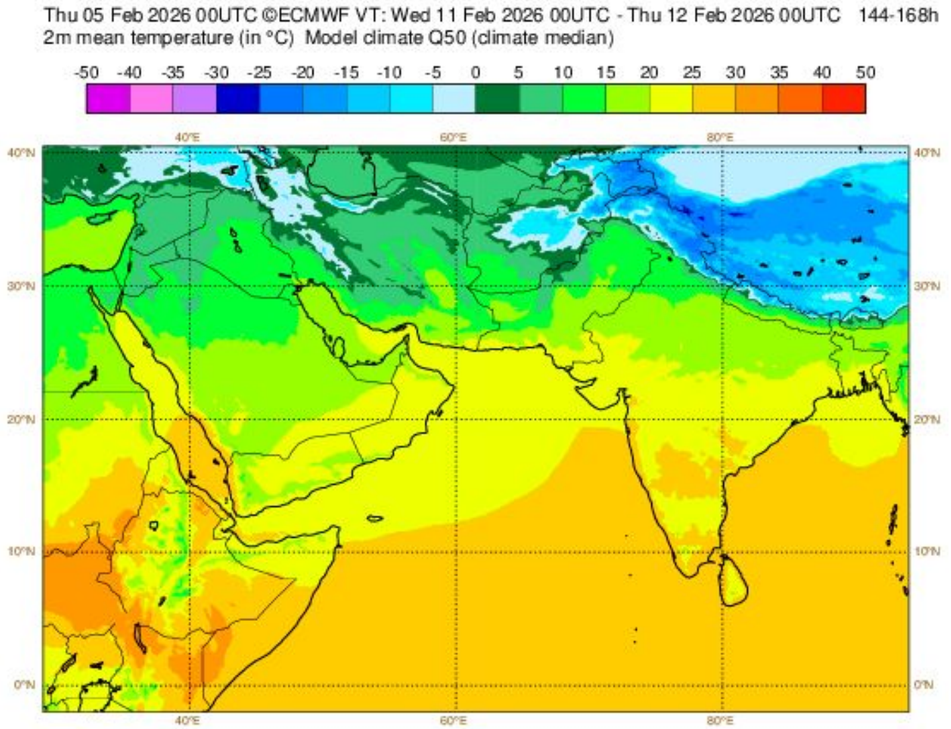
Quantile

50

Area

Middle East and India

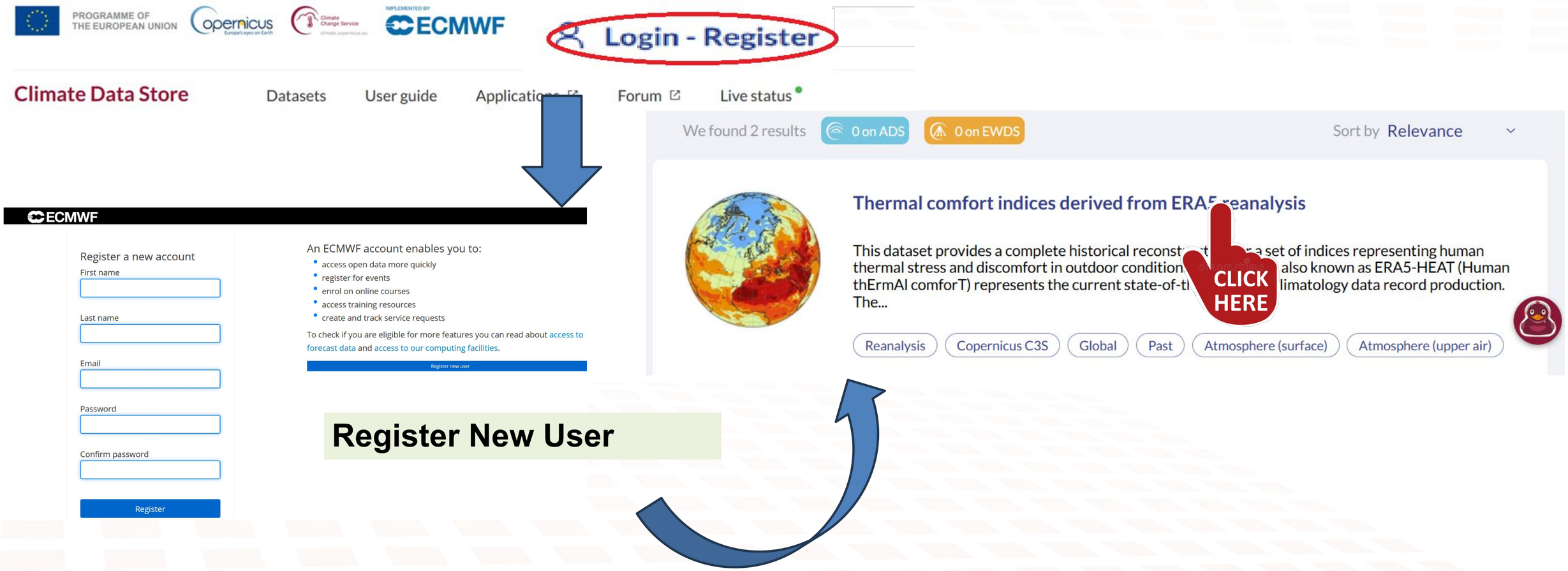




Climate Data Store

https://cds.climate.copernicus.eu › derived-utci-historical

Thermal comfort indices derived from ERA5 reanalysis



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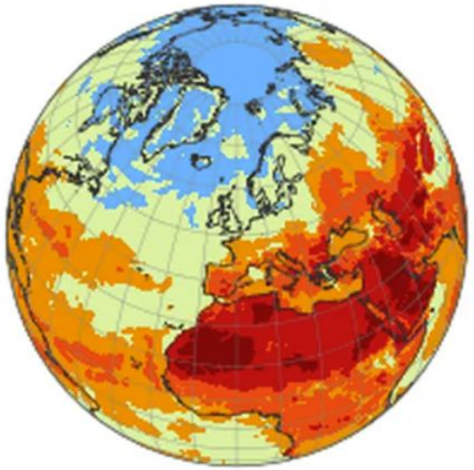
Thermal comfort indices derived from ERA5 reanalysis

Overview | Download | Documentation

This dataset provides a complete historical reconstruction for a set of indices representing human thermal stress and discomfort in outdoor conditions. This dataset, also known as ERA5-HEAT (Human thErmAl comforT) represents the current state-of-the-art for bioclimatology data record production.



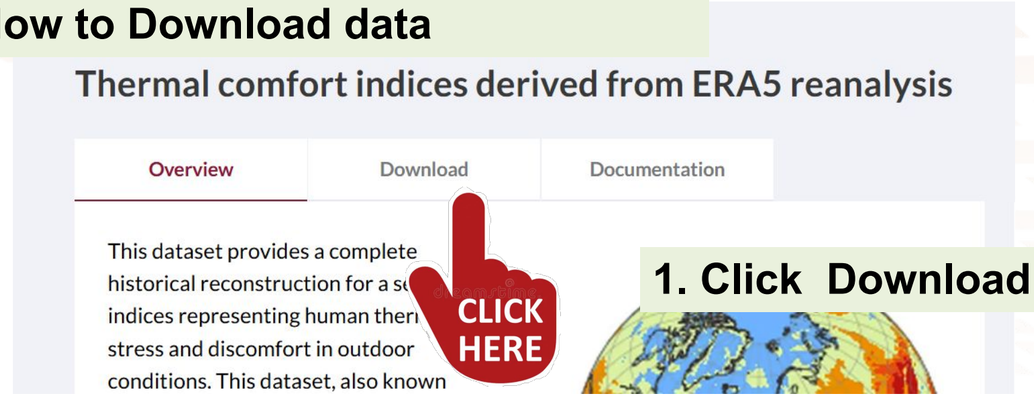
The dataset is organised around two main variables:

- the mean radiant temperature (MRT)
- the universal thermal climate index (UTCI)

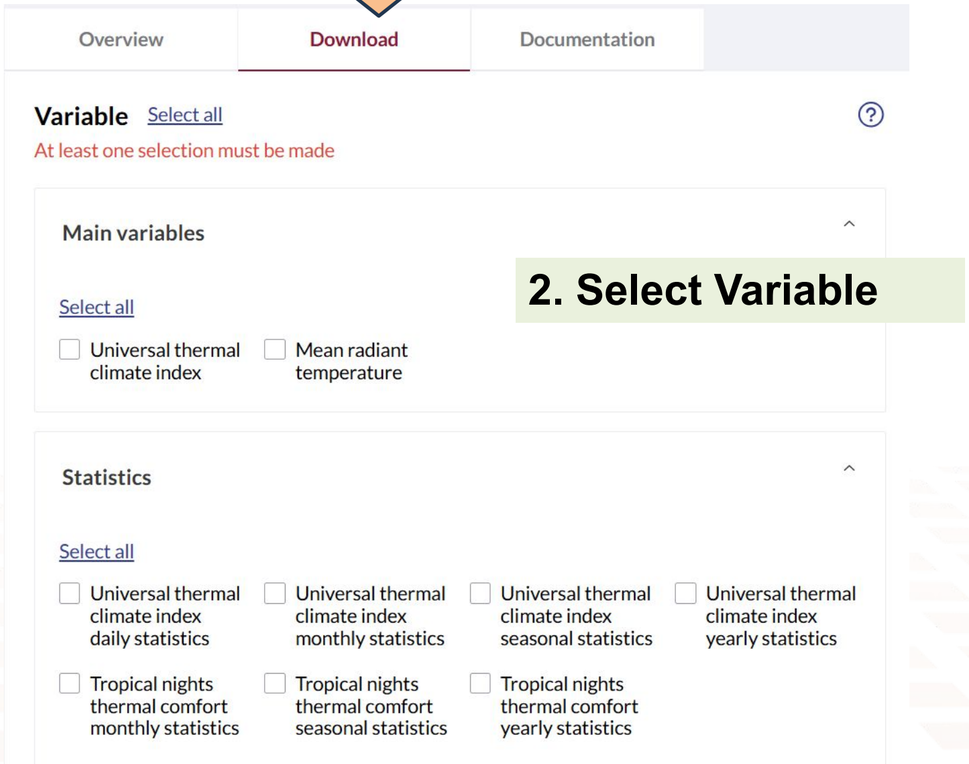
Data description

Data type	Gridded
Projection	Regular latitude-longitude grid
Horizontal coverage	Global except for Antarctica (90N-60S, 180W-180E)
Horizontal resolution	0.25° x 0.25°
Vertical resolution	Surface level
Temporal coverage	From January 1940 to near real time for the most recent version.
Temporal resolution	Hourly data, with additional daily, monthly, seasonal and yearly statistics.
File format	NetCDF
Conventions	Climate and Forecast (CF) Metadata Convention v1.6

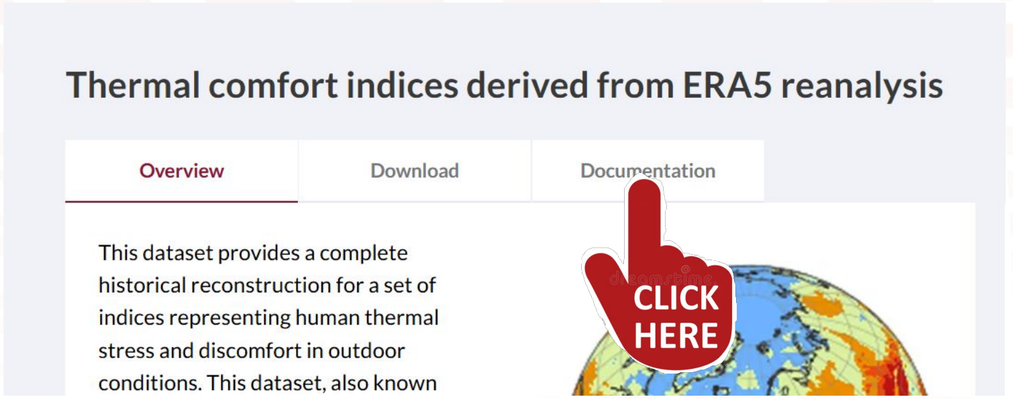
How to Download data



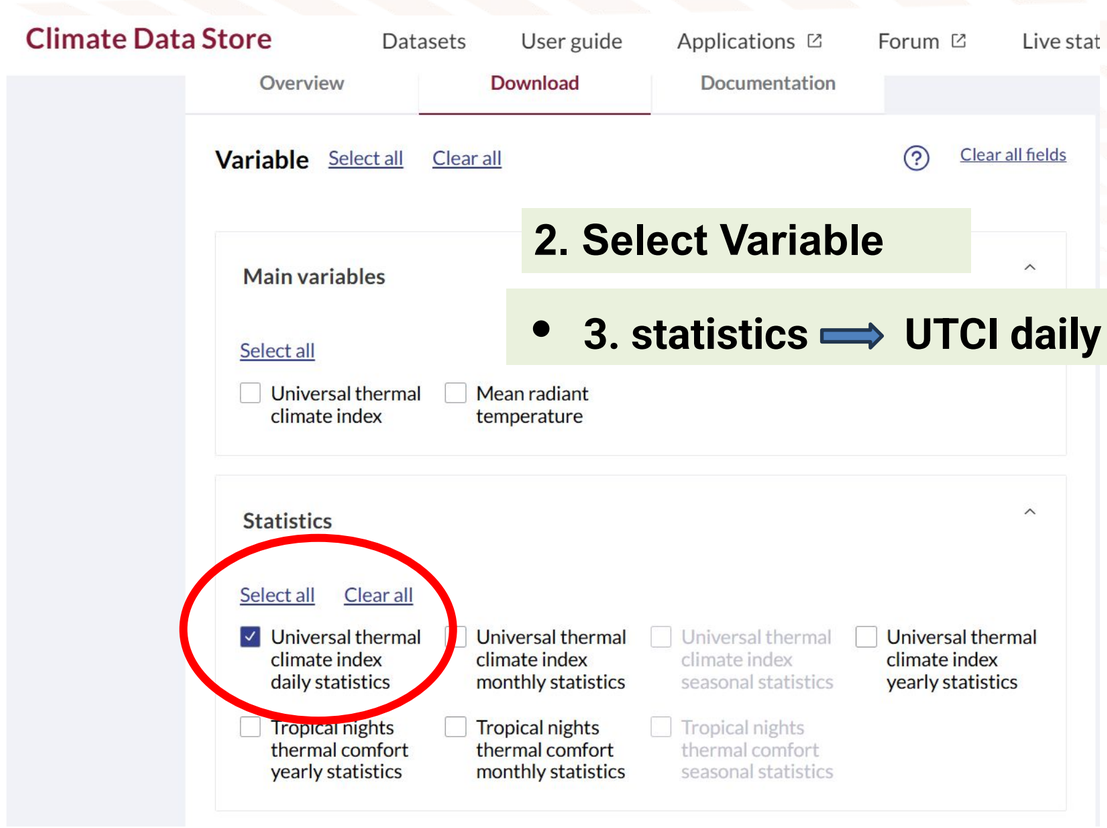
1. Click Download

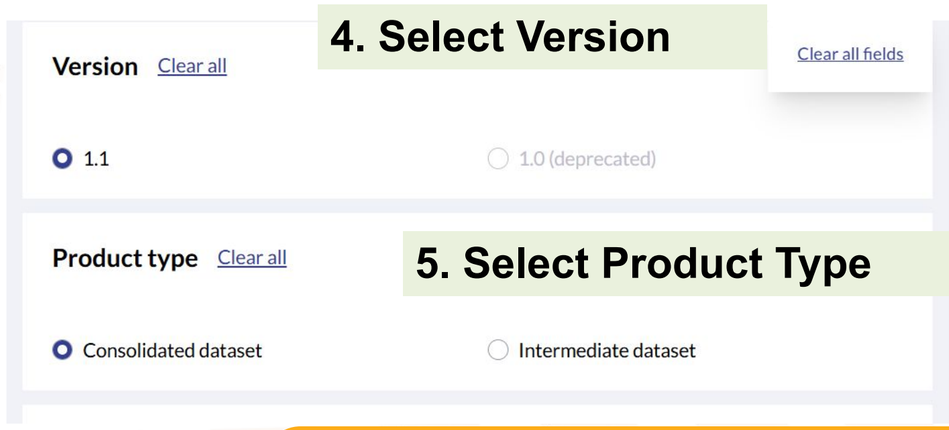


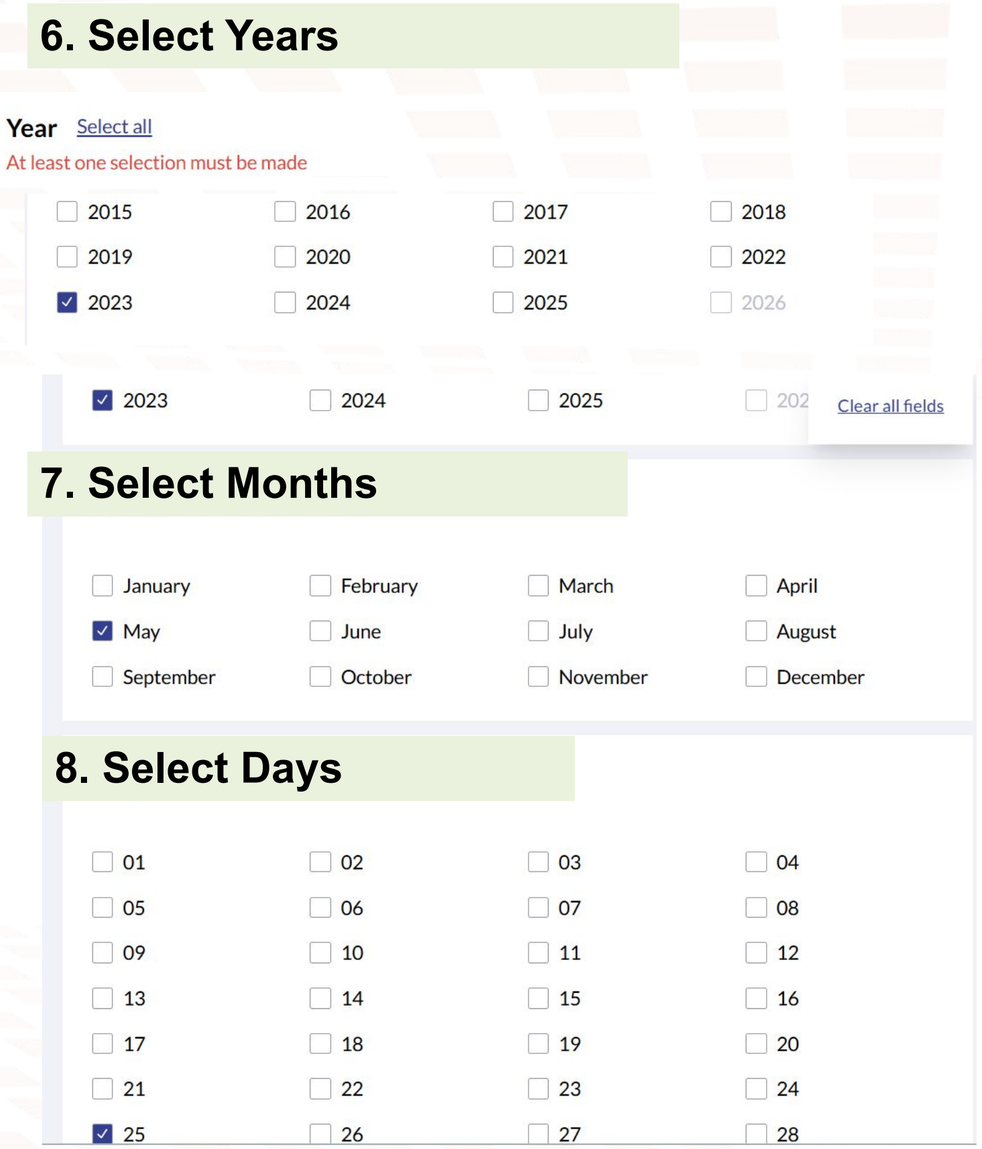
2. Select Variable



*** Click Documentation to learn more about data**


Climate Data Store
Datasets
User guide
Applications
Forum
Live stat
Overview
Download
Documentation
Variable
Select all
Clear all
Clear all fields
2. Select Variable
Main variables
Select all
Universal thermal climate index
Mean radiant temperature
• 3. statistics ⟹ UTCI daily statistic
Statistics
Select all
Clear all
Universal thermal climate index daily statistics
Universal thermal climate index monthly statistics
Universal thermal climate index seasonal statistics
Universal thermal climate index yearly statistics
Tropical nights thermal comfort yearly statistics
Tropical nights thermal comfort monthly statistics
Tropical nights thermal comfort seasonal statistics


4. Select Version
Version
Clear all
Clear all fields
1.1
1.0 (deprecated)
Product type
Clear all
5. Select Product Type
Consolidated dataset
Intermediate dataset


6. Select Years
Year
Select all
At least one selection must be made
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2023
2024
2025
Clear all fields
7. Select Months
January
February
March
April
May
June
July
August
September
October
November
December
8. Select Days
01
02
03
04
05
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09
10
11
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22
23
24
25
26
27
28

8. Select Geographic Area

Geographical area

Clear all fields

Whole available region

With this option selected the entire available area will be provided

Sub-region extraction

North: 30

West: 50

East: 100

South: b

Geographical area

10. Download Data

Your requests

All | Accepted | Running | Failed | Successful

Product	Submission	End	Status	Actions
Thermal comfort indices derived from ERA5 reanalysis > Details	2026-02-03 08:04:58pm		Running	Check status
Thermal comfort indices derived from ERA5 reanalysis > Details	2026-02-03 06:37:09pm	2026-02-03 06:37:22pm	Successful 00:00:12	Download 234.08 KB

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✓ Accepted

9. Submit form

Corresponding API request

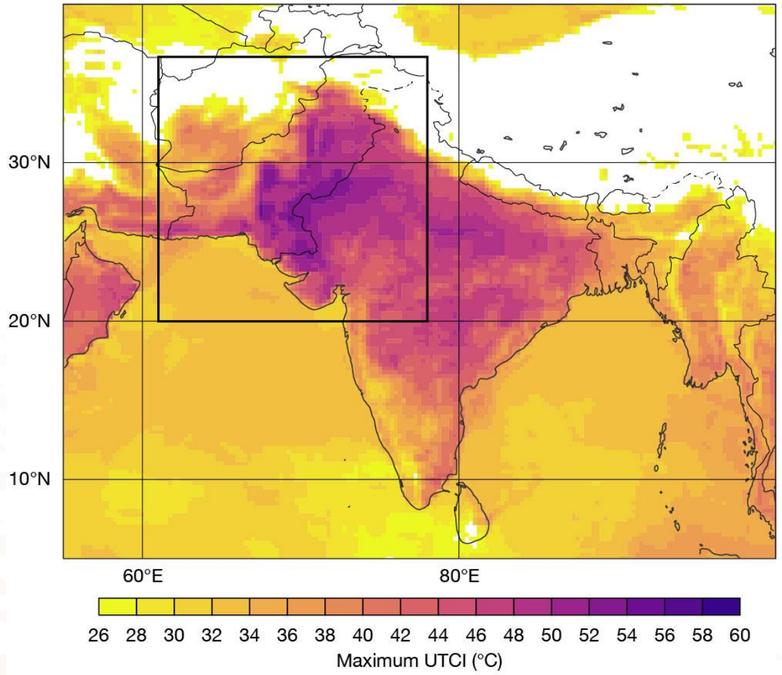
</> Show API request code

mit form

Clear all fields

CLICK HERE

a map of the maximum UTCI from ERA5 on 14 May 2022 at the peak of the heatwave, which saw UTCI values of up to 55°C.



IBF Matrix for Cold Extremes

UTCI (Cold stress)	Wind Chill (WCT)	EFI (Negative)	EFI (Wind)	Interpretation	Action
Very strong / Extreme	**Severe**	High	High	**Rare, dangerous cold stress** (high impact + unusual + windy)	**Emergency**
strong	**Moderate**	High	Low	**Unusual cold, limited wind** (cold anomaly, moderate impact)	**Preparedness**
Moderate	**Severe**	Low	High	**Expected wind chill** (impact driven by wind exposure)	**Safety advice**
Slight / None	**Moderate**	High	Low	**low impact**	**Monitor**

IBF Matrix for Heat Extremes

UTCI (Warm stress)	WBGT Risk Level	EFI (Positive)	Interpretation	Action
Very strong heat stress	**High risk**	**High**	**Rare, dangerous heat stress** (severe impact)	**Emergency response**
Very strong heat stress	**High risk**	**Moderate**	**Impact-driven heat hazard**	**Sector alerts & protective actions**
Strong heat stress	**Moderate risk**	**High**	**Unusual heat with significant impacts**	**Preparedness**
Moderate heat stress	**Moderate risk**	**High**	**Low impact**	**Monitor**

ANY QUESTIONS?

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Partnership | Progress | Prosperity

REGIONAL WORKSHOP ON IMPACT-BASED FORECASTING

Training-of-Trainers and National Demonstration Planning for Temperature-Related Hazards

THANK YOU!