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Copernicus Climate Change Service

Development of R-based scripts and manual to calculate daily maps of the Universal Thermal Climate Index (UTCI)

Issued by: KNMI / Gerard van der Schrier

Date: 02/03/2021

Ref: C3S_D311a_Lot4.3.1.10_script_and_manual_UTCI_v1

Official reference number service contract: 2017/C3S_311a_Lot4_KNMI/SC1

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1. Introduction

A fundamental issue in human biometeorology is the assessment of the influence of the atmospheric environment has on the comfort of a human body, in a thermophysiologically meaningful and useful way. Many indices have been formulated, like the heat index and the windchill index (see e.g. Driscoll, 1992 for a review). However, the simple formulation of these indices makes the applicability of the indices always limited to e.g. a particular season or under specific circumstances. A more comprehensive approach would include complete heat budget models, which take all mechanisms of heat exchange into account. Input variables needed include air temperature, water vapour pressure, wind velocity, mean radiant temperature including solar radiation, in addition to metabolic rate and clothing insulation.

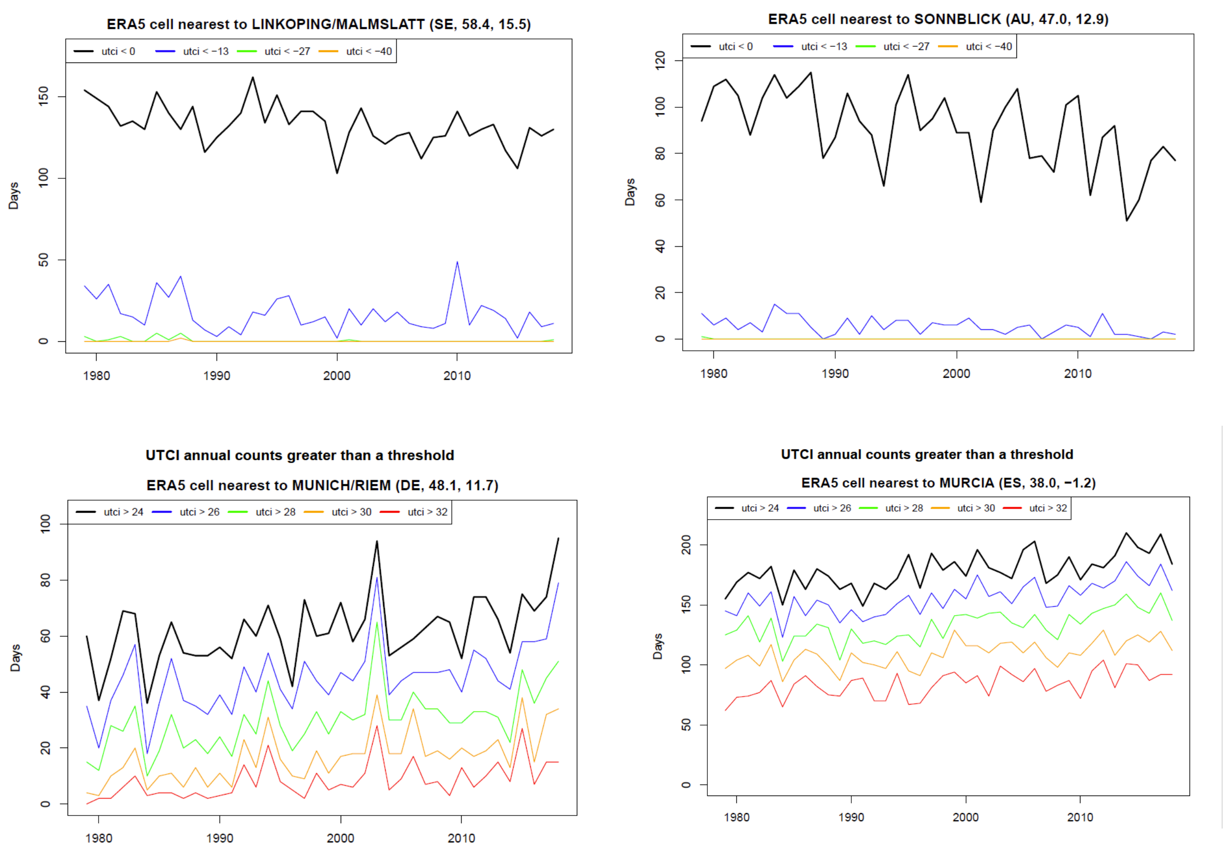
A recent example of the more comprehensive approach is the Universal Thermal Climate Index (UTCI). Jendritzky et al. (2012) based this new index on the most advanced multi-node model of thermoregulation representing progress in science within the last three to four decades, both in thermo-physiological and heat exchange theory. The UTCI was then derived conceptually as an equivalent temperature (ET). Thus, for any combination of air temperature, wind, radiation, and humidity (stress), UTCI is defined as the isothermal air temperature of the reference condition that would elicit the same dynamic response (strain) of the physiological model (Jendritzky et al. 2012).

The relevance of a comfort index is made clear by e.g. DiNapoli et al. (2018) as extreme high temperatures, such as those experienced during a heatwave, representing a serious meteorological hazard to human health and well-being. Notable episodes of severe and sustained high temperatures include the 2003 European heatwave and the 2010 Russian heatwave which resulted in tens of thousands of deaths (Barriopedro et al. 2011). With the growing evidence that heatwaves are likely to get more intense, frequent and longer-lasting in the future, a historic perspective of how thermally hazardous environmental conditions have changed over time – including not only heat waves but also cold snaps – is called for. This motivated Urban et al. (2019) to calculate the UTCI using ERA5 data and DiNapoli et al. (2018) to add the UTCI to the operational forecast from ECMWF. More recently, DiNapoli et al. (2020a, 2020b) focused on the calculation of one of the central elements in the UTCI, the so-called Mean Radiant Temperature (MRT) and produced their version of the UTCI based on the ERA5 reanalysis. MRT is part of UTCI calculations documented in this report and the detailed equations are given in Matzarakis et al. (2011). Commercial software (RayMan) is available for MRT, but this has not been used for the current set of scripts.

Figure 1 gives four examples of the UTCI for different stations across Europe. Here counts of days above or below certain thresholds are shown to give a flavor of the dataset and to demonstrate the ability of the dataset for use to monitor changes in the frequency of days which exceed some comfort level.

The algorithm to calculate the UTCI are based on inputs provided by http://www.utci.org/

Figure 1 –Examples of counts of days with UTCI values above or below a threshold, for four different stations in Europe. The top row gives examples for Linköping and Sonnblick with counts of days below the UTCI levels 0, -13, -27 and -40. The bottom row gives examples for Munich and Murcia with counts of days above the UTCI thresholds 24, 26, 28, 30 and 32.



2. Assumptions

The package introduced in this Deliverable calculates the Universal Thermal Climate Index and the manual guides the reader to calculate the UTCI based on the pan-European E-OBS observational dataset. For the current work, a few assumptions and simplifications needed to be made.

The generalizations follow existing practices as used in the approach of DiNapoli et al. (2018, 2002a,2002b) and include assumptions about radiation related parameters, such as surface emissivity, albedo and transmittance which are set to default values and treated as constant (Kantor and Unger 2011). Specifically, the albedo used in the package described here is 0.23 and the coefficient alpha, the absorptance of the outer surface of the person, is set at 0.85 following Fanger (1970).

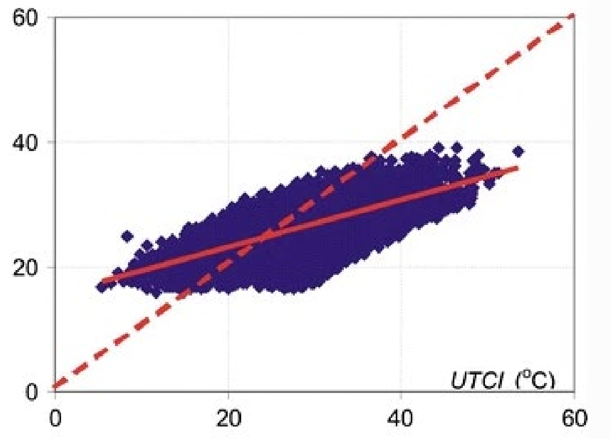
While the UTCI lends itself to the calculation of an instantaneous value for the comfort index, the current approach uses daily maximum temperatures as input, combined with daily averages of global radiation, relative humidity and windspeed. The use of daily maximum temperature is motivated to make the values applicable to day-time activities. The use of daily averages of the other parameters relates to the lack of sub-daily observational information in the E-OBS dataset for the time at which the daily maximum temperature is reached. This contrasts with the approach of DiNapoli et al. (2020b) who calculated UTCI for summer days using ERA-Interim atmospheric parameters retrieved at 06:00, 09:00, 12:00, 15:00 and 18:00 UTC.

The operational procedure for the UTCI calculation must be computer time efficient. This excludes the repeatedly running of the originally proposed calibration standards. Instead, the operational procedure follows a regression approach based on the outcome of some 100,000 simulations with the help of the advanced Fiala-model (Fiala et al, 1999) covering all (i.e. also the most extreme on the global scale) encountered combinations of the meteorological input variables.

3. Comparison against the Wet Bulb Globe Temperature

An extensive comparison of the UTCI against other comfort indices was made by Blazejczyk et al. (2012). From that comparison, the information is retrieved where the UTCI was compared to the Wet Bulb Globe Temperature (WBGT): the heat stress index most widely used by far throughout the world. It was developed by the US Navy as part of a study on heat-related injuries during military training. The WBGT index consists of weighting of dry-bulb temperature, natural (un-aspirated) wet-bulb temperature and black-globe temperature. For indoor conditions, when the black-globe temperature equals approximately ambient dry temperature, the index consists of only wet-bulb and black-globe temperatures.

Figure 2: Universal thermal climate index (UTCI) vs WBGT wet bulb globe temperature. Solid line Regression, dashed line identity. Figure from Blazejczyk et al. (2012).



Based on the WBGT index, the American Conference of Government Industrial Hygienists (ACGIH) published the Permissible heat exposure threshold limits values, which refer to those heat stress conditions under which nearly all workers may be repeatedly exposed without adverse health effects (ACGIH 2004). These criteria were adopted by other American institutes which adds to the standing the WBGT has in the community. Nevertheless, the inherent limitation of the WBGT is its limited applicability across a broad range of potential scenarios and environments, because of the inconvenience of measuring the black-globe temperature. This is often the motivation to use a simplified version of the WBGT based on air temperature and vapour pressure.

For the WBGT (reflecting hot conditions only), the correlation with UTCI is very weak. R-squared coefficients are 43.3% and the slope of the regression line is 0.384.

The WBGT has not been included in the package which is documented in this report. Users interested in calculating heat stress load using the WBGT are referred to a package available at: https://github.com/mdljts/wbgt. This contains an R script which is a wrapper for Liljegren's C implementation (Liljegren et al. 2008).

4. Input data files

The self-calibrating UTCI requires input files for maximum temperature, minimum temperature, relative humidity, global radiation and wind speed.

Table 1: Input parameters to the UTCI

Variable	description	unit
tx	Daily maximum temperature	°C
tn	Daily minimum temperature	°C
rh	Relative humidity	%
rs	Radiation	MJ/m^2
ws	Wind speed	m/s

5. UTCI package introduction

The `UTCI` package may be used for computing UTCI from data in netcdf gridded format or from a time series such as station data. When used for gridded data the UTCI package is controlled by the package `GridClimInd` which takes care of sending the `UTCI` package vectors of data from the netcdf file in the correct format. This controlling software has been optimised to incorporate chunking and multi-processor (cluster computing) usage if required.

Filenames in the following are examples and do not need to be adhered to.

6. UTCI package user manual for computing UTCI from gridded data

Where do I find the package?

The package is available from Github at: **https://github.com/ECA-D/UTCIr**

How should I install the package?

Installation requires the inclusion of the packages `GridClimInd`, `ClimInd`, `PETr` and `scPDSIr` which are available from GitHub at: **https://github.com/ECA-D/gridclimind**, **https://github.com/ECA-D/climind,** https://github.com/ECA-D/PETr and https://github.com/ECA-D/scPDSIr.

There are dependencies on system libraries such as `netcdf4` and `udunits`, on Ubuntu these are installed by:

```
sudo apt-get install libnetcdf-dev libudunits2-dev
```

Install additional packages

Depends R (>= 3.6)

install.packages(c('ncdf4','PCICt','functional','proj4','caTools','SPEI','Runit','snow','ncdf4.helpers','snow','udunits2'))

Take the following steps:

- download UTCIr package from github

- unzip UTCIr-master.zip

- R CMD build UTCIr-master

- R CMD INSTALL UTCIr_0.1.0.tar.gz

Continue with PETr

- download PETr package from github

- unzip PETr-master.zip

- R CMD build PETr-master

- R CMD INSTALL PETr_0.1.0.tar.gz

Continue with scPDSIr

- download scPDSIr package from github

- unzip scPDSIr-master.zip

- R CMD build scPDSIr-master

- R CMD INSTALL scPDSIr_0.1.0.tar.gz

Continue with climind:

- *download climind package from github*

- *unzip climind-master.zip*

- *R CMD build climind-master*

- *R CMD INSTALL climind_1.0.0.tar.gz*

Continue with `gridclimind`:

- *download gridclimind package from github*

- *unzip gridclimind-master.zip*

- *R CMD build gridclimind-master*

- *R CMD INSTALL gridclimind_1.0.0.tar.gz*

Which script should I run to reproduce the example?

Run test script `run_UTCI_grid_test.r` which is found in directory: UTCI/test_data/

This routine produces the following UTCI output file:

UTCI _testfile.nc, which will be written to: UTCI/test_data/UTCI_output

This same directory already contains a static master file with which the new output is compared: UTCI_testfile_master.nc.

If the package installation is OK the following messages will appear:

"UTCI output matches master file"

General comments

Variable names

If the users variable names differ from those given, they can be modified to suit in the json file which is found in:

```
gridclimind-master/inst/extdata/metadata_config_files
```

so for e.g. to re-map precipitation to “pr” go to line 31 in the json file and change rr (the standard name) to:

```
  "prec": "pr",
```

Note do not to modify the left hand side (i.e. “prec” in the example above).

Other information needed is retrieved from the netcdf file.

All gridded data input must be consistent in dimensions – i.e. latitude, longitude and time.

Example of usage:

```
in.dir <- “input/”
out.dir <-  “output/”
UTCI.file <- "<name_of_output_file>.nc"
out.file <- sprintf("%s%s", out.dir, UTCI.file)

input.files <- c(paste0(in.dir,"tx_0.1deg_regular_1980-2019.nc"),
               paste0(in.dir,"tn_0.1deg_regular_1980-2019.nc”)
               paste0(in.dir,"rh_0.1deg_regular_1980-2019.nc”)
               paste0(in.dir,"rs_0.1deg_regular_1980-2019.nc”)
               paste0(in.dir,"ws_0.1deg_regular_1980-2019.nc”)


create.UTCI.from.files(input.files, out.file, input.files[1],
author.data,  parallel=FALSE, start=1980, end=2019, cal_start=1980,
cal_end=2019)
```

The first input file (`input.files[1]`) details such as lat, lon and time are used to generate the output file.

`Author.data` is a list provided by the user giving additional information to go into the output file, e.g. `author.data <- list(data = “E-OBS”)`

`parallel=FALSE` will use a single processor. The user may set this to use more processors if available. For e.g. 5 processors, set: `parallel=5`
`start` and `end` refer to the start and end of the input data (for gridded data this must reflect all of the input data as the output file is based on the input – a subset would result in a failed write).
`cal_start` and `cal_end` refer to the start and end of the desired calibration period.

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