’International Climate Assessment & Dataset (ICA&D)’

Algorithm Theoretical Basis Document (ATBD)

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Date : March 15, 2022
Version: 1

Contents

1 Project description

1.1 Objectives

The ICA&D (International Climate Assessment & Dataset) climate services concept successfully combines the work of WMO‘s Expert Team on Climate Change Detection and Indices (ETCCDI) and WMO‘s Data Rescue (DARE) activities. The concept builds on the sofware developed for the European Climate Assessment & Dataset (ECA&D), a webportal for daily station data and derived indices brought together under regional cooperation. ICA&D combines the climate monitoring and assessment activities developed in ECA&D with DARE activities.

ECA&D started in 2003 as the follow-up to ECA (for which KNMI was responsible member since 1998). Between 2003 and 2008 the project has been partially funded by EUMETNET. From 2009 onwards, KNMI has committed itself to fund ECA&D. ECA&D has now obtained the status of Regional Climate Centre (RCC) for high resolution observation data in WMO Region VI (Europe and the Middle East).

The objective of ECA&D is to analyze the temperature and precipitation climate of WMO region VI, with special focus on trends in climatic extremes observed at meteorological stations. For this purpose, a dataset of 20th-century daily surface air temperature and precipitation series has been compiled (Klein Tank et al. 2002a) and tested for homogeneity (Wijngaard et al. 2003). The objective of ICA&D is to do this for other regions of the world.

To enable periodic assessments of climate change on a regional scale, a sustainable system for data gathering, archiving, quality control, analysis and dissemination has been realized. Data gathering refers to long-term daily resolution climatic time series from meteorological stations throughout the region which are provided by contributing parties (mostly National Meteorological Services (NMSs)). Archiving refers to transformation of the series to standardized formats and storage in a centralized relational database system. Quality control uses fixed procedures to check the data and attach quality and homogeneity flags. Analysis refers to the calculation of (extremes) indices according to internationally agreed procedures specified by the CCL/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI, `http://www.clivar.org/organization/etccdi/etccdi.php`). Finally, dissemination refers to making available both the daily data (including quality flags) and the indices results to users through a dedicated website.

1.2 Users

Because of its daily resolution, the ICA dataset enables a variety of climate studies, including detailed analyses of changes in the occurrence of extremes in relation to changes in the mean. Web statistics, personal contacts and references in numerous publications, advice reports and applications show that ICA&D serves many users. Also the ECA&D report "Climate of Europe, assessment of observed daily temperature and precipitation extremes" (Klein Tank et al. 2002b) and its successor "Towards an operational system for assessing observed changes in climate extremes" (van Engelen et al. 2008) have received much praise. The project is widely recognized as an example of KNMIs leading international role in the area of climate data exchange and research.

1.3 Requirements

1. Not all countries will be able to submit their contribution in a standardized format at regular time intervals. Therefore, the continuation of individual treatment of each participant is crucial for success. This implies that dedicated solutions should be developed for each data provider, with the level of automation dependent on the technical and manpower possibilities of the respective participants.

2. The data come with different use permissions. We are allowed to redistribute some series to the general public, whereas others are only for index calculation and use in the calculation of the gridded data products. The system should allow for different permission flags.

3. Since there is always a time lag between the most recent data contributed by participants and the present date, the observations from SYNOP messages for the same or nearby stations that are transmitted through the Global Telecommunication System (GTS) should temporarily be used to fill the gap. Once the 'official' series are available from the data providers in participating countries, the temporary SYNOP data should be replaced. Regular updates, using SYNOP data and readily available participant data (see § 2.1) are on a monthly basis. Requesting updates from all data participants is done on a less frequent basis. Each update of the daily data will be followed by a recalculation of quality control scores, indices, climatology, trends and homogeneity. This is followed by a calculations of provisional gridded datafiles for precipitation and daily maximum, minimum and averaged temperature for the past month. These SYNOP is currently only used for the European region, but might be implemented in other regions in the future.

4. The minimum set of metadata for each series, which is required to judge the quality and representativeness of the observations, is described in Aguilar et al. (2003). Metadata information is important since not all station observations conform closely to the recommendations of instrumentation, exposure and siting which are given in the

WMO-CIMO Guide. Moreover, the recommendations have changed over time. The minimum set of metadata should be stored along with the data series. Some of these metadata are used in the blending process.

5. The system should adopt and comply with (inter)nationally agreed standards as much as possible. This refers both to data format and database standards as well as metadata description standards.

6. A subset of the stations with ICA&D series is part of the GCOS Surface Network (GSN). For some of these stations, the daily series are collated and archived also at the WMO World Data Center A in Asheville (U.S.A.). Discrepancies between the series in ICA&D and those in GSN should be carefully monitored. Data series in GSN that are not part of ICA&D will be copied.

7. The ICA&D website, as a dissemination tool for data and indices results, should be easily accessible and flexible for many users. Researchers and operational climatologists have very different requirements. The possibility of different interfaces should be explored ranging from bulk download to customizable queries through the data and indices results. Also the output formats on screen and print should be flexible providing reports in different layouts. The daily data should be available to users in different stages of processing. This means that the 'raw' data files (as received from the participants, including explanatory e-mails) as well as the reformatted and quality-controlled data should be stored.

8. The existence of copies of (subsets of the) ICA datasets elsewhere on the Internet in reformatted files should be discouraged. Already, STARDEX (`https://www.cru.uea.ac.uk/projects/stardex/`), GDCN (`https://lwf.ncdc.noaa.gov/oa/climate/research/gdcn/gdcn.html`) and the Climate Explorer (`https://climexp.knmi.nl/`) extracted and published copies of the entire dataset. The problem is that these ad-hoc copies often stay without regular updates. To improve this situation, specific agreements with responsible persons should be reached so that the required subsets are delivered straight from the ICA&D source or provided at the ICA&D website.

1.4 Infrastructure and software

At the moment, two dedicated ICA&D systems are in use: the develop & test environment and the operational system (outside the firewall). All procedures are run on a developer platform and the results are copied to the operational platform. The operating system is Linux. The webserver uses Drupal.

A MySQL database is used to store the data and corresponding metadata. Most of the software used to update the database are written in Bash, Fortran, C and R code.

1.5 Data flow

The necessary steps in data processing are:

1. New data import
2. Quality control
3. Blending
4. Indices calculation
5. Climatology calculation
6. Trend calculation
7. Homogeneity analysis
8. Website

For each step, the main method is described in the sections below.

2 New data import

2.1 Design rules

2.1.1 NMHSs and data holding institutes

Participant data comes in various file formats. Importing this data into the database tables is entirely done by hand, running relevant scripts to do the conversions. The conversions differ for each data source. Dependent on the permissions granted by the data providers, data series can either be: downloadable or non-downloadable. Non-downloadable data are only used in the calculation of the trends, indices and the gridded datasets, while the downloadable data are published on the web as well. Most station series are updated irregularly, each time after the data providers are contacted.

2.1.2 Synoptical data through the GTS

The data provided by the participants is always received with some delay. It is not possible for all of the participants to deliver (near) real time data, because of validation and verification. To update each series at the time that participant data has not yet arrived, SYNOP messages are used. The source for these synoptical data is the ECMWF MARS-archive (see http://www.ecmwf.int/services/archive/). This archive is a complete and consistent representation of SYNOP messages distributed over the GTS. Currently, synoptical data is retrieved from the MARS-archive only for the European region, but might be implemented in other regions in the future.

2.2 Current implementation

Within the ICA&D relational database, various types of tables are distinguished: core tables that hold the unique raw data, working tables that hold temporarily stored data and so-called derived tables that hold derived data calculated according to the rules specified in the remainder of this document. Derived data is updated by running the various processes. It is necessary to store these derived data for better performance of subsequent procedures and/or the website. Data for different elements are stored in separate tables. Based on the use permissions that participants have given to their data, two different targets are distinguished. Likewise, tables have extensions for the targets: public and mixed. *Mixed* indicates public (downloadable) data combined with non-public (non-downloadable) data. The data in the *mixed* tables are used for indices, trends and gridding, while only the data in *public* are available for download on the website. Data in the *public* tables are a subset of those in the *mixed* tables.

3 Quality control

3.1 Design rules

Quality control (QC) procedures flag each individual observation in a series. Separate QC procedures are performed for the station series (non-blended) and the blended series. Three QC flags are currently implemented:

- Flag=0: 'valid'
- Flag=1: 'suspect'
- Flag=9: 'missing'

The following conditions apply for each element.

daily precipitation amount RR:
...must be equal or exceed 0 mm
...must be less than 300.0 mm
...must not be repetitive (i.e. exactly the same amount) for 10 days in a row if amount larger than 1.0 mm
...must not be repetitive (i.e. exactly the same amount) for 5 days in a row if amount larger than 5.0 mm

...dry periods receive flag = 1 (suspect), if the amount of dry days lies outside a 14·bivariate standard deviation

daily maximum temperature TX:
...must exceed -90.0 °C
...must be less than 60.0 °C
...must exceed or equal daily minimum temperature (if exists)
...must exceed or equal daily mean temperature (if exists)
...must not be repetitive (i.e. exactly the same) for 5 days in a row
...must be less than the long term average daily maximum temperature for that calendar day + 5 times standard deviation (calculated for a 5 day window centered on each calendar day over the whole period)
...must exceed the long term average daily maximum temperature for that calendar day - 5 times standard deviation (calculated for a 5 day window centered on each calendar day over the whole period)

Daily minimum temperature TN:
...must exceed -90.0 °C
...must be less than 60.0 °C
...must be less or equal to daily maximum temperature (if exists)
...must be less or equal to daily mean temperature (if exists)
...must not be repetitive (i.e. exactly the same) for 5 days in a row
...must be less than the long term average daily minimum temperature for that calendar day + 5 times standard deviation (calculated for a 5 day window centered on each calendar day over the whole period)
...must exceed the long term average daily minimum temperature for that calendar day - 5 times standard deviation (calculated for a 5 day window centered on each calendar day over the whole period)

Daily mean temperature TG:
...must exceed -90.0 °C
...must be less than 60.0 °C
...must exceed or equal daily minimum temperature (if exists)
...must be less or equal to daily maximum temperature (if exists)
...must not be repetitive (i.e. exactly the same) for 5 days in a row
...must be less than the long term average daily mean temperature for that calendar day + 5 times standard deviation (calculated for a 5 day window centered on each calendar day over the whole period)
...must exceed the long term average daily mean temperature for that calendar day - 5 times standard deviation (calculated for a 5 day window centered on each calendar day over the whole period)

The default QC flag is 0 ('valid'). If one of the conditions above is not met: a QC flag of 1 ('suspect') is assigned. If data is missing: QC=9 ('missing'). The conditions are tested in an automated procedure, but a manual intervention is possible for non-blended series and the manual QC flag will be propagated to the blended series. For instance, precipitation extremes flagged 'suspect' are overruled if supplementary evidence exists (e.g. from radar images or weather charts) that the particular extreme is plausible.

If for a calendar day 10 or more samples exist, then the long-term average or standard deviation is calculated for that day. In order to adjust the day-to-day variability associated with the sampling, the long-term averages are smoothed. The (smoothed) long-term average is only calculated if the total number of days present is 25 or more. If a calendar day does not meet these requirements (e.g. for a leap day), the quality checks associated with long term averages are not performed for that day.

4 Blending

4.1 Design rules

The procedure to calculate the optimal combination of ICA station and nearby station (which can be an ICA station or a synoptical station) has the following steps (applying spherical trigonometry):

1. Convert LAT and LON into decimal degrees. E.g. for station De Bilt this yields

Latitude:	52:06N	LAT_{ICA}	= 52+6/60 = 52.10
Longitude:	05:11E	LON_{ICA}	= 5+11/60 = 5.18

2. For every other station, also convert LAT and LON into decimal degrees

Latitude:	$HH_{LA}:MM_{LA}$	LAT_{OTHER}	$= HH_{LA}+MM_{LA}/60$
Longitude:	$HH_{LO}:MM_{LO}$	LON_{OTHER}	$= HH_{LO}+MM_{LO}/60$

   If Latitude on southern hemisphere: $LAT_{OTHER} = -1 \cdot LAT_{OTHER}$
   If Longitude on western hemisphere: $LON_{OTHER} = -1 \cdot LON_{OTHER}$

3. Find a combination ICA-OTHER station by minimizing the distance (here in km):

   distance = radius_earth $\times$ ARCCOS(SIN(atan$\cdot LAT_{ICA}$) $\times$ SIN(atan $\cdot\ LAT_{OTHER}$) + COS(atan $\cdot\ LAT_{ICA}$) $\times$ COS(atan $\cdot\ LAT_{OTHER}$) $\times$ COS(atan $\cdot$ (LON_{OTHER} - LON_{ICA})))
   where: radius_earth = 6378.137 kilometers, and atan = ARCTAN(1)/45

Substituting for De Bilt, with LAT/LON from WMO synoptical or ICA-stations yields:

distance = radius_earth × ARCCOS(SIN(atan · 52.10) × SIN(atan · LAT_{OTHER}) + COS(atan · 52.10) × COS(atan · LAT_{OTHER}) × COS(atan · (LON_{OTHER} - 5.18)))

Repeat distance for every OTHER station, keeping LAT_{ICA} and LON_{ICA} fixed (in the example above, for De Bilt). The OTHER station with lowest distance is the station that is nearest to De Bilt (in this example). Only data from stations that are no more than 12.5 km away from the original ICA station, is used.

4. As a last step, the difference in elevation of the ICA station and OTHER station is considered. Only data from stations located within 25 m height difference is taken into account.

Next, the blended series are constructed. Suppose we have a station series from 1900 until 2005, with missing data between 1930 and 1935 and also after 2005. Now that we know what other stations are nearby we are considering the data from these stations to 'infill' the gaps or data values that are flagged as suspect during QC (as illustrated in the figure below; see also § 3).

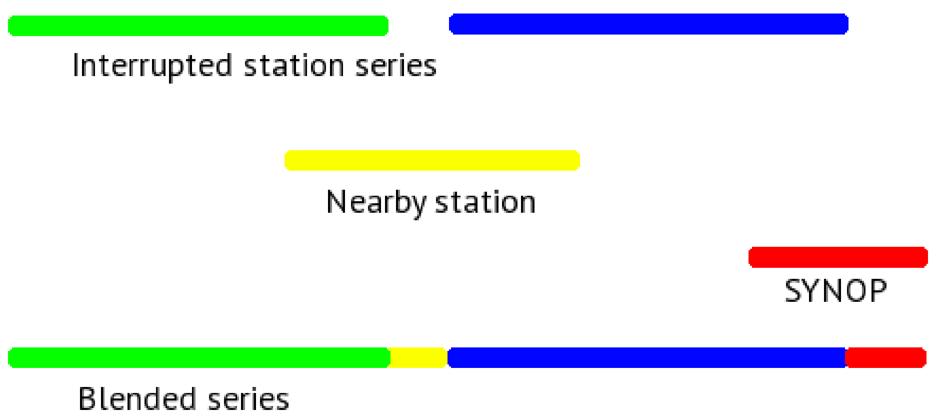

Figure 1: Blending figure

The logic that is applied when constructing the blended series is as follows. First, valid data from nearby ICA stations is taken to 'infill' the gaps, i.e. days with qc=1 or missing data. If no valid data from nearby ICA stations is available, valid data from nearby synoptical stations is taken to 'infill' the gaps. If there is less than 10 years difference between the year of the last date of the series and the current date, the series might be extended with synop data from nearby synoptical stations in the future as well (only implemented for Europe currently).

The extension of validated series with (unvalidated) synop data has some consequences for the quality of the resulting blended series. This is the principle motivation to limit the length of the synop data series which is added to existing validated series. These issues are the subject of van den Besselaar et al. (2012).

5 Indices calculation

5.1 Design rules

Indices are calculated for the *mixed* blended series only and over a time span which is as long as the record allows. For an index to be calculated for a particular year, at least 350 days with valid daily data must exist. For an index to be calculated for a half-year period, at least 175 days with valid daily data must exist. For an index to be calculated for a seasonal period, at least 85 days with valid daily data must exist. For an index to be calculated for a monthly period, at least 25 days with valid daily data must exist. Indices results are stored in the database only if a series contains at least 10 years of valid data.

A number of indices are calculated on the basis of the blended daily series for the categories Cold, Drought, Heat, Rain, Temperature and Compound. The acronyms are: TG, TN, TX, DTR*, ETR, GD4, GSL*, vDTR, CFD, FD*, HD17, ID*, CSDI*, TG10p, TN10p*, TX10p*, SU*, TR*, WSDI*, TG90p, TN90p*, TX90p*, RR*, RR1, SDII*, CDD, CWD*, R10mm*, R20mm*, RX1day*, RX5day*, R75p, R75pTOT, R95p, R95pTOT*, R99p, R99pTOT*, SPI3, SPI6, TXx*, TNx*, TXn*, TNn*, CD, CW, WD, WW, CSU, PRCPTOT, HI, BEDD. Those with * are part of the ETCCDI list of 27 worldwide indices available from `http://cccma.seos.uvic.ca/ETCCDI/indices.shtml`.

For the CDD and CWD spell duration indicators, a spell can continue into the next year and is counted against the year in which the spell ends. For example, a dry spell (CDD) beginning in December 2000 and ending in January 2001 is contributes to the dry spells of 2001.

The exact definition of each index is given in the next sections. Each index is calculated as annual , ONDJFM half-year, AMJJAS half-year, DJF, MAM, JJA, SON and monthly values.

5.2 Calculation of percentiles

Zhang et al. (2005) brought to the attention that percentiles, calculated on the basis of data from a 'base'-period of the record, and subsequently applied to data from the 'out-of-base' period, will introduce inhomogeneities in the resulting exceedance series. The inhomogeneities are strongest for high percentiles and for data with strong auto correlation.

In their article, they offer an alternative way to calculate percentiles when they are applied to the base-period. This method of calculating percentiles is adopted by ICA&D. This procedure is: (Zhang et al. 2005, §4)

1. The 30-yr base period is divided into one 'out of base' year, the year for which exceedance is to be estimated, and a 'base period' consisting of the remaining 29 yr from which the thresholds would be estimated.

2. A 30-yr block of data is constructed by using the 29-yr base period dataset and adding an additional year of data from the base period (replicating one year in the base period). This constructed 30-yr block is used to estimate thresholds.

3. The out-of-base year is then compared with these thresholds, and the exceedance rate for the out-of-base year is obtained.

4. Steps 2 and 3 are repeated an additional 28 times, by repeating each of the remaining 28 in-base years in turn to construct the 30-yr block.

5. The final index for the out-of-base year is obtained by averaging the 29 estimates obtained from steps 2, 3 and 4.

5.2.1 Empirical quantile estimation

The quantile of a distribution is defined as

$$Q(p) = F^{-1}(p) = \inf\{x : F(x) \geq p\}, 1 < p < 1$$

where $F(x)$ is the distribution function. Let $\{X_{(a)}, \ldots, X_{(n)}$ denote the order statistics of (i.e. sorted values of X), and let $\hat{Q}_i(p)$ denote the ith sample quantile definition. The sample quantiles can be generally written as

$$\hat{Q}_i(p) = (1 - \gamma)X_{(j)} + \gamma X_{(j+1)}.$$

Hyndman & Fan (1996) suggest a formula to obtain medium un-biased estimate of the quantile by letting $j = \text{int}(p * n + (1 + p)/3))$ and letting $\gamma = p * n + (1 + p)/3 - j$, where $\text{int}(u)$ is the largest integer not greater than u. The empirical quantile is set to the smallest or largest value in the sample when $j < 1$ or $j > n$ respectively. That is, quantile estimates corresponding to $p < 1/(n + 1)$ are set to the smallest value in the sample, and those corresponding to $p > n/(n + 1)$ are set to the largest value in the sample.

5.3 Smoothing of indices

Next to the actual index values, smoothed index values are provided based on the application of a LOWESS (locally weighted scatterplot smoothing) smoother. This smoother fits simple models to localized subsets of the data to build up a function that describes the deterministic part of the variation in the data, point by point.

The code is based on routines provided by W. S. Cleveland (Bell Laboratories, Murray Hill NJ).

The smoother span f gives the proportion of points in the plot which influence the smooth at each value. The value of f is set to:

$$f = \frac{30}{\text{length of record in years}}.$$

This gives higher values for f when the length of the series is short, giving more smoothness.

The number of 'robustifying' iterations which should be performed is set to 3.

The parameter δ is used to speed up computation: instead of computing the local polynomial fit at each data point it is not computed for points within δ of the last computed point, and linear interpolation is used to fill in the fitted values for the skipped points. This parameter is set to 1/100th of the range of the input data, which is generally regarded as a standard value.

5.3.1 Cold indices

GD4

- *Growing degree days (sum of TG > 4 °C) (°C)*

Let TG_{ij} be the daily mean temperature at day i of period j. Then the growing degree days are:

$$GD4_j = \sum_{i=1}^{I} (TG_{ij} - 4 \mid TG_{ij} > 4\,^{\circ}C)$$

GSL

- *Growing season length (days)*

Let TG_{ij} be the mean temperature at day i of period j. Then counted is the number of days between the first occurrence of at least 6 consecutive days with:

$$TG_{ij} > 5\,^{\circ}C$$

and the first occurrence after 1 July of at least 6 consecutive days with:

$$TG_{ij} < 5\,^{\circ}C$$

CFD

- *Maximum number of consecutive frost days (TN < 0° C) (days)*

Let TN_{ij} be the daily minimum temperature at day i of period j. Then counted is the largest number of consecutive days where:

$$TN_{ij} < 0\,^{\circ}C$$

FD

- *Frost days (TN < 0° C) (days)*

Let TN_{ij} be the daily minimum temperature at day i of period j. Then counted is the number of days where:

$$TN_{ij} < 0\,^{\circ}C$$

HD17

- *Heating degree days (sum of* 17 °*C - TG) (° C)*

Let TG_{ij} be the daily mean temperature at day i of period j. Then the heating degree days are:

$$HD17_j = \sum_{i=1}^{I}(17\,^{\circ}C - TG_{ij})$$

ID

- *Ice days (TX < 0° C) (days)*

Let TX_{ij} be the daily maximum temperature at day i of period j. Then counted is the number of days where:

$$TX_{ij} < 0\,^{\circ}C$$

CSDI

- *Cold-spell duration index (days)*

Let TN_{ij} be the daily minimum temperature at day i of period j and let $TN_{in}10$ be the calendar day 10th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Then counted is the number of days per period where, in intervals of at least 6 consecutive days:

$$TN_{ij} < TN_{in}10$$

TG10p

- *Days with TG < 10th percentile of daily mean temperature (cold days) (days)*

Let TG_{ij} be the daily mean temperature at day i of period j and let $TG_{in}10$ be the calendar day 10th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Then counted is the number of days where:

$$TG_{ij} < TG_{in}10$$

TN10p

- *Days with TN < 10th percentile of daily minimum temperature (cold nights) (days)*

Let TN_{ij} be the daily minimum temperature at day i of period j and let $TN_{in}10$ be the calendar day 10th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Then counted is the number of days where:

$$TN_{ij} < TN_{in}10$$

TX10p

- *Days with TX < 10th percentile of daily maximum temperature (cold day-times) (days)*

Let TX_{ij} be the daily maximum temperature at day i of period j and let $TX_{in}10$ be the calendar day 10th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Then counted is the number of days where:

$$TX_{ij} < TX_{in}10$$

TXn

- *Minimum value of daily maximum temperature (° C)*

Let TX_{ij} be the daily maximum temperature on day i of period j. Then the minimum daily maximum temperature for period j is:

$$TXn_j = min(TX_{ij})$$

TNn

- *Minimum value of daily minimum temperature (° C)*

Let TN_{ij} be the daily minimum temperature on day i of period j. Then the minimum daily minimum temperature for period j is:

$$TNn_j = min(TN_{ij})$$

5.3.2 Compound indices

The indices CD, CW, WD, and WW are based on Beniston (2009).

CD

- *Days with TG < 25th percentile of daily mean temperature and RR < 25th percentile of daily precipitation sum (cold/dry days)*

Let TG_{ij} be the daily mean temperature at day i of period j and let $TG_{in}25$ be the calendar day 25th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and let $RR_{wn}25$ be the 25th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days where:

$$TG_{ij} < TG_{in}25 \qquad \text{and} \qquad RR_{wj} < RR_{wn}25$$

CW

- *Days with TG < 25th percentile of daily mean temperature and RR > 75th percentile of daily precipitation sum (cold/wet days)*

Let TG_{ij} be the daily mean temperature at day i of period j and let $TG_{in}25$ be the calendar day 25th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and let $RR_{wn}75$ be the 75th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days where:

$$TG_{ij} < TG_{in}25 \qquad \text{and} \qquad RR_{wj} > RR_{wn}75$$

WD

- *Days with TG > 75th percentile of daily mean temperature and RR < 25th percentile of daily precipitation sum (warm/dry days)*

Let TG_{ij} be the daily mean temperature at day i of period j and let $TG_{in}75$ be the calendar day 75th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and let $RR_{wn}25$ be the 25th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days where:

$$TG_{ij} > TG_{in}75 \qquad \text{and} \qquad RR_{wj} < RR_{wn}25$$

WW

- *Days with TG > 75th percentile of daily mean temperature and RR > 75th percentile of daily precipitation sum (warm/wet days)*

Let TG_{ij} be the daily mean temperature at day i of period j and let $TG_{in}75$ be the calendar day 75th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and let $RR_{wn}75$ be the 75th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days where:

$$TG_{ij} > TG_{in}75 \qquad \text{and} \qquad RR_{wj} > RR_{wn}75$$

5.3.3 Drought indices

CDD

- *Maximum number of consecutive dry days (RR < 1 mm) (days)*

Let RR_{ij} be the daily precipitation amount for day i of period j. Then counted is the largest number of consecutive days where:

$$RR_{ij} < 1\ mm$$

SPI6

- *6-Month Standardized Precipitation Index*

SPI is a probability index based on precipitation. It is designed to be a spatially invariant indicator of drought. SPI6 refers to precipiation in the previous 6-month period (+ indicates wet; - indices dry).

See for details and the algorithm: Guttman (1999).

SPI3

- *3-Month Standardized Precipitation Index*

SPI is a probability index based on precipitation. It is designed to be a spatially invariant indicator of drought. SPI3 refers to precipiation in the previous 3-month period (+ indicates wet; - indices dry).

See for details and the algorithm: Guttman (1999).

HI

- *Huglin Index*

The Huglin Index is an index specifically aimed at grap growth (Huglin 1978) and defined using daily averaged temperature TG_i and the daily maximum temperature TX_i for day i in the period 1 April to 30 September:

$$HI = \sum_{01/04}^{30/09} \frac{(TG_i - 10) + (TX_i - 10)}{2} K$$

where K is a daylength coefficient. The daylight coefficient is a function of the latitude of the station but a clear definition is absent. The value of K is determined using table 1.

latitude	daylight coefficient K
$\leq$ 40°N	1.00
40°N-42°N	1.02
42°N-44°N	1.03
44°N-46°N	1.04
46°N-48°N	1.05
48°N-50°N	1.06

Table 1: The daylight coefficient as used in the Huglin index as a function of latitude.

BEDD

- *Biologically Effective Degree Days*

The Biologically Effective Degree Days index has been specifically targeted to describe grape growth (Gladstones 1992). The BEDD index is based on a growing degree days measure. Let TX_i and TN_i be the daily maximum and daily minimum temperature for day i. Then BEDD is calculated by

$$BEDD = \sum_{01/04}^{30/09} \min\left[\max\left[\left(\frac{TX_i + TN_i}{2}\right) - b, 0\right], 9\right],$$

where $b = 10$ is an appropriate value for grape growth.

5.3.4 Heat indices

SU

- *Summer days ($TX > 25$ °C) (days)*

Let TX_{ij} be the daily maximum temperature at day i of period j. Then counted is the number of days where:

$$TX_{ij} > 25\,^{\circ}C$$

TR

- *Tropical nights (TN > 20 °C) (days)*

Let TN_{ij} be the daily minimum temperature at day i of period j. Then counted is the number of days where:

$$TN_{ij} > 20\,^{\circ}C$$

WSDI

- *Warm-spell duration index (days)*

Let TX_{ij} be the daily maximum temperature at day i of period j and let $TX_{in}90$ be the calendar day 90th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Then counted is the number of days per period where, in intervals of at least 6 consecutive days:

$$TX_{ij} > TX_{in}90$$

TG90p

- *Days with TG > 90th percentile of daily mean temperature (warm days) (days)*

Let TG_{ij} be the daily mean temperature at day i of period j and let $TG_{in}90$ be the calendar day 90th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Then counted is the number of days where:

$$TG_{ij} > TG_{in}90$$

TN90p

- *Days with TN > 90th percentile of daily minimum temperature (warm nights) (days)*

Let TN_{ij} be the daily minimum temperature at day i of period j and let $TN_{in}90$ be the calendar day 90th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Then counted is the number of days where:

$$TN_{ij} > TN_{in}90$$

TX90p

- *Days with TX > 90th percentile of daily maximum temperature (warm day-times) (days)*

Let TX_{ij} be the daily maximum temperature at day i of period j and let $TX_{in}90$ be the calendar day 90th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Then counted is the number of days where:

$$TX_{ij} > TX_{in}90$$

TXx

- *Maximum value of daily maximum temperature (°C)*

Let TX_{ij} be the daily maximum temperature on day i of period j. Then the maximum daily maximum temperature for period j is:

$$TXx_j = max(TX_{ij})$$

TNx

- *Maximum value of daily minimum temperature (°C)*

Let TN_{ij} be the daily minimum temperature on day i of period j. Then the maximum daily minimum temperature for period j is:

$$TNx_j = max(TN_{ij})$$

CSU

- *Maximum number of consecutive summer days (TX > 25°C) (days)*

Let TX_{ij} be the daily maximum temperature for day i of period j. Then counted is the largest number of consecutive days where:

$$TX_{ij} > 25°C$$

5.3.5 Rain indices

RR

- *Precipitation sum (mm)*

Let RR_{ij} be the daily precipitation amount for day i of period j. Then sum values are give by:

$$RR_j = \sum_{i=1}^{I} RR_{ij}$$

RR1

- *Wet days ($RR \geq$ 1 mm) (days)*

Let RR_{ij} be the daily precipitation amount for day i of period j. Then counted is the number of days where:

$$RR_{ij} \geq 1\ mm$$

SDII

- *Simple daily intensity index (mm/wet day)*

Let RR_{wj} be the daily precipitation amount for wet day w ($RR \geq$ 1.0mm) of period j. Then the mean precipitation amount of wet days is given by:

$$SDII_j = \frac{\sum_{w=1}^{W} RR_{wj}}{W}$$

CWD

- *Maximum number of consecutive wet days ($RR \geq$ 1 mm) (days)*

Let RR_{ij} be the daily precipitation amount for day i of period j. Then counted is the largest number of consecutive days where:

$$RR_{ij} \geq 1\ mm$$

R10mm

- *Heavy precipitation days (precipitation $\geq$ 10 mm) (days)*

Let RR_{ij} be the daily precipitation amount for day i of period j. Then counted is the number of days where:

$$RR_{ij} \geq 10\ mm$$

R20mm

- *Very heavy precipitation days (precipitation $\geq$ 20 mm) (days)*

Let RR_{ij} be the daily precipitation amount for day i of period j. Then counted is the number of days where:

$$RR_{ij} \geq 20\ mm$$

RX1day

- *Highest 1-day precipitation amount (mm)*

Let RR_{ij} be the daily precipitation amount for day i of period j. Then maximum 1-day values for period j are:

$$RX1day_j = \max\left(RR_{ij}\right)$$

RX5day

- *Highest 5-day precipitation amount (mm)*

Let RR_{kj} be the precipitation amount for the five-day interval k of period j, where k is defined by the last day. Then maximum 5-day values for period j are:

$$RX5day_j = \max\left(RR_{kj}\right)$$

R75p

- *Days with RR > 75th percentile of daily amounts (moderate wet days) (days)*

Let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and let $RR_{wn}75$ be the 75th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days where:

$$RR_{wj} > RR_{wn}75$$

R75pTOT

- *Precipitation fraction due to moderate wet days (> 75th percentile) (%)*

Let RR_j be the sum of daily precipitation amount for period j and let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and $RR_{wn}75$ the 75th percentile of precipitation at wet days in the 1961–1990 period. Then $R75pTOT_j$ is determined as:

$$R75pTOT_j = 100 \times \frac{\sum_{w=1}^{W} RR_{wj},\ where\ RR_{wj} > RR_{wn}75}{RR_j}$$

R95p

- *Days with RR > 95th percentile of daily amounts (very wet days) (days)*

Let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and let $RR_{wn}95$ be the 95th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days where:

$$RR_{wj} > RR_{wn}95$$

R95pTOT

- *Precipitation fraction due to very wet days (> 95th percentile) (%)*

Let RR_j be the sum of daily precipitation amount for period j and let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and $RR_{wn}95$ the 95th percentile of precipitation at wet days in the 1961–1990 period. Then $R95pTOT_j$ is determined as:

$$R95pTOT_j = 100 \times \frac{\sum_{w=1}^{W} RR_{wj},\ where\ RR_{wj} > RR_{wn}95}{RR_j}$$

R99p

- *Days with RR > 99th percentile of daily amounts (extremely wet days) (days)*

Let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and let $RR_{wn}99$ be the 99th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days where:

$$RR_{wj} > RR_{wn}99$$

R99pTOT

- *Precipitation fraction due to extremely wet days (> 99th percentile) (%)*

Let RR_j be the sum of daily precipitation amount for period j and let RR_{wj} be the daily precipitation amount at wet day w ($RR \geq 1.0$ mm) of period j and $RR_{wn}99$ the 99th percentile of precipitation at wet days in the 1961–1990 period. Then $R99pTOT_j$ is determined as:

$$R99pTOT_j = 100 \times \frac{\sum_{w=1}^{W} RR_{wj},\ where\ RR_{wj} > RR_{wn}99}{RR_j}$$

5.3.6 Temperature indices

TG

- *Mean of daily mean temperature (°C)*

Let TG_{ij} be the mean temperature at day i of period j. Then mean values in period j are given by:

$$TG_j = \frac{\sum_{i=1}^{I} TG_{ij}}{I}$$

TN

- *Mean of daily minimum temperature (°C)*

Let TN_{ij} be the minimum temperature at day i of period j. Then mean values in period j are given by:

$$TN_j = \frac{\sum_{i=1}^{I} TN_{ij}}{I}$$

TX

- *Mean of daily maximum temperature (°C)*

Let TX_{ij} be the maximum temperature at day i of period j. Then mean values in period j are given by:

$$TX_j = \frac{\sum_{i=1}^{I} TX_{ij}}{I}$$

DTR

- *Mean of diurnal temperature range (°C)*

Let TX_{ij} and TN_{ij} be the daily maximum and minimum temperature at day i of period j. Then the mean diurnal temperature range in period j is:

$$DTR_j = \frac{\sum_{i=1}^{I}(TX_{ij} - TN_{ij})}{I}$$

ETR

- *Intra-period extreme temperature range (°C)*

Let TX_{ij} and TN_{ij} be the daily maximum and minimum temperature at day i of period j. Then the extreme temperature range in period j is:

$$ETR_j = \max(TX_{ij}) - \min(TN_{ij})$$

vDTR

- *Mean absolute day-to-day difference in DTR (°C)*

Let TX_{ij} and TN_{ij} be the daily maximum and minimum temperature at day i of period j. Then calculated is the absolute day-to-day differences in period j:

$$vDTR_j = \frac{\sum_{i=2}^{I} |(TX_{ij} - TN_{ij}) - (TX_{i-1,j} - TN_{i-1,j})|}{I}$$

6 Climatology calculations

6.1 Design rules

Climatologies for all indices described in Sect. 5.1 are calculated. Normal periods used in ICA&D are 1951–1980, 1961–1990, 1971–2000, 1981–2010 and 1991–2020. A climatological value for a particular index and a particular station is calculated if at least 70% of the data are available.

These climatologies are used in the 'indices of extremes' webpages. Both anomalies of an index, for a particular year and season, can be plotted with respect to the 1961-1990 climatology, and maps of the 1951–1980, 1961–1990, 1971–2000, 1981–2010 and 1991–2020 climatologies can be plotted.

7 Trend calculation

7.1 Design rules

A trend is calculated for each of the indices and for each of the aggregation periods for which the indices are calculated. Of all values considered in a period, at least 70% of them must contain valid index data (i.e., not missing) for the trend to be calculated.

Calculation of the trend value is done by a least squares estimate of a simple linear regression. The regression is performed by routine e02adf Numerical Algorithms Group (NAG, `http://www.nag.co.uk/`), where all points have equal weight. Data points with 'missing' values are not part of the inputdata for this routine. The routine calculates a least-squares polynomial approximation of degree 0 and 1, using Chebyshev polynomials as the basis. Subsequent evaluation of the Chebyshev-series representation of the polynomial approximation are carried out using NAG's e02aef routine. These routines give a value for the intercept a_0 and a value of the slope a_1:

$$\mathbf{y}_i = a_0 + a_1\mathbf{x}_i + \mathbf{e}_i,$$

with $\mathbf{e}_i$ a residual.

This follows (von Storch & Zwiers 1999, §8.3.8). To test the null hypothesis that the slope a_1 has a value of 0 against the hypothesis that the slope is distinguishable from 0, we calculated

$$t = \frac{a}{(\sigma_E/\sqrt{S_{XX}})}.$$

This value is then compared against critical values from the t-distribution with $n-2$ degrees of freedom. Here

$$\sigma_E^2 = \frac{1}{n-2}\sum_{i=1}^{N}(\mathbf{y}_i - a_0 - a_1\mathbf{x}_i)^2$$

is the squared sum of errors of the fit and

$$S_{XX} = \sum_{i=1}^{N}(\mathbf{x}_i - \overline{\mathbf{x}})^2 .$$

Because we have fitted a linear model that depends upon only one factor, the t and F tests are equivalent. In fact: $F = t^2$, and the square of a t random variable with $n-2$ degrees of freedom is distributed as $F(1, n-2)$. We will use the F-statistic here, which is identical to a two-sided t-test. The F-statistic is calculated by

$$F = \frac{SSR}{\sigma_E^2},$$

where

$$SSR = \sum_{i=1}^{N}(a_0 + a_1\mathbf{x}_i - \overline{\mathbf{y}})^2 .$$

The t-test is not robust against departures from the independence assumption. In general, time series in climatology will be auto correlated. Under these circumstances, the t-test becomes too liberal and rejects the null-hypothesis too often. Having some auto correlation in a series actually decreases the number of degrees of freedom. To account for this, an estimate of the equivalent sample size is made (von Storch & Zwiers 1999, §6.6.8). The equivalent sample size is then:

$$n'_x = \frac{n_x}{1 + 2\sum_{k=1}^{n_x-1}\left(1 - \frac{k}{n_x}\right)\rho_x(k)}$$

where $\rho_x(k)$ is the auto correlation function and n_x the number of degrees of freedom. Note the factor 2 in the denominator; it is missing in von Storch & Zwiers (1999, eq. 6.26) but should be there.

Given the number of degree of freedom and the t-value, a significance level can be calculated. This calculation makes use of the Numerical Recipes function `BETAI` Press et al. (1989), for the calculation of the incomplete beta function.

For each of the indices described in § 5.1 the trend is calculated over the following periods:

1. 1851 – last year
2. 1901 – last year
3. 1951 – last year
4. 1901 – 1950
5. 1951 – 1978
6. 1979 – last year

8 Homogeneity analysis

8.1 Design rules

In any long time series, changes in routine observation practices may have introduced inhomogeneities of non-climatic origin that severely affect the extremes. Wijngaard et al. (2003) statistically tested the daily ECA series (1901–1999) of surface air temperature and precipitation with respect to homogeneity. Their methodology has been implemented in ECA&D and ICA&D. A two-step approach is followed. First, four homogeneity tests are applied to evaluate the daily series using the testing variables: (1) the annual mean of the diurnal temperature range DTR (= maximum temperature - minimum temperature), (2) the annual mean of the absolute day-to-day differences of the diurnal temperature range vDTR and (3) the annual wet day count RR1 (threshold 1 mm). The use of derived annual variables avoids auto correlation problems with testing daily series. Second, the test results are condensed for each series into three classes: 'useful–doubtful–suspect'.

The four homogeneity tests are:

1. Standard Normal Homogeneity Test (SNH, Alexandersson (1986))
2. Buishand Range test (BHR, Buishand (1982))
3. Pettitt test (PET, Pettitt (1979))
4. Von Neumann Ratio test (VON, von Neumann (1941))

All four tests suppose under the null hypothesis that in the series of a testing variable, the values are independent with the same distribution. Under the alternative hypothesis the SNH, BHR and PET test assume that a step-wise shift in the mean (a break) is present. These three tests are capable to locate the year where a break is likely. The fourth test (VON) assumes under the alternative hypothesis that the series is not randomly distributed. This test does not give information on the year of the break. The calculus of each test is described below (from Wijngaard et al. 2003).

Y_i (i is the year from 1 to n) is the annual series to be tested, $\bar{Y}$ is the mean and s the standard deviation.

8.1.1 Standard normal homogeneity test

Alexandersson (1986) describes a statistic $T(k)$ to compare the mean of the first k years of the record with that of the last $n-1$ years:

$$T(k) = k\bar{z}_1^2 + (n-k)\bar{z}_2^2 \qquad k = 1, \ldots, n$$

where

$$\bar{z}_1 = \frac{1}{k}\frac{\sum_{i=1}^{k}(Y_i - \bar{Y})}{s} \quad \text{and} \quad \bar{z}_2 = \frac{1}{n-k}\frac{\sum_{i=k+1}^{n}(Y_i - \bar{Y})}{s}$$

If a break is located at the year K, then $T(k)$ reaches a maximum near the year $k = K$. The test statistic T_0 is defined as:

$$T_0 = \max\left(T(k)\right) \qquad \text{for } 1 \leq k < n$$

The test has further been studied by Jarušková (1994). The relationship between her test statistic $T(n)$ and T_0 is:

$$T_0 = \frac{n(T(n))^2}{n - 2 + (T(n))^2}$$

The null hypothesis will be rejected if T_0 is above a certain level, which is dependent on the sample size. Critical values are given in Table 2.

Table 2: 1% critical values for the statistic T_0 of the single shift SNHT as a function of n (calculated from the simulations carried out by Jarušková (1994)) and the 5% critical value (Alexandersson 1986).

n	20	30	40	50	70	100
1%	9.56	10.45	11.01	11.38	11.89	12.32
5%	6.95	7.65	8.10	8.45	8.80	9.15

8.1.2 Buishand range test

In this test, the adjusted partial sums are defined as

$$S_0^* = 0 \quad \text{and} \quad S_k^* = \sum_{i=1}^{k}(Y_i - \bar{Y}) \quad k = 1, \ldots, n$$

When a series is homogeneous the values of S_k^* will fluctuate around zero, because no systematic deviations of the Y_i values with respect to their mean will appear. If a break is present in year K, then S_k^* reaches a maximum (negative shift) or minimum (positive shift) near the year $k = K$. The significance of the shift can be tested with the 'rescaled adjusted range' R, which is the difference between the maximum and the minimum of the S_k^* values scaled by the sample standard deviation:

$$R = (\max S_k^* - \min S_k^*)/s \qquad 0 \leq k \leq n \quad \text{for max and min separately}$$

Buishand (1982) gives critical values for $R/\sqrt{n}$ (see Table 3).

Table 3: 1% and 5% critical values for $R/\sqrt{n}$ of the Buishand range test as a function of n (Buishand 1982); the value of $n = 70$ is simulated.

n	20	30	40	50	70	100
1%	1.60	1.70	1.74	1.78	1.81	1.86
5%	1.43	1.50	1.53	1.55	1.59	1.62

8.1.3 Pettitt test

This test is a non-parametric rank test. The ranks $r_1, \ldots, r_n$ of the $Y_1, \ldots, Y_n$ are used to calculate the statistics:

$$X_k = 2\sum_{i=1}^{k} r_i - k(n+1) \quad k = 1, \ldots, n$$

If a break occurs in year E, then the statistic is maximal or minimal near the year $k = E$:

$$X_E = \max |X_k| \quad \text{for } 1 \leq k \leq n$$

The significance level is given by Pettitt (1979). Critical values for X_E are given in Table 4.

Table 4: 1% and 5% critical values for X_E of the Pettitt test as a function of n; values are based on simulation.

n	20	30	40	50	70	100
1%	71	133	208	293	488	841
5%	57	107	167	235	393	677

8.1.4 Von Neumann ratio

The von Neumann ratio N is defined as the ratio of the mean square successive (year to year) difference to the variance (von Neumann 1941):

$$N = \sum_{i=1}^{n-1}(Y_i - Y_{i+1})^2 / \sum_{i=1}^{n}(Y_i - \bar{Y})^2$$

When the sample is homogeneous the expected value is $N = 2$. If the sample contains a break, then the value of N tends to be lower than this expected value (Buishand 1981). If the sample has rapid variations in the mean, then values of N may rise above two (Bingham & Nelson 1981). This test gives no information about the location of the shift. Table 5 gives critical values for N.

Table 5: 1% and 5% critical values for N of the von Neumann ratio test as a function of n. For $n \leq 50$ these values are taken from Owen (1962); for $n = 70$ and $n = 100$ the critical values are based on the asymptotic normal distribution of N (Buishand 1981).

n	20	30	40	50	70	100
1%	1.04	1.20	1.29	1.36	1.45	1.54
5%	1.30	1.42	1.49	1.54	1.61	1.67

In ICA&D, test results are calculated for the following periods (identical to the trend periods):

1. 1851 – last year
2. 1901 – last year
3. 1951 – last year
4. 1901 – 1950
5. 1951 – 1978
6. 1979 – last year

Of all years considered in a period, at least 70% of them must contain valid data (i.e., not missing). Only temperature series and precipitation series are tested on homogeneity. Other elements, like sea level pressure are not tested. The test results are condensed into a single flag for each series according to:

- Class 1: 'useful' – 1 or 0 tests reject the null hypothesis at the 1% level
- Class 2: 'doubtful' – 2 tests reject the null hypothesis at the 1% level

- Class 3: 'suspect' – 3 or 4 tests reject the null hypothesis at the 1% level

For temperature, where two variables are tested, the two categories are calculated separately for each variable. If the results are different, the least favourable category is assigned to the temperature series of the station. If not all 4 individual tests can be calculated the flag is 'missing'. This means the homogeneity of the series in the considered period could not be determined.

On the website the trends in the climate change indices are only presented for series that are classified as 'useful' or 'doubtful' in the considered period.

For the indices CW, CD, WW and WD the homogeneity results of the temperature series are used.

9 Website

9.1 Design rules

The main categories of the website are:

1. Home: homepage that introduces the project and provides news items
2. Observational data: download of bulk and customized datasets based on interactive queries of the ICA database; the results of these queries range from PDF-documents of station metadata to zipped downloadable datasets
3. Derived data: download and graphs of derived data such as indices of extremes
4. Meta data: information about the data
5. Guidance: links to e.g. the FAQ, documents and indices library

The interactive web interface uses (pull down) menus that together build a query, including time period selection, station/country selection and element/index selection. Based on this query selections of daily data can be retrieved or indices/trends/anomaly plots or maps can be shown. The content of each pull down menu is linked to the choice made in another pull down menu. For instance if country selection is 'The Netherlands' only stations for that country are shown in the menu item station selection. There are no restrictions to the order of the selections. Because the website information is directly (on the fly) retrieved from the ICA database it is always up-to-date.

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