

Introduction to RClimDex v1.9

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Acknowledgements to version 1

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Acknowledgements to version 2

The version 2 of RClimDex was developed by Xuebin Zhang, Yang Feng and Rodney Chan at the Climate Research Division of Environment Canada. The new version of RClimDex is made possible by Pacific Climate Impacts Consortium and their climdex.pcic package. All indices calculation now depends on the fast and well tested implementation of ClimDex from the climdex.pcic package.

Release notes

Major changes in version 2:

1. Indices calculation replaced by climdex.pcic from RClimDex
2. Batch processing support
3. UX overhaul

Changelog

2.0:

Release version.

Updated manual.

Removed outlier checking for precipitation upper limit in quality control.

1.9-1:

Fix bug where indices calculation crashed when only one variable is present. (the others are all NAs)

1.9:

If base period contains years at the start or end with all missing values, the base period will be shorten accordingly.

Longitude and Latitude are replaced by Northern Hemisphere and Southern Hemisphere to better reflect the parameter.

Fix bug where selecting a different output directory than the input data file will sometimes result in an error. ('/' syntax issue)

Fix bug where outliers are set against tmax or tmin even if they are purposely not provided. (all missing values)

NA mask rules are implemented in climdex.pcic instead of RClimDex.

Updated manual to reflect UX change for station selection.

1.8-2:

Edits to FD0,SU25,TR20,ID0 to FD,SU,TR,ID to be more consistent.

1.8-1:

Made some minor edits to vignettes in terms of spelling, grammer and structure.

1.8:

Change the version numbering from 0.1-8 -> 1.8.

Remove support for LS trend and plots for indices calculation.

Updated dependency from climdex.pcic version 1.1-1 to 1.1-6

Updated function calls from RClimDex to climdex.pcic for version 1.1-6 from version 0.7-2

Fix bug where repeated indices calculation with multiple files will skip the first file.

Fix bug where "indcal" will appear in the names of output files from the first dataset when processing multiple files.

0.1-7:

Vignettes is added to package.

Manual has been updated with more details.

Startup message has been added for clearer instruction.

Check for precipitation exceeding upper limit.

Output indices plot as pdf instead of jpg.

Change quality control rules to allow some datasets to be flagged but not disrupted from processing.

Log messages are updated to be more natural.

Fix bug in multiple dataset where parameters are changed due to data quality, the changed will revert back after that file instead of remaining for the rest of the files.

Fix bug in leap days being NA instead of being repeated of 28th February.

0.1-6:

Datasets are padded with NA to ensure the datasets filled up a whole year.

0.1-5:

Change NA mask rules to 15 NA threshold for annual and 3 NA threshold for monthly.

Fix bug where any NA in values resulted in invalid dates.

Fix bug where NA mask was not apply to TMAXmean and TMINmean.

Updated RX5day, RX1day. There were issues in old RCLimindex NA mask.

Updated missing marker to accept character values.

Updated thresholds such that some indices calculation are skiped when there are too many NA.

0.1-4:

Initial pacakage version - UX overhaul, batch processing support, indices calculation replaced by climdex.pcic from RCLimDex.

Updated GSL. There were issues in counting one less day in old RCLimindex. (missing +1)

Updated TNn. There were issues with January, even one NA will trigger NA for that month. (missing na.rm=T)

1 Introduction

ClimDex is a Microsoft Excel based program that provides an easy-to-use software package for the calculation of indices of climate extremes for monitoring and detecting climate change. It was developed by Byron Gleason at the National Climate Data Centre (NCDC) of NOAA, and has been used in CCI/CLIVAR workshops on climate indices from 2001.

The original objective was to port ClimDex into an environment that does not depend on a particular operating system. It was very natural to use **R** as our platform, since **R** is a free and yet very robust and powerful software for statistical analysis and graphics. It runs under both Windows and Unix environments. In 2003 it was discovered that the method used for computing percentile-based temperature indices in ClimDex and other programs resulted in inhomogeneity in the indices series. A fix to the problem requires a bootstrap procedure that makes it almost impossible to implement in an Excel environment. This has made it more urgent to develop the **R** based package.

RClimDex is designed to provide a user friendly interface to compute indices of climate extremes. It computes all 27 core indices recommended by the CCI/CLIVAR Expert Team for Climate Change Detection Monitoring and Indices (ETCCDI) as well as some other temperature and precipitation indices with user defined thresholds. The 27 core indices include almost all the indices calculated by ClimDex (Version 1.3). This version of RClimDex has been developed under **R** 2.15.2. It also depends on the **R** library of `climdex.pcic` (Version 1.1-6) and `PCICt` (Version 0.5-4) for computing the 27 core indices as well as the **R** library of `Tcl/Tk` (Version 2.15.2) for the graphical user interface. This RClimDex package should run with **R** 2.15.2 or a later version. The depended **R** libraries are available from the official CRAN website and needs to be downloaded and installed before the installation of the RClimDex package.

A main objective of constructing climate extremes indices is to use for climate change monitoring and detection studies. This requires that the indices be homogenized. Data homogenization has been planned but is not implemented in this release. Current RClimDex only includes a simple data quality control procedure that was provided in ClimDex. As in ClimDex, we require that data are quality controlled before the indices can be computed. This manual provides step-by-step instructions on the following.

1. The installation of **R** and setting up the user environment
2. Quality control of daily climate data
3. Calculation of the 27 core indices

2 Installation of R

2.1 Brief introduction to R

R is a language and environment for statistical computing and graphics. It is a GNU implementation of the S language developed by John Chambers and colleagues at Bell Laboratories (formerly AT&T, now Lucent Technologies). S-plus provides a commercial implementation of the S language.

2.2 Installing R

RClimDex requires the base package of **R** (Version 2.15.2 or later). The installation of **R** involves a very simple procedure. First, connect to the **R** project website at www.r-project.org, then follow the links to download the most recent version of **R** for your computer operating system from any mirror site of CRAN.

For Microsoft Windows XP and later, download the base **R** Windows installer. Run that installer and **R** will be automatically installed on your computer, with a shortcut to **R** on your desktop. The Tcl/Tk library is included in the default installation of **R**.

For Linux, download the proper precompiled binaries and follow the instruction to install **R**. For other UNIX systems, you may need to download the source code and compile it yourself.

For Mac OSX 10.9 (Mavericks) and above, download the latest version of the **R** signed package. Validate the signature using `pkgutil` for example `-check-signature R-3.2.1.pkg` in the *Terminal*. Run the **R** signed package to install. Select custom install during installation to enable Tcl/Tk library. Connect to XQuartz website at xquartz.macosforge.org to use X11 which is required for the graphical user interface of RClimDex. Download the latest XQuartz image and install. There is now an R app in Launchpad.

For Mac OSX 10.5 (Leopard) to 10.8 (Mountain Lion), download the last supported legacy version of the **R** signed package of the corresponding Mac OSX version. Validate the signature by checking the MD5 checksum with the website. For example to check the MD5 checksum type in `md5 R-3.2.1.pkg` in the *Terminal* application. Run the **R** signed package to install and during installation select custom install to enable Tcl/Tk library. **R** is now installed and in the Application folder. For Mac OSX 10.8 (Mountain Lion), connect to XQuartz website at xquartz.macosforge.org to use X11 which is required for the graphical user interface of RClimDex. Download the latest XQuartz image and install.

2.3 Running R

For Windows, double click the **R** icon on your desktop, or launch it through Windows *Start* Menu. This usually gets you into the **R** user interface. **R** 64bit will also be installed if your system supports 64bit. It is recommended to use **R** 64bit if your system is 64bit. You may quit the program by clicking on the

top menu under *File* then *Exit*.

Under Linux, just run the command *R* to give you the **R** console. You may quit by typing in the command *q()*.

Under OSX, click on the **R** app in Launchpad, or double click the **R** icon in your Application folder. This usually gets you into the **R** user interface. You may quit the program by clicking on the top menu under *R* then *Quit R*.

3 Installation of RCLimDex

RCLimDex is now an **R** package. Most recent version of RCLimDex is available from the ETCCDI website at <http://etccdi.pacificclimate.org/software.shtml>, where registration is required. Please install RCLimDex as a local package in **R**. RCLimDex now depends on the `climdex.pcic`. With an internet connection, launch **R** in the same directory as the RCLimDex package. Then run the following commands:

```
install.packages("climdex.pcic")
```

```
install.packages("RCLimDex_1.9-1.tar.gz", repos=NULL, type="source")
```

Select a CRAN mirror to install or update the **R** package of `climdex.pcic` then run the other command to install RCLimDex.

RCLimDex has been developed under **R** 2.15.2. This version of RCLimDex depends on the **R** library of `climdex.pcic` (Version 1.1-6) and PCICt (Version 0.5-4) for computing the 27 core indices as well as the **R** library of Tcl/Tk (Version 2.15.2) for the graphical user interface. The depended **R** libraries will be downloaded and installed automatically during the installation of the RCLimDex package.

For Windows, you may change the current **R** working directory by clicking on the top menu under *File* then *Change dir...*, afterwards select the directory where you store the RCLimDex package before installing.

Under OSX, please click on the top menu under *Misc* then *Change Working Directory...* to change the current **R** working directory. Please select the directory where RCLimDex package is stored before installing.

4 RCLimDex

4.1 Getting started on RCLimDex

RCLimDex can be loaded like any other **R** packages. All dependent libraries will also be loaded. Please type in the following into the **R** console:

```
library("RCLimDex")
```


In order to launch RClmDex user interface and to begin using RClmDex, simply type in the following into the **R** console.

```
rclimdex.start()
```

You may type in the command into the **R** console again to relaunch the user interface. RClmDex is not programmed to support concurrent sessions within the same **R** console, therefore please launch one user interface at a time.

Alternatively you may launch another separate **R** console in another window for an additional session of RClmDex. Please note that RClmDex only supports one current session per **R** console.

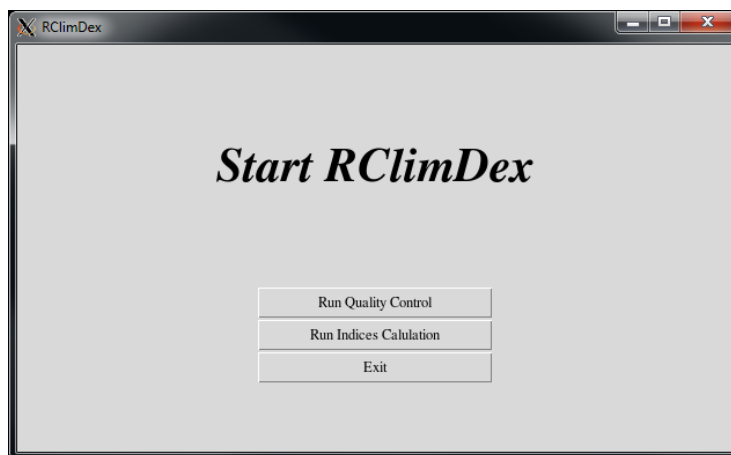


Figure 1: RClmDex main menu.

4.2 Quality control

4.2.1 Description of RClmDex quality control procedures

We highly recommend to executing the quality control step of RClmDex before proceeding to indices calculation. Simply press the *Run Quality Control* button to begin as shown in Figure 1. Data quality control consists of the following procedures.

1. Replace all user-defined missing values, with default as -99.9, into NA (internal R missing value).
2. Replace all unreasonable values into NA. If any of the following cases occurs, it usually means there is a significant issue in the dataset and require user to review. Please review the log subdirectory after quality control is completed.
 - (a) Daily precipitation value less than zero millimeter.
 - (b) Daily maximum temperature less than daily minimum temperature.

- (c) Daily temperature values greater than 70 degree Celsius or less than -70 degree Celsius.
 - (d) Leap days. (i.e. 29th February)
 - (e) All values corresponding to an impossible date. (i.e. 32nd March 2013, 12th June 20AA, etc.)
 - (f) Any non-numeric values.
3. Identifies outliers of daily temperature values outside of user-defined region, with default as values further than 3 times standard deviation from the mean value for that calendar day. Users can define other multiples of standard deviation away from mean. Note that the outliers are most often valid values.

4.2.2 Loading datasets for quality control

In the *File Open Window*, you may select the dataset to execute the quality control of RCLimDex. You may need to change directory to where the dataset is stored. RCLimDex expects file extension of either *.csv* or *.txt* however you may display files of all types by selecting *ALL files* in the *Files of type* drop-down menu (See Figure 2). Please note that the dataset must be formatted as described in Appendix B.

Windows and Linux users may press and hold *shift* key or *ctrl* key (OSX users may use *cmd* key) to select multiple datasets. When multiple datasets are selected, RCLimDex would perform quality control based on the same parameters selected on the quality control menu to all datasets in sequence. The output filenames of multiple datasets correspond with their filenames respectively and cannot be changed.

4.2.3 Quality control main menu and parameters

The following is a brief description to each parameter as shown in Figure 3.

1. Output file location: The local directory where RCLimDex will store the output files from quality control.
2. Station name or code: Output filename prefix. (Only available when processing only one dataset)
3. Number of standard deviation for temperature: The threshold for outliers from daily record. Any daily temperature values away from mean in terms of standard deviation for that particular calendar day above threshold will be flagged as outlier in the log file.
4. Missing marker: Character string as the indicator for missing values in input dataset.

The output file location is where all outputs from RCLimDex will be stored. After a successful quality control execution, you will find a *csv* file ending with a suffix of *.indcal.csv*, which is the post quality controlled dataset. Please select this dataset instead of your original dataset for the indices calculation. In addition, there is a log file in *txt* format with details about the quality control a *log*

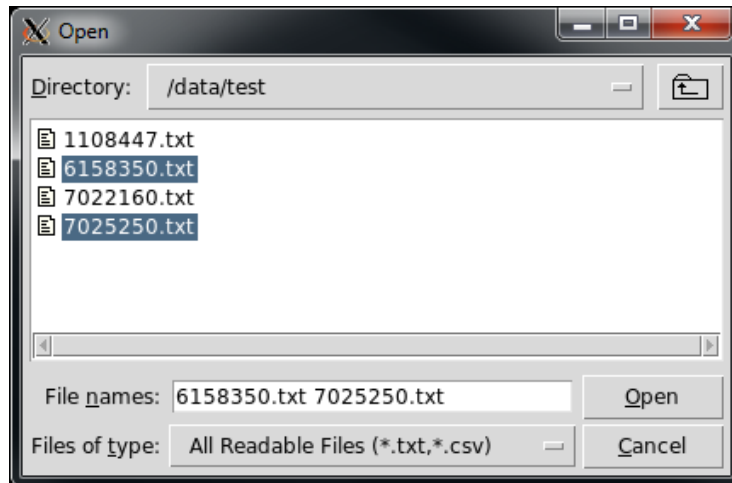


Figure 2: File selection for quality control.

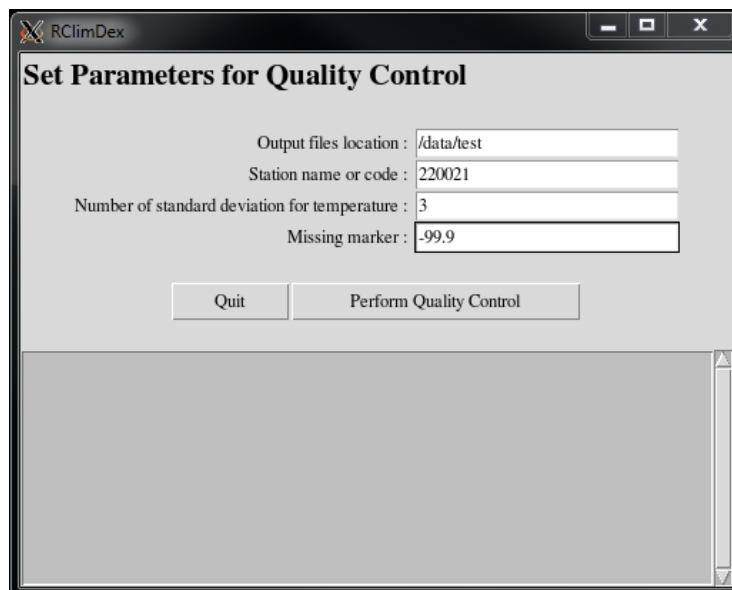


Figure 3: Quality control menu of RCLimDex.

subdirectory that contains plots and statistics about the quality control. Lastly, there are the *indices* subdirectory which would be where the indices calculation outputs be stored. If you are only executing quality control on one dataset, you may rename the output filename.

The other parameters relates to the actual quality control. They are the outlier settings in terms of standard deviation away from mean value, an upper limit for precipitation values in millimeters and the missing marker. Please note that the default missing marker of -99.9 will always be used in addition to your user-defined missing marker.

Press the *Perform Quality Control* button to begin quality control and press the *Quit* button to exit to main menu. Also note that quality control will not automatically quit after completion. If you desire to perform indices calculation on the post quality controlled dataset, simply press the *Quit* button to go back to the main menu then press the *Run Indices Calculation* button on the main menu.

Under the buttons, there are log messages in which RClimDex communicates with the user. It will provide details for current status, including but not limited to which file is loaded, what process is being executed, was the quality control successfully performed and number of files remaining to process.

4.2.4 Quality control results and plots

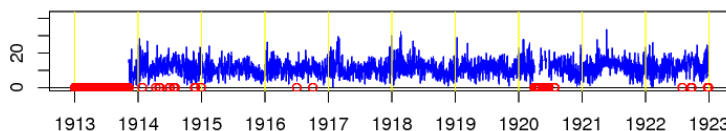


Figure 4: A sample plot from quality control. Red circle indicates values were flagged by quality control.

Please note that while unreasonable values are removed, other problematic data like outliers are simply flagged in a log file and are not changed. They simply alert the user to pay more attention and make correction only if needed.

Besides the main results of post quality controlled dataset, there are a few more outputs from quality control of RClimDex. All of these outputs are in the log subdirectory. Please review these log files for a better understanding of the changes quality control made to the dataset.

- (a) *filename.indcal.csv*; The post quality control data file.
- (b) *log.datestamp.timestamp.txt*; Detail log from RClimDex.
- (c) *log/filename_prcpPLOT.pdf*; Plot of daily precipitation values and histogram of precipitation values.
- (d) *log/filename_tmaxPLOT.pdf*; Plot of daily maximum temperature values.

- (e) `log/filename_tminPLOT.pdf`; Plot of daily minimum temperature values.
- (f) `log/filename_dtrPLOT.pdf`; Plot of daily diurnal temperature range values.
- (g) `log/filename_prpQC.csv`; Table of all daily precipitation values that were flagged and removed.
- (h) `log/filename_tmaxQC.csv`; Table of all daily maximum temperature values that were flagged and removed.
- (i) `log/filename_tminQC.csv`; Table of all daily minimum temperature values that were flagged and removed.
- (j) `log/filename_tepstdQC.csv`; Table of all outlier temperature values that were only flagged.
- (k) `log/filename_nastatistic.csv`; Summary table of the annual and monthly sums of values flagged and removed.

For the outlier tables, there are twelve columns. Three columns each for date, daily maximum temperature, daily minimum temperature and diurnal temperature range. For all temperature columns, there are the lower bound of accepted values, the temperature value of that day and the upper bound of accepted values. The boundaries for outliers are user-defined by the number of standard deviation away from mean. A record is added to the outlier table if any outlier temperature values are flagged for that day.

All plots in quality control provide a quick visual understanding of where values are flagged. As seen in Figure 4, the red circles in the plots are where values are flagged. For daily precipitation values, a histogram is provided as well.

4.3 Indices calculation

4.3.1 Loading data files for indices calculation

In the *File Open Window*, you may select the dataset from which indices are calculated. You may need to change directory to where the quality controlled dataset is stored. RClimDex expects file extension of `.indcal.csv`, which is a post RClimDex quality controlled dataset. You may also display files of all types by selecting *ALL files* in the *Files of type* dropdown menu and select files that are in the format as described in Appendix B. Please note that we highly recommend users to first go through quality control of RClimDex prior to indices calculation.

User may want to check and review the values flagged by the RClimDex quality control prior to indices calculation. You may make changes to the post quality controlled dataset (`.indcal.csv` file) by a spreadsheet editor such as Excel or Numbers in Windows and OSX or any text editor in Linux.

Windows and Linux users may press and hold *shift* key or *ctrl* key (OSX users may use *cmd* key) to select multiple files. When multiple data files are selected, RClimDex would perform indices calculation based on the same parameters

and indices selected on the indices calculation menu to all selected datasets in sequence. The output filenames of multiple files corresponds with their original filenames respectively and can not be changed.

4.3.2 Indices calculation main menu and parameters

The following is a brief description to each parameter as shown in Figure 6.

1. Output file location: The local directory where RClimDex will store the output files from indices calculation.
2. Station name or code: Output filename prefix. (Only available when processing only one dataset)
3. Missing marker: Character string as the indicator for missing values in input dataset.
4. Base period: The base period usually is a long enough period preferably more than 10 years in which climatology do not change much for a given station.
 - (a) First year: Starting year of base period. (Always begin on 1st of January)
 - (b) Last year: Ending year of base period. (Always end on 31st of December)
5. Station location: It will affect indices such as CSDI and GSL based on the hemisphere the station is located. Please select datasets from the same hemisphere when processing multiple dataset. Station location only have options to select between Northern Hemisphere or Southern Hemisphere.
6. Threshold of daily maximum temperature:
 - (a) Upper: User defined threshold for summer days, similar to SU.
 - (b) Lower: User defined threshold for ice days, similar to ID.
7. Threshold of daily minimum temperature:
 - (a) Upper: User defined threshold for tropical nights, similar to TR.
 - (b) Lower: User defined threshold for frost days, similar to FD.
8. Threshold of precipitation (mm): User defined total counts of daily precipitation above the user defined threshold, similar to R10 and R20.
9. Indices selections: Please refer to Appendix A for more information and full definition can be found in Appendix C.

The output files location is where all outputs from RClimDex will be stored. There is a log file in *txt* format about the indices calculation. There are also the *indices* subdirectory which would be where the indices calculation outputs be stored. You may only rename the output filename if you are not processing multiple dataset. The current version of RClimDex does not support different indices calculation selection for each individual dataset when processing multiple dataset. In other words, only the indices selected are calculated for multiple

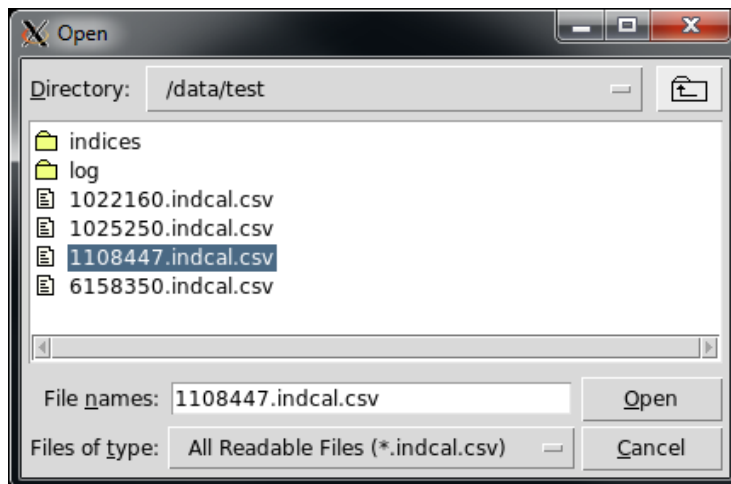


Figure 5: File selection for indices calculation.

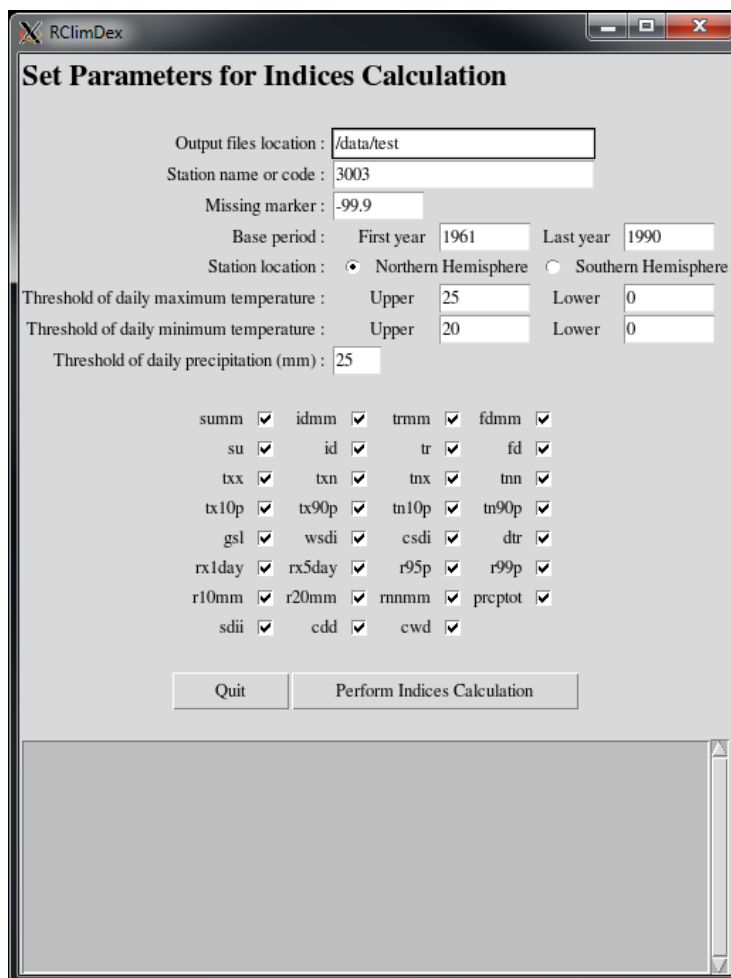


Figure 6: Indices calculation menu of RCLimDex.

dataset. Please note that the default missing marker of -99.9 will always be used in addition to your user-defined missing marker.

The base period always begin from the 1st of January and ends on the 31st of December of the user defined period. RClimDex determines the hemisphere from the station location with radio button for Northern or Southern Hemisphere. Keep in mind to have all datasets from the same hemisphere when processing multiple datasets because RClimDex assumes same parameters when processing multiple datasets which includes the hemisphere. The threshold values for temperature are for user-defined frost days, summer days, ice days and tropical nights, where precipitation threshold is for user defined number of days with daily precipitation values above threshold.

Each index can be individually selected to be or not to be calculated for the datasets. More information about the indices can be found in Appendix A and full definition can be found in Appendix C. Press the *Perform Indices Calculation* button to begin and press the *Quit* button to exit to main menu. Also note that indices calculation will not automatically quit after completion.

RClimDex communicates with the user in the log message box below the buttons. This is where details about the current status, such as which dataset is loaded, what process is being performed, number of datasets remaining, etc. are displayed.

A List of ETCCDI core Climate Indices

ID	Indicator name	Definitions	Units
FD	Frost days	Annual count when TN(daily minimum) < 0°C	days
SU	Summer days	Annual count when TX(daily maximum) > 25°C	days
ID	Ice days	Annual count when TX(daily maximum) < 0°C	days
TR	Tropical nights	Annual count when TN(daily minimum) > 20°C	days
GSL	Growing season length	Annual (1st Jan to 31st Dec in NH, 1st July to 30th June in SH) count between first span of at least 6 days with TG > 5°C and first span after 1st July (1st January in SH) of 6 days with TG < 5°C	days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	°C
TNx	Max Tmin	Monthly maximum value of daily minimum temp	°C
TXn	Min Tmax	Monthly minimum value of daily maximum temp	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temp	°C
TN10p	Cool nights	Percentage of days when TN < 10th percentile	%
TX10p	Cool days	Percentage of days when TX < 10th percentile	%
TN90p	Warm nights	Percentage of days when TN > 90th percentile	%
TX90p	Warm days	Percentage of days when TX > 90th percentile	%

ID	Indicator name	Definitions	Units
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX>90th percentile	days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN<10th percentile	days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP >= 1.0mm) in the year	mm/day
R10	Number of heavy precipitation days	Annual count of days when PRCP >= 10mm	days
R20	Number of very heavy precipitation days	Annual count of days when PRCP >= 20mm	days
Rnn	Number of days above nn mm	Annual count of days when PRCP >= nn mm, nn is user defined threshold	days
CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with RR >= 1mm	days
R95p	Very wet days	Annual total PRCP when RR > 95th percentile	mm
R99p	Extremely wet days	Annual total PRCP when RR > 99th percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR >= 1mm)	mm

B Data format

All indices calculation are outputted as comma-separated values (CSV) files for tables and portable document format (PDF) files for all plots. RClmDex likewise accepts CSV files as input data. RClmDex also accepts space-delimited ASCII text file as input data. Space-delimited format has each element separated by one or more spaces. The input dataset must satisfy the following requirements.

1. The input dataset **must** have the file extension *.csv* or *.txt*
2. Columns **must** be *YEAR MONTH DAY PRCP TMAX TMIN* in that order
3. The records **must** be in calendar date order. Missing dates are allowed.

This is an example of an input dataset as a space-delimited ASCII file.

1950	2	3	-99.9	-3.1	-6.8
1950	2	4	0	-1.3	-3.6
1950	2	5	0	-0.5	-7.9
1950	2	6	11.4	-1	-9.1
1950	2	9	0	-1.8	-8.4

This is an example of an input dataset as a CSV file.

1950,2,3,-99.9,-3.1,-6.8
1950,2,4,0,-1.3,-3.6
1950,2,5,0,-0.5,-7.9
1950,2,6,11.4,-1,-9.1
1950,2,9,0,-1.8,-8.4

C Indices definition

Definitions for indicators are listed in Appendix A. For practical reasons, in this version of the software, not all indices are calculated on a monthly basis. Monthly indices are calculated if no more than 3 days are missing in a month, while annual values are calculated if no more than 15 days are missing in a year. No annual values will be calculated if any one month's data are missing. For threshold indices, a threshold is calculated if at least 75% of data are present. For spell duration indicators (marked with a *), a spell can continue into the next year and is counted against the year in which the spell ends.

A cold spell (CSDI) for example in the Northern Hemisphere beginning on 31st December 2000 and ending on 6th January 2001 is counted towards the total number of cold spells in 2001.

1. **FD**

Let Tn_{ij} be the daily minimum temperature on day i in period j . Count the number of days where:

$$Tn_{ij} < 0^{\circ}\text{C}$$

2. **SU**

Let Tx_{ij} be the daily maximum temperature on day i in period j . Count the number of days where:

$$Tx_{ij} > 25^{\circ}\text{C}$$

3. **ID**

Let Tx_{ij} be the daily maximum temperature on day i in period j . Count the number of days where:

$$Tx_{ij} < 0^{\circ}\text{C}$$

4. **TR**

Let Tn_{ij} be the daily minimum temperature on day i in period j . Count the number of days where:

$$Tn_{ij} > 20^{\circ}\text{C}$$

5. **GSL**

Let T_{ij} be the daily mean temperature on day i in period j . Count the number of days between the first occurrence of at least 6 consecutive days with:

$$T_{ij} > 5^{\circ}\text{C}$$

and the first occurrence after 1st July (1st January in SH) of at least 6 consecutive days with:

$$T_{ij} < 5^{\circ}\text{C}$$

6. **TXx**

Let Tx_{ij} be the daily maximum temperature in month i , period j . The maximum daily maximum temperature each month is then:

$$TX_{ij} = \max(Tx_{ij})$$

7. **TNx**

Let Tn_{ij} be the daily minimum temperature in month i , period j . The maximum daily minimum temperature each month is then:

$$TN_{ij} = \max(Tn_{ij})$$

8. **TXn**

Let Tx_{ij} be the daily maximum temperature in month i , period j . The minimum daily maximum temperature each month is then:

$$TX_{ij} = \min(Tx_{ij})$$

9. **TNn**

Let Tn_{ij} be the daily minimum temperature in month i , period j . The minimum daily minimum temperature each month is then:

$$TN_{ij} = \min(Tn_{ij})$$

10. **Tn10p**

Let Tn_{ij} be the daily minimum temperature on day i , period j and let Tn_{in10} be the calendar day 10th percentile centered on a 5-day window (calculated using method in Appendix D). The percentage of time is determined where:

$$Tn_{ij} < Tn_{in10}$$

11. **Tx10p**

Let Tx_{ij} be the daily maximum temperature on day i , period j and let Tx_{in10} be the calendar day 10th percentile centered on a 5-day window (calculated using method in Appendix D). The percentage of time is determined where:

$$Tx_{ij} < Tx_{in10}$$

12. **Tn90p**

Let Tn_{ij} be the daily minimum temperature on day i , period j and let Tn_{in90} be the calendar day 90th percentile centered on a 5-day window (calculated using method in Appendix D). The percentage of time is determined where:

$$Tn_{ij} > Tn_{in90}$$

13. **Tx90p**

Let Tx_{ij} be the daily maximum temperature on day i , period j and let Tx_{in90} be the calendar day 90th percentile centered on a 5-day window (calculated using method in Appendix D). The percentage of time is determined where:

$$Tx_{ij} > Tx_{in90}$$

14. **WSDI***

Let Tx_{ij} be the daily maximum temperature on day i , period j and let Tx_{in90} be the calendar day 90th percentile centered on a 5-day window (calculated using method in Appendix D). Then the number of days per period is summed where, in interval, of at least 6 consecutive days:

$$Tx_{ij} > Tx_{in90}$$

15. **CSDI***

Let Tn_{ij} be the daily minimum temperature on day i , period j and let Tn_{in10} be the calendar day 10th percentile centered on a 5-day window (calculated using method in Appendix D). Then the number of days per period is summed where, in interval, of at least 6 consecutive days:

$$Tx_{ij} > Tx_{in90}$$

16. **DTR**

Let Tx_{ij} and Tn_{ij} be the daily maximum and minimum temperature respectively on day i , period j . If I represents the number of days in j , then:

$$DTR = \frac{\sum_{i=1}^I (Tx_{ij} - Tn_{ij})}{I}$$

17. **RX1day**

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

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

18. **RX5day**

Let RR_{kj} be the daily precipitation amount for the 5-day interval ending on day k in period j . Then maximum 5-day values for period j are:

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

19. **SDII**

Let RR_{wj} daily precipitation amount on wet days, $w(RR \geq 1\text{mm})$, in period j . If W represents the number of wet days in j , then:

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

20. **R10**

Let RR_{ij} be the daily precipitation amount on day i in period j . Count the number of days where:

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

21. **R20**

Let RR_{ij} be the daily precipitation amount on day i in period j . Count the number of days where:

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

22. **Rnn**

Let RR_{ij} be the daily precipitation amount on day i in period j . If nn represents any reasonable daily precipitation value in millimeters then, count the number of days where:

$$RR_{ij} \geq nn$$

23. **CDD***

Let RR_{ij} be the daily precipitation amount on day i in period j . Count the largest number of consecutive days where:

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

24. **CWD***

Let RR_{ij} be the daily precipitation amount on day i in period j . Count the largest number of consecutive days where:

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

25. **R95p**

Let RR_{wj} daily precipitation amount on wet days, $w(RR \geq 1\text{mm})$, in period j and let RR_{wn95} be the 95th percentile on wet days in the base period. If W represents the number of wet days in the period, then:

$$R95p_j = \sum_{w=1}^W RR_{wj}, \text{ where } RR_{wj} > RR_{wn95}$$

26. **R99p**

Let RR_{wj} daily precipitation amount on wet days, $w(RR \geq 1\text{mm})$, in period j and let RR_{wn99} be the 99th percentile on wet days in the base period. If W represents the number of wet days in the period, then:

$$R99p_j = \sum_{w=1}^W RR_{wj}, \text{ where } RR_{wj} > RR_{wn99}$$

27. **PRCPTOT**

Let be the RR_{ij} daily precipitation amount on day i in period j . If I represents the number of wet-days in j , then:

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

D Threshold estimation and base period temperature indices calculation

D.1 Empirical quantile estimation

The quantile of a distribution is defined as

$$Q(p) = F^{-1}(p) = \inf\{x : F(x) \geq p\}, 0 < p < 1$$

where $F(x)$ is the distribution function. Let $\{X_{(a)}, \dots, X_{(n)}\}$ denote the order statistics of $\{X_1, \dots, X_n\}$ (i.e. sorted values of $\{X\}$), and let $\hat{Q}_i(p)$ denote the i th sample quantile definition. The sample quantiles can be generally written as

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

Hyndman and Fan (1996) suggest a formula to obtain medium un-biased estimate of the quantile by letting $j = \text{int}(p \times n + (1 + p)/3)$ and letting $\gamma = p \times n + (1 + p)/3 - j$, 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.

D.2 Bootstrap procedure for the estimation of exceedance rate for the base period

It is not possible to make an exact estimate of the thresholds due to sampling uncertainty. To provide temporally consistent estimate of exceedance rate throughout the base period and out-of-base period, we adapt the following procedure (Zhang et al. 2004) to estimate exceedance rate for the base period.

- (a) The base period is divided into one *out-of-base* year, the year for which exceedance is to be estimated, and a *base-period* consisting the remaining years from which the thresholds would be estimated.
- (b) A n -year block of data is constructed by using the $n - 1$ year *base-period* data set and adding an additional year of data from the *base-period* (i.e. one of the years in the *base-period* is repeated). This constructed n -year block is used to estimate thresholds.
- (c) The *out-of-base* year is then compared with these thresholds and the exceedance rate for the *out-of-base* year is obtained.
- (d) Steps (b) and (c) are repeated for additional $n - 2$ times, by repeating each of the remaining $n - 2$ in-base years in turn to construct the n -year block.
- (e) The final index for the *out-of-base* year is obtained by averaging the $n - 1$ estimates obtained from steps (b), (c) and (d).

References

- [1] Hyndman, R.J., and Y. Fan, 1996: Sample quantiles in statistical packages. *The American Statistician*, **50**, 361-367.
- [2] Zhang, X., G. Hegerl, F.W. Zwiers, and J. Kenyon, 2005: Avoiding inhomogeneity in percentile-based indices of temperature extremes. *J. Climate*, **18**, 1647-1648.