Homogenization of climate series

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Homogeneity of time series

Statistically, time series are homogeneous when their characteristics (mean, standard deviation, seasonality, etc.) remain stable along time.

However, this ***absolute homogeneity*** cannot be achieved by most climate series in the context of climate change. Therefore, our goal is to obtain time series in which changes in their statistical parameters accurately reflect the actual climate variations occurring in the areas where the observatories are located. These series will thus be considered homogeneous because they conform to the concept of ***relative homogeneity***.

The opposite of *homogeneity* is *heterogeneity*, although the term *inhomogeneity* is mostly used in the climate community.

Causes of inhomogeneities

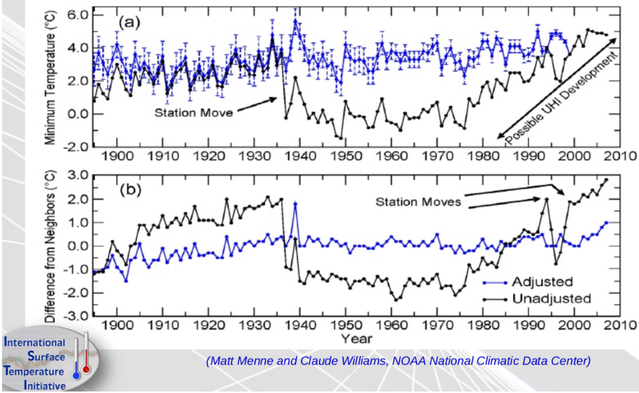
Series of quality controlled meteorological observations are the basis to study the climate and its variability in time and space.

However, any change in the conditions of observation can introduce biases into the measurements (WMO, 2020), namely:

- Station moves
- Instrument changes
- Changes in the instrument shelter (type, deterioration, etc.)
- Changes in the surroundings of the observatory (urbanization, growth of nearby trees, land use changes, etc.)
- Changes in the time of observation or of observer (especially in the case of visual observations such as cloudiness, visibility, etc.)
- Changes in data processing (calculation of daily mean temperature, etc.)

Types of biases

Inhomogeneity biases can be sudden or gradual (more difficult to detect and correct). Example of inhomogeneities in annual mean minimum temperature at Reno, Nevada, USA:



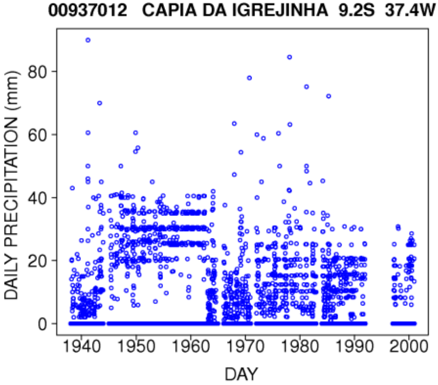
(Matt Menne and Claude Williams, NOAA National Climatic Data Center)

Their detection and correction is very important for a reliable study of climate variability and trends.

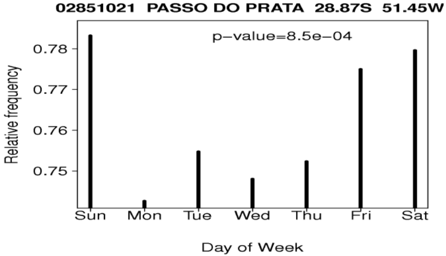
Examples of problems in daily precipitation

Sugahara *et al.* (2010) illustrate some common problems in daily precipitation, such as:

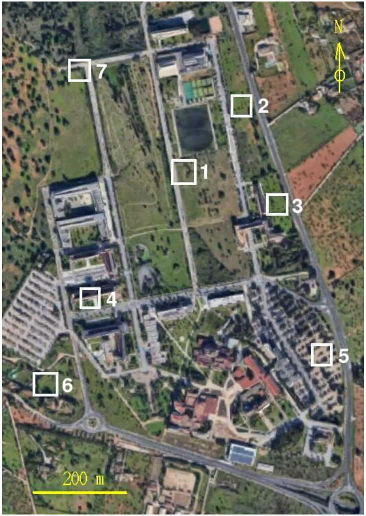
(Left) Rounding (plus a bias between 1945 and 1963)
(Right) Weekend missing observations (and accumulation on Mondays)



Frequency of zero precipitation:



Case study on spatial variability



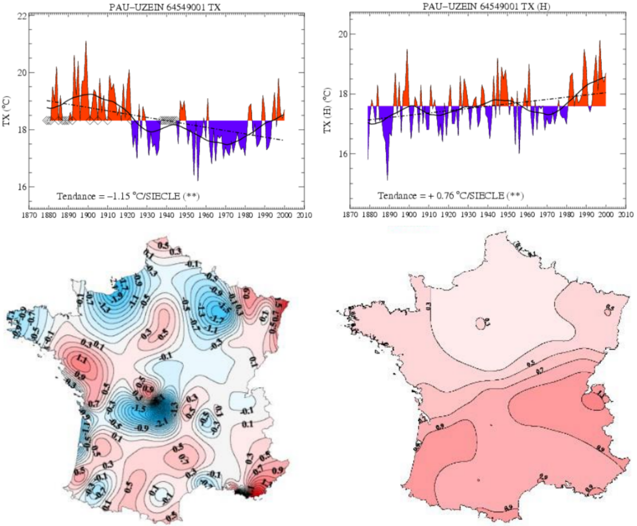
During June 2016, temperature was measured at a network of sensors with an average separation of about 250 m on the campus of the University of the Balearic Islands, and differences in the **average** maximum and minimum temperatures between the sensors were around 1°C (Guijarro *et al.*, 2023a).

Note how small relocations of an observatory can impact the observed temperature trends when climate warming is expected to increase mean temperatures by a few tenths of degree Celsius every ten years.

Implication: Do not forget to record any historical change in observation conditions in the station metadata.

Example of impact of homogenization on trends

1901-2000 T.max. trends in France before and after homogenization:



(Mestre, 2000)

Sources of information about climate series homogenization

Good introductory information can be found in the following publications (full references at the end):

- Peterson *et al.* (1998): Homogeneity Adjustments of 'In Situ' Atmospheric Climate Data: A Review.
- Aguilar *et al.* (2003): Guidelines on climate metadata and homogenization.
- WMO (2020): Guidelines on Homogenization.

More varied information and case studies can be obtained from the series of publications derived from the excellent homogenization seminars held by the Hungarian Meteorological Service and published in the Időjárás journal and in WMO WCDMP series.

The latest seminars included presentations on the homogenization of **daily** series, very important for the analysis of extremes and not dealt with in the above listed references.

Available homogenization software packages

While some climatologist use the general concepts and theory on inhomogeneities to develop their own methods to detect and correct the biases in their series, others take advantage of the existing software available for public use.

Currently, the most commonly used homogenization software packages are, in alphabetical order: ACMANT, Climatol, HOMER and sons, MASH, PHA and RHtests. (See comparisons with monthly temperature and precipitation in Guijarro *et al.*, 2023b and with daily temperature in Killick, 2016.)

- **ACMANT** is very tolerant to missing data. It tries to detect all biases at the price of including many false positives. (DOS/Windows *.exe program. Version 4.4 is free software, while version 5 must be purchased from the author.)
- **Climatol**' level of detection can be tuned by the user. By default, it tends to be conservative, letting the smaller biases pass undetected to avoid false positives. It can use very short series because of its full tolerance to missing data. (R package, hence open software and multiplatform.)

- **HOMER** was the software delivered by the international COST Action ES0601 (*Advances in homogenisation methods of climate series: an integrated approach, "HOME"*). (Open software, programmed in R.) It has a very low tolerance to missing data and requires manual interaction by experienced users. However, it is no longer maintained. Some more automatic derivatives have been produced by German and Swedish climatologists, but they do not seem to have been released for public use.
- **MASH** is mainly used in Hungary and nearby countries, but has also been used elsewhere. Versions 3.x had a low tolerance to missing data in the MULTITEST comparisons made before the new version 4 was available. Contact the Hungarian Meteorological Service if you need assistance to apply it. (DOS/Windows collection of *.bat and *.exe programs.)
- **PHA** was developed by NOAA to homogenize monthly temperature series and is being used by other institutions dealing with global temperature data. It has also been used to homogenize monthly relative humidity in China. (Fortran source, needs compilation.)
- **RHtests** homogenizes series one by one and requires the user to provide a well correlated homogeneous reference to perform relative homogenization. As observational series cannot guarantee its homogeneity, reanalysis series are often used as references. (Open software, programmed in R.)

Use case: Operational homogenization of daily series of several variables

Lorenzo *et al.* (2024) presented at a homogenization seminar the operational homogenization of all Spanish **daily** series with a minimum of 5 years of observation in 1975-2020 of:

- Precipitation (at least 10 years of observation were required here)
- Maximum and minimum temperature
- Sunshine duration
- Relative humidity
- Station level pressure
- Average 10' wind speed
- Maximum wind gusts

The software used was the *climatol* R package because it: i) implements quality controls to detect and correct outliers and long runs of identical values in the series; ii) can redistribute daily precipitation when it has been accumulated during a few days; and iii) allows the use of almost all of your climate series, either long or short, which will be completed by estimating values to fill in any missing data. (Software updates and guidance texts and videos available at https://climatol.eu)

References

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- Peterson TC, Easterling DR, Karl TR, Groisman P, Nicholls N, Plummer N, Torok S, Auer I, Boehm R, Gullett D, Vincent L, Heino R, Tuomenvirta H, Mestre O, Szentimrey T, Salinger J, Førland E, Hanssen-Bauer I, Alexandersson H, Jones P, Parker D (1998): Homogeneity Adjustments of 'In Situ' Atmospheric Climate Data: A Review. *Int. J. Climatol.*, 18:1493-1518.
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Many thanks for your attention!!!