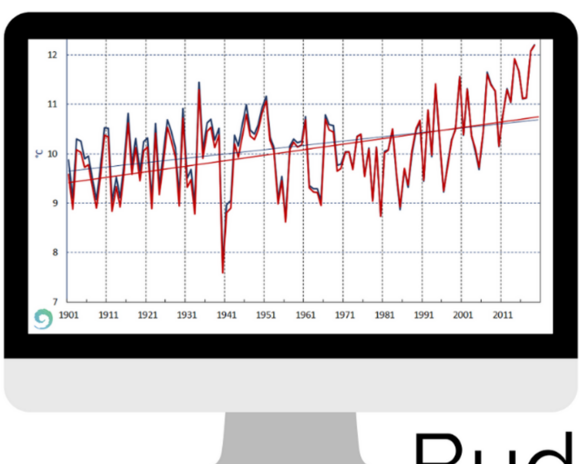
ABSTRACT BOOK

10th SEMINAR FOR HOMOGENIZATION AND QUALITY CONTROL

AND

5th CONFERENCE ON SPATIAL INTERPOLATION TECHNIQUES IN CLIMATOLOGY AND METEOROLOGY



ONLINE

12-14 October 2020

Budapest,Hungary

2020

10th Seminar for Homogenization and Quality Control and
5th Conference on Spatial Interpolation Techniques in Climatology and Meteorology

Budapest, Hungary 12- 14 October 2020

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PROGRAMME

Budapest, Hungary
12-14 October 2020

Monday, 12 October
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Implementing homogenization in national meteorological services – the WMO Task Team on Homogenization guidance

Victor Venema:
The deleted chapter on future research needs

Tamás Szentimrey:
Mathematical questions of homogenization and summary of MASH

15:00 – 15:20 coffee break

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Quality control and homogenization of the daily series of the ECA&D database under the INDECIS project

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Johan Södling:
A method for creating realistic temporal gaps in time series data

Ciara Ryan, Mary Curley, Conor Murphy and Seamus Walsh:
Developing a high quality, long term rainfall network for the Island of Ireland 1900-2018.

Yizhak Yosef; Enric Aguilar; Pinhas Alpert:
Long-term trends in extreme temperature and precipitation indices for Israel based on a new daily homogenized database

Elinah Khasandi Kuya, Herdis Motrøen Gjelten & Ole Einar Tveito:
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15:00 – 15:20 coffee break

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Roeland Van Malderen, E. Pottiaux, A. Klos, P. Domonkos, M. Elias, T. Ning, O. Bock, J. Guijarro, F. Alshawaf, M. Hoseini, A. Quarello, E. Lebarbier, B. Chimani, V. Tornatore, S. Zengin Kazancı, and J. Bogusz:
Break detection in integrated water vapour benchmark datasets

Moritz Buchmann:
Evaluating the robustness of snow climate indicators using a unique set of parallel snow measurement series

Gernot Resch, Barbara Chimani, Roland Koch, Wolfgang Schöner, Christoph Marty:
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Transformation of CarpatClim datasets for grid-box average datasets

Moritz Bandhauer, Francesco Isotta, Monika Lakatos, Beatrix Izsák, Olivér Szentes, Cristian Lussana, Ole Einar Tveito and Christoph Frei:
Evaluation of the precipitation climate E-OBS and ERA5 with high-resolution grid datasets in European regions

Irene Garcia Marti, **Gerard van der Schrier**, Else van den Besselaar, Cristina Rojas Labanda, Fidel Gonzalez-Rouco:
Development of the E-OBS wind strength dataset

Mónika Lakatos, Tamás Szentimrey, Beatrix Izsák, Olivér Szentes, Lilla Hoffmann, Andrea Kircsi, Zita Bihari:
Comparative study of CARPATCLIM, E-OBS and ERA5 dataset

15:00 – 15:20 coffee break

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Andrés Chazarra Bernabe:
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Svetlana Aniskevich, **Viesturs Zandersons**:
Change point detection in monthly mean air temperature observations in Latvia

Elke Rustemeier; M. Ziese; A. Rauthe-Schöch; A. Becker; P. Finger; U. Schneider:
Evaluation of interpolation scheme and extreme value indices based on GPCC's Full Data Daily

Miroslav Trnka, **Petr Štěpánek**, Zdeněk Žalud, Pavel Zahradníček, Martin Možný, Jan Balek, Daniela Semerádová, Monika Bláhová, Eva Svobodová:
Climate monitoring products for farmers in the Czech Republic

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ABSTRACTS

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STATEMENT

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Climate data management constitutes an essential element of the climate services value chain. WMO is committed to facilitate Members' efforts to convert observations and model outputs into meaningful climate data sets, which are quality controlled, safely stored and accessible. Various activities are run currently by WMO and its Members to advance climate data management in terms of standard setting and standard implementation.

Guided by the new WMO governance structure, WMO experts:

- are continuing extending content of the recently endorsed Manual on the High-quality Global Data Management Framework for Climate (WMO-No. 1238),
- are finalizing Guidelines on quality control and climate reference stations,
- are contributing to a broader open-source initiative to develop a single reference Climate Data Management System for climate, hydrological and other environmental data,
- help implementing a new GTS message to exchange daily climate data (DAYCLI message),
- are preparing for the 1991-2020 Climatological Standard Normals update,
- are continuing support to data rescue activities worldwide
- help implementing regional and national projects to strengthen climate data management capabilities of Members worldwide,
- etc.

A recent milestone was marked by the publication of WMO Guidelines on Homogenisation (WMO-No. 1245), an extensive and excellent collaboration by world-leading experts.

Exchange of knowledge is a key tool for capacity development in its broadest sense. The conference series on homogenization and spatial interpolation offers a sustained platform for knowledge exchange in order to help implementing state-of-the-art statistical methods and tools to underpin climate science and services. WMO Members appreciate the tireless efforts of the Hungarian National Meteorological and Hydrological Service to continue this highly successful conference series.

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IMPLEMENTING HOMOGENIZATION IN NATIONAL METEOROLOGICAL SERVICES – THE WMO TASK TEAM ON HOMOGENIZATION GUIDANCE

Blair Trewin, Enric Aguilar, Ingeborg Auer, Jose Antonio Guijarro, Peer Hechler, Mónika Lakatos, Matthew Menne, Ghulam Rasul, Clara Rojas, Tamás Szentimrey, Victor Venema, Xiaolan Wang

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The World Meteorological Organization (WMO) established a Task Team on Homogenization (TT-Hom) which operated between 2014 and 2018. Its primary output was to produce a guidance document on climate data homogenization, which was published in early 2020.

The main purpose of the document is to provide guidance to National Meteorological Services (NMSs) on the practical development and maintenance of homogenized climate data sets. It is especially directed towards NMSs in less developed countries, and who may have little or no experience with the concept or implementation of homogenization. Data in such countries is of high value to their own management decisions as their climate changes, as well as being an important contributor to global and regional data sets. Another important audience for the document is the broader group of staff in NMSs (such as network managers) who may not be doing homogenization themselves, but whose decisions are important in being able to maintain homogeneous data in the longer term.

The guidance has five chapters:

– Some key prerequisites to developing homogenised data sets, such as data quality control, the existence and maintenance of metadata, data rescue where applicable, and the use of parallel observation programs for significant changes.
– Detailed guidance on homogenization and how to implement it.
– Guidance on selecting homogenization software which is suitable for the data set for which it is being used.
– The history of climate data homogenization.
– Theoretical aspects of homogenization.

A key aspect for NMSs is maintaining homogenized data sets on an ongoing basis. Many such data sets have originally been developed on a one-off basis, often as part of a research project, and are not maintained after the initial development (apart, sometimes, from appending new, unadjusted data to those stations which are still operating). It is important to have a process in place to maintain the data set. This includes engaging with network managers and others to ensure that suitable arrangements (such as parallel observations) are in place as changes inevitably occur, and that resources are in place to develop new data set versions periodically. Case studies will be presented of recommended practice in this area.

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THE DELETED CHAPTER ON FUTURE RESEARCH NEEDS

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Generating a benchmark dataset makes one aware of how much we do not know about inhomogeneities yet. Writing a WMO guidance on homogenization, similarly, makes one aware of how much we do not know about homogenization yet.

While writing and editing the guidance we started writing up the research that is still needed. Quite often we could not recommend what to do, but only explain what is commonly done or thought be to best.

Next to many such more practical questions there are also many fundamental problems that need our attention. Break detection is a difficult problem if the signal to noise ratio is low. Methods to adjust the distribution may need to take into account the physical reasons for inhomogeneities and that they are likely not fully predictable. We thus need to understand the physics of the inhomogeneities much better. In the end this should not only lead to better estimates of how the climate has changed, but also to specific estimates of the uncertainties after homogenization due to the inhomogeneities.

An early draft of the chapter can be found on EarthArXiv. https://eartharxiv.org/8qzrf/

I look forward to further research suggestions and ideas for priorities in the Q&A.

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MATHEMATICAL QUESTIONS OF HOMOGENIZATION AND SUMMARY OF MASH

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There are several methods and software for the homogenization of climate data series but there is not any exact mathematical theory of the homogenization. At the examinations mainly the physical experiences are considered while the mathematical formulation of the problems is neglected in general. Moreover occasionally there are some mathematical statements at the description of the methods in the papers – e. g. capability to correct the higher order moments – but without any proof and this way is contrary to the mathematical conventions of course. As we see the basic problem of the homogenization is the unreasonable dominance of the practical procedures over the theory and it is the main obstacle of the progress. Therefore we try to formulate some questions of homogenization in accordance with the mathematical conventions. The planned topics to be discussed are as follows.

- The mathematical definition of the inhomogeneity and the aim of homogenization. It is necessary to clarify that the homogenization of climate data series is a distribution problem instead of a regression one.
- Relation of monthly and daily data series homogenization.
- Mathematical overview on the methodology of spatial comparison of series, inhomogeneity detection, correction of series.
- Relation of theoretical evaluation and benchmark for methods, validation statistics.

The earlier versions of our method MASH (Multiple Analysis of Series for Homogenization; Szentimrey) were developed formerly at the Hungarian Meteorological Service. These procedures aimed to homogenize the daily and monthly data series in the mean i.e. the first order moment. The new version MASHv4.01 has been developed for joint homogenization of mean and standard deviation using some mathematical results. Theoretically in case of normal distribution the homogenization of mean and standard deviation is sufficient since if the first two moments are homogenous then the higher order moments are also homogeneous. An automatic algorithm was also developed at this new version in order to make the homogenization easier for the users.

We will present a summary of the method MASH.

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RELATIVE STATISTICAL HOMOGENIZATION OF OBSERVATIONAL NETWORKS WITH A LOW SIGNAL TO NOISE RATIO

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Relative statistical homogenization compares a candidate station to its neighbouring reference stations. Relative methods assume that the reference stations experience the same large-scale climate signal, but have deviations due to inhomogeneities (typically modelled as a step function) and noise (typically modelled as white noise, sometimes as short range correlated noise).

Science has studied this problem in much detail for the case of one time series with one break. Climatologists also studied more realistic cases, with multiple station series and multiple breaks per series, but mostly for dense observational networks, which are rare globally and going back in time. Our recent work suggests that statistical homogenization in case of multiple stations and multiple breaks is especially hard when the signal to noise ratio is below one.

We studied the detection problem for a series (the difference of a pair of stations) superimposing a break signal and a noise signal. The signal to noise ratio of such a series is defined as the standard deviation of the break signal divided by the standard deviation of the noise signal.

The optimal break positions for a certain number of breaks are determined by searching for the combination that minimizes the unexplained variance. This variance and a penalty function is used to determine the number of breaks.

The fundamental problem in case of multiple breaks is that randomly inserted test breaks are already able to explain half of the break variance. The combination which maximizes the explained noise variance would be random with respect to the breaks and will thus have this noise variance plus half of the break variance. Because this combination explains more noise than expected in a pure noise signal, it will be regarded as statistically significant. The statistical test rightly detects that the series contains inhomogeneities, but when the signal to noise ratio is low the positions of the breaks will be mostly determined by the noise. The paper gives the full details and also shows that a cross-term of the break and the noise signal further increases the variance of the solution.

Studying the so-called ANOVA joint correction method, we found that when all breaks are correctly detected this correction will remove large-scale trend biases due to inhomogeneities. After correction the size of the random trend error is determined by the noise variance of the difference time series and not by the break variance. When there are errors in the break positions and thus especially when the signal to noise ratio is low, any biases in trends will only be partially corrected and in this case the break variance is also important.

Furthermore, we have developed a method to estimate the statistical properties of inhomogeneities, in particular it estimates whether the break signal is a Brownian Motion (BM) signal or stems from Random Deviations (RD) from a baseline. We find that the German network contains Random Deviations only and relatively few breaks: 4.1 breaks per century. The American network, on the other hand, also contains Brownian Motion inhomogeneities and the RD breaks

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are frequent: 17.1 breaks per century. We likely detect a smaller percentage of breaks than we previously thought.

From these statistical properties of the inhomogeneities one can estimate the trend errors due to the inhomogeneities. These station trend errors are considerable, 0.82 °C per century for America and 0.58 °C per century for Germany. Directly estimating these trend errors from the trends of difference time series gives slightly smaller numbers. One reason the German trend errors are so large are that the number of breaks is small.

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CAPACITY OF ACMANTV4 FOR HOMOGENIZING CLIMATIC DATASETS OF NATIONAL METEOROLOGICAL SERVICES

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Climatic time series homogenization is applied for various purposes and under various conditions considering the number and spatial density of the time series involved, the temporal resolution of the data, the availability of metadata, among other factors.

National meteorological services usually possess large climatic databases, which are expected to be of high quality in all aspects including the temporal homogeneity of the data. The homogeneity of national and regional mean temperature data is particularly important, as the related climatic trends show the intensity of global warming signal. Nevertheless, the homogeneity is important for all climatic variables, in all spatial scales, and for the data of all kinds of temporal resolution.

ACMANT homogenization method has been developed in the recent decade to solve the fast and accurate homogenization of large climatic datasets. The method produced excellent results in international method comparison tests, and was used in World Meteorological Organization trainings in 2014 and 2015. The newest version ACMANTv4 can be applied for the homogenization of surface air temperature, precipitation total, relative humidity, sunshine duration, radiation, wind speed and atmospheric pressure time series of either daily or monthly resolution. ACMANTv4 is a fully automatic, relative homogenization method. In the homogenization of large datasets, the program selects the most appropriate set of partner series for each candidate series. The method can be applied for the joint homogenization of time series of different lengths, and it is characterised by high missing data tolerance. The software, together with its Manual and Scientific description are freely downloadable from https://github.com/dpeterfree/ACMANT.

In the presentation the following aspects will be discussed: i) Proven strengths of ACMANTv4; ii) Factors which may reduce the efficiency of homogenization; iii) Possibilities of further developments; iv) Need of further efficiency tests; v) Factors influencing the spread of the use of ACMANTv4.

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QUALITY CONTROL AND HOMOGENIZATION OF THE DAILY SERIES OF THE ECA&D DATABASE UNDER THE INDECIS PROJECT

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One of the objectives of the INDECIS* project was to provide homogenized and quality controlled daily series of the essential climatic variables stored in the European Climate Assessment & Dataset (ECA&D), to obtain reliable series of climatic indexes focused on priority economic sectors: agriculture, natural disaster reduction, energy, health, water resources and tourism.

A first phase of the work consisted in developing databases with homogeneous series of the nine studied variables (fraction of total cloudiness, wind speed, relative humidity, sea level atmospheric pressure, precipitation, snow depth, sunshine hours and maximum and minimum temperatures) with which, after introducing known inhomogeneities, try different homogenization methods and select the most appropriate one in each case.

In this second phase, the real series have been treated with a quality control package developed for this purpose (INQC) and then homogenized by means of the Climatol package.

INQC allowed to detect frequent problems in the databases, such as: repeated data sections, impossible dates, impossible or anomalous values, internal inconsistency, anomalous jumps between consecutive data, and discontinuities in the statistical distribution of the data, accumulated rainfall, too long sequences of the same data or of rainy days, too frequent repetitions of non-consecutive data, and rounding issues.

Subsequently, Climatol was applied to detect jumps in the mean and adjust the series to the last homogeneous subperiod, infilling all missing data. The high number of daily series to be treated (from 1000 to 13500 depending on the variable) and there heterogeneous spatial density caused serious difficulties. Finally the series had to be homogenized one by one using the 20CR reanalysis as a reference, but only up to 2014 (the last year of the reanalysis). Thus, for each series and with the help of the nearest 20CR series, the jumps in the monthly average were detected and the daily data were then adjusted.

In future work, the use of other reanalysis will be explored, comparing the correlations of their series with the real ones and evaluating the different levels of uncertainty.

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*INDECIS is a part of ERA4CS, an ERA-NET initiated by JPI Climate, and funded by FORMAS (SE), DLR (DE), BMWFW (AT), IFD (DK), MINECO (ES), ANR (FR) with co-funding by the European Union (Grant 690462).

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BIRTH OF BART: AUTOMATION AND EVALUATION OF THE INTERACTIVE MODE OF THE HOMOGENISATION SOFTWARE HOMER

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The official homogenised monthly temperature data set of the Swedish observational network is outdated and a new homogenisation protocol is to be established. As a part of this task, an automatic homogenisation software is to be chosen. A new automated version of HOMER, called Bart, is a candidate. The new software keeps the flexibility and transparency of its parent interactive method but adds the speed and reproducibility of an automatic method.

The homogenisation software HOMER has proven to be a reliable tool for the homogenisation of temperature (and precipitation) observation series. The homogenisation with HOMER requires the interaction of an operator, which makes the procedure time consuming, sensitive to arbitrary choices or error by the operator, and difficult to reproduce.

HOMER uses three methods for the detection of homogeneity breaks: A pairwise detection method (PRODIGE) on annual, seasonal or monthly basis, a joint two-factor detection method (cghseg), and an ACMANT style method for the detection of homogeneity breaks in the amplitude of the seasonal cycle. The operator reviews the results of the different methods and confirms or rejects suggested breaks. HOMER can also be run in automatic mode, where all suggested breaks from the joint-detection and the ACMANT style detection methods are confirmed and all suggested breaks from the pairwise method are rejected. Note, that also the automatic mode of HOMER requires some interactions, such that nor this mode is suitable for batch processing.

The homogenisation with HOMER of temperature observations at SMHI has previously been performed with a set of criteria for the confirmation of a suggested homogeneity break. These criteria has been implemented in the HOMER (interactive mode) source code by assigning the break signals from the methods different weights and applying a threshold for the sum of the weighted break signals each year for the confirmation of a break year. Homogeneity breaks described in meta data can be treated as an additional detection method with it's own weight. The user can chose to adjust these threshold and weights to fit their needs. All user interactions are removed to enable batch processing. The modified version of HOMER is named Bart, as Bart is the child of HOMER.

The Bart tool are applied on the synthetic benchmark data set INDECIS and to Swedish observational data from about 150 meta stations (about 240 coupled time series), including stations from other nordic countries, over the time period from 1860 to 2019. Two set of criteria is used: The critera previously used at SMHI (Bart-SMHI) and criteria to recreate the standard automatic mode of HOMER (HOMER-auto). For the INDECIS data set, the positions of the breaks are known and a corresponding data set without breaks are available. The results are compared with results of other state-of-art homogenisation tools ACMANT and CLIMATOL along with known potential homogeneity breaks from meta data.

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The overall performance of Bart-SMHI is shown to compare well with the other established methods and exceeds the performane of HOMER-auto. Bart-SMHI reconstructs the network trend best and has the lowest bias. Bart-SMHI and CLIMATOL tend to under-homogenise the data, whereas HOMER-auto and to some extent also ACMANT tend to over-homogenise the data. Bart-SMHI also reconstructs the trend of the current SMHI homogenised monthly temperature data of the Swedish observational network well. About 1/4 of the accepted homogeneity breaks are supported in meta data.

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ANALYSIS OF PARALLEL MEASUREMENTS OF DAILY MAXIMUM AND MINIMUM TEMPERATURES IN GREECE

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Long climate records include also non climatic variations due to e.g. station relocations (from urban centers to airports), changes and calibrations of instruments, changes in the procedures of data collection and handling. These non-climatic variations (inhomogeneities), impede the use of climate records for climate change studies, especially for changes in extremes and weather variability using daily data. One important cause of inhomogeneities is the introduction of automatic weather stations (AWS) that replaced the conventional meteorological stations and methods of observation. This introduction is often accompanied by station relocation. In order to cope with the problem, WMO recommends a period of parallel observations, the duration of which depends on the observed parameter. The WMO guidance is 12 months for wind speed and direction, 24 months for temperature, humidity, sunshine and evaporation, and 60 months for precipitation. In literature, several studies analyzing parallel measurements can be found. Also the International Surface Temperature Initiative has set up the Parallel Observations Science Team (POST) aiming at compiling a database with parallel measurements. In this work we present the preliminary results of analyzing parallel measurements of daily maximum and daily minimum temperature, coming from the weather station network of the Hellenic National Meteorological Service (HNMS).

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A METHOD FOR CREATING REALISTIC TEMPORAL GAPS IN TIME SERIES DATA

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This paper proposes a method for making data masks for data gaps. By using the length of existing gaps in some data set, and the length between them, as training data the method can then simulate new synthetic gaps from this information. In this paper we train the model on a set of Swedish stations measuring monthly temperature data, and then evaluate how the synthetic gaps created from this training data compares to observed gaps from stations that the model has not been trained on. This is done by comparing the percentiles of data gap length between the synthetically created gaps and observed gaps. The results show a good model performance, with exception of the very longest gaps. The purpose of making gaps in data is to evaluate gap filling techniques - by creating synthetic gaps in a time series where the actual values are known, and then filling in these gaps with a gap filling method, one can compare the gap filled values with the true original values, and can then evaluate the performance of the gap filling.

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DEVELOPING A HIGH QUALITY, LONG TERM RAINFALL NETWORK FOR THE ISLAND OF IRELAND 1900-2018.

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Ireland has a rich history of weather observation extending back to the mid-18th Century. Previous work to develop long-term series include work by Murphy et al. (2018) to compile a 305-year continuous monthly rainfall series for the island of Ireland (1711–2016) using previously unpublished work by the Bristish Meteorological Office. This comprehensive monthly series builds on the work of Noone et al. (2015) which developed a monthly rainfall series for 25 stations throughout Ireland for the period 1850–2015. However, until now there has not been a concerted effort to construct a long-term daily rainfall series for Ireland using historical records.

The main objective of this work was to create a digital archive of the paper records of Ireland's longest meteorological stations, and from these imaged records and additional rainfall registers to extend the availability of long-term daily rainfall data prior to 1941. The stations were selected based on record length, continuity and spatial distribution. The data have been homogenised following quality control and missing data infilling using software developed at Met Éireann. Detailed metadata collected during transcription was used to inform the quality assurance and homogenisation process.

Whilst the methods used to rescue the data will be briefly discussed, the presentation will focus on quality assurance and homogenisation of the data series. The techniques used for infilling missing data and the associated errors will also be shown. Finally, the final long-term data series reviewed.

Murphy, C., Broderick, C., Burt, T. P., Curley, M., Duffy, C., Hall, J., Harrigan, S., Matthews, T. K. R., Macdonald, N., McCarthy, G., McCarthy, M. P., Mullan, D., Noone, S., Osborn, T. J., Ryan, C., Sweeney, J., Thorne, P. W., Walsh, S., and Wilby, R. L. (2018) A 305-year continuous monthly rainfall series for the island of Ireland (1711–2016). *Climate of the Past*, 14, 413–440. https://doi.org/10.5194/cp-14-413-2018

Noone, S., Murphy, C., Coll, J., Matthews, T., Mullan, D., Wilby, R.L. and Walsh, S. (2015) Homogenization and analysis of an expanded long-term monthly rainfall network for the Island of Ireland (1850–2010). *International Journal of Climatology*, 36, 2837– 2853. https://doi.org/10.1002/joc.4522

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LONG-TERM TRENDS IN EXTREME TEMPERATURE AND PRECIPITATION INDICES FOR ISRAEL BASED ON A NEW DAILY HOMOGENIZED DATABASE

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Climate change analyses are studied through the analysis of long-term records which usually are compromised by artificial non-climatic factors such as station relocation, instrumental modification and local environmental changes. The impact of these factors on the analysis must be assessed and corrected before computing any trends. This study examines the 1950-2017 temporal changes in climate extremes over Israel, which is located in the East Mediterranean, a region which suffers from a scarcity of long and reliable datasets. Therefore, a thorough homogenization routine was developed by jointly applying some of the state-of-the-art homogenization methods (CLIMATOL, ACMANT, HOMER) to the long-term Israeli records. Most of our analysis was based on relative homogenization methods which compare the difference or examine the ratio between the base station and a reference time series. In addition, the Kolmogorov–Zurbenko Adaptive filter (KZA) was applied to the monthly precipitation amount in order to check the time series' behavior. This filter was developed to detect breaks in nonparametric signals embedded in heavy background noise. It detects sudden changes over a low frequency signal of any nature submerged in heavy noise.

A new daily adjusted dataset was generated, including 34 temperature stations and 60 precipitation stations. Based on this comprehensive dataset, 38 extreme indices recommended by the Expert Team on Climate Change Detection and the Expert Team on Sector-specific Climate Indices were calculated. Results showed highly significant changes in temperature extremes associated with warming, especially for those indices derived from daily minimum temperature along a reduction in the total precipitation amount and a tendency toward more intense wet days. We will present our homogenization routine followed by some of the observed trends in the extreme indices over Israel. Additionally, a short discussion about "Is it possible to fit together extreme climate change indices in the era of accelerated warming?" will be held.

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HOMOGENIZATION OF NORWAY'S MONTHLY TEMPERATURE AND PRECIPITATION SERIES

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Norwegian Meteorological Institute Climatological standard normals are applied to describe expected weather and climate conditions at given locations and also acts as a reference for current conditions. Homogenization of Norway's monthly temperature and precipitation time series for the period 1961-2018 was therefore undertaken for the purpose of calculating new climatological standard normals for the period 1991 -2020. The Norwegian observation network has changed considerably during the last 20-30 years, introducing non-climatic changes such as automation and relocation. Homogenization was therefore necessary to provide a consistent basis for the new normals. ClimNorm is a network activity under the Nordic Framework for Climate Services that aims to support the national climate services in the Nordic region in their efforts to calculate new climatological normals for the period 1991 -2020. Because of this collaboration, we were able to use time series from neighboring stations in Finland and Sweden in the homogeneity analysis. HOMER software package was applied to detect and adjust inhomogeneities in 145 monthly temperature series (including 30 series from Sweden and 7 from Finland). The results of the homogeneity testing indicate that approximately 92% of the temperature series had inhomogeneities. The annual adjustment factor ranged from −0.94°C to 1.01 °C. 99% of the breaks were confirmed by metadata. Relocation of the station was the most common reason for inhomogeneity, explaining more than 40 % of the inhomogeneities found by HOMER. Results further demonstrated the benefits of including Swedish and Finnish series as reference series in the homogeneity testing of Norway's temperature series. Results also showed a wider range of anomalies in the raw series than in homogenized series confirming that homogenization contributes to better spatial consistency of the temperature series. This clearly provides a strong guidance on the reliability of the adjusted dataset. CLIMATOL will be used for the homogeneity analysis of precipitation series. This is a work in progress, and some preliminary results will be presented.

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JOINT HOMOGENIZATION OF TIME SERIES WITH UNEQUAL LENGTH BY APPLYING THE MASH PROCEDURE

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The Hungarian Meteorological Service (OMSZ) is celebrating its 150th birthday this year. Thanks to the continuous recording of archive data, new data was added to the database. These should be checked and homogenized for the period 1871-1900 before being subjected to climatic analyses.

Homogenization of the data series raises the problem that how to homogenize together the long and short data series, since the meteorological observation system was upgraded significantly in the last decades. It is possible to solve these problems with method MASH (Multiple Analysis of Series for Homogenization, Szentimrey) due to its adequate mathematical principles for such purposes. When the station network is upgraded and we have short data series besides the long series, the common section must be homogeneous together with the long as well as with the short data series, while the two or three systems have to be homogeneous themselves too. MASH is able to fulfill these criteria, as it is based on hypothesis testing and it involves an iteration procedure. The solution is that we synchronize the common part's inhomogeneities within three different MASH processing for the three datasets with different length.

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BREAK DETECTION IN INTEGRATED WATER VAPOUR BENCHMARK DATASETS

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The performance of various break detection methods is examined on three sets of benchmark datasets, each consisting of 120 daily time series (1995-2011) of integrated water vapor (IWV) differences between Global Navigation Satellite System (GNSS) data and the numerical weather prediction reanalysis (ERA-Interim) data. The benchmark was developed with the use of known climatic characteristics and earlier estimates of inhomogeneities of IWV data in 120 observing sites of GNSS data. The benchmark includes homogeneous and inhomogeneous sections with added breaks in the latter. Three different variants of the benchmark time series are produced, with increasing complexity, but the mean break frequency (2.5 per time series) and break magnitude distribution is the same for each variant. While “Easy” dataset includes annual and sub-annual cycles of the means, breaks and a white noise only, “Moderate” dataset includes first order autoregressive noise. “Complex” dataset is developed in a way that non-climatic trends and data gaps are added to the model of Moderate dataset. The purpose of “Complex” experiments is to examine the performance of break detection methods in a more realistic case when the reference series are not homogeneous. The performance of break detection methods is evaluated with detection skill scores, centered root mean square errors (CRMSE) and trend differences relative to the trends of the homogeneous series. We found that most methods underestimate the number of breaks and have a significant number of false detections. Despite this, the degree of CRMSE decrease after adjustments is significant (roughly between 40 and 80%) in the Easy and Moderate experiments, and the ratio of trend bias reduction is even exceeding the 90% of the raw data error. For the Complex experiment, the improvement ranges between 15 to 35% with respect to the raw data, both in terms of RMSE and trend estimations. In most experiments the best results were achieved by two newly developed break detection methods: a maximum likelihood multiple break method and a Standard Normal Homogeneity Test based method.

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EVALUATING THE ROBUSTNESS OF SNOW CLIMATE INDICATORS USING A UNIQUE SET OF PARALLEL SNOW MEASUREMENT SERIES

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Snow on the ground is an important climate variable which is normally measured either as snow depth or height of new snow. Like any other meteorological variable, manually measured snow is prone to local influences, changes in the environment or procedure of the measurements. In order to investigate the robustness of snow measurement series towards such non-climatic changes, a unique set of parallel manual snow measurements over 25 years from 23 station pairs between 490 and 1800 m a.s.l. was compiled. A sensitivity analysis based on typical snow climate indicators (e.g. mean snow depth, sum of new snow) from these parallel time series was carried out to find the most robust snow climate indicators for climatological analyses. Results show that there are only small differences in the sensitivity of the various snow climate indicators with regards to local changes. However, the indicators number of days with snow on the ground as well as the maximum snow depth are least affected by local influences and changes at station level. Median values of all station pairs reveal relative differences of about 7% for the number of days with snow cover and 11-16% for all other indicators. However, in extreme cases, the deviations within a single station pair can reach 25-40%.

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HOMOGENIZATION OF LONG-TERM SNOW OBSERVATIONS

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Snow is an important component of the climate system, treated as one of the most obvious visual evidences of climate change and important for countries with mountainous environments. Most of the existing tools and algorithms that are being used for homogenization have been developed for air temperature and precipitation, whereas their application to snow depth measurements has only been rarely attempted. Until now, there have only been smaller efforts to develop methods and tools for snow series.

The project hom4snow from SLF and University of Graz tries to break new ground by developing innovative methods that can be applied to the homogenization of longterm snow observations, as well as to demonstrate the impact of the developed adjustments on climatologies and trends. For that, we are using daily longterm snow measurements from the Swiss-Austrian domain of the two most frequently measured parameters, snow depth (HS) and new snow height (HN).

The existing method PRODIGE has been successfully used for the detection of multiple inhomogeneities. For corrections, the INTERP-method is being improved by adding a quantile-mapping-based approach. We are comparing the impacts of previously used seasonal fixed correction factors and improved quantile-mapping approach on selected HS-time series from MeteoSwiss, SLF, the Austrian Weather Service (ZAMG) and the Austrian Central Hydrographic Office (HZB) for showing the improvements of the new method.

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MATHEMATICAL QUESTIONS OF SPATIAL INTERPOLATION AND SUMMARY OF MISH

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We focus on the basic mathematical and theoretical questions of spatial interpolation of meteorological elements. Nowadays in meteorology the most often applied procedures for spatial interpolation are the geostatistical interpolation methods built also in GIS software. The mathematical basis of these methods is the geostatistics that is an exact but special part of the mathematical statistics. However special meteorological spatial interpolation methods for climate variables also can be developed on the basis of the mathematical statistical theory. The main difference between the geostatistical and meteorological interpolation methods can be found in the amount of information used for modelling the necessary statistical parameters. In geostatistics the usable information or the sample for modelling is only the predictors, which are a single realization in time. While in meteorology we have spatiotemporal data, namely the long data series which form a sample in time and space as well. The long data series is such a specialty of the meteorology that makes possible to model efficiently the statistical parameters in question. The planned topics to be discussed are as follows.

- Temporal scales, from daily values to climatological mean values.
- Interpolation formulas and loss functions depending on the spatial probability distribution of climate variables.
- Estimation and modelling of climate statistical parameters (e.g.: spatial trend, covariance or variogram) for interpolation formulas using spatiotemporal sample and supplementary model variables (topography). Use of background information (e.g.: dynamical model results, satellite, radar data) for spatial interpolation.
- Creation of gridded climatological databases.

The earlier versions of our method MISH (Meteorological Interpolation based on Surface Homogenized Data Basis; Szentimrey and Bihari) were developed formerly at the Hungarian Meteorological Service. At MISH method we use spatiotemporal data for modelling the climate statistical parameters and the interpolation system is based on these results. The earlier modelling system was elaborated for the monthly and daily expected values and the spatial correlations. At the new version MISHv2.01 the monthly and daily standard deviations and the daily temporal correlations also can be modelled. Consequently the modelling subsystem of MISH is completed for all the first two spatiotemporal moments on monthly and daily scales. If the joint spatiotemporal probability distribution of the given variable is normal then the above spatiotemporal moments determined uniquely this distribution that is the mathematical model of the climate. Another development is modelling of the interpolation error RMSE (Root Mean Square Error) in order to characterize quantitatively the uncertainties of the interpolation.

We will present a summary of the method MISH.

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TRANSFORMATION OF CARPATCLIM DATASETS TO GRID-BOX AVERAGE DATASETS

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The CarpatClim datasets were developed for grid points, i.e. the meteorological variables were interpolated to grid points, while the E-OBS datasets were constructed as grid-box averages.

For comparability we have transformed the CarpatClim datasets for grid-box averages.

For this purpose, beside the gridded values with 0.1 x 0.1-degree resolution we used also certain modelled climate statistical parameters. These statistical parameters were modelled during the construction of CarpatClim datasets and they were also outputs of our MISH (Meteorological Interpolation based on Surface Homogenized Data Basis; Szentimrey and Bihari) procedure applied for gridding. There is a MISH specialty that the necessary statistical parameters - like spatial trend and correlation structure - are modelled for a very dense half minutes grid and saved. We developed a mathematical procedure and applied it for the gridded series using these saved parameters. Now we have two versions of CarpatClim datasets for temperature (Tx, Tn) and precipitation, namely grid point and grid-box average datasets.

Comparison of CarpatClim grid-point and CarpatClim _BOX is presented too.

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EVALUATION OF THE PRECIPITATION CLIMATE E-OBS AND ERA5 WITH HIGH-RESOLUTION GRID DATASETS IN EUROPEAN REGIONS

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E-OBS is a widely used pan-European dataset based on in-situ observations. It has recently received a major update and is now available as an ensemble dataset. ERA5 is the new model-based reanalysis from ECMWF with global coverage. Aside from the methodological upgrades, both datasets have a comparable spatial resolution and go back several decades into the past. Consequently, an evaluation that aims at understanding the potential and limitations of these datasets and that tries to gain insight on their relative merits is of key interest.

The focus of this evaluation is on the representation of daily precipitation on a meso-beta scale in three mountainous European regions. They cover complex topography as well as different climates and thus represent a challenge for climate datasets. For all three regions, high-resolution grid datasets exist that methodologically best suit the corresponding climate and that include the densest station network. Hence, they are considered as reference datasets. The Nordic Gridded Climate Datasets (NGCD-1 and NGCD-2) cover the whole Fennoscandian region, and CARPATCLIM is used for the Carpathian region. For the Alpine region, we use the APGD (Alpine Precipitation Grid Dataset) as reference. By calculating climate indices, information about the spatial distribution, the annual cycle and extreme quantiles is gained. Furthermore, the accuracy of the two test datasets is quantified using the MSESS and by comparing ensemble estimates of daily area-mean precipitation, the uncertainty structure is tested for reliability.

Increased precipitation in the mountains and along the Norwegian coast, as well as comparatively dry conditions in the lee of the mountains clearly emerge in all investigated datasets. E-OBS was found to perform best in flat areas with a dense station network; however, it tends to underestimate precipitation, especially in data sparse areas. ERA5, on the other hand, shows a relatively uniform skill structure with a constant overestimation of precipitation. Overall, both datasets allow climate analyses at European level on a meso-beta scale if the limitations are considered.

The current study was performed in the framework of the COPERNICUS C3Surf project (C3S_311a_Lot4), ending in 2021.

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DEVELOPMENT OF THE E-OBS WIND STRENGTH DATASET

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The presentation shows the first steps towards the development of a pan-European dataset with daily values of wind speed. This dataset is a new member of the E-OBS dataset and shares the spatial resolution of 0.1° of the other E-OBS members. The dataset will start in 1981 and its final version will extent to the present.

Building on the results of the “New European Wind Atlas” project, a vast dataset with daily values of average wind strength for the whole of Europe is compiled and quality controlled. These data are used in a Generalized Additive Model (GAM) to provide an estimate of maps of daily wind speed across Europe. GAM is easy to interpret and more flexible than the Generalized Linear Models as the relation between independent and dependent variables are not assumed to be linear.

The GAM approach allows for the use of co-variates, like surface roughness, elevation and slope in the estimate of spatially continuous wind speed values. In addition, we added the monthly mean value of the wind strength and the spatially-detailed climatology of wind strength from a regional reanalysis as additional co-variates.

First results of this dataset are presented for specific cases, like major storms, and an estimate is given for the uncertainty in the wind strength estimate.

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COMPARATIVE STUDY OF CARPATCLIM, E-OBS AND ERA5 DATASET

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Recently the pan-European observational dataset E-OBS has been considered as a reference for several European climate analyses. Moreover, the usage of the newly available global reanalysis ERA5 is increasing for climate change studies. CARPATCLIM is a regional climate dataset for the Carpathian region in central-eastern Europe. Among others the E-OBS and ERA5 dataset were tested against CARPATLIM and against other regional datasets in the framework of the COPERNICUS C3S_311a_Lot4 project.

CARPATCLIM dataset encompassing gridded daily observations for the Carpathian region. It is available on a 0.1°(~10 km×10 km) grid and includes homogenized, gridded daily time series of various meteorological parameters from 1961 to 2010. The method and software used in CARPATCLIM project (www.carpatclim-eu.org.) for data quality control, homogenization, data completion was the MASH (Szentimrey). Interpolation of the homogenized time series was carried out by applying the MISH (Szentimrey and Bihari) procedure. The temperature and precipitation grids are available on the CARPATCLIM webpage and also via Copernicus: https://surfobs.climate.copernicus.eu/dataaccess/access_carpatclim.php.

The common time period of E-OBS, ERA5 and CARPATCLIM is 1979-2010. Different measures, evaluation statistics were computed for comparison of the gridded Tx, Tn and precipitation fields for this period. Analysis of Variance (ANOVA) method was applied for instance, which is an adequate statistical method to explore the statistical structure of different datasets. ANOVA can be used effectively for the characterization of the spatiotemporal statistical properties of CARPATCLIM, E-OBS and ERA5. In addition, different evaluation scores, yearly cycle, absolute and monthly extremes, quantiles, wet days frequency, several climate indices for temperature were computed. Trend analysis (exponential trend model for precipitation and linear trend model for temperature) and homogeneity test for the gridded data were applied too. The differences between the datasets come from the station density behind the grids and also the methods used for homogenization and gridding determine the results. The main outcomes of this comparative study are presented on graphs and maps in this work.

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DEVELOPMENT OF HIGH RESOLUTION GRIDDED DATASETS OF MONTHLY TEMPERATURE SINCE 1916 FOR SPAIN

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This article describes the methodology used in the Spanish State Meteorological Agency (AEMET) for obtaining gridded datasets of monthly minimum, maximum and mean temperature with 1 km × 1 km spatial resolution for Spain, covering the period 1916–2018. These datasets have been created for climate analysis and monitoring, and will be updated periodically to extend the time coverage. The data used to produce the grids have undergone a quality control process in order to remove or correct erroneous data. The spatial interpolation method consists on a multiple linear regression with ordinary kriging of the regression residuals, using terrain height, easting, northing and distance to the coast as independent variables in the regression. The performance of the interpolation method and the accuracy of the grids are evaluated using a cross-validation approach to estimate the errors. Some examples of derived products are shown, as well as a temperature analysis over the 1916-2018 period in Spain based on the gridded datasets.

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ACTUALIZATION OF NATIONAL CLIMATE CLASSIFICATION MAP OF PERU

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The National Meteorology and Hydrology Service of Peru (SENAMHI) elaborated the new national climate classification map in order to share an estimate of the climate sources of different regions of the country, with the purpose of guiding the government planning processes of the economic, environmental and social aspects.

The first climate classification map of Peru was developed and published by SENAMHI in 1988. It was prepared using the climate classification system of Warren Thornthwaite, 1931. For this, twenty year meteorological data between 1964 and 1984 from 250 meteorological stations of the national network were used.

For the preparation of the current Map, for comparative purposes, the same climate classification system of Thornthwaite was used. 30 years of meteorological data were used between the period of 1981 and 2010, from 500 meteorological stations of the national network, in addition with meteorological data from country neighbors: Ecuador, Colombia and Bolivia, following the recommendation of the World Meteorology Organization (WMO).

For the elaboration of this new map, a new spatial interpolation technique was used, linear regression with the weighted inverse distance error adjustment using satellite information and involves a validation of the statistical model through cross validation. This technique provides information on the relationship between the regional geographic reality and the climate. In addition, a national validation process was carried out with the intervention of national experts familiar with the subject through face to face and virtual workshops throughout the country.

The updated climate classification map presents 38 types of climate in Peru with a better representation of the climates in the region. This product provides national climate information in a graphic and synthetic way that allows connection with natural ecosystems and main human activities.

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POSTERS

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CLIMATIC CHARACTERISTICS USED IN THE DESIGN ROADWAY

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The following climatic characteristics are used when designing pavements:

• average annual temperature

• frost index

These characteristics are obtained by evaluating air temperature measurements. According to international conventions, this temperature is measured at 2 m above the ground at 7:00, 14:00 and 21:00. during the day. For the needs of Slovakia these measurements are regularly performed by the Slovak Hydrometeorological Institute. For practical purposes, changes in daily temperatures are expressed by the average daily air temperature. The design value Tm is determined from long-term air temperature measurements and the average annual temperature map is used for road construction needs.

The frost index Im [° C] is determined as the sum of the absolute values of consecutive negative average daily temperatures in winter. The frost index is the most commonly used climatic characteristic in the field of road design in Slovakia. For experimental air temperature measurements, the frost index is determined by adding the negative average daily air temperatures Ts in winter.

For the purpose of developing map products of the frost index, we used the MASH program to homogenize the average daily air temperature data.

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EVALUATION OF INTERPOLATION SCHEME AND EXTREME VALUE INDICES BASED ON GPCC‘S FULL DATA DAILY

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Precipitation is a globally fundamental parameter that has an influence in many fields and determines the hydro-meteorological cycle.

The Global Precipitation Climatology Centre (GPCC) provides the daily *in-situ* precipitation product Full Data Daily (FDD). The FDD is a reliable raster product, based on global land-surface precipitation totals. The database includes data provided by national meteorological and hydrological services, regional and global data collections as well as WMO GTS-data. The FDD is characterized in particular by the detailed quality control of the input data.

To understand the influence of the interpolation procedure on raster extremes not only in theory, but also to quantify the regional differences and the influence of the number of stations, we created a 9-year test data set. The FDD test data set covers the period Jan 2000 - Dec 2008 with daily temporal resolution and 1° spatial resolution.

This paper introduces a test study on the methodological decisions for FDD. For this purpose, we tested different methods for a selected time period. The study aims to analyze 1) the impact of the interpolation method. We recalculated a sub-period of FDD using modified Spheremap or krigging as interpolation scheme. Two two global data sets are generated each with a different interpolation method. 2) We have a look into the difference between extreme area values (1°x1° resolution) and mean extreme values in the same area by a) calculating the extreme value indices ETCCDI on the time series first and interpolating later and b) interpolating first and then calculating the ETCCDI.

This gives us the oppertunity to estimate and quantify the influence of the methodical decisions and to improve the understanding of the FDD.

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CHANGE POINT DETECTION IN MONTHLY MEAN AIR TEMPERATURE OBSERVATIONS IN LATVIA

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Nowadays with increasing length of meteorological observation time series it is possible to comprehensively monitor climate change, therefore it is crucial to provide qualitative and homogeneous data sets. With swiftly developing methods, sensors and surrounding conditions it is more challenging to maintain comparable observations without significant shifts due to non-natural causes. Data homogenization procedure is meant to overcome such problems by using various statistical tools.

Homogenization process consists of two main stages - identification of change points and observation data correction. In order to perform appropriate data modification it is vital to estimate exact time when any significant shift happened, and later calculate the magnitude of shift. There is a broad list of change point detection methods including various statistical tests and models, likelihood ratio approaches, machine learning algorithms, etc., thus it is necessary to understand the specification of the data and strengths and weaknesses of every method.

In order to compare various change point detection methods, monthly mean air temperature observation in Latvia in the period 1949-2018 from 22 stations was used. In addition a list of metadata with all the documented changes in station observation was used for reference. For every observation station five geographically closest stations were defined and air temperature differences were calculated. For every difference data set statistical properties were checked and it was concluded that in the majority data are non-normal, aren't independent and have a statistically significant trend. These results should be taken into account while identifying the break points.

For change point identification following methods were analysed: Standard normal homogeneity test, Buishand range test, Pettitt test, Hodges-Lehmann test, Pruned Exact Linear Time Method and Decision trees. For all single change point methods only first estimation of shift point time was used.

For the most significant changes (i.e. changes in station location) that happened not at the very end of the observation period (e.g. Riga station) almost all considered methods worked well. For the changes in station location that happened in 2016 (e.g. Daugavpils and Jelgava stations) only decision trees managed to identify changes. Yet despite successfully identifying changes at the end of the period, machine learning algorithms identified additional suspicious break points compared to metadata. In addition all methods (except Pruned Exact Linear Time Method) identified changes in the very middle of the time period at some stations (e.g. Daugavpils, Liepaja, Rezekne). While metadata recorded no changes in these stations, Mann-Kendall test showed that difference datasets had a significant trend. Therefore these change points could be falsely identified due to non-eliminated tendencies in the observations or possibly could characterize non-recognized slowly developing differences in the stations (e.g. urbanization). Similar breakpoints were identified by Climatol procedure that was performed on the same observation data.

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Further we plan to look into more detail at the observation data properties and its influences on the results, perform similar analysis for simulated homogeneous and non-homogeneous observations with analogous properties and consider iterative procedure for single change point detection methods.

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CLIMATE MONITORING PRODUCTS FOR FARMERS IN THE CZECH REPUBLIC

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Global Change Research Institute (GCRI) is a public research institution, European center of excellence investigating the ongoing global change and its impact on the atmosphere, biosphere and human society through the use of the latest techniques and instrumentation. The research focuses primarily on the development of climate and its future scenarios, on the carbon cycle and the effects of changing conditions on the production and biodiversity of ecosystems and on the impacts on the future development and behavior of our society.

Our mission is to provide to public, state authorities, politicians and experts the climate information (free of charge). This is accomplished through special web portals. The most important is a drought monitoring system (www.intersucho.cz), that's focused on monitoring agricultural drought and their forecast for 10 days ahead by numerical weather prediction models. The second portal is focused on the presentation of climate models outputs (GCM and RCM) for the Czech Republic (www.klimatickazmena.cz). The results are divided into climate, agriculture, water regime, landscape and forestry groups. The newly prepared portal is then focused on monitoring and forecasting of selected biotic and abiotic noxious factors (www.agrorisk.cz). This also includes early warning of late spring frosts, strong winds, high temperatures, drought or occurrence of pets and diseases.

All these publicly available products are based on precisely prepared meteorological and climatological data. Measured data went through thorough data quality control. time series homogenization and where required filling gaps. Numerical weather prediction models or climate model outputs are bias corrected by own DAP method (Distribute Adjust by Percentile). The prepared station records are also interpolated into a 500×500 m resolution grid (again by own methods), which are developed for individuals purposed of the products (from hourly data to the long-term averages, various elements etc.).

In our contribution we present both methodology of preparing data (quality control, homogenization, interpolations) and then also the above mention products that follow from such prepared datasets.

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