PUBLIZIERBARER Endbericht Studien

(gilt nicht für andere Projekttypen)

A) Projektdaten

Titel:	HOM-START - Homogenisation of climate series on a daily basis, an application to the StartClim dataset
Programm:	ACRP, 1st Call for Proposal
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Projekt- und Kooperationspartner (inkl. Bundesland):	
Projektwebsite:	http://www.zamg.ac.at/forschung/klimatologie/klimawandel/homstart/
Schlagwörter:	Climate change, climate data, homogenization, trends, extreme events, uncertainties
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Klimafonds-Nr:	A963509
Projektstart & Ende	01.01.2010 - 31.12.2010

B) Projektübersicht

1 Executive Summary

Das Ziel dieses Projektes war die Erstellung eines für Österreich repräsentativen, homogenisierten Datensatzes der täglichen Temperaturminima und –maxima sowie des Niederschlages. Dieser neue, für die klimatische Auswertung von Extremereignissen geeignete Datensatz, basiert auf dem qualitätskontrollierten StartClim-Datensatz.

Messreihen unterschiedlicher Klimaelemente sind ein wichtiges Werkzeug für Klimastudien und die Klimafolgenforschung, da sie unser Verständnis für die Klimaänderungen in den letzten Jahrhunderten verbessern. Allerdings sind die meisten Messreihen durch Inhomogenitäten verfälscht, welche Klimasignale überlagern und dadurch reduzieren oder amplifizieren können. Gründe für Inhomogenitäten sind vielfältig, so können etwa Stationsverlegungen, die Änderungen der Messgeräte oder der Beobachtungszeiten einen entscheidenden Einfluss haben. Es besteht in der wissenschaftlichen Gemeinschaft Konsens darüber, daß Inhomogenitäten in den Zeitreihen gefunden und korrigiert werden müssen, bevor man sie für die Untersuchung von Klimaänderungen verwenden kann.

Im letzten Jahrzehnt wurden unterschiedliche Ansätze für die Detektion von Brüchen und die Homogenisierung der Zeitreihen entwickelt. Üblicherweise basieren diese Methoden auf einem Vergleich mit benachbarten (Referenz-) Stationen. Diese werden auf Grund ihrer Korrelation zu der bearbeiteten Station ausgewählt. Die meisten dieser Methoden wurden allerdings für die Jahres- oder Monatsdaten entwickelt und korrigieren nur das Mittel der Zeitreihe. Da in letzter Zeit der Focus der klimatischen Untersuchungen sich immer mehr auf Extremereignisse verlagert, wird es immer wichtiger qualitätskontrollierte, homogenisierte Daten entsprechend hoher Auflösung zu verwenden. Hier reichen die Methoden von einfachen Klassifizierungen bis zu komplexeren Verfahren, die multiple Inhomogenitäten detektieren und, im Falle der Temperatur, temperaturabhängige Korrekturen berechnen. Das Hauptproblem der Homogenisierung täglicher Daten im Vergleich zu der Homogenisierung monatlicher Werte besteht darin, dass die Stärke der Inhomogenität mit der Wetterlage variieren kann. Die besten Methoden basieren auf einer Abschätzung der Änderung der Häufigkeitsverteilung des Parameters. Zwar sind auch diese Methoden nicht multivariat, berücksichtigen also keine weiteren Parameter die zB. spezielle Wetterlagen charakterisieren, aber sie untersuchen die Verteilung des zu homogenisierenden Parameters selbst und verwenden unterschiedliche Anpassungsfaktoren für die unterschiedlichen Perzentile der Häufigkeitsverteilung. Diese Methoden werden hauptsächlich für kleine regionale Datensätze verwendet, für kontinentale bzw. globale Datensätze fehlen ausreichend viele geeignete Referenzstationen. Die Unsicherheiten, die durch die Korrektur der Inhomogenitäten gegeben sind, bedürfen weiterer Forschungsaktivitäten.

Für die Homogenisierung der täglichen Temperaturextrema in Österreich wurde ein Verfahren verwendet, das für die Detektion einer variablen Anzahl von Brüchen PRODIGE verwendet und die Inhomogenitäten mittels der Methode SPLIDHOM angepasst werden. Die verwendete Homogenisierungsroutine beinhaltet außerdem Module für das Downloaden der verwendeten Daten aus der Datenbank, die automatische Selektion der höchstkorrelierten Referenzstationen, die Weiterverarbeitung der Daten und die Dokumentation der Homogenisierung und der Ergebnisse. Für die Homogenisierung des Niederschlages wurde das Modul für die Anpassung der Datenreihe durch eine, für diese Zwecke angepasste, Version von INTERP ersetzt.

Das Verfahren wurde getestet und auf 71 österreichische Messreihen von Maximum- und Minimumtemperatur sowie des Niederschlages angewandt. Der so erzeugte homogenisierte Datensatz ermöglicht verlässliche Studien über den Einfluss der Klimaänderung auf Extremereignisse. In dem Projekt wurden Trends von 27, von der WMO vorgeschlagenen, Kimaindizes berechnet und auf ihre Signifikanz getestet. Dabei liegt das Hauptaugenmerk zum einen auf den Extremwerten der Temperaturverteilung, die auf menschliche Gesundheit und Wohlbefinden sowie die Umwelt Einfluss haben können. Zum anderen kon-

zentrieren sie sich auf die Intensität und Heftigkeit von Niederschlagereignissen sowie langen Trockenperioden.

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2 Hintergrund und Zielsetzung

Instrumental time series of different climate elements are an important requisite for climate and climate impact studies. Long-term time series can essentially improve our understanding of climate change during the last century. However, as extensively discussed in literature (e.g. Aguilar et al., 2003, Auer et al., 2007) most instrumental time series are affected by inhomogeneities which can mask or amplify climate change signals. Causes for these inhomogeneities are manifold, e.g. station relocation, instrumentation changes or changes in observing times. It is widely accepted that inhomogeneities in time series have to be detected and if necessary adjusted before performing any kind of climate change analysis (Aguilar et al., 2003, Brunet et al., 2007).

During the last decade, various procedures for the detection and homogenisation of inhomogeneities in time series have been developed (Alexandersson and Moberg, 1997; Caussinus and Mestre, 2004; Böhm et al., 2001; Easterling and Peterson, 1995). In general, these methods are based on comparisons with neighbouring (so-called reference) stations, relying on the availability of highly-correlated measurements. However, most methods were primarily designed for and applied to annual or monthly time series and mostly only adjust the mean state of the time series. Since many climate research studies are recently focusing on changes in extreme events the need for quality controlled, homogenised data on a sub-monthly scale is steadily growing.

During the last few years first approaches have been developed to solve this problem (e.g. Vincent et al., 2001; Trewin and Trevitt, 1996; Della-Marta and Wanner, 2006, Brandsma and van der Meulen, 2008). These attempts to cope with potential inhomogeneities in daily data range from simple time series classifications (useful, doubtful and suspect time series) as given in the European ECA&D dataset (Wijngaard et al., 2003) to more sophisticated methods which detect multiple inhomogeneities and apply temperature dependent adjustments.

The main challenge of the homogenisation of daily compared to monthly data is that - at least in the case of temperature - the magnitude of inhomogeneities may differ with varying weather situations. The most promising methods are based on the estimation of changes in the overall distribution of an element (Trewin and Trevitt, 1996; Della-Marta and Wanner, 2006; Mestre et al., 2010; Stepanek and Zahradnicek, 2008). Even though these methods do not account for different meteorological parameters that characterize special weather situations, they do examine the distribution of the element itself and apply variable adjustments depending on the percentiles. These methods have mostly been tested on small, regional datasets. However, recently Kuglitsch et al. (2009) applied the method PHENHOM to a greater dataset of daily summer maximum temperature series in the Greater Mediterranean Region, followed by a heat wave analyses in the eastern Mediterranean Region including homogenised daily minimum temperatures (Kuglitsch et al., 2010). This method was further improved by an additional treatment of autocorrelation and an improved choice of regression parameters (Toreti et al., 2010). However, the uncertainties accompanying the break adjustment have not been studied sufficiently so far.

The method opted for the homogenisation of daily extreme temperatures in Austria contains the method PRODIGE (Caussinus and Mestre, 2004) for the detection of a multiple number of breakpoints and the method SPLIDHOM (Mestre et al., 2010) for the calculation of adjustments. The homogenisation procedure further includes an automated selection of highly correlated reference stations, data retrieve from the database, data handling and presentation of results. In case of precipitation the break adjustment module is replaced by an adapted version of INTERP (Vincent et al., 2001).

The method was tested and applied to 71 daily minimum temperature (TN), maximum temperature (TX) and precipitation series in Austria, resulting in a new dataset of homogenised daily precipitation totals and extreme temperatures. This new dataset makes reliable studies on changes in climate extreme events possible. Here, 27 climate change detection indices suggested by the WMO (Alexander et al., 2006, Klein

Tank et. al, 2009) were evaluated and tested for significance. The temperature-related indices focus on the tails of the temperature distribution, such as high night-time temperatures or long-lasting cold periods, which can have major impacts on human health and well-being (e.g. Fischer and Schär, 2010) and can affect our environment. On the contrary, the precipitation-related indices focus on intensity and length of heavy precipitation events as well as long lasting dry periods.

3 Projektinhalt und Ergebnis

Since the projects main focus is the adaptation, improvement, testing and further the application of the homogenisation methods, the methods will be explained in detail in this section. The first part of the section is dealing with the method applied to the extreme temperature series and the second part focuses on the homogenisation method for daily precipitation data.

Extreme **temperature**

A combined application of the method PRODIGE (Caussinus and Mestre, 2004) for the detection of an unknown number of breakpoints and the method SPLIDHOM (Mestre et al., 2010) for the calculation of adjustments and the correction of time series was selected for the homogenisation of extreme temperature series in Austria. The performance of different detection and homogenisation methods was tested in a pre-project, resulting in the above mentioned selection. However before any detection of breakpoints, the first step of the homogenisation procedure is the optimal choice of reference stations. Reference stations are chosen according to their horizontal distance (less than 100 km) and their vertical distance (less than 200 m) from the candidate series and most importantly a high correlation coefficient ($\rho > 0.8$) of the temperature series. The distance criteria were included to prevent spurious correlations. Additional criteria for the selection of reference stations are a common minimum length of 5 years and not more than 1000 missing values. The map in figure 1 shows all stations which are utilized in this study. The larger black circles indicate the location of all candidate series, which are part of the STARTCLIM dataset (Schöner et al., 2003), while the black points indicate all additional climate stations which are used as reference stations. Additional information about the stations which were tested for inhomogeneities is given in table 1.

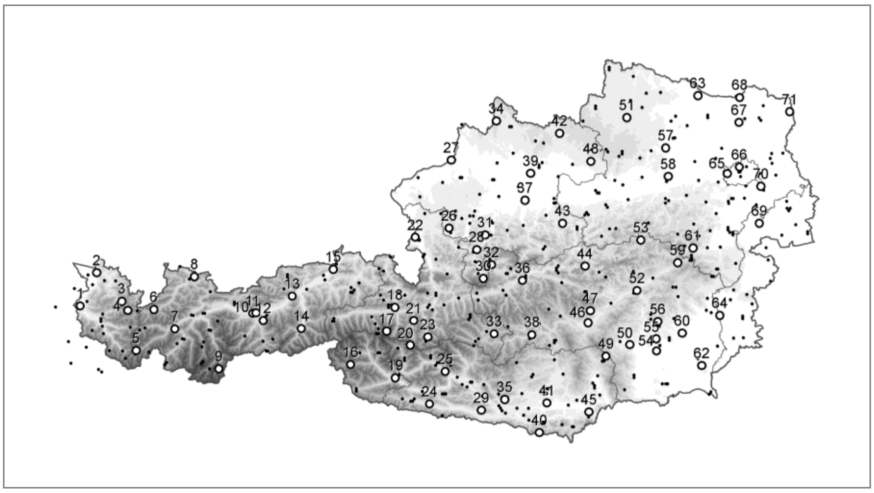

Figure 1: Location of the examined stations (large black circles – candidate station) and all other stations available in Austria (black points – reference stations). Note that not all reference station series cover the same period of time. Stations outside of Austria were provided by METEO Swiss. Numbers correspond to table 1.

After selecting reference stations, breaks detection is performed for all difference time series (candidate series minus reference series). In the break detection method PRODIGE an adapted penalized log-likelihood procedure is used to detect an unknown number of multiple breakpoints in annual, seasonal or monthly temperature difference series. Beside the statistical break detection, metadata from the station archive supports and further localizes the break date. After the first break detection the method SPLIDHOM (Mestre et. al, 2010) was used for correcting the breaks. In practice break detection and break adjustment were realized alternately, by evaluating the applied adjustment, if necessary adapting the break date, recalculating the adjustment etc. SPLIDHOM is a method for sequential adjustment of breaks in time series, relying on the good relationship between the candidate series and the highest correlated reference station. The adjustments are temperature dependent and therefore take the higher order moments into account. The uncertainties of the adjusted breaks are determined by means of a bootstrapping method and by altering reference stations. In that way not only the break intensity but also the break uncertainties are evaluated in order to decide which breaks need to and can be corrected. The uncertainties associated with the 1977 break adjustment in the TN series in Mürzzuschlag are shown in figure 2 for 3 different seasons. The boxplots, which were calculated by a bootstrapping method with a sample size of 50, indicate the uncertainty of the applied adjustment. The orange lines in the lower panel in figure 2 depict the adjustments calculated with the 2nd and 3rd highest correlated reference series. Especially in the winter and spring months the uncertainties of the adjustment calculated with the highest correlated reference station are very small. Concerning the other two reference stations, uncertainties rise up to the order of magnitude of the adjustment itself for the lower temperatures. These differences might be connected to local phenomena like cold air pools. However, since the shape and slope of the adjustments are similar we can still consider the break adjustment to be reliable.

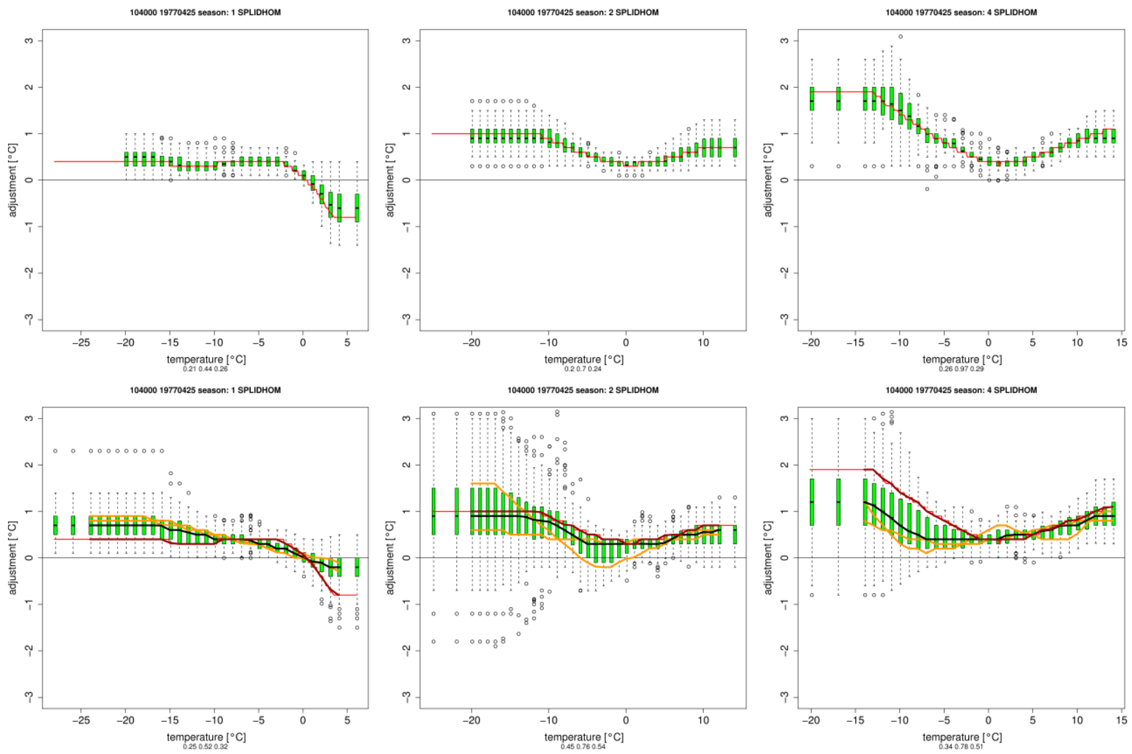

Figure 2: top: The red lines indicated the adjustment for the TN series in Mürzzuschlag calculated by SPLIDHOM using the highest correlated reference station. The boxplots represent the uncertainties of the correction, which were calculated with a bootstrapping method. Each boxplot is based on 50 samples. The dotted line shows the data range, while the small circles indicate outliers. Season 1, 2 and 4 (shown in the different columns) represent winter, spring and autumn respectively. bottom: Similar to upper row but including adjustments calculated with

two further reference stations. Red is again the adjustment of the highest correlated station and orange of the two other reference stations. The black line indicates the mean of the 3 adjustments.

Number	Name	Classification	Altitude [m]	TX info	TN info	PRECIP info
1	Feldkirch	city	439	1	1	0
2	Bregenz	lake side; city	436	0	0	1
3	Schoppernau	valley; village	835	0	0	0
4	Schröcken	valley; village	1260	1	1	0
5	Galtür	narrow valley; village	1587	2	2	1
6	Holzgau	valley; village	1100	2	2	0
7	Landeck	valley; village	818	1	1	1
8	Reutte	valley; village	870	1	1	0
9	Obergurgl	narrow valley; village	1938	2	2	0
10	Innsbruck airport	valley; airport	579	1	0	0
11	Innsbruck university	valley; city centre	577	1	1	0
12	Patscherkofel	moutain	2247	2	2	1
13	Jenbach	valley; village	530	1	1	0
14	Mayrhofen	valley; village	643	1	1	1
15	Kufstein	valley; municipality	492	0	0	0
16	St. Jakob im Def.	narrow valley; village	1388	1	0	0
17	Mooserboden	moutain	2036	0	2	2
18	Zell am See	lake side; city	751	2	1	0
19	Lienz	valley; city	659	1	1	0
20	Sonnblick	moutain	3105	2	2	2
21	Rauris	valley, village	941	1	1	2
22	Salzburg airport	airport	430	1	1	1
23	Bad Gastein	valley; village	1089	2	2	2
24	Reisach	valley; village	646	1	1	0
25	Kolbnitz	valley; village	603	1	1	1
26	Mondsee	lake side; village	482	1	2	0
27	Reichersberg	lowland; village	350	0	1	0
28	Bad Ischl	valley; village	469	1	1	0
29	Villacher Alpe	moutain	2140	2	2	0
30	Krippenstein	moutain	2050	2	2	1
31	Feuerkogel	moutain	1618	2	2	2
32	Bad Aussee	lake side; village	660	1	2	1
33	Tamsweg	valley; village	1022	1	1	2
34	Kollerschlag	lowland; village	725	0	1	0
35	Kanzelhöhe	moutain	1526	1	1	1
36	Irdning - Gumpenstein	valley; municipality	710	1	1	0
37	Kremsmünster	lowland; monostary	383	1	1	0
38	Stolzalpe	valley; village	1299	1	1	0

39	Hoersching	village; airport	298	1	0	0
40	Loibl	moutain; pass	1098	1	1	0
41	Klagenfurt	valley; city	447	2	1	0
42	Freistadt	valley; municipality	548	1	1	2
43	Großraming	valley; village	379	1	1	0
44	Hieflau	valley; village	779	1	0	0
45	St. Michael ob Bleiburg	valley; village	500	0	0	0
46	Zeltweg	valley; municipality	670	0	0	0
47	Seckau	valley; municipality	874	0	1	0
48	Pabneukirchen	lowland; municipality	595	1	1	0
49	Preitenegg	small moutain; village	1060	1	1	0
50	Lobming	lowland; village	414	1	1	0
51	Stift Zwettl	lowland; monostary	505	1	0	0
52	Bruck an der Mur	valley; small city	489	0	0	0
53	Mariazell	valley; village	865	1	2	0
54	Graz airport	city; airport	337	1	1	0
55	Graz university	city centre	366	1	1	0
56	Schöckl	moutain	1436	2	2	1
57	Krems	river side, city	190	1	1	2
58	St. Pölten	city centre	272	1	1	2
59	Mürzzuschlag	valley; small city	758	0	1	0
60	Gleisdorf	lowland; village	375	0	1	0
61	Reichenau an der Rax	valley; municipality	485	0	1	0
62	Bad Gleichenberg	lowland; village	300	0	1	0
63	Retz	lowland; village	256	2	2	0
64	Wörterberg	lowland; village	400	1	2	0
65	Wien - Mariabrunn	city	227	2	2	2
66	Wien - Hohe Warte	city	198	1	1	0
67	Oberleis	lowland; village	420	1	0	2
68	Laa an der Thaya	lowland; village	185	1	1	0
69	Eisenstadt	small city	184	1	1	0
70	Schwechat	airport	184	1	1	0
71	Hohenau	lowland; village	155	1	1	2

Table 1: Information about the candidate stations (0 - no homogenisation necessary; 1 - homogenisation; 2 - homogenisation not possible)

Precipitation

Similar to temperature, a combined application of the method PRODIGE (Caussinus and Mestre, 2004) for the detection of an unknown number of breakpoints and an adapted version of INTERP (Vincent et al., 2002) for the calculation of adjustments and the correction of time series was selected for the homogenisation of daily precipitation time series in Austria. Before starting the homogenisation procedure, reference stations had to be chosen. Since precipitation is a more variable parameter than temperature the threshold for the correlation coefficient had to be slightly modified and is selected to be $\rho > 0.7$ on a monthly basis and $\rho > 0.6$ on a daily basis. Furthermore, precipitation stations from the hydrographic service of Austria (HZB) were included as reference stations. The map in figure 3 shows all stations which were tested for inhomogenities (large black circles) and all available reference stations (red: ZAMG stations and blue: HZB stations). More information about the stations selected for homogenisation can be found in Table 1.

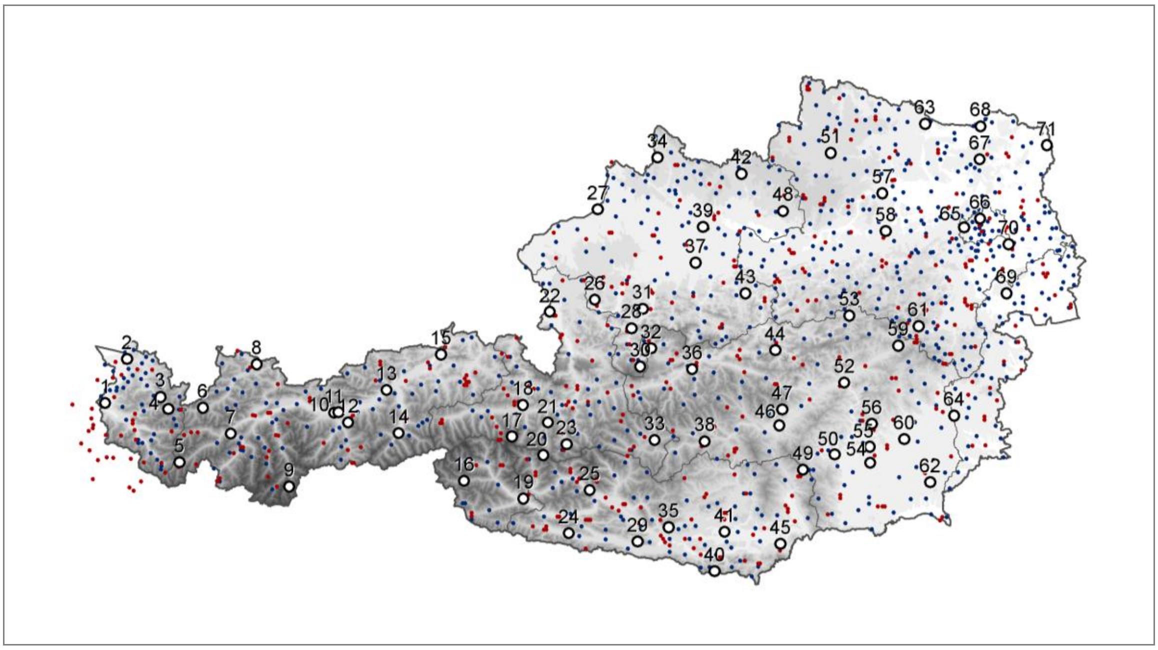

Figure 3: Map of Austria with all STARTCLIM stations (large black circle), plus additional reference stations operated by ZAMG (red) and HZB (blue). Stations outside of Austria were provided by METEO Swiss. Numbers correspond to table 1.

The method PRODIGE (Caussinus and Mestre, 2004) was used to detect a multiple number of breaks in daily precipitation series. Contrary to temperature series, precipitation time series were tested for changes in precipitation sums and also precipitation frequency. Therefore monthly or seasonal time series with the number of days exceeding 5mm of precipitation were constructed. This time series were compared to the respective series from the neighboring stations in order to perform the break detection. Concerning precipitation sums, monthly ratio (candidate/reference) time series were tested for inhomogeneities.

After break detection a correction method following the basic idea of the INTERP procedure (Vincent et al., 2002) is applied to the daily precipitation time series. The break adjustments are calculated on a seasonal basis to decrease the influence of potential outliers, following the equation:

$$adjustment[season] = median\left(\frac{cand_{aft,season}}{ref_{aft,season}}\right) \Big/ median\left(\frac{cand_{bef,season}}{ref_{bef,season}}\right)$$

where cand and ref refer to candidate and reference series respectively, aft and bef indicate before and after a potential break date. The median is more appropriate than the arithmetic mean due to the statistical distribution of precipitation sums. Contrary to INTERP, the adjustments are not smoothed in this method as the differences between the seasons are less pronounced than for temperature and any kind of smoothing would increase the uncertainty of the adjustments. Moreover, the adjustment for precipitation is multiplicative meaning that each daily measurement is multiplied by a specific factor which makes the absolute adjustment dependent on the precipitation sum itself.

The uncertainties of the adjustments are estimated by comparing adjustments calculated with different reference stations and by means of bootstrapping. The monthly dataset is resampled 50 times in order to recalculate the seasonal adjustments and to gain information about the possible range of values. In general, a visual recognition of breaks in seasonal or annual precipitation series is hard due to the large interannual variations. However, a good and illustrative counterexample was found at the station Galtür (number 5 in figure 3). Figure 4 displays the annual precipitation sum of this station. A period of higher precipitation sums is evident in the original precipitation sums (black line) between 1987 and 1974. In the homogenised datasets (red and orange lines) these breaks are removed by adjustments of up to 40% between 1974 and 1987 and very small adjustments before the first break.

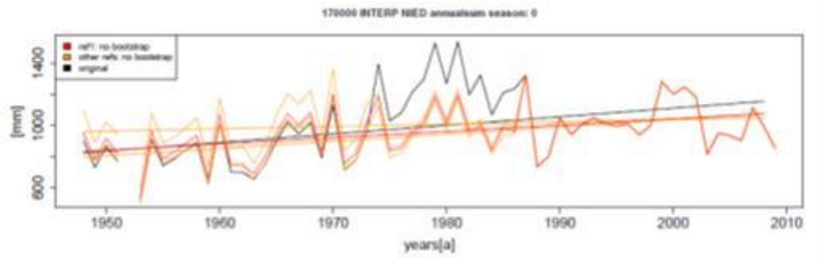

Figure 4: Annual precipitation sums [mm] for Galtür (170000). The black line displays the original data, red the applied homogenization and orange the homogenization if one of the other two reference stations would have been used.

1 Results and conclusions

Similar to the last section, “Results and conclusions” are also outlined in two separate parts, first dealing with extreme temperatures and second with daily precipitation totals.

1.1 Extreme temperatures

The method described in the previous section was applied to 71 minimum (TN) and maximum (TX) temperature series in Austria (figure 1). For some series homogenisation was not possible due to large uncertainties in the break adjustments or a lack of suitable reference stations. These stations, 14 TN and 17 TX series, are indicated with grey circles in figure 5. Most of the series where homogenisation was not possible are either located at high elevations where station coverage is low (e.g Feuerkogel, Patscherkofel, Sonnblick, Krippenstein), in narrow valleys (e.g. Galtür, Obergurgel, Bad Gastein) or close to lakes (e.g. Mondsee – only TN, Bad Aussee – only TN, Zell am See – only TX). The latter two are strongly influenced by local effects, topographic or hydrological, which drastically reduce the number of highly correlated reference stations and increase uncertainties in the adjustment.

Break statistics

In the remaining 57 TN and 54 TX series a total number of 139 (TX: 74 and TN: 65) breaks were detected. Almost half of the temperature series were affected by only one break, another 20% by two breaks, approximately 25% of the stations were classified as homogeneous after break detection while in a small number of stations more than two breaks were detected (see figure 5).

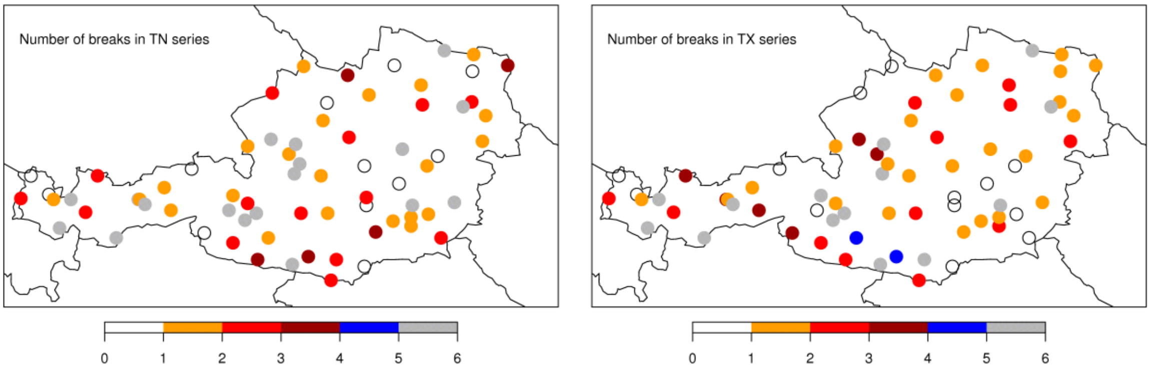

Figure 5: Number of detected breaks in TN (left) and TX (right) series. White circles: homogeneous time series, yellow dots: series with one break, red dots: series with 2 breaks, dark red dots: series with 3 breaks, blue dots: series with 4 breaks, grey dots: stations where homogenisation was not possible.

Compared to many other European countries, metadata quality in Austria is remarkably good and a high number of detected breaks coincide with events recorded in the station archive. In Table 2 a list of metadata events together with the number of breaks occurring at the same time is given. Remarkable 74% of the events match with information from the station archive, with 36% being caused by station relocation. Only 16% of the breaks could not be confirmed by meta information.

Metadata event	Number
Station Relocation	50
Instrumentation change	23
Screen shelter	16
Observer change	8
other information	6
break without metadata	36
Total	139

Table 2: Typ and number of metadata events accompanied by a detected and adjusted break point.

The strength of the mean break adjustments are evaluated in figure 6, with seasonal adjustment for TX on the right compared to seasonal adjustments for TN on the left.

In general, the mean seasonal adjustment over all stations is negative, although almost zero for TN in summer and autumn and for TX in the winter months, indicating an intensification of the overall warming trend. Largest adjustments occur in the summer months, with amplitudes of up to 2.5 °C. In winter adjustments stay within the range of ±1.5°C, which is linked to the lower variations in the temperature distribution. However, most adjustments are rather small within a range of ±0.5°C.

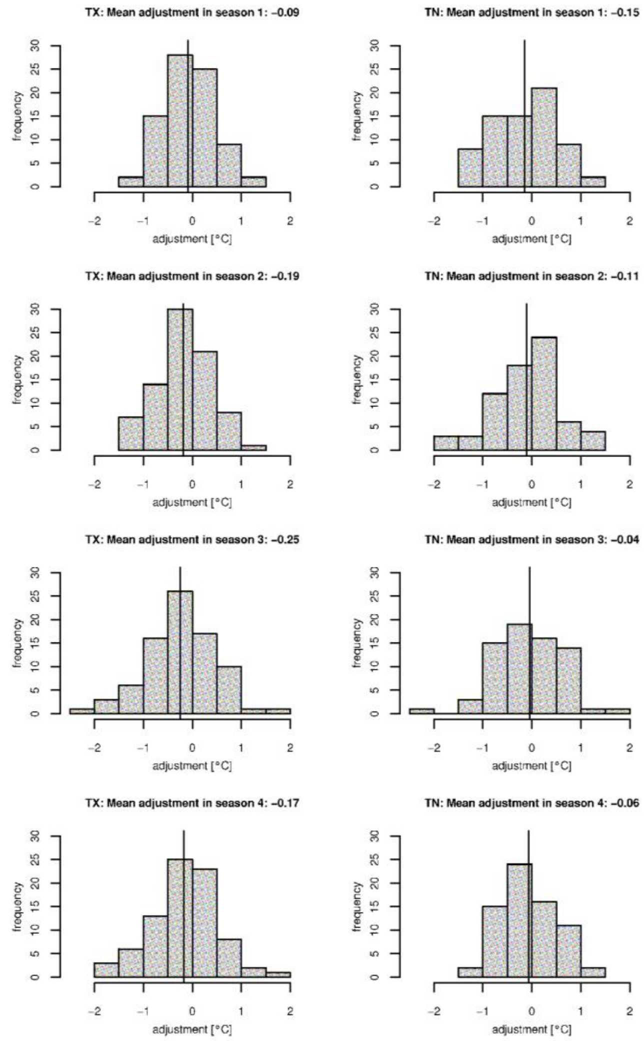

Figure 6: Mean break adjustment of all homogenised time series for the different seasons (1: winter, 2: spring, 3: summer, 4: autumn), left for TX and right for TN. In the title and as a vertical line the mean adjustment is indicated.

- Trends in climate change detection indices

16 temperature based climate change detection indices, namely frost days (FD), summer days (SU), icing days (ID), tropical nights (TR), growing season length (GSL), monthly maximum of TX (TXx), monthly maximum of TN (TNx), monthly minimum of TX (TXn), monthly minimum of TN (TNn), cold nights (TN10p), cold day-times (TX10p), warm nights (TN90p), warm day-times (TX90p), warm spell duration index (WSDI), cold spell duration index (CSDI) and diurnal temperature range (DTR), were evaluated for the homogenised as well as the original temperature time series following the WMO guidelines (Alexander et al., 2006, Klein Tank et. al, 2009). The first 5 indices (FD, SU, ID, TR, GSL) result from a "peak-over-threshold" method and represent the number of days where temperatures exceed a predefined threshold, such as summer days being days with TX higher than 25°C. The following 4 indices (TXx, TXn, TNx, TNn) refer to absolute extreme values and therefore very much dependent on data quality. The subsequent indices are based on a so-called "block-maximum" method. Here the 10th and 90th percentiles

are calculated for a 5 day window centred on each calendar day within a defined base period, resulting in an annual cycle of e.g. 10th percentiles of TX. Similar to the "peak over threshold" method the number of days exceeding this threshold is counted. Klein Tank and Konnen (2003) note that indices based on percentiles, since being site specific, should be preferred for spatial comparisons. Finally, duration indices (WSDI & CSDI) define periods of persistent cold or warmth. A full descriptive list of the indices can be obtained from http://cccma.seos.uvic.ca/ETCCDMI/list_27_indices.shtml. For the trend assessment, a simple least squares method is applied to the annual and seasonal indices.

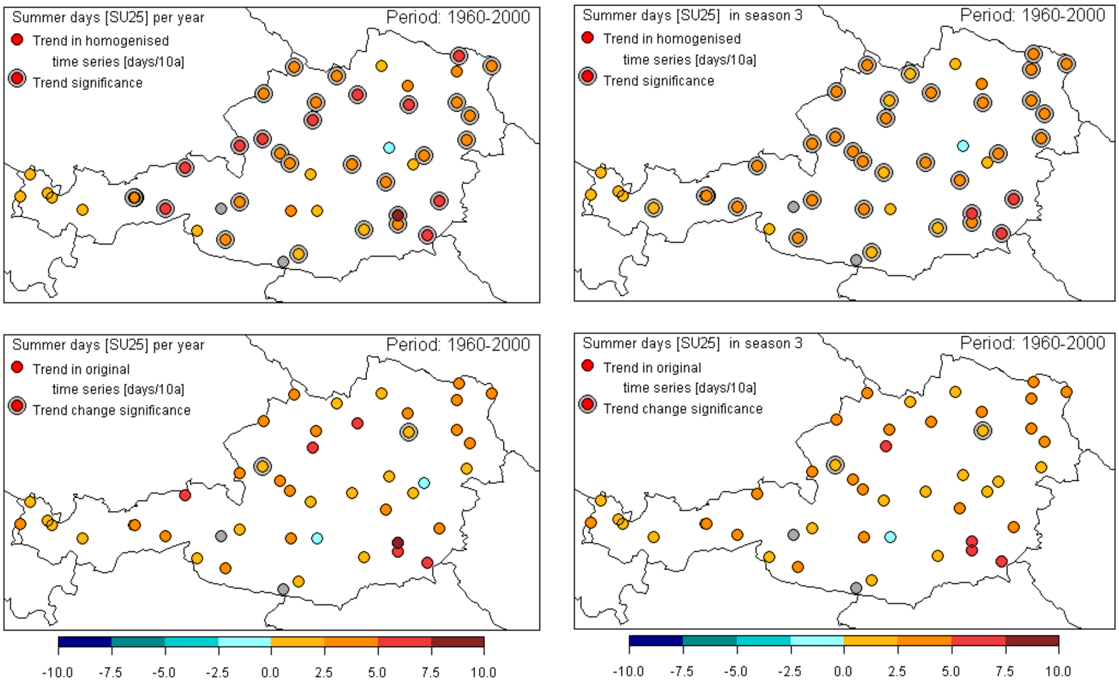

Figure 7: Comparison of trends in the number of summer days [days/decade] before and after homogenisation for the period 1960-2000 for all stations Austria. The map shows bullets with concentric bands for each station. The inner circle in the upper panel shows the amplitude of the trend in summer days of the homogenised time series. The grey bands indicate whether the trend is significant. The lower panel shows the trend amplitude before homogenisation.Trend change significance is again indicates with a grey band. On the left trends are shown for the annual number of summer days and on the right for the number of summer days during the summer months (season 3).

The inner circles in figure 7, 9 and 10 indicate the magnitude of the trend, for both the homogenised time series and the original time series in figure 7 and 10 only the homogenised time series in figure 8. Using a so-called moving-block-bootstrap procedure (Kiktev et al., 2003) the uncertainty of the trend is calculated on a 5% significance level. The time series of each station is sampled 50 times and instead of sampling single values a sequence of consecutive values is chosen to account for the autocorrelation in the data. The length of each sequence depends on the autocorrelation. Following Moberg and Jones (2005) each sequence is chosen to consist of 2 values. A trend is considered as significant if this confidence interval does not contain a zero trend. In figure 7, 9 and 10 the significant trends are indicated with grey bands around the circle of the trend magnitude of the homogenised time series. Further, trends in homogenised data are considered significantly different from trends in original data if the uncertainty range of the trends calculated from original and homogeneous data do not overlap. In figure 7 and 10 the significant trend changes are indicated with grey bands around the trend circles of the original time series.

The period 1960-2000 has been chosen for evaluation. Thus maps include all stations where homogenisation was possible and which cover the whole period, adding up to 47 TX series and 43 TN series. Figure 7 illustrate trend magnitudes, trend significance and trend change significance for the climate change detection index summer days

(SU) for the annual values and seasonal summer values. Summer days are defined as days where TX exceeds 25°C. A widespread significant positive trend in summer days is visible in all 4 graphs. For the annual and seasonal values the trend generally increases due to the homogenisation. However, trend changes due to the homogenisation are only significant at two stations, Mondsee and St. Pölten (number 26 and 58 in figure 1). The trend change due to the homogenisation in St. Pölten is shown in more detail in figure 8.

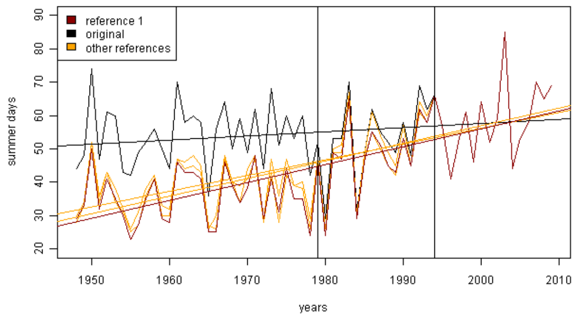

Figure 8: Number of summer days at the station in St. Pölten: in black the original time series, red the homogenised time series and orange the time series homogenised with the 2nd and 3rd highest correlated reference station.

The black line indicates the number of summer days calculated on the basis of the original TX series, while the red and orange lines show the summer days based on the homogenised data set. Especially the break adjustment in 1979 (horizontal black line) drastically reduces the number of summer days and accordingly raises the trend. Uncertainties related to the choice of reference stations are rather small, indicating a reliable break adjustment.

In figure 9 trends and trend significances of cold day-times (TX10p) are shown for all 4 seasons. In winter (season 1) trends cover a wide range from -0.02 days/decade in Krems (number 57 in figure 1) up to -4.9 days/decade at stations in the alpine regions (e.g. Innsbruck or Irdning; number 11 and 36 in figure 1). The range between the stations is slightly decreasing towards the summer months, while the mean trend over all stations is growing more negative reaching -2.9 days/decade in the summer season. However, in autumn the trends are partly reversing the sign suggesting a slight increase in cold days especially in the eastern parts of Austria. The same feature is found in other climate change indices based on daily TX series, e.g. TX90p, SU25, ID (icing days: TX < 0°C), while TN series show only a weak signal in TN10p. On a monthly basis the HISTALP dataset (Auer et. al. 2007) shows similar features, with less warming in the months September, October and November. The distinct behaviour of extreme temperature based indices in autumn is also confirmed for other countries (e.g. Yan et al, 2002, Cahynová and Huth, 2009). Cahynová and Huth (2009) further analysed the relationship between trends in daily TX, TN and mean temperatures and the circulation pattern for the Czech Republic and found that, depending on the classification of synoptic patterns, changes in the atmospheric circulation can explain a great part of this cooling trend.

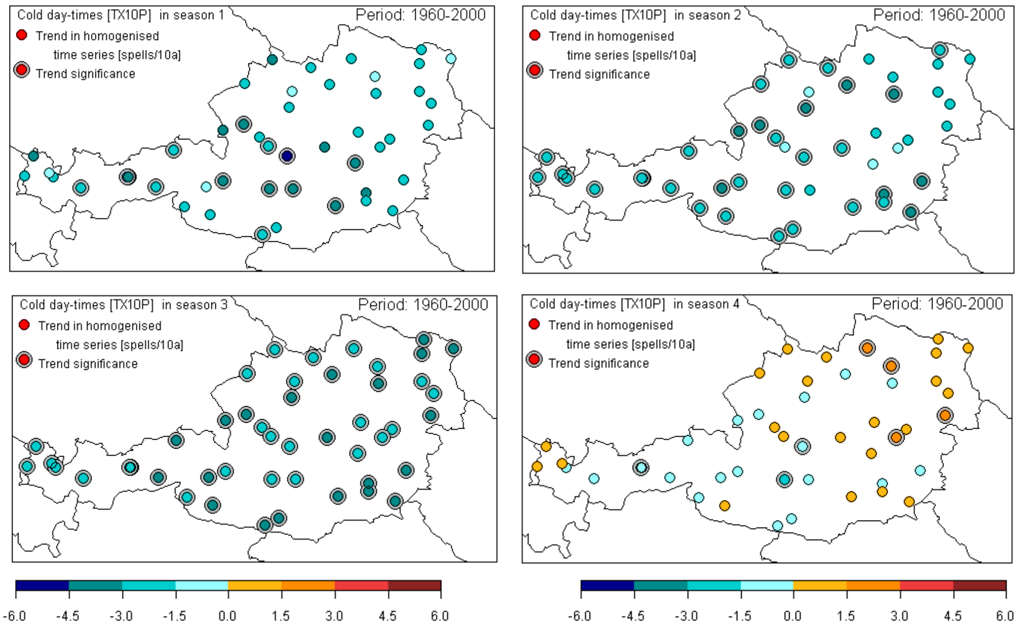

Figure 9: Same as upper panel in Figure but for TX10p (cold day time) for all seasons (1: winter, 2: spring, 3: summer, 4: autumn)

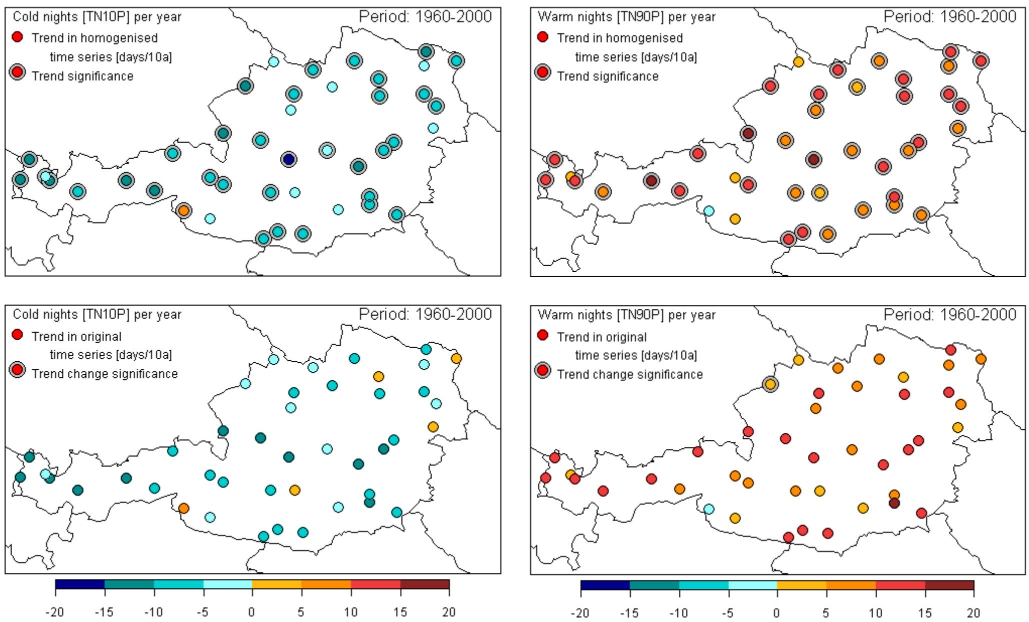

Figure 10: Same as Figure but for TN10p (cold night times) on the left and TN90P (warm night times) on the right.

Figure 10 depicts the two percentile threshold based indices for TN, cold nights (TN10p) and warm nights (TN90p). Both indices show significant trends at almost all stations, with an increasing number of warm nights and a decreasing number of cold nights. The only station with a reverse trend in both indices is located in the narrow Defreggen valley in the Southern Alps. The reason is puzzling, as the trend seems to represent a climatic signal because no breaks where detected and no adjustment was applied to the series.

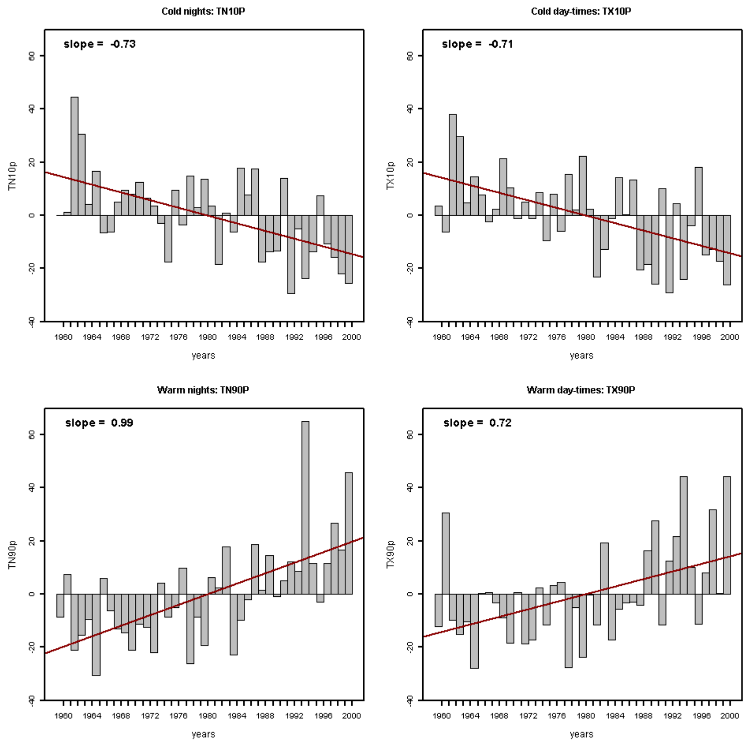

Figure 11: Anomalies of the mean number of cold nights, cold day-times, warm nights and warm day-times over all stations in the dataset. The red line shows the linear trend.

Finally, the trends of percentile based indices for both TX and TN are compared by building the anomaly of the annual mean over all indices of all available homogenised stations in the period 1960 to 2000 (figure 11). Even though the inter-annual variability is strong for all indices, a clear warming trend is visible. The trends in the 10th and 90th percentile of the TX series have the same magnitude, indicating a consistent warming of maximum temperatures. On the contrary, the trend of the higher percentiles of the minimum temperature series is stronger than for the lower percentiles (figure 11, left column). In the diurnal temperature range (DTR) this trend is however not clearly visible. A slight increase in DTR can be found in the southern parts of Austria, while the signal is rather diverse in the other parts of the country. Alexander et al. (2006) supports these results on a global scale showing that trends in indices derived from minimum temperature show more distinct changes than those based on maximum temperatures. However, similar studies in Italy (Simolo et al., 2010, Brunetti et al., 2006, Toreti et al., 2008) or Spain (Brunet et al., 2007) show more pronounced trends in the TX series.

1.2 Precipitation

The homogenisation method described above was applied to 71 daily precipitation series (see figure 3). Contrary to the extreme temperature series, significant breaks could only be detected in a small number of precipitation series. At these stations the break adjustment method was applied. For another 11 stations homogenisation efforts turned out to be unsuccessful, due to missing reference stations or large uncertainties in the adjustments (see table 3). A list of all stations with information about the homogenisation is given in Table 1.

	number	percentage
homogeneous	49	69%
homogenisation not possible	11	15.5%
homogenised	11	15.5%
	71	100%

Table 3: Statistics of the homogenisation of the precipitation dataset.

- Trends in climate change detection indices

Based on the new homogenised dataset of daily precipitation totals 10 precipitation-related climate change detection indices were evaluated (Alexander et al., 2006, Klein Tank et al, 2009). Among those are: Maximum one-day precipitation (RX1day) per year, maximum five-day precipitation (RX5day) per year, simple daily intensity index (SDII) which is the mean precipitation amount on a wet day, heavy precipitation days (>10mm - R10mm), very heavy precipitation days (>20mm, R20mm), extremely heavy precipitation days (>30mm, R30mm), consecutive dry days (CDD), consecutive wet days (CWD), precipitation due to wet days (>95th percentile; R95pTOT), precipitation due to very wet days (>99th percentile; R99pTOT) and total precipitation sums on wet days (PRCPTOT). Wet days are defined as days with more than 1mm of precipitation. A full descriptive list of all climate change indices can be obtained from http://cccma.seos.uvic.ca/ETCCDMI/list_27_indices.shtml.

The calculation period was defined to be 1971-2000, because 55 out of 60 precipitation series cover the full 30-year period. Five mountain stations were excluded from this analysis due to large uncertainties in the measurements caused by stronger wind speeds (Sevruk et al., 1994). In contrary to the temperature-based climate change detection indices, precipitation indices are generally much more variable and show far greater regional differences.

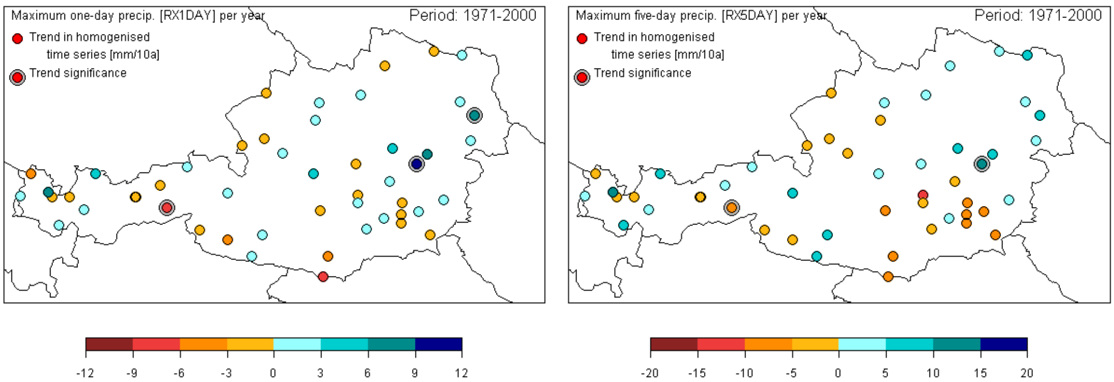

Figure 12: Trend of maximum one-day precipitation for the period 1971-2000 for all homogenised precipitation series in Austria (left). On the right trends of maximum five-day precipitation for the same period and the same stations are shown.

Both graphs in figure 12 clearly show the variable behavior of daily precipitation sums, especially related to absolute maxima. A tendency, although not very significant, towards weaker precipitation events can be seen in the southeastern parts of Austria. The northeast experiences a weak intensification of maximum five-day precipitation sums, which is however less pronounced in the one-day precipitation sums. In the western, alpine regions the signal is even more variable with stations with positive and negative trends located very close to each other.

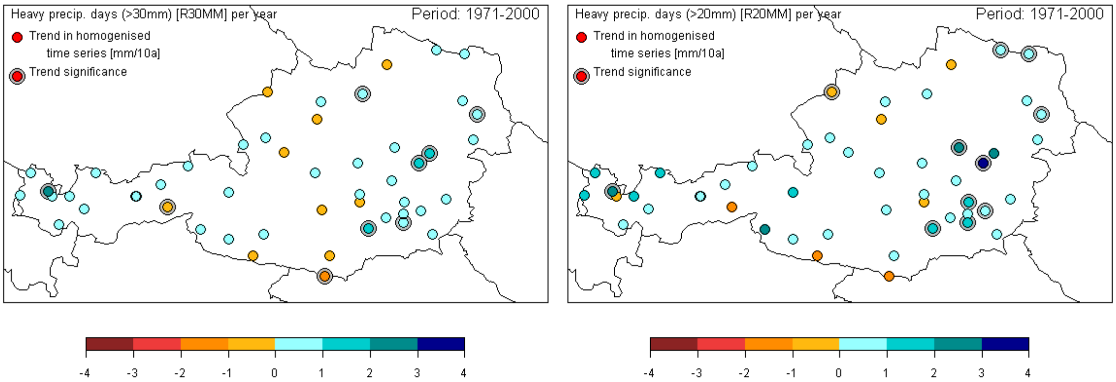

Figure 13: Left: Trend of the number of days with precipitation sums greater 30 mm for all homogenised precipitation series in Austria. Right: Trend of the number of days exceeding a precipitation sum of 20 mm for the same stations.

In contrast to absolute indices, exceedance indices seem more representative and more robust when dealing with precipitation data. Especially the right graph in figure 13 shows an intensification of precipitation events larger than 20 mm/day in the east and southeast of Austria, with Mürzzuschlag and Mariazell (number 59 and 53 in figure 3) being in the center of increasing heavy precipitation days. The rest of the stations do not show a uniform geographic pattern, but a rather random distribution with slightly more stations with positive trends.

Another interesting feature is the strong and significant trend in heavy precipitation days (RR>20mm) at the station in Mürzzuschlag (black line, figure 14). In order to gain confidence in the trend, the annual precipitation totals were compared to those of (on an annual basis highly correlated) neighboring stations. Figure 14 (right) shows the location of these stations. The plot on the left shows the annual precipitation sums of these 5 stations and the linear trend for the period 1970 to 2009. All trends, even though on a higher level than at the station in Mürzzuschlag, have very similar slopes indicating a strong increase in annual precipitation sums in this region.

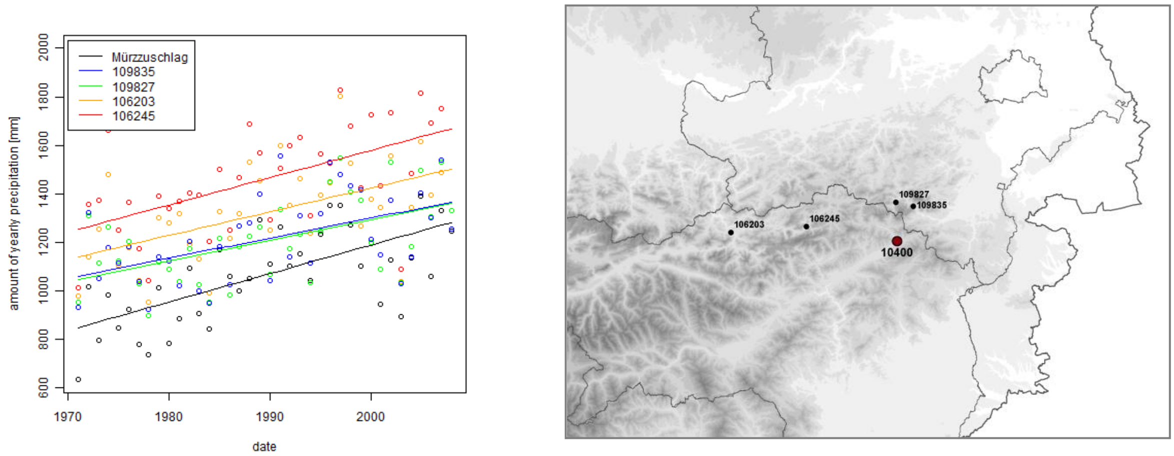

Figure 14: Annual preciptation totals for the station Mürzzuschlag (10400) and 4 highly correlation stations in the neighbourhood. The solid lines indicate a linear trend for all stations.

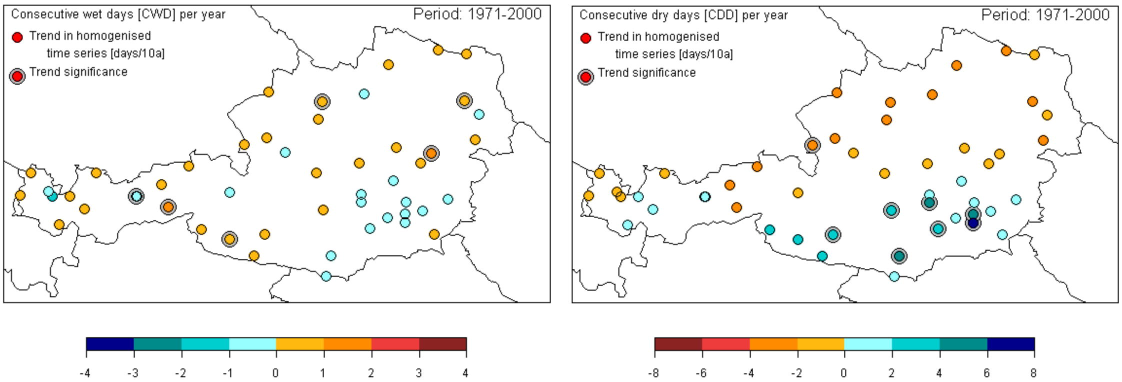

Figure 15: Left: Trend of number of consecutive wet days (CWD) per year for all Austrian stations for the period 1970 to 2000. Right: Trend of the number of consecutive dry days (CDD) per year for the same stations and the same period.

The consecutive dry days (CDD) index is the only evaluated precipitation index which shows a clear geographic pattern. The CDD index is defined as the maximum number of consecutive days with less than 1mm of precipitation. South of the alpine divide a trend towards longer dry periods, with most of the trends being significant, is evident in figure 15 (right). In the northern part CDD trends are solely but not significantly negative. In the west (Tirol and Vorarlberg) the signal is even less pronounced with weaker trends.

However, the apparent CDD pattern is not balanced by reversed trends in the CWD (consecutive wet days) index. The CWD trends are shown in figure 15 (left).

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3 Schlussfolgerungen und Empfehlungen

The new homogenised and quality controlled dataset of daily minimum and maximum temperature as well as precipitation totals covering a period of 61 years (1948-2009) is now available for further analysis and investigations. In order to perform climate change studies based on extreme values in Austria this dataset forms an essential basis. From our point of view the following ideas for further use of this dataset are considered:

The new dataset can be compared to output from a regional climate model, in order to assess the model uncertainties and to make more reliable statements concerning the future of climate extremes. Therefore climate change indices are calculated from both the simulated time series and the homogenised daily time series covering a period of at least 30 years. After interpolation of the measurement series on a 2D field the data can be compared. Results will shed light on the reliability of climate model output on a daily basis and on the potential of regional climate model for reliable statements concerning the future evolution of climate extreme.

Grids will be constructed on the basis of the homogenised temperature data in order to evaluate the 2D changes related to the homogenisation. These grids already exists based on the STARTCLIM data and should be updated using the homogenised dataset.

Different climate extreme studies will be performed on the basis of this dataset, e.g. dealing with the evolution of dry periods in the south of Austria or the autumn trend reversal connected to TX. Within this project climate change detection indices were evaluated for one fixed period for extreme temperatures and an even shorter period for precipitation series. An additional analysis of other periods and the trend changes between different periods could be one possibility. The autumn trend reversal should be investigated in more detail, e.g. in combination with an analysis on the circulation pattern.

Furthermore, the homogenisation methods for daily extreme temperatures and daily precipitation totals are readily available for further application. The only requirement of the method is the existence of a sufficient number of reference stations. In any project dealing with daily time series this method, if not already done, should be applied on the time series in order to make results more accurate.

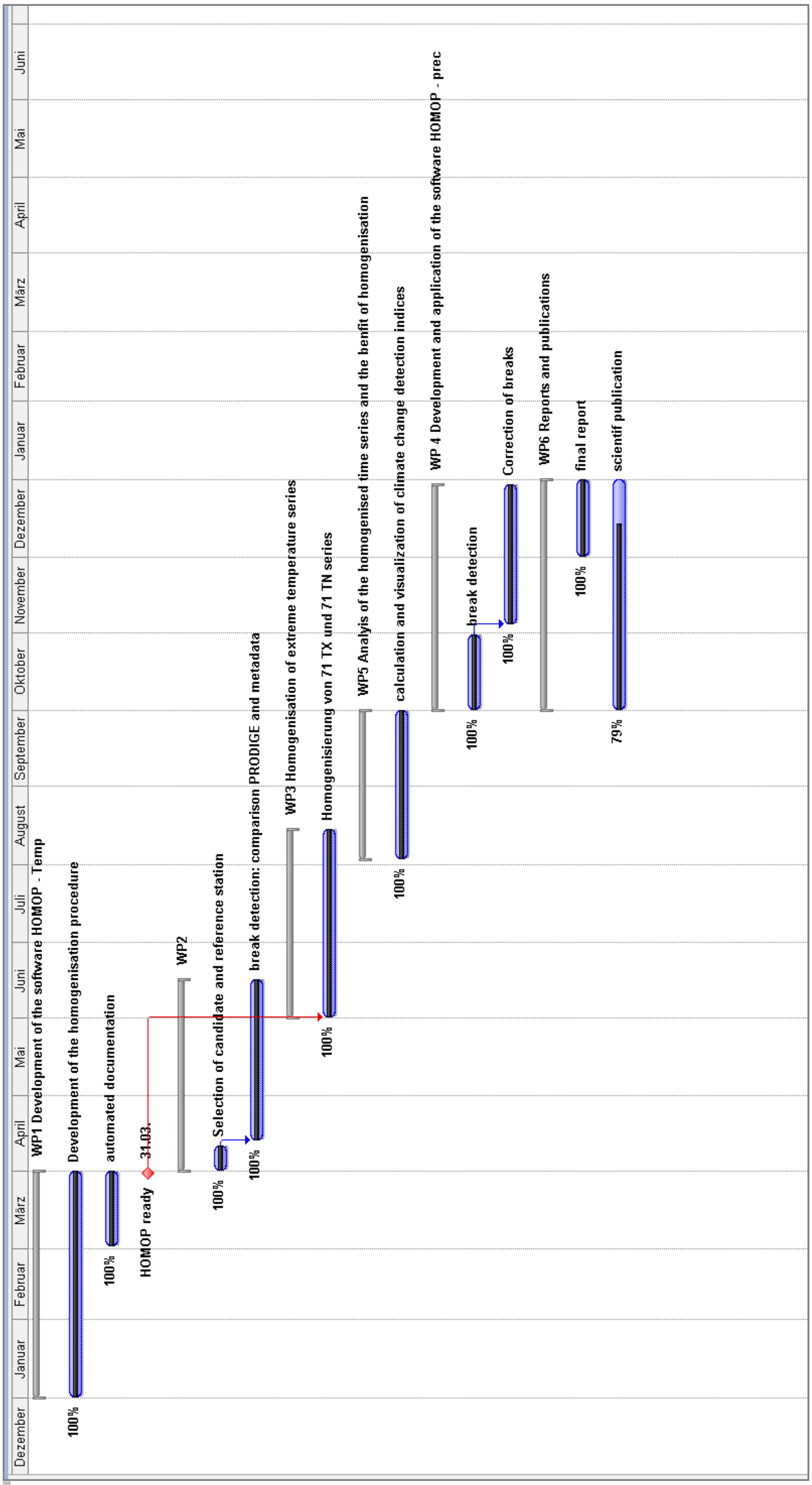
Concerning the methods for temperature homogenisation the international community is putting efforts in the homogenisation of data on a sub daily time scale. In the field of daily precipitation homogenisation there is still a high potential for further development of the method. The break adjustment method which was used in this project could unfortunately not be validated or compared to other methods because no benchmark dataset exists for daily precipitation series. However, within the COST-Action Home (ES0601) the development of a benchmark dataset for daily precipitation time series is planed, which can be used to validate our homogenisation method. After proper validation results can be compared to those from other methods, to find advantages and disadvantages of different approaches and to further improve the procedures.

C) Projektdetails

4 Methodik

The homogenisation method applied to the extreme temperature series was chosen, adapted and tested in a pre-project. In principal the method relies on the existence of highly correlated reference stations, both for break detection and break adjustment. A statistical break detection is supported by an extensive collection of meta data about the stations history. The temperature dependent adjustments are calculated with the highest correlated neighbouring station. The reliability of the break adjustment is then estimated by altering reference stations and by applying a bootstrapping technique. Since the spatial and temporal variability of precipitation is larger than of temperature, break adjustments in precipitation series were only calculated on a seasonal basis. Since very little is known about the changes in the distribution of precipitation totals caused by e.g. station relocation or an instrumentation change, only the mean value of the precipitation series is adjusted. (comp. chapter 3)

5 Arbeits und Zeitplan



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5 Publikationen und Disseminierungsaktivitäten

The new homogenised and quality controlled dataset of daily maximum and minimum temperature as well as daily precipitation totals covering a period of 61 years (1948-2009) is now available for further analysis and investigations. Information on the homogenisation methods and the homogenised data can be freely downloaded from http://www.zamg.ac.at/forschung/klimatologie/klimawandel/homstart.

Paper (peer-reviewed):

Nemec J, Gruber C, Chimani B, Auer I: 2012. Trends in extreme temperature indices in Austria based on a new homogenised dataset of daily minimum and maximum temperature series. International Journal of Climatology, (only minor correctios, in revision).

Graue Literatur/Beiträge:

Johanna Nemec, Barbara Chimani, Christine Gruber, Ingeborg Auer. 2011. Ein neuer Datensatz homogenisierter Tagesdaten. ÖGM bulletin/2011/1: 19-20.

23. 2. 2011. Ein neuer Datensatz für die Klimaforschung – homogenisierte Tagesdaten. Presseaussendung

Mai 2011. Fragebogen für Umweltbundesamt

Hom-Start Homogenization of climate series on a daily basis, an application to the StartClim dataset. 2011. Beitrag für die 2. Ausgabe des Newsletters zur Klimawandelanpassung

Conference presentations

Ingeborg Auer, Johanna Nemec, Barbara Chimani, Konrad Türk, Christine Gruber: HOMSTART – Der homogenisierte StartClim Datensatz – eine neue Datengrundlage für die Österreichische Klimaforschung. 12. Österreichischer Klimatag, 21.-22. September 2011, Wien.

Ingeborg Auer, Johanna Nemec, Barbara Chimani, Konrad Türk, Christine Gruber: HOMSTART – a new homogenized daily data set for regional climate change research, 8th ECSN Data Management Workshop, 12.-14. Oktober 2011, Edinburgh, UK.

Ingeborg Auer, Johanna Nemec, Barbara Chimani, Konrad Türk, Christine Gruber: Erfahrungen mit der Homogenisierung täglicher Extremtemperaturen und täglicher Niederschlagswerte. Österreichischer Meteorologentag, 3.-4. November 2011, in Klagenfurt.