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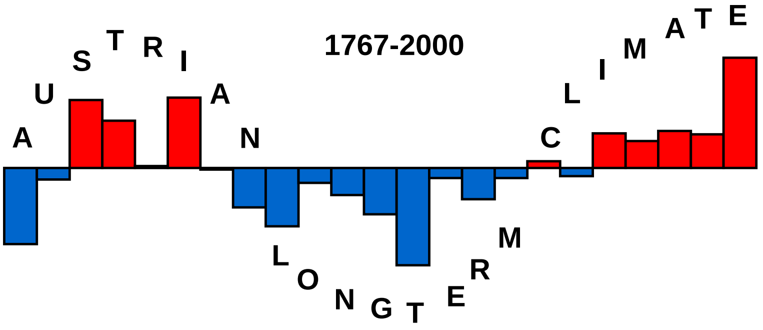
AUSTRIAN LONG-TERM CLIMATE 1767-2000

MULTIPLE INSTRUMENTAL CLIMATE TIME SERIES FROM CENTRAL EUROPE

ALOCLIM



Ingeborg Auer, Reinhard Böhm, Wolfgang Schöner
Zentralanstalt für Meteorologie und Geodynamik

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Contents of the CD

1. Detected breaks (9 xls-files)
2. Diagrams of time series (9 xls-files)
3. Homogenised data (9 sub-directories of the climate elements, each containing one xls-file for each station)
4. Meta data
   - 4.1. Mean daily courses and obversing time breaks (1 xls-file)
   - 4.2. Meta quick looks (16 xls-files for each station plus one colour key)
   - 4.3. Single station meta files (16 doc-files for each station plus one file for a combined series)
   - 4.4. Site photos (16 doc-files for each station)
   - 4.5. Site maps (16 doc-files with recent site maps plus 9 doc-files with historic site maps)

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1 Introduction

Analysing climate variability based on instrumental data is strongly dependent on the length and the spatial density of the available time series, on the number of usable climate elements and on data quality in terms of non-climatic inhomogeneities. However, most of the existing national, regional and global datasets have certain shortcomings concerning one or more of these basic requirements. An extensive dataset that claims to describe climate variability should fulfil all of these requirements.

Datasets like NCEP/NCAR (Derber et al, 1991, Kalnay et al., 1996), ERA-15 (Gibson et al., 1997) and ERA-40 (Uppala et al., 2000) are collections of synoptic data combined with modelling. They are three-dimensional in space, offer a high level of “real time quality”, provide a high spatial and temporal resolution and contain the full range of meteorological elements. However, these datasets only cover the most recent 15 to 50 years and their quality in terms of long-term homogeneity is questionable.

Global climate datasets at the centennial time-scale are rare and usually contain only one or a few climate elements (e.g. mean temperature, mean daily extremes, precipitation, air pressure). The two leading datasets are the gridded datasets of the Climatic Research Unit (CRU) at the University of East Anglia (Jones, 1994; Hulme and Jones, 1994) and the station datasets of the National Climatic Data Centre (NCDC) of NOAA (Vose et al., 1993). These datasets (based on monthly means) fulfil the requirements in terms of global coverage and of homogeneity on a global scale but they do have certain shortcomings in terms of homogeneity at the regional and local scales. These shortcomings are mainly due to inadequacies in network density and station history information (metadata).

Several high density, centennial scale, single-element datasets already exist on a regional or national basis (e.g. Moberg and Alexandersson, 1997; Easterling et al, 1996; Folland and Salinger, 1995; Hanssen-Bauer and Førland, 1994; Torok and Nicholls, 1996), but there are still to few of them to construct a global picture regarding climate variability. Such datasets have a high potential to solve the homogeneity problems due to their higher spatial density (which improves homogeneity test results) and their better metadata information (which is usually kept in the archives of the National Weather Services but is not easily accessible to international research groups). Despite their potential, these datasets suffer from a lack in the number of climate elements observed both on a national and regional level.

There has been one attempt to create a "real" climate variability, long-term, homogenised, multiple instrumental dataset. This was carried out by the Scandinavian countries (Frich et al., 1996) and resulted in the North Atlantic Climate Dataset (NACD). It is the only dataset, to date, that meets all the requirements of a climate variability dataset as listed above. We took the NACD as an ideal example for our own work in Austria within the two year project, Austrian long-term climate (ALOCLIM), 1996-1998.

The main objectives of ALOCLIM were:

- To establish an Austrian climate data base, on a monthly basis, which :
  a) is long term (going as far back in the historical record as possible);
  b) is homogenised (using the information from metadata and statistical homogeneity tests);
  c) contains multiple climate variables (not only temperature or precipitation, but also sunshine duration, air pressure, etc.)
  d) is "borderless", i.e., not limited by the borders of the Austrian territory

- and to use these data for multiple climate time series research.

ALOCLIM profited from collaborations with the National Weather Services of the Czech Republic, Hungary, Slovakia and Slovenia. The German and Swiss Weather Services supported ALOCLIM by providing long-term climatic series for their countries.

This book will illustrate and discuss the complete procedure of homogenisation, from data and metadata processing, to homogeneity testing and adjustment, to the analyses of the changes from the original to the homogenised series and finally the presentation of Austrian climate variability during the instrumental period. In order to keep the size of the book to reasonable dimensions it has been supplemented by the enclosed CD-ROM, which includes data, diagrams of time series, metadata and an analysis of all adjustments performed.

2 History of meteorological observations in Austria

The following short historical summary describes the background of the data that are the basis of the analyses of climate variability in Austria during the instrumental period. In November 1918, the areal coverage of Austria was reduced during the shift from the old Monarchy to the much smaller Republic. This has implications for the extent of the study region and the homogeneity of the data produced. This study will concentrate mainly on data collected for the territory of the Austrian Republic, which covers an area of 84,000 km^2. Nevertheless, some information about the history, structure and organisation of the meteorological network of the much larger Monarchy territory of more than 600,000 km^2 will also be used. This may be helpful not only for this study but other research as well, because the initial organisational ideas are the roots not only of the recent Austrian climate network, but also of the networks of the other successor states. The history of this large region in Central Europe creates a degree of homogeneity of climate data in the region, in spite of all the political changes.

The earliest meteorological measurements from the recent territory of Austria were part of the “Accademia del Cimento” initiative developed by Ferdinand II of Tuscany. His aim was to create a meteorological network that was in accordance with modern scientific ideas. The convent of the Jesuits at Innsbruck was one of the four stations outside Italy that were part of this network. Measurements were taken since 1653 and continued for several years. However, these measurements, as well as the later records taken at the “Collegio Societas Jesu” in Vienna from 1734 to 1773, were misplaced. In December 1762, the director of the astronomical observatory of the Benedictine monastery in Kremsmünster, Placidus Fixlmiller, began a series of meteorological measurements and observations, which have remained uninterrupted since then. The first four years of the record are not systematic enough to be used as part of a homogeneous climate time series, but since 1767 the Kremsmünster series has been the longest and one of the most homogeneous climate series in the region. Thus, 1767 can be regarded as the first year of the “instrumental period” in Austria. In 1775 Maximilian Hell and Anton Pilgram, from the astronomical observatory of Vienna, started the second longest Austrian series. In 1777 another series was begun in Innsbruck at the former Jesuit College, thanks to the private interest of Franz von Zallinger, a University professor of Physics and Mathematics. These three sites now constitute the backbone of the Austrian long-term instrumental data. In the 1780s, the three series were included in the international network of the “Societas Meteorologica Palatina” of Mannheim. They survived the sudden end of the society after only 10 years and also the following decades of general warfare in Europe. The first attempts to create meteorological networks at the regional scale started in the 1810s when stability had returned to the continent, which enabled some longer term planning. In Austria, a scientific society in Carinthia led by two eminent scientists, Matthias Achazel and Johann Prettner, developed a regional meteorological network which started in Klagenfurt in 1813 and increased to 15 stations by 1848, the first year of a large scale all-Austrian network. Two other private initiatives, which increased the number of "pre-weather service" series, began in 1836, at the Institute of Physics at the University of Graz and in 1842, at an agricultural estate near Salzburg.

The idea to initiate a network for the entire territory of the Austrian Monarchy came from Bohemia. In 1817 a scientific society, whose main interest was in the field of agriculture, started to develop a regional meteorological network similar to that in Carinthia. It was managed by the astronomical observatory in Prague, whose director Karl Kreil developed a plan in the 1840s to construct an homogeneous and dense network of meteorological stations in Austria. The Austrian Academy of Sciences officially approved this plan in May 1848. Karl Kreil was able to realise his ideas within the framework of the Meteorological Commission of the Academy, and he did so with astonishing speed. Based on the two already existing regional networks in Bohemia and Carinthia, and with some additional new stations along railway lines and a few others run by interested private "friends of science", Kreil was able to publish the first yearbook in 1848 including climate data from 31 sites. Only a few years later, in July 1851, he became director of the new "Zentralanstalt für Meteorologie und Erdmagnetismus" in Vienna, which is still responsible for the meteorological network in Austria. Fig.2.1 illustrates the long-term, 150-year, evolution of the network managed by the Zentralanstalt. It shows the number of stations for the whole territory of the Monarchy and for the area of the smaller Republic, together with the station density for the post-1918 territory of Austria (84,000 km^2).

The curve for the Republic shows a steady increase until the 1890s, when a density of 20km mean station distance was reached. This has been the typical station density of the network since then, and has only been interrupted twice during the years of the First and the Second World Wars. The curve for the larger Monarchy territory shows two breaks in the early 1860s (due to the incorporation of Lombardy into the new Italian state) and in the early 1870s (due to the organisational partition into a western and an eastern part of the Monarchy). During the First World War there were only slight reductions in the network for the years 1914 and 1915 followed by a strong reduction in 1916. The data for 1917-1918 were not published in the Austrian yearbooks for the regions not belonging to the Austrian Republic.

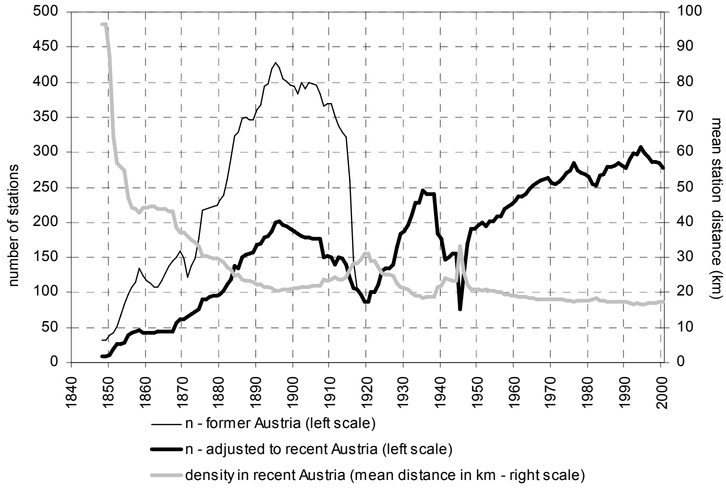

Fig.2.1. Evolution of the meteorological network in Austria (number of stations) 1848 – 2000

Due to economic difficulties the network recovered slowly in the early 1920s, but by the 1930s the long-term typical mean station distance of 20km was again achieved. A sharp break in the network density occurred during the years of World War II. Many observers had to serve in the German Army and could not be replaced. A number of traditional monastery sites were terminated due to the monastery liquidation policy of the German administration and for 1945 many series have gaps in their records due to warfare itself in Austria. The worst loss of Austrian climatological data occurred in 1944. The complete original historical data of all the Austrian stations were transported to the archives of the German "Reichswetterdienst" immediately after the occupation of Austria in 1938, and burned during a bombing of the city in 1944. This had serious consequences for climatology in Austria, which, with a few exceptions, could only be reconstructed from 1944 and then only from the printed yearbooks. Original daily data for the ALOCLIM sites from the 1930s and earlier exist only for Vienna, Sonnblick, Kremsmünster, Innsbruck and Graz plus daily data from Salzburg that had been published in the yearbooks. All of the other data (including also a certain part of metadata information) was lost or destroyed in 1944.

The recovery of the network after 1945 was astonishingly rapid, the 20km station distance margin was again reached after only a few years and has remained relatively stable since then. An all time maximum of more than 300 climate stations with full observing programmes, (single element stations like those for sunshine and precipitation are not counted within these statistics) was established in 1994. The slight reduction since then may be an initial expression of the new and more economical approach to meteorology and to science in general. Economic arguments tend to describe a station density that is too high, whilst scientific arguments focus on the necessity for observing networks to keep up with modelling, which currently is about to surpass the observational network density. Automation may be the answer to this problem (compare the respective graph in Fig. 4.10), which is mainly a consequence of personnel shortages, however, this will not solve the issue regarding the homogeneity of long series.

3 Data

To meet the main objectives, i.e. the creation of a long-term, multiple and homogenised monthly climate dataset, it was necessary to digitise most of the data from the instrumental period prior to 1948. The digitising of series had only previously been carried out for mean temperature (Böhm, 1992) and precipitation totals (Auer, 1993). Multiple series of more than 10 climate elements existed for only two sites, Sonnblick (Auer et al., 1992 and Auer et al., 1993) and Vienna (Auer et al., 1989). The main digitising source was the series of Austrian Meteorological Yearbooks, which started in 1848. In addition to the values of the corresponding year, a number of the old yearbooks (1876 and earlier) also contain multi-annual to centennial data summaries of time series that started earlier than the first yearbook (Table 3.1). Although not all these early series were used in this study, this information may also be of interest for other purposes.

Table 3.1. Multi-annual early climatic datasets published in Austrian Meteorological Yearbooks 1848 to 1876

Meteorological Yearbook of Austria 1848/49 (Kreil, K., 1854 **Jahrbücher der k.k..Central-Anstalt für Meteorologie und Erdmagnetismus, I.Band, 1848 und 1849, 490pp)**	
1-32	Extended meta data incl. location descriptions of all stations of the Austrian monarchy
35-74	Meta data and data of all elements of Wien-Sternwarte (astronomical observatory) 1775-1850
75-114	Meta data and data of all elements of Milano 1763-1850
115-148	Meta data and data of all elements of Praha 1775-1851
149-185	Meta data and data of all elements of Kremsmünster 1763-1851
186-195	Meta data and data of all elements of Salzburg (1842-1851)
196-207	Meta data and data of all elements of Trieste (1841-1850)
208-212	Meta data and data of all elements of Trento (1816-1832)
213-416	Meta data and data of 1848 and 1849
Meteorological Yearbook of Austria 1850 (Kreil, K., 1854 **Jahrbücher der k.k..Central-Anstalt für Meteorologie und Erdmagnetismus, II.Band, 1850, 257pp)**	
I-XVI	Location description of all stations of the Austrian monarchy
1-108	Meta data and data of 1850
139-156	Meta data and monthly data of all elements of Udine (1803-1842)
157-163	Meta data and monthly data of all elements of Fünfkirchen/Pecs (1819-1832)
164-168	Meta data and monthly data of all elements of Suczawa (1832-1834), Wadowice (1834-1838), Stanislau (1839-1850)
169-179	Meta data and monthly data of all elements of Graz (1836-1845)
180-199	Meta data and monthly data of all elements of Krakau/Krakow (1826-1847)
200-210	Meta data and monthly data of all elements of Senftenberg (1843-1852)
Meteorological Yearbook of Austria 1852	
279-289	Meta data and monthly data of pressure, temperature (mean, max, min), cloudiness, days with rain, days with snow, days with thunderstorm, days with fog for Wilten (Innsbruck) (1829-1854)
310-326	Meta data and monthly data of pressure, temperature, precipitation for Udine (1803-1842)
327-346	Meta data and monthly data of pressure, temperature, vapour pressure, relative humidity for Milano/Mailand (1835-1855)
Meteorological Yearbook of Austria 1863	
26-27	Meta data and monthly data of temperature means for Arvaváralija (1850-1863)
33-34	Meta data and monthly data of pressure, temperature, vapour pressure, relative humidity, precipitation, days with precipitation, days with thunderstorm for Bad Ischl (1855-1862)
53	Meta data and monthly data of air pressure for Trieste (1852-1863) and Venezia (1853-1863)
Meteorological Yearbook of Austria 1864	
165-182	Meta data and monthly data of all elements of Arad (1856-1865), Bodenbach (1828-1865), Kitzbühel (1852-1859), Lugos (1862-1865), Oravicza (1830-1847), Reichenhall (1835-1865), Ruszkberg (1860-1865), Schlössl (1838-1865)

Table 3.1. – continued

Meteorological Yearbook of Austria 1866	
191-204	Monthly data of Krakau/Cracow 1826-1865 (temperature)
Meteorological Yearbook of Austria 1870	
227-246	Monthly data of Krakau/Cracow 1826-1870 (clear days, overcast days, days with precipitation, days with snowfall, days with fog, days with thunderstorm, days with hail)
Meteorological Yearbook of Austria 1871	
Complete monthly dataset (all elements) of station Wien-Favoritenstrasse 1852-1872 (all elements)	
Meteorological Yearbook of Austria 1872	
196-217	Meta-data and complete monthly dataset of station Bodenbach (northern Czech Republic) 1828-1873
Meteorological Yearbook of Austria 1873	
183-202	Meta-data and complete monthly dataset of station Pola (Croatia) - many climate elements
Meteorological Yearbook of Austria 1876	
178	Monthly data of precipitation, days with precipitation, days with snow, days with thunderstorm for station Csákova (Banat) (1862-1869)

It is advantageous for climate analysis, as well as for homogeneity testing, adjusting and gap-closing of time series not to be restricted by national borders. Thanks to the co-operation of the data-holders from neighbouring countries, a number of series close to the border around Austria could be incorporated into the ALOCLIM dataset. These were three sites from the German Weather Service, two sites from the Czech Hydrometeorological Institute, two from the Slovak Hydrometeorological Institute, two from the Hungarian Meteorological Service, three from the Slovenian Hydrometeorological Institute, three from the Hydrometeorological Service of the Province of Bozen/Bolzano and three from Meteo-Swiss. Data not available in digitised form from neighbouring Weather Services were acquired from the different sources shown in Table 3.2. This table also includes several sources of Austrian and neighbouring country metadata used by the ALOCLIM project.

Table 3.2. Multi-annual early climatic data and metadata descriptions for the ALOCLIM region not published in the Austrian yearbooks

Aschwanden, A., M. Beck, Ch. Häberli, G. Haller, M. Kiene, A. Roesch, R. Sie und M: Stutz, 1996: Klimatologie der Schweiz: Klimatologie 1961-1990, Heft 2, Band 1 von 4, Bereinigte Zeitreihen. Die Ergebnisse des Projekts KLIMA90, Band 1: Auswertungen. 137 Seiten, Herausgegeben von der Schweizerischen Meteorologischen Anstalt, Zürich.
Attmannspacher, W., (ed.), 1981: 200 Jahre meteorologische Beobachtungen auf dem Hohenpeißenberg 1781-1980. Ber. d. Deutschen Wetterdienstes 155, 84pp and 112 tables
Metadata and monthly data of all elements 1781-1980 of Hohenpeißenberg(Germany) plus extensive reference list
Auer, I., 1992: Die Niederschlagsverhältnisse seit 1927 im Sonnblickgebiet nach Totalisatorenmessungen ergänzt durch Messergebnisse von Talstationen nördlich und südlich des Alpenhauptkammes. 86.-87. Jb. d. Sonnblick-Vereines, 1988-1989, S 1-31, Wien
Completed and homogenised monthly series of 7 totalizers around Sonnblick-observatory until 1990, description of homogenising procedure, time series analyses.
Auer, I., 1993: Niederschlagsschwankungen in Österreich. Österr. Beitr. zu Met. und Geophys., H.7, 73pp
Description of systematic homogenisation of 62 Austrian long-term precipitation series (based on monthly totals), the longest beginning in 1845, all series until 1991. Analysis of homogenised data based on single stations, gridded series and decadal maps.

Table 3.2. – continued

Auer, I., R. Böhm und H. Mohnl, 1993: Die hochalpinen Klimaschwankungen der letzten 105 Jahre beschrieben durch Zeitreihenanalysen der auf dem Sonnblick gemessenen Klimaelemente. 88-89. Jb. d. Sonnblickvereines f.d.J. 1990-1991, S 3-48, Wien.
Metadata description, time series analyses of a number of climate elements of mountain observatory Sonnblick (Austria).
Austaller, H., 1988: Die Temperaturreihe von Kremsmünster. Dissertation Univ.Wien, 223pp
Extensive and high quality analysis of the long temperature series of Kremsmünster (Austria) including historical and metadata information, tables of monthly temperature means 1796-1985 (homogenised).
Böhm, R., 1992: Lufttemperaturschwankungen in Österreich seit 1775. Österr. Beitr. zu Met. und Geophys., H.5, 96pp
Description of systematic homogenisation of 58 Austrian long-term temperature series (based on monthly means), the longest beginning in 1775, all series until 1989. Analysis of homogenised data based on single stations, analysis of regional differences and of the mean Austrian temperature evolution.
Dietl, H., 1939: Windverhältnisse auf dem Hochobir (2141 m). Dissertation Univ.Wien
Metadata and wind climatology of Hochobir (Austria)
Fischer, E., 1939: Beiträge über die Reduktion von Terminbeobachtungen auf wahre 24-stündige Mittel in Bezug auf die relative Feuchtigkeit. Dissertation Univ.Wien, 59pp
Study about the systematic errors due to different observation times for relative humidity in Austria
Gisler O., M. Baudenbacher und W. Bosshard, 1997: Homogenisierung schweizerischer klimatologischer Messreihen des 19. und 20. Jahrhunderts. Schlussbericht NFP 31, 118 Seiten, vdf Hochschulverlag AG an der ETH Zürich.
Gutmann, J., 1936: Die Aufstellung des Sonnenscheinautographen auf dem Sonnblick. 44. Jahresbericht des Sonnblickvereines für das Jahr 1935, S 60-67
Gutmann, J., 1948: Beobachtungs- und Meßmethoden des Wetterdienstes (Anleitung zur Ausführung und Verwertung meteorologischer Beobachtungen). Zentralanstalt für Meteorologie und Geodynamik, Publ. No. 158, 143 Seiten, Druck und Verlag der Österreichischen Staatsdruckerei, Wien.
Hann, J., 1884: Jelinek's Anleitung zur Ausführung meteorologischer Beobachtungen nebst einer Sammlung von Hilfstabellen. Neu herausgegeben und umgearbeitet von Dr. J. Hann, Druck der kaiserlich - königlichen Hof- und Staatsdruckerei, 185 Seiten, Wien.
Hann, J., 1887: Die Vertheilung des Luftdruckes über Mittel- und Süd-Europa. Geographische Abhandlungen, Vol.II/2, 220pp
Detailed analysis of air pressure measurements in Europe including error analysis, isobaric maps, station comparison and description of sites with longest measurements.
Hann, J., 1909: Übersicht über die Ergebnisse der meteorologischen Beobachtungen beim Berghause auf dem Obir in Kärnten. 17. Jahresber. d. Sonnblickvereins f. d. J. 1908, 16-22
Tables of monthly temperature means (1851-1908), monthly pressure means (1880-1908), monthly precipitation totals (1879-1908) of mountain station Obir (Austria)
Hauer, H., 1950: Festschrift anlässlich des 50jährigen Bestehens des Observatoriums Zugspitze. 50 Jahre meteorologische Beobachtungen des Observatoriums Zugspitze. Deutscher Wetterdienst in der US-Zone, Zentralamt Bad Kissingen, 200 Seiten +5 SW-Tafeln, Bad Kissingen
Helmes, L., 1982: Bestimmung der atmosphärischen Trübung aus den Aufzeichnungen des Sonnenscheinschreibers Campbell-Stokes. Diplom Arbeit Institut für Meteorologie der Johannes Gutenberg-Universität, 79 Seiten, Mainz.
Hydrographischer Dienst in Österreich, 1949: Anleitung zur Beobachtung und Messung von Niederschlag, Lufttemperatur und Schneedecke, 27 Seiten. Herausgegeben vom Hydrographischen Zentralbüro im Bundesministerium für Land- und Forstwirtschaft. Wien.
Jelinek, C., 1869: Anleitung zur Anstellung meteorologischer Beobachtungen und Sammlung von Hilfstabellen. Erste Ausgabe, Druck der kaiserlich-königlichen Hof- und Staatsdruckerei, Wien.
Jelinek, C., 1876: Anleitung zur Anstellung meteorologischer Beobachtungen und Sammlung von Hilfstabellen. Zweite umgearbeitete und vermehrte Ausgabe, Druck der kaiserlich-königlichen Hof- und Staatsdruckerei, Wien.
Jeanneret, F., 1975: Klimatologie der Schweiz N. Grundlagen zum Klima der Schweiz: Klimatologische Bibliographie 1921-1973. Beiheft zu den Annalen der SMA (Jahrgang 1974), S N/1-N123, herausgegeben von der SMA Zürich.

Table 3.2. – continued

Lemans, A.M., 1981: Klimatologie der Schweiz Heft 27/E Niederschlag, 13. teil: Gebietsniederschläge. Beiheft zu den Annalen der SMA (Jahrgang 1980), herausgegeben von der Schweizerischen Meteorologischen Zentralanstalt, S E/485-E570, Zürich.
Kartas, H., 1986: Das Klima der Villacher Alpe. Diplomarbeit, Univ.Wien, 187pp
Historical and metadata description of Villacher Alpe.
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Data collection finally produced 601 monthly long-term single element series of 137 sites and 20 different climate elements. Table 3.3 shows the site names, locations and the starting year of each single element series. Gaps of single months to a few years in a series were tolerated and closed with programme "complete" (see chapter 5). Series with multi-annual gaps were not used or were cut at the end of the most recent gap. "Long-term" is defined as at least 100 years with a few exceptions of some shorter series used to close spatial gaps and gaps concerning elements like sunshine (for which only 10 centennial series exist in the region). For temperature and air pressure there are some series starting in the late 18th century. Twenty-two of the sites have a minimum of five and a maximum of twenty single element series – thus these will be called "multiple" or "core" sites. The spatial coverage of the region is shown in Fig.3.1, multiple and high-level sites are specially marked.

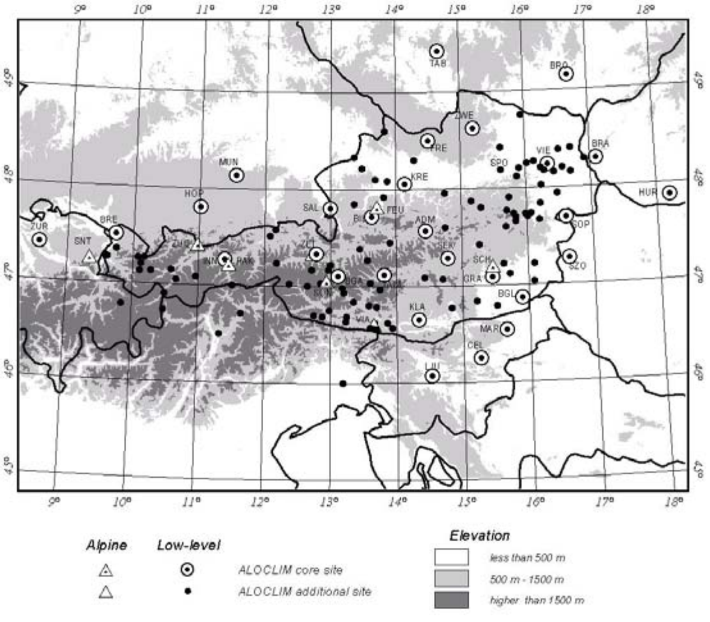


Fig. 3.1. Network of sites with digitised monthly long-term climate time series

Table 3.3. Site names, locations and starting years of original monthly series available in the study region

							AIR TEMPERATURE					DAYS WITH:				PRECIPITATION				CLOUDINESS			HUMIDITY		
Station	abbreviation	country	longitude	latitude	altitude (m asl)	AIR PRESSURE	mean	mean daily max.	mean daily min.	abs. max.	abs. min.	T_{min} < 0 deg C	T_{max} < 0 deg C	T_{max} ≥ 25 deg C	T_{max} ≥ 30 deg C	totals	maximum daily total	days with ≥ 1mm	BRIGHT SUNSHINE	mean	clear days	overcast days	relative humidity	vapour pressure	THUNDERSTORM
Admont	ADM	A	14° 27'	47° 34'	646		1883			1846	1846					1884				1853					
Arnoldstein	ARN	A	13° 42'	46° 33'	576											1880									
Bad Bleiberg	BBL	A	13° 40'	46° 37'	907											1874	1855	1888							
Bad Gastein	BGA	A	13° 07'	47° 06'	1100		1854	1854	1854	1854	1854					1855	1864	1888		1854	1920	1920	1865	1865	1885
Bad Gleichenberg	BGL	A	15° 54'	46° 52'	303		1881	1882	1882	1861	1861					1879			1930	1861	1920	1920	1862	1861	1878
Bad Ischl	BIL	A	13° 38'	47° 43'	469	1855	1855	1882	1882	1855	1855					1858	1862	1888		1862	1920	1920	1860	1860	1855
Baden	BAD	A	16° 14'	48° 01'	260											1901									
Bozen/Bolzano	BOZ	I	11° 20'	46° 30'	272		1850									1871									
Brand Laaben	BRL	A	15° 52'	48° 07'	360											1899									
Bratislava	BRA	SK	17° 06'	48° 17'	280	1852	1850	1891	1891	1901	1901	1856	1856	1856	1856	1857	1857	1857	1934	1873	1873	1873	1872	1872	1891
Bregenz	BRE	A	09° 44'	47° 30'	424	1875	1869	1880	1880	1869	1869					1873	1869	1888		1869	1920	1920	1870	1870	1869
Brenner	BRN	A	11° 31'	47° 00'	1372		1897																		
Brixen/Bressanone	BRX	I	11° 39'	46° 43'	569		1865									1865									
Brno	BRO	CZ	16° 42'	49° 09'	246		1871	1871	1871	1871	1871	1871	1871	1871	1871	1871	1871	1871		1871					
Bromberg	BRM	A	16° 12'	47° 40'	420											1898									
Bruck an der Mur	BMU	A	15° 16'	47° 25'	482					1875	1875					1876				1875					
Bucheben	BUC	A	12° 58'	47° 10'	1140											1898									
Celje	CEL	SLO	15° 15'	46° 15'	244		1900	1906	1906	1863	1863	1932	1932	1932	1943	1853			1951	1932	1932	1932	1905	1905	1940
Damüls	DAM	A	09° 35'	47° 17'	1365											1895									
Davos	DAV	CH	09° 51'	46° 47'	1590		1901												1886						
Deutschbrodersdorf	DBR	A	16° 29'	47° 56'	193											1893									
Deutschlandsberg	DLB	A	15° 13'	46° 50'	410		1893									1893									
Ebnit	EBN	A	09° 45'	47° 21'	1100											1893									
Feistritz an der Gail	FEI	A	13° 36'	46° 34'	590											1896									
Feldkirch	FEL	A	09° 37'	47° 16'	440		1875									1875				1875					
Feuerkogel	FEU	A	13° 43'	47° 49'	1618		1930	1930	1930	1930	1930					1929				1930	1930	1930	1931	1931	1931
Freistadt	FRE	A	14° 30'	48° 30'	548		1876			1877	1877					1877				1877					
Fürstenfeld	FUE	A	16° 05'	47° 02'	273											1877									
Galtuer	GAL	A	10° 12'	46°58'	1648		1896									1896									
Gaschurn	GAS	A	10° 01'	47°00'	980		1885									1885									
Gleisdorf	GLE	A	15° 43'	47° 07'	373											1888									
Gmunden	GMU	A	13° 49'	47° 55'	426		1899									1892									

Table 3.3. – continued

Station							AIR TEMPERATURE					DAYS WITH:				PRECIPITATION				CLOUDINESS			HUMIDITY		
	abbreviation	country	longitude	latitude	altitude (m asl)	AIR PRESSURE	mean	mean daily max.	mean daily min.	abs. max.	abs. min.	$T_{min} < 0$ deg C	$T_{max} < 0$ deg C	$T_{max} \geq 25$ deg C	$T_{max} \geq 30$ deg C	totals	maximum daily total	days with ≥ 1mm	BRIGHT SUNSHINE	mean	clear days	overcast days	relative humidity	vapour pressure	THUNDERSTORM
Graz-University	GRA	A	15° 27'	47° 05'	366	1837	1837	1881	1881	1853	1853	1884	1884	1884	1884	1864	1837	1888	1922	1837	1894	1894	1837	1837	1837
Gröbming	GRB	A	13° 54'	47° 27'	766		1896																		
Großenzersdorf	GRO	A	16° 34'	48° 12'	153		1905									1905									
Heiligenblut	HEI	A	12° 51'	47° 02'	1315		1877									1895									
Hieflau	HIE	A	14° 45'	47° 36'	492											1895									
Hohenpeissenberg	HOP	D	11° 01'	47° 48	986	1781	1781	1880	1880							1879	1880	1879	1886	1879			1879	1880	
Hurbanovo	HUR	SK	18° 12'	47° 52'	124	1872	1872	1877	1877	1877	1877	1881	1881	1881	1881	1871	1871	1871	1934	1872	1873	1873	1872	1872	1891
Innerkrems	INK	A	13° 45'	46° 58'	1520											1895									
Innsbruck-University	INN	A	11° 24'	47° 16'	577	1830	1777	1891	1891	1877	1877	1877	1877	1877	1877	1866	1866	1877	1906	1829	1877	1877	1866	1866	1829
Kaiserbrunn	KAI	A	15° 48'	47° 44'	540											1884									
Kals	KAL	A	12° 39'	47° 00'	1336											1895									
Kirchbichl	KIR	A	12° 05'	47° 31'	498											1895				1893					
Klagenfurt-airport	KLA	A	14° 20'	46° 39'	447	1844	1813	1860	1860	1848	1848	1875	1901			1814	1830	1888	1884	1844	1920	1920	1844	1844	1813
Kollerschlag	KOL	A	13° 50'	48° 36'	725		1886									1887									
Kornat	KOR	A	12° 53'	46° 41'	1037											1870									
Krems	KRM	A	15° 37'	48° 25'	203											1867				1874					
Kremsmünster	KRE	A	14° 08'	48° 03'	383	1822	1767	1836	1836	1837	1837	1873	1873	1873	1873	1820	1820	1874	1884	1763	1874	1874	1833	1840	1763
Krimml	KRI	A	12° 11'	47° 14'	1009		1891																		
Kufstein	KUF	A	12° 10'	47° 35'	495		1896									1905				1925					
Lackenhof	LAK	A	15° 09'	47° 52'	835		1896																		
Lambach	LAM	A	13° 52'	48° 05'	360											1893									
Landeck	LAN	A	10° 35'	47° 09'	785											1887									
Langen am Arlberg	LAG	A	10° 07'	47° 08'	1218		1881									1881									
Längenfeld	LAF	A	10° 58'	47° 05'	1188		1896																		
Latschach/Faakersee	LAT	A	13° 56'	46° 34'	610											1895									
Lech	LEC	A	10° 08'	47° 12'	1480											1896									
Leibnitz	LEI	A	15° 31'	46° 47'	332											1901									
Linz	LIN	A	14° 17'	48° 18'	263		1816									1852									
Ljubljana	LJU	SLO	14° 31'	46° 04'	299	1891	1876	1876	1876	1876	1876	1891	1891	1891	1891	1871	1891	1891	1949	1891	1891	1891	1891	1891	1891
Maedihütte	MDH	A	16° 08'	48° 16'	380											1897									
Mallnitz	MAL	A	13° 11'	46° 59'	1185											1895									
Marchegg	MAG	A	16° 55'	48° 17'	140											1896									

Table 3.3. – continued

Station						AIR PRESSURE	AIR TEMPERATURE					DAYS WITH:				PRECIPITATION			BRIGHT SUNSHINE	CLOUDINESS			HUMIDITY		THUNDERSTORM
	abbreviation	country	longitude	latitude	altitude (m asl)		mean	mean daily max.	mean daily min.	abs. max.	abs. min.	$T_{min} < 0$ deg C	$T_{max} < 0$ deg C	$T_{max} \geq 25$ deg C	$T_{max} \geq 30$ deg C	totals	maximum daily total	days with ≥ 1mm		mean	clear days	overcast days	relative humidity	vapour pressure	
Maria Luggau	MLG	A	12° 45'	46° 42'	1140											1895									
Maribor	MAR	SLO	15° 39'	46° 32'	275	1948	1876	1901	1901	1864	1864					1876									
Marienberg/Mte.Maria	MAI	I	10° 29'	46° 44'	1323		1858									1858									
Matzen	MAZ	A	16° 42'	48° 24'	190											1896									
Millstatt	MIL	A	13° 35'	46° 48'	791											1895									
Mondsee	MON	A	13° 22'	47° 51'	491											1892									
Mooserboden	MOO	A	12° 43'	47° 10'	2036		1915									1912									
München	MUN	D	11° 33'	48° 08'	535	1825	1825	1880	1880							1879				1825	1879	1879	1879	1842	
Mürzzuschlag	MRZ	A	15° 41'	47° 36'	700											1893									
Nasswald	NAS	A	15° 42'	47° 46'	620											1901									
Nauders	NAU	A	10° 30'	46° 54'	1360											1896									
Neulengbach	NLB	A	15° 54'	48° 12'	220											1897									
Neumarkt	NEU	A	14° 26'	47° 05'	842		1867									1881									
Neunkirchen	NKI	A	16° 04'	47° 44'	370											1863									
Obdach	OBD	A	14° 42'	47° 04'	875		1896																		
Oberdrauburg	ODR	A	12° 59'	46° 45'	635		1874																		
Obertauern	OTA	A	13° 34'	47° 16'	1742		1909									1876									
Obervellach	OVE	A	13° 12'	46° 56'	675											1895									
Orth an der Donau	ORT	A	16° 42'	48° 09'	150											1901									
Patscherkofel	PAK	A	11° 28'	47° 13'	2247		1931	1940	1940											1932	1932	1932			1941
Pottschach	POT	A	16° 01'	47° 42'	415											1884									
Praegraten	PRG	A	12° 23'	47° 01'	1340											1895									
Radenthein	RDT	A	13° 42'	46° 47'	685		1892																		
Radstadt	RAD	A	13° 27'	47° 23'	858		1896									1895									
Rauris	RAU	A	13° 00'	47° 13'	934		1876									1876									
Reichenau an der Rax	REI	A	15° 50'	47° 42'	486		1865									1865									
Reichersberg	RBG	A	13° 22'	48° 20'	350											1881									
Retz	RET	A	15° 57'	48° 45'	256		1896									1895									
Ried im Innkreis	RIE	A	13° 29'	48° 13'	435		1872									1872									
Ried im Oberinntal	RID	A	10° 40'	47° 03'	880											1896									
Rohr im Gebirge	ROR	A	15° 44'	47° 54'	685											1896									
Sachsenburg	SAC	A	13° 21'	46° 50'	550											1864									

Table 3.3. – continued

Station	abbreviation	country	longitude	latitude	altitude (m asl)	AIR PRESSURE	AIR TEMPERATURE					DAYS WITH:				PRECIPITATION			BRIGHT SUNSHINE	CLOUDINESS			HUMIDITY		THUNDERSTORM
							mean	mean daily max.	mean daily min.	abs. max.	abs. min.	T_{min} < 0 deg C	T_{max} < 0 deg C	$T_{max} \geq$ 25 deg C	$T_{max} \geq$ 30 deg C	totals	maximum daily total	days with ≥ 1mm		mean	clear days	overcast days	relative humidity	vapour pressure	
Salzburg-Airport	SAL	A	13° 00'	47° 48'	430	1842	1842	1876	1876	1874	1874	1874	1874	1874	1874	1864	1874	1874		1842	1874	1874	1849	1849	1842
Säntis	SNT	CH	09° 21'	47° 15'	2500	1883	1864									1888		1901	1888	1883			1901	1901	
St. Andrä i. Lav./ St.Paul	SAN	A	14° 50'	46° 46'	404		1852																		
St. Anton / Arlberg	STA	A	10° 17'	47° 08'	1298											1872									
St. Pölten	SPO	A	15° 37'	48° 11'	282		1893									1894									
St. Sebastian	SSB	A	15° 18'	47° 48'	872											1884									
Schmittenhöhe	SMH	A	12° 44'	47° 20'	1973		1880									1880									
Schöckl	SCH	A	15° 28'	47° 12'	1445		1901	1933	1933	1929	1929									1929	1929	1929			1929
Schröcken	SCR	A	10° 05'	47° 16'	1263											1895									
Seckau	SEK	A	14° 47'	47° 17'	874		1891	1891	1891	1890	1890					1891	1890	1891		1891	1920	1920	1891	1891	1890
Semmering	SEM	A	15° 50'	47° 39'	1000		1890																		
Sieghartskirchen	SIE	A	16° 01'	48° 15'	195											1896									
Sonnblick	SON	A	12° 57'	47° 03'	3105	1887	1887	1887	1887	1887	1887	1887	1887	1887	1887	1891	1891	1891	1887	1887	1887	1887	1887	1887	1887
Sopron	SOP	HU	16° 36'	47° 41'	234		1871	1874	1874	1871	1871					1871	1871	1871							
Szombathely	SZO	HU	16° 38'	47° 16'	221		1874	1874	1874	1874	1874					1876	1876	1876							
Stift Zwettl	ZWE	A	15° 12'	48° 37'	505		1883	1883	1883	1883	1883					1883	1883	1888		1883	1920	1920	1883	1883	1883
Stixenstein	STI	A	15° 59'	47° 44'	470											1884									
St.Peter im Katschtal	STP	A	13° 36'	47° 02'	1220											1889									
Tabor	TAB	CZ	14° 40'	49° 25'	452		1875	1875	1875	1875	1875	1875	1875	1875	1875	1875	1875	1875		1886					
Tamsweg	TAM	A	13° 49'	47° 07'	1012		1919			1866	1866					1893				1919					
Udine	UDI	I	13° 12'	46° 00'	51											1803									
Villach	VIL	A	13° 52'	46° 37'	493											1888									
Villacher Alpe/Obir	VIA	A	13° 40'	46° 36'	2140	1880	1851	1882	1882	1848	1848					1879		1888	1884	1851	1920	1920	1881	1881	1875
Waidegg	WAD	A	13° 14'	46° 38'	635											1895									
Waidhofen/Ybbs	WAI	A	14° 45'	47° 57'	421		1896									1896									
Warth	WAR	A	10° 11'	47° 16'	1500											1901									
Weissbriach	WAB	A	13° 15'	46° 41'	800											1895									
Weiz	WIE	A	15° 38'	47° 13'	465											1894									
Wien - Hohe Warte	VIE	A	16° 21'	48° 14'	203	1775	1775	1836	1836	1829	1829	1872	1872	1872	1872	1845	1841	1868	1881	1793	1872	1872	1829	1829	1793
Wien - Mariabrunn	WMA	A	16° 14'	48° 12'	226		1896									1893									
Wien - Rosenhügel	WRO	A	16° 17'	48° 10'	252											1884									
Wien - Zentralfriedhof	WZE	A	16° 26'	48° 09'	170											1884									

Table 3.3 – continued

							AIR TEMPERATURE					DAYS WITH:				PRECIPITATION				CLOUDINESS			HUMIDITY		
Station	abbreviation	country	longitude	latitude	altitude (m asl)	AIR PRESSURE	mean	mean daily max.	mean daily min.	abs. max.	abs. min.	$T_{min} < 0$ deg C	$T_{max} < 0$ deg C	$T_{max} \geq 25$ deg C	$T_{max} \geq 30$ deg C	totals	maximum daily total	days with $\geq$ 1mm	BRIGHT SUNSHINE	mean	clear days	overcast days	relative humidity	vapour pressure	THUNDERSTORM
Wiener Neustadt	WNE	A	16° 13'	47° 50'	285		1857			1857	1857					1857									
Wolfsegg	WOL	A	13° 41'	48° 06'	660											1895									
Wolkersdorf	WOK	A	16° 31'	48° 23'	180											1896									
Wörterberg	WOE	A	16° 06'	47° 13'	400											1901									
Zell am See	ZEL	A	12° 47'	47° 20'	766		1875			1875	1875					1875				1875					1875
Zugspitze	ZUG	D	10° 59'	47° 25'	2962	1901	1901	1901	1901							1901	1901	1901	1901	1901	1901	1901	1901	1901	1901
Zürich	ZUR	CH	08° 34'	47° 23'	569	1864	1864									1830			1886	1864			1901	1901	
number of series (all): 601		**per element:**				**19**	**73**	**29**	**29**	**31**	**31**	**13**	**13**	**12**	**12**	**122**	**22**	**24**	**17**	**37**	**23**	**23**	**24**	**24**	**23**

Nine of the 20 climate elements (mean air pressure, mean temperature and mean daily extremes, precipitation totals, sunshine, mean cloudiness, mean relative humidity and mean vapour pressure) could successfully be homogenised on a monthly basis and will be the subject of this study. The other 11 elements (most of them derived from the 9 main elements as for example "number of frost days", "clear days"…) posed major problems in the first round of homogenising and will be subject to a follow-up study with extensive use of long-term daily data (see section 5.5).

Data collection and digitising activities resulted in a dataset that covers the overwhelming majority of the available long-term climate information for the instrumental period in Austria and the surrounding regions. The following chapters describe the improvement of these original data in terms of the elimination of non-climatic inhomogeneities.

4 Metadata

Metadata is the sum of all additional information regarding the way meteorological data are acquired. Station history information is of fundamental importance, mainly for the determination of break points in climate time series and as a support to statistical tests (chapter 5). This kind of information is harder to find in the archives of the Meteorological Services than the real data. It is usually not published, is in the local language, the older parts are sometimes illegible and the relevant climate information is only a small percentage of a large volume of irrelevant information. One of the intentions of ALOCLIM was to search, collect and process the relevant climate station history information into a systematic form, in order to provide the necessary background information in addition to the climate data themselves. For Austria, metadata were derived from annual yearbooks (see Table 3.1.), from original climate data sheets and from observer instructions (see Table 3.2.). For the neighbouring countries, site metadata were supplied by the respective data holders or compiled from published papers shown in Table 3.2. Metadata increases the quality of the homogenisation process and therefore, it should be an integral part of homogenising procedures, if at all possible. Homogenisation, without using the available metadata information, must be characterised as a narrow road between the two abysses of subjectivity and statistical estimates.

4.1 Single station meta-information

The available metadata are single station files, for which Table 4.1 provides an example for ALOCLIM site OBIR (the first part of the combined series Villacher Alpe/Obir). The CD-ROM that accompanies this book includes the metadata files of 17 main ALOCLIM sites (directory "single station meta files"). They include as much information as possible structured into four groups:

1. the general descriptions of the surroundings of the station (topography, land use, degree of urbanisation, including recent population numbers, etc.);
2. the general quality of the series;
3. the main historical features sub-divided according to relocations of the station; and
4. a detailed description of each sub-section of the series concerning observers, observation hours, instrument sites and instruments.

For six other former Austrian, now Italian stations (Bozen-Bolzano, Brixen-Bressanone, Marienberg-Monte Maria, Riva, Rovereto and Trento) the older pre-1916 Austrian metadata have been added to the meta-directory of the CD-ROM.

Table 4.1. Example for a single station metadata file: Obir

OBIR **ALOCLIM coordinates: 14 29 E, 46 30 N, 2040 m asl.**

1. General description:

The Obir series are the older part of the combined ALOCLIM series “Villacher Alpe”. The ALOCLIM series of Villacher Alpe is a combined series of the sites Obir (1851-1944) and Villacher Alpe (since 1929). For the combined series, the old Obir data have been adjusted to the Villacher Alpe data, using the long overlapping period for adjusting. In the combined series, the Obir-data end at the beginning of the Villacher Alpe series (e.g. 1929 for temperature, 1934 for air pressure…).

Hochobir was a mountain site 2040m asl., on the southern summit ridge of the solitary mountain Obir, 95m below the summit (Rainerhaus – 1 I). Since 1891 there has been an additional site (Hann-Warte – section 1 II) on the summit, with wind- and temperature recorders. This site was not used for ALOCLIM. Obir is situated slightly N of the W-E mountain chain of the Karawanken, 80km S of the main ridge of the Alps, 100km NE of the Adriatic Sea. It is some 1500m above the northern, 1000m above the southern adjacent valleys. The summit has steep walls to the W, N and E, less steep alpine meadow terrain to the S.

2. General quality description:

Obir was and is still remote from populated areas, without access by public cable cars, only during summer months a limited number of tourists visit the mountain, a few staying over night. Obir has been regarded as one of the main stations of the Austrian network with great care for maximum observing quality. Observers on Hochobir have been mining employees from 1848 to 1876, since 1878 it has been a first order observatory.

3. Main historical features (relocations):

Section 1-I: (1847-12 to) 1851-01 to 1944-06
Observatory Hochobir, z=2040m

Section 1-II: 1891-01 to 1944-06
Obir II - Hann-Warte, z=2140m

4. Detailed description of the sections:

Gauss-Krueger coordinates in meters (M31)

Section 1-I: x=152190, y=88625, ground level 2040 m asl, (1847-12 to) 1851-01 to 1944-06
The site Rainerhaus (also called “Berghaus” or “Obir III”, later “Hochobir”) was in and near a building on the southern summit ridge of the solitary mountain Obir, 95m below the summit. After an initial period (1847 to 1850) of not systematic observations, observing quality increased, and since 1851 the measurements could be used for time series analysis. Until 1876 the station was managed by the lead-mining company and situated in and around the wooden mining building. The building burned down in March 1865, but was soon re-opened in the same year. After the closing of the mines in 1876 there was a longer than one year break of observations. In 1878 the house was re-opened for touristic reasons, the housekeepers being the observers. Since 1882 Hochobir was a first order station of the Austrian meteorological network with professional observers. 1906 to 1908 the house was completely rebuilt on the same place, now being a stone building, which remained the same until its closing. In World War II the station was transformed into a military station of the German army. This caused severe problems in that region with mixed population and guerrilla-warfare. On 10th of July 1944 the station was closed. In Autumn of 1944 the building was burned down and was never re-opened again.

Table 4.1. – continued

Observers:

(1847 to 1869: Mathias Wriessnigg, mining employee) – (1847 to 1860: Mathias Dimnig, mining employee) – (1860 to 1879 : Lorenz Malle, mining employee) – (1871 to 1875: Franz Karun, mining employee) – (1878 to 1881-07: Joseph Emmerling) – (1881-07 to 1884: Ferdinand Jamnig) – (1884 to 1888: Anton Pissonitz) – (1888 to 1909-02: Johann Matteweber) – (1909 to 1910: Heinrich Weissmann and Josef Kogler) – (1911 to 1914: Marie Wanderer) – (1915 to 1931-11: Michael Urantschitsch) – (1931-11 to 1932-10: Friedrich Maurer) – (1932-10 to 1935-05: Eduard Wutte) – (1935-05 to 1944: Herbert Pfeffer) – (1939 to 1944: additional military staff)

Observation hours:

(1847-12 to 1868: 7,14,21) – (1869: 7,14,20) – (1870 to 1871: 7,14,21) – (1872 to 1875-03: different obs. hours in quick change) – (1875-04 to 1878: 6,14,20) – (1879 to 1944: 7,14,21)

Instrument sites:

Information available for the following years:

Thermometer and hygrometer:
1847-12 to 1907-11: In a wooden shelter next to the S-wall of the building, ht= 0.9m
1907-11 to 1923: In a metal screen in front of a first floor NNW-window, ht=3.5m
1923 to 1944: In a double blinded wooden screen at the same place, ht=3.5m

Barometer:
1868 to 1907-11: In a 1st floor room, hb=2042m asl.
1907-11 to 1944: In the observing room of the new house, hb=2044m asl.

Rain gauge:
1878 to 1944: 6m S of the house, hr=1.5m

Sunshine recorder:
1883-09 to 1944: next to the rain gauge, hs not known, shadowing from the house in the morning and evening hours

Wind:
No wind recording at Obir site I (see Obir II – Hann-Warte)

Instruments:

Information available for the following years:

Thermometers:
td:
1847 to 1851: thermometer of unknown type
td,tw:
1852: Psychrometer of unknown type
td: 1853 to 1879: thermometer of unknown type
td,tw:
1879 to 1909: td Kappeller 256, tw Kappeller 249
1909 to ?: Psychrometer td Jaborka 3268, tw Jaborka 3267
Psychrometric measurements until 1944, instruments not known
tmax-min
since 1881 tmax and tmin
1901: Six-thermometer Koppe
1908: tmax – tmin Casella

Barometers:
1868 to 1907-07: Station barometer Kappeller 13
1907-07 to 1918: Station barometer Kappeller 789
1918 to 1936: Station barometer Kappeller 1146
1936 to 1944: Station barometer Fuess 11755

Hygrometers:
Since 1879: Hair hygrometer, specific instruments not mentioned

Rain gauge:
1878 to 1944: measured but no specific instruments mentioned
1901: Change to new rain gauge (500cm^2)

Table 4.1. – continued

Sunshine recorders:
1883-09 to 1901-12: Campbell Stokes, English instrument
1902-08 to 1915: Same instrument after repair
1916 to 1930-12: Campbell Stokes type, Usteri-Rainacher, 1922, 1926-10, 1929-09 possible breaks due to changes in recording paper or due to instrument repair
1929-11 to 1944: Campbell Stokes type, Fuess

Anemometers:
Wind direction and mean velocity estimated at this site, measurements at site Obir-II, Hann-Warte

Measured elements
1847-12 to 1944:Temperature, temperature-extremes, cloudiness, thunderstorm
1868 to 1944: Air pressure
1878 to 1944: precipitation sums
1879 to 1944: vapour pressure, relative humidity
1883-09 to 1944 : sunshine duration

Section 1-II: x=152510, y=88615, ground level 2140 m asl, 1891-10 to 1944-06
The summit site Obir-II, also called “Hann-Warte” was established in order to get less disturbed wind information. The Hann-Warte was a small instrument cabin, 4m from the bottom of the Obir-summit to the roof-top. It was equipped with a wind recorder and a temperature recorder. Once a day the observers of the Rainerhaus made comparative temperature measurements to adjust the recorder. 1944 Obir-II was closed together with the main site at Rainerhaus. 1946 to 1947 there were attempts to use the site again, but in Autumn 1947 the Hann-Warte burned down and not re-erected again.

Observers:
Same observers as for Obir-I (Rainerhaus)

Observation hours:
No observation hours, only recorders

Instrument sites:
Information available for the following years:

Thermometer:
1891-10 to 1944-06: Metal screen in front of the N-window of the Hann-Warte, ht=2.7m above summit level

Anemometers:
1m above the roof-top of the Hann-Warte, 5m above summit-level

Instruments:
Information available for the following years:

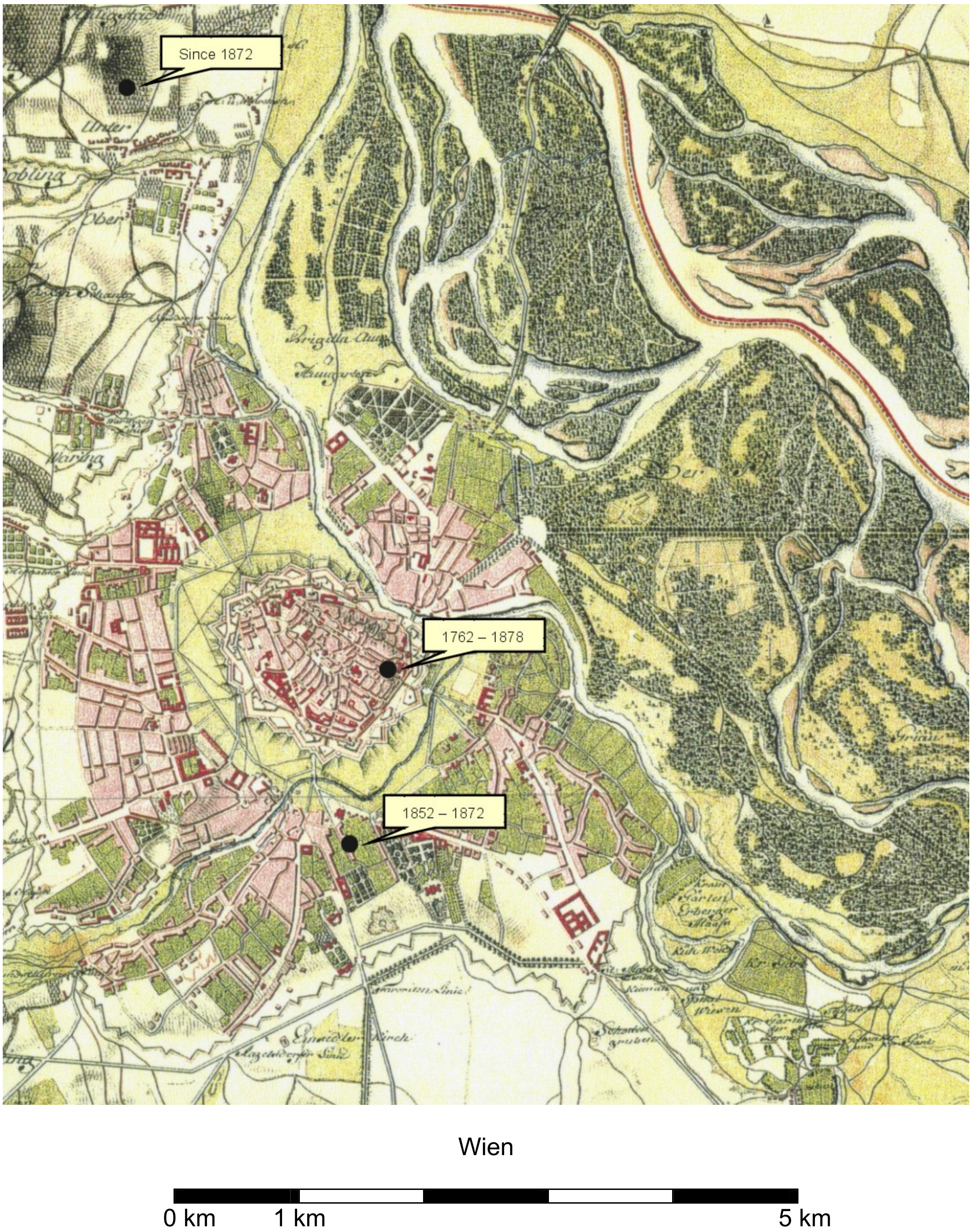
Thermometers:
1891-10 to 1944-06: One temperature recorder and one Thermometer, specific instruments not mentioned

Anemometers:
1891-10 to 1944-06: Wind recorder Casella

Measured elements:
1891-10 to 1944-06: temperature, wind direction, wind velocity

Fig. 4.1 provides an example of the maps with the locations of the sub-sections of the series for Vienna including the changing environment of the urban site. The two maps of 1775 and the 1990s underline the necessity of having information about the environment of a site, especially of an urban site which has experienced a high degree of urbanisation. All other maps are included in the CD-ROM (directory “station maps”).

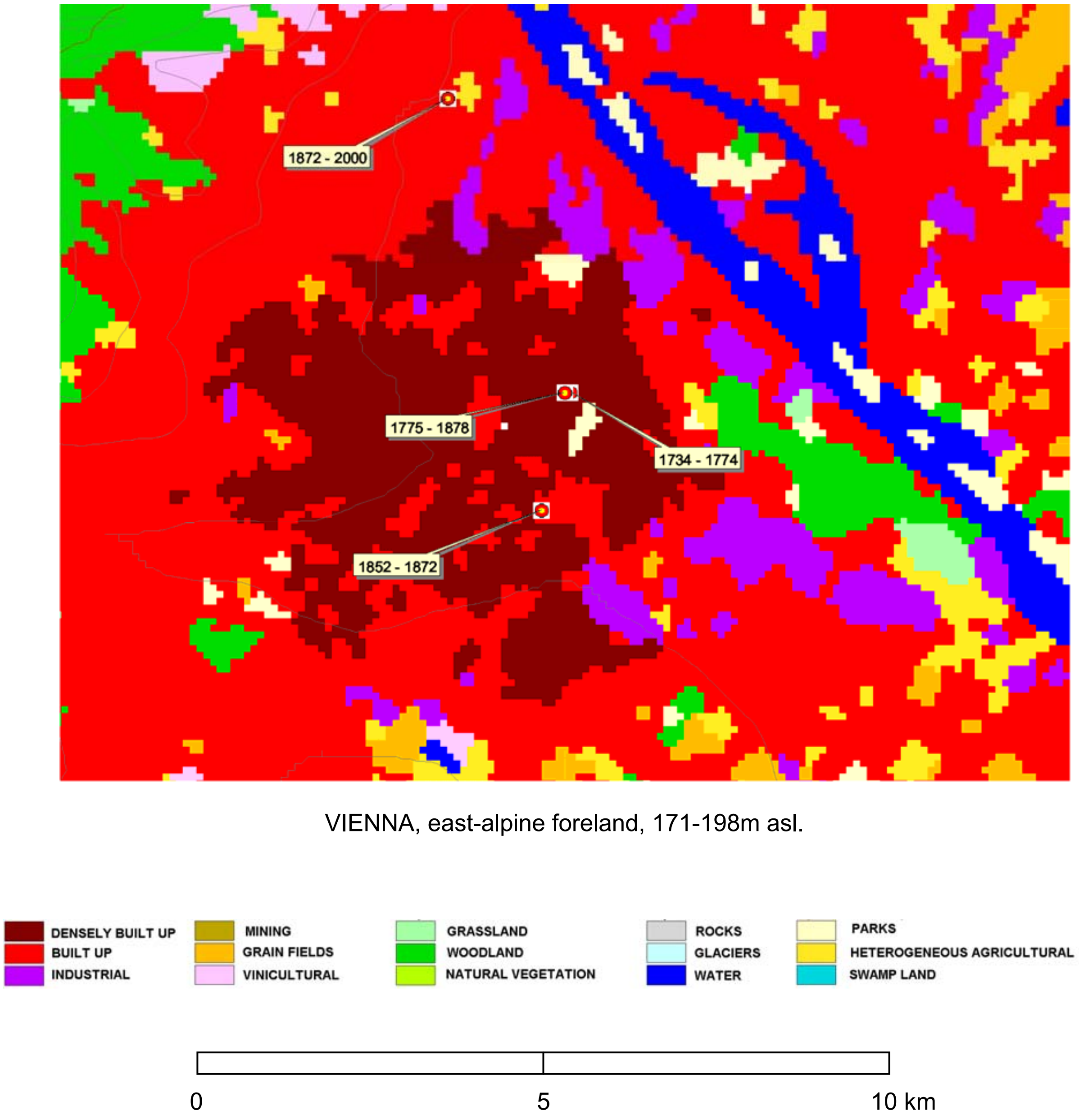
HISTORIC SITE ENVIRONMENT MAP 1775 AND SITE LOCATIONS (1762 – 1872)



Source: Erste oder Josephinische Landesaufnahme (1764-1787), Sectio 71
Original at Österreichische Nationalbibliothek,
Reproduced 1989 by Bundesamt für Eich- und Vermessungswesen, Wien
With kind permission of: Bundesamt für Eich- und Vermessungswesen, A-1080 Wien, Krotenthallergasse 3

Fig. 4.1. Example of station maps (Vienna 1775 and 1991)

SITE ENVIRONMENT MAP (1991) AND SITE LOCATIONS (1734 – 2000)



VIENNA, east-alpine foreland, 171-198m asl.

grey lines: altitude (100m equidistance)

Sources:
Landuse map of Austria, Steinnocher K. (1996): Integration of spatial and spectral classification methods for building a land-use model of Austria. International Archives of Photogrammetry and Remote Sensing, Vol. 31, Part B4, pp. 841-846
Digital elevation model of Austria (ZAMG)
ALOCLIM – single station meta files

Fig. 4.1. - continued

To enable the quick and easy use of the metadata during the procedure of applying statistical tests, a large part of the information of the station history files has been compressed into so called “meta quick looks”. A single graph provides a quick overview of the station history including general information as well as the detailed description of many items in (see the example for Sonnblick in Figure 4.2, this, and 16 other quick-looks, are included in the CD-ROM – directory "meta quick looks"). Along the horizontal time axis the bars provide information about the observers, instruments and so on. Interruptions represent breaks in the record, if the bars are replaced by lines this indicates that there is no specific information about the item in the respective years.

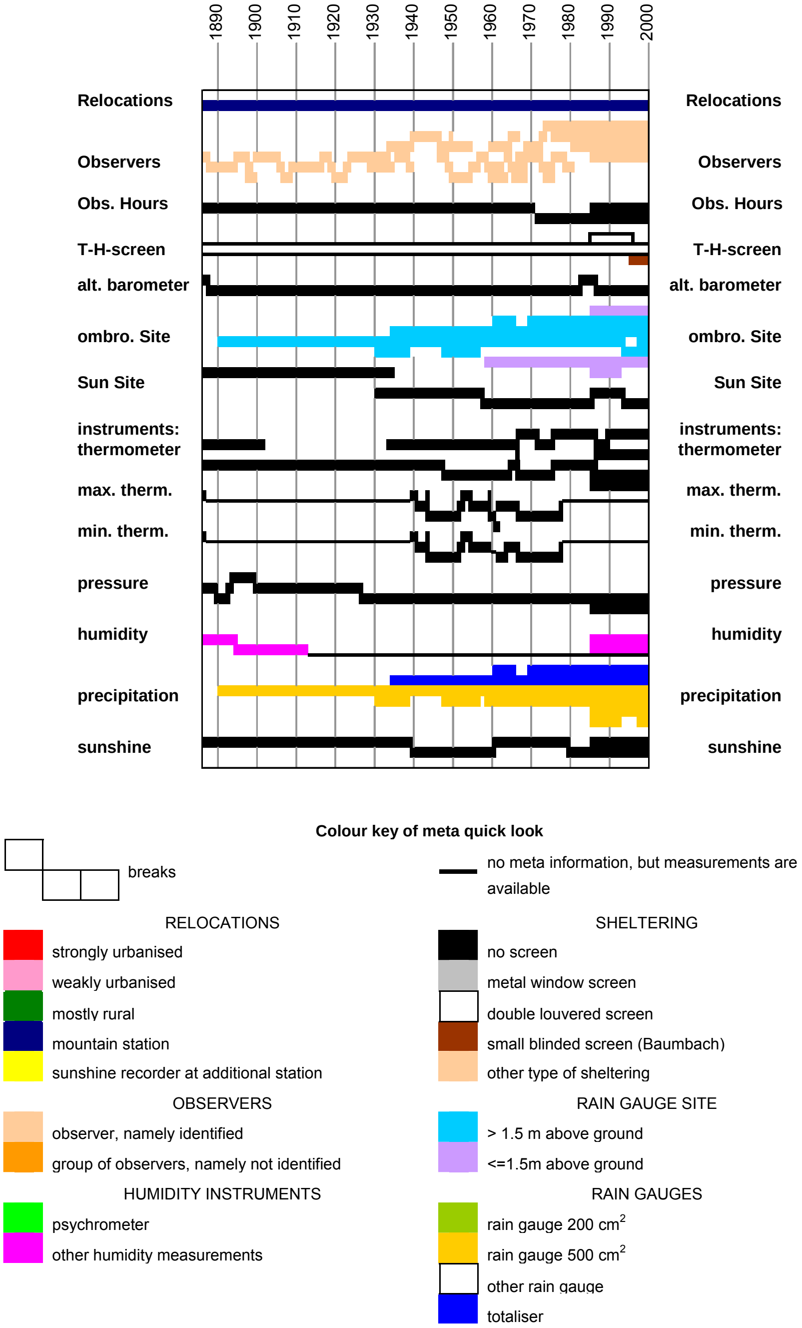


Fig. 4.2. Example of a "meta-quick-look" (Sonnblick)

The single station metadata have been used intensively in the homogenising process (this will be described in detail in chapter 5). Metadata serve to remove breaks in the series without statistical testing, simply by using the meta-information about breaks. We called these breaks “quantitatively documented breaks”, for example: if there were comparative measurements on both sites during a relocation, or comparative measurements with different instruments. In the case of “quantitatively un documented breaks”, which are detectable and quantifiable by statistical tests only, the single station meta-information enable easier identification of the exact time of the break, and help in the determination of the significance of the test signals.

4.2 General meta-information for the network

Included under the term “general information”, metadata information about simultaneous changes or evolutions concerning the whole or larger parts of the network, e.g., meteorological units, observation hours, introduction of thermometer screens, heights of thermometers and/or rain gauge orifices above ground, etc., point at systematic inhomogeneities affecting larger regions. Such general break points are not easily detectable by relative homogeneity tests, as all series will be similarly affected and there is a lack of uninfluenced comparative series. A comparative analysis of the single station meta-files resulted in a number of such general evolutions and breaks in the Austrian network, which will be described here. A precondition for comparative analyses of different meta-topics is their completeness or at least a high coverage in time of meta-information. As a result of the losses of data and metadata in 1944 (see chapter 2) a 100% meta coverage was not attainable. Fig.4.3 provides an impression of how much meta information is available for analysis. Almost 100% knowledge is provided regarding relocations, observers and observing times. A satisfactory amount of knowledge (91 to 99% coverage) also exists for all information concerning instrument installation (screens, height above ground etc.). The instruments themselves could not be individually identified in each case. Only barometers (identified during 91% of observing time) and sunshine recorders (93%) are well known and can be analysed. For station thermometers, meta-coverage drops to 72% and for hygrometers, rain gauges, min- and max-thermometers we know about individual instruments and their characteristics for less than 70% of the respective series lengths. A metadata coverage level of 70% was defined as the lower limit for the following analysis of general breaks or evolutions in the network.

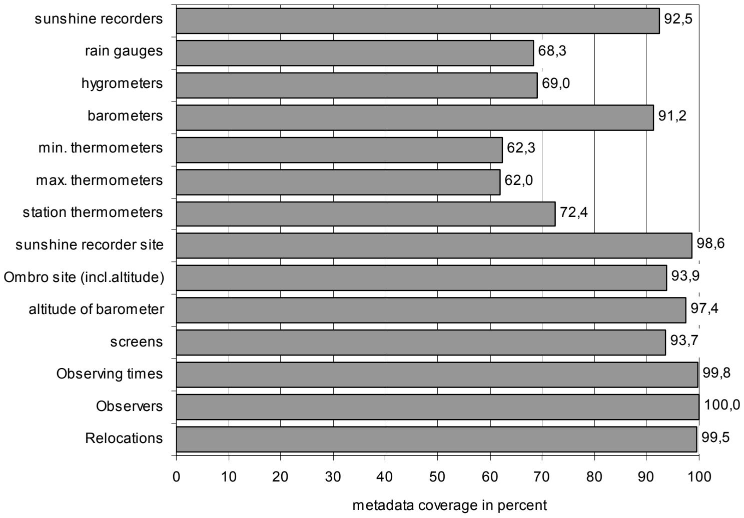


Fig. 4.3. Coverage of 17 ALOCLIM sites with metadata information (in Percent of years with measurements)

4.2.1 Measuring units

Dealing with old data always requires a certain knowledge about old measuring units. With respect to the Austrian meteorological data, the following dates were of importance concerning systematic changes of measuring units:

- Jan 1st 1852: Change in cloudiness estimation from quarters (sub-divided in tenths of quarters) to tenths of the visible sky (octas have never been in use for climate observations).
- Jan 1st 1871: Change to metric units. Before this date, temperature data were published in deg. Réaumur (1 deg C = 0.8 deg R, no change in the zero degree point), geographical altitudes in Toises (1 Toise = 1.94903m) or in “Wiener Fuß” or “Wiener Schuh” (1 Wiener Fuß = 1 Wiener Schuh = 0.31603m) or “Wiener Klafter” (1 Klafter = 1.8965m) and air pressure, vapour pressure, and precipitation in “Pariser Linien” (1 par.line = 2.25583mm).
- Jan 1st 1876: Geographical longitude: change from E of Cap Ferro to E of Greenwich (Cap Ferro = $17^0 41'$ W).
- Jan 1st 1978: Air pressure in mbar (1mbar = 0.75006mmHg).
- Jul 1st 1984: Air pressure in hPa (1mbar = 1hPa).

4.2.2 Observing times

At the beginning of the instrumental period all meteorological observations should have been carried out according to “True Solar Time” (Kreil, 1848). However, the old astronomic observatories (which incorporated the main bulk of climate measurements before 1850) used “Mean Local Time” (MLT). After 1850, Mean Local Time was used as the basis for measurements of most of the climate elements. It should be mentioned that before 1873 the following astronomic manner of writing was used: noon = 0 hours, midnight = 12 hours; since 1873: noon = 12 hours, midnight = 0 or 24 hours.

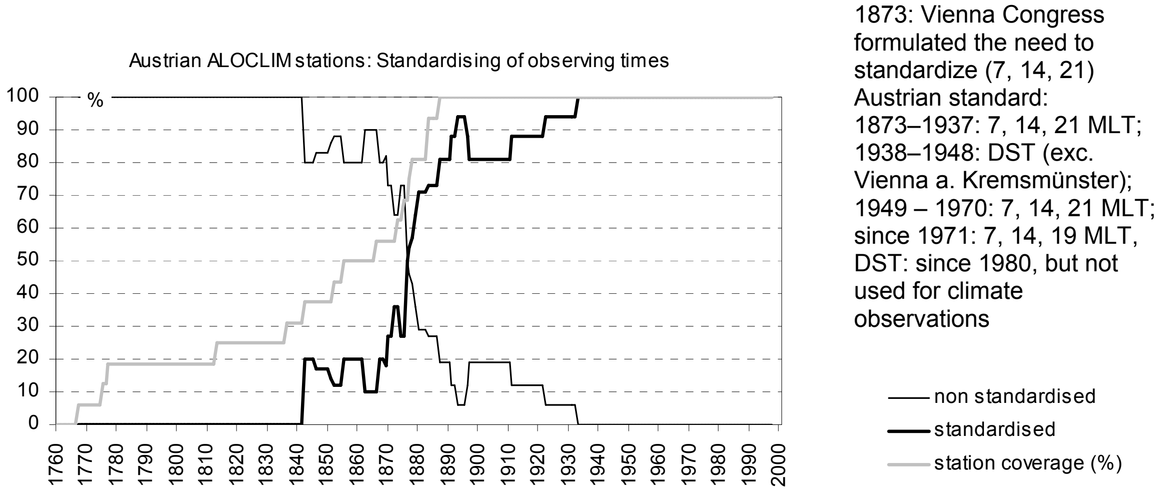
Prior to 1873 there was no general standard for observation hours. Most of the stations used 3 observations per day but at varying times. Morning observations were carried out from 5 to 8 am, the second observation between 1 and 3pm and the evening observation varied from 6 to 10pm. There were no changes from day to day, but at some stations the observing times changed from season to season. Despite the fact that since the mid-19th century the meteorological network was managed by one central Institute, it was not until 1873 that the Vienna Congress recognised the need to standardise the observation hours (to 0700h, 1400h, 2100h in MLT). Daylight Saving Time was in public use from 1938 to 1948 and has been in use since 1980, but DST has been neglected for climate observations in the latter period (observations are continuously carried out according to MLT). However, between 1938 and 1948, DST was effectively used for the observations at most of the Austrian stations. Since Jan. 1st 1971, the Austrian Weather Service defined a new standard: 0700h, 1400h, 1900h MLT. Table 4.2 summarises the standard observing times of the Austrian network.

Table 4.2. Austrian standards for climatological observation hours
MLT = mean local time, DST = daylight saving time

period	1873-1937	7, 14, 21	MLT	
	1938-1948		DST	except Vienna and Kremsmünster
	1949-1970	7, 14, 21	MLT	
	since 1971	7, 14, 19	MLT	
	since 1980		DST	in public use, but not for climate observations

For all ALOCLIM stations it was possible to recover the observing hours for each year of the series.

The definition of a standard does not necessarily mean that the standard is applied instantly. The process of standardising after the observing time definition in 1873, for example, took quite a long time; an 80% level of standardised observing hours was reached by the 1880s, it took until the 1930s to reach a 100% standardised network (see Figure 4.4). The more recent definition in 1971, in contrast, was put into practice immediately. During the 1980s and 1990s a trend towards a new standard took place within the Austrian network, due to the automation of the network, which allowed a change from the old estimation formulae of the “true mean” based on 3 daily observations to a measured “true mean”. Fig.4.5 shows statistics of the frequencies of changes of observing times of the 17 ALOCLIM stations as a time series in 10-year sub-intervals. The early period of non-standardised observation hours is clear to see, up to 1.5 changes per station and decade occurred before 1870, indicating that there was much confusion within the network during these times. The changes from 1870 to 1930 were all due to standardising. The change in 1971 resulted in another peak in the change-statistics.



1873: Vienna Congress formulated the need to standardize (7, 14, 21)
Austrian standard:
1873–1937: 7, 14, 21 MLT;
1938–1948: DST (exc. Vienna a. Kremsmünster);
1949 – 1970: 7, 14, 21 MLT;
since 1971: 7, 14, 19 MLT,
DST: since 1980, but not used for climate observations

Fig. 4.4. Time Series for the development of standardising the observation hours at the ALOCLIM stations after the 1873-definition

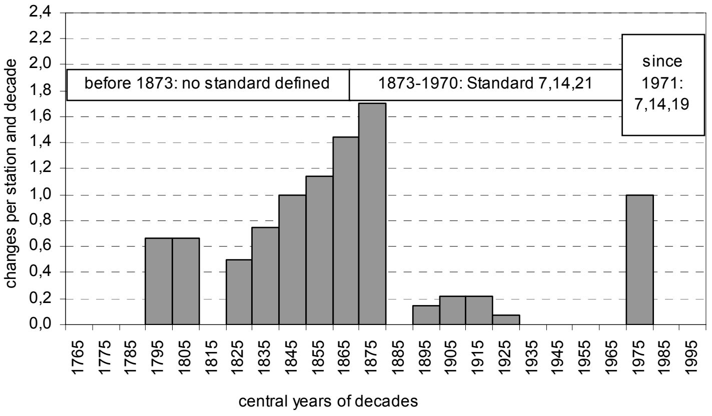


Fig. 4.5. Time series of observation time changes per station and per decade for the ALOCLIM network

All the described observation time changes caused systematic biases in the original time series, comparable to the real climatic signal. However, all of these biases could be eliminated for the elements air pressure, temperature, vapour pressure and relative humidity as “quantitatively documented inhomogeneities”. This elimination was possible due to the existence of 24-hourly data for a set of 50 automatic stations over a period of 10 years. The system is described in chapter 5. For precipitation and sunshine series, changes of observing times can be considered to be unimportant. The inhomogeneities for cloudiness, however, had to be treated as “quantitatively not known” using the corresponding procedure based on relative homogeneity testing.

4.2.3 Relocations

Relocations are regarded as one of the main causes of breaks in climate time series. Relocations may change the altitude of the site, the shadowing, the ventilation or some other surrounding factors. Taking a closer look at metadata, relocation itself is not necessarily the physical reason for a break, but rather the accompanying changes of observers, instruments, and instrument installations etc. Nevertheless, a relocation of a complete measuring site is a prominent feature in the station history and, therefore, it is also used as the first structuring element in the ALOCLIM meta-files. The term “section” of the station history (see the example in Table 4.1, or the single station meta-files on the CD-ROM) represents a period of unchanged location. Minor changes in location of single instruments for example, within a garden or from one room to another within a house are not regarded as relocations, they are stored in the meta-files as “instrument site changes” and are treated separately in section 4.2.7. The 17 ALOCLIM stations have produced a total of 2,325 observing years, with an average observing length of 155 years. Measurements were taken at 76 different sub-locations with a mean length of a sub-period of 33.2 years. The lengths of the sub-sections vary greatly and range from 2 months (Bad Gastein, 1972) to a still unterminated section of 234 years at Kremsmünster (1767-2000). Fig.4.6 shows the frequency distribution of sub-interval lengths of the 17 stations, and Fig. 4.7 shows the time series of the number of relocations per station and per decade.

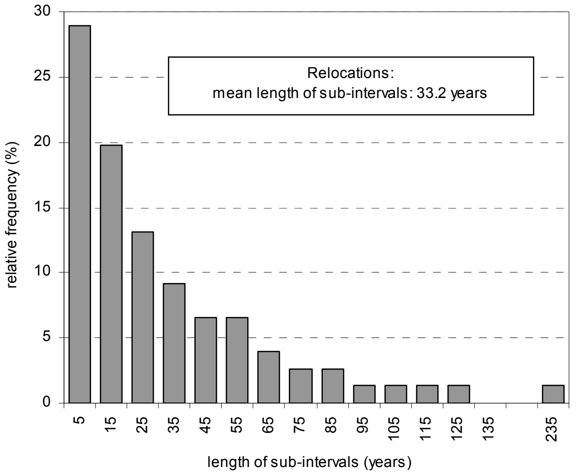


Fig. 4.6. Relocations: Frequency distribution of sub-interval lengths in the ALOCLIM network

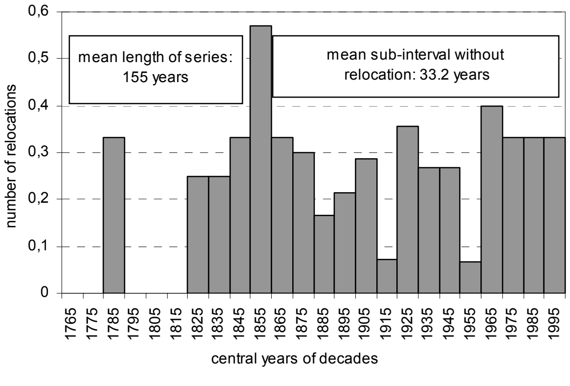


Fig. 4.7. Time series of the number of relocations per station and per decade for the ALOCLIM stations

The frequency distribution underlines once more, the fact that long climate time series with a permanent location are very rare. The exceptional 234 years period at Kremsmünster may be an outstanding case not only for Austria, but also in international terms. The second longest series in Austria is the 114 years of the Sonnblick observatory. All the other ALOCLIM sites have moved from time to time, most of the sub-periods (nearly 30%) between two relocations are shorter than 10 years. Fig.4.6 shows that there is no long-term tendency towards either shorter or longer sub-intervals, only the three longest series tended to be rather stable prior to 1820. During the 1850s there were many relocations when the newly founded Weather Service tried to find appropriate sites for the new network.

4.2.4 Surroundings

The surroundings of a site can influence the measurements taken there in many different ways and on many different scales. There is a wide spectrum of forcing, for example, the single tree that shades the temperature site, decreases the precipitation amount by shadowing or increases it by reducing the wind speed, and the urban influences on the temperature field, or the influence of land use on humidity. The recent state of the ALOCLIM sites is described well by the land-use maps on the CD-ROM (with one example shown in Fig. 4.1) which represent the situation in 1991 (Steinnocher, 1996) at a horizontal resolution of 1 km. Smaller scales, like the single tree example, are sometimes mentioned in the single station meta-files, but a statistical analysis was only possible for the environmental characteristics “mountain station”, “rural environment”, “weakly urbanised”, and “strongly urbanised”. Fig. 4.9 shows the time series of the percentage of rural (the combined groups of rural and mountain stations) and of urban (the combined groups of strongly and weakly urbanised) environment. In cases of a non-homogeneous environment, the classifications were based on a scale of only a few kilometres. Böhm (1998b) showed that the city as a whole does not affect the meteorological measurements, only the neighbouring few kilometres exert an influence. It is normally considered that the degree of urbanisation and its influence on climatic time series (temperature series mainly) systematically increases due to increases in population, city areas and economic development (compare the population evolution at ALOCLIM sites in Fig.4.8.). However, this is not the case for the ALOCLIM network. The time series in Fig.4.9 show that after an initial phase of increasing urban environment from the 1760s to the 1820s (0% to more than 70%), it has been the share of the measuring sites in the rural environment that has slightly increased. In particular, the years since the 1880s show a long-term trend from 40% rural sites to 70% by the 1990s. The most significant step towards a rural network occurred in the 1940s when a number of urban stations were relocated to airports. In the ALOCLIM network the systematic tendency to relocate away from city centres exceeded the growth of the cities over the past 120 years.

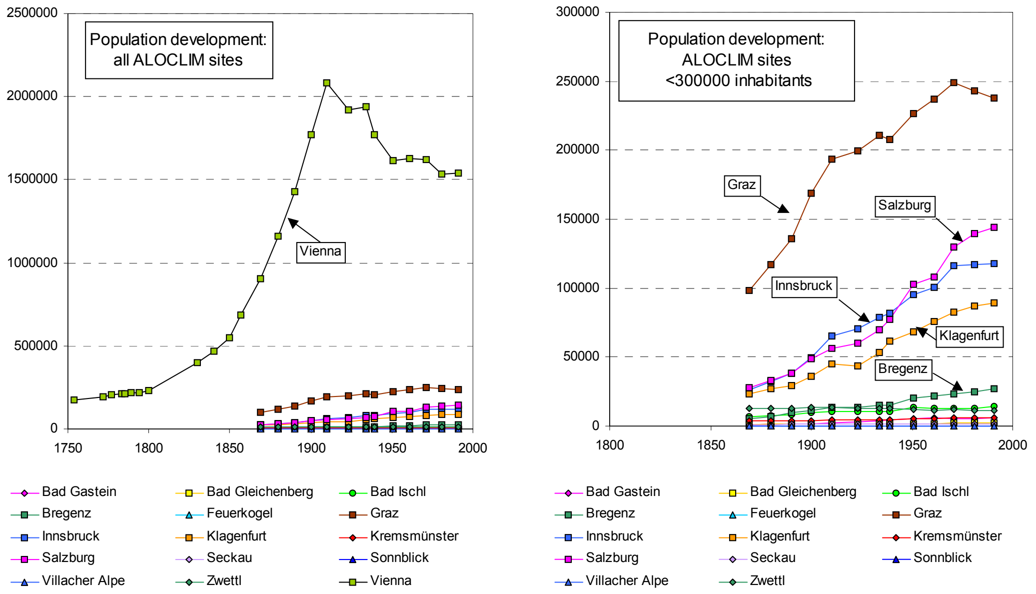


Fig.4.8. Population development at ALOCLIM sites (Source: Österreichisches Statistisches Zentralbüro)

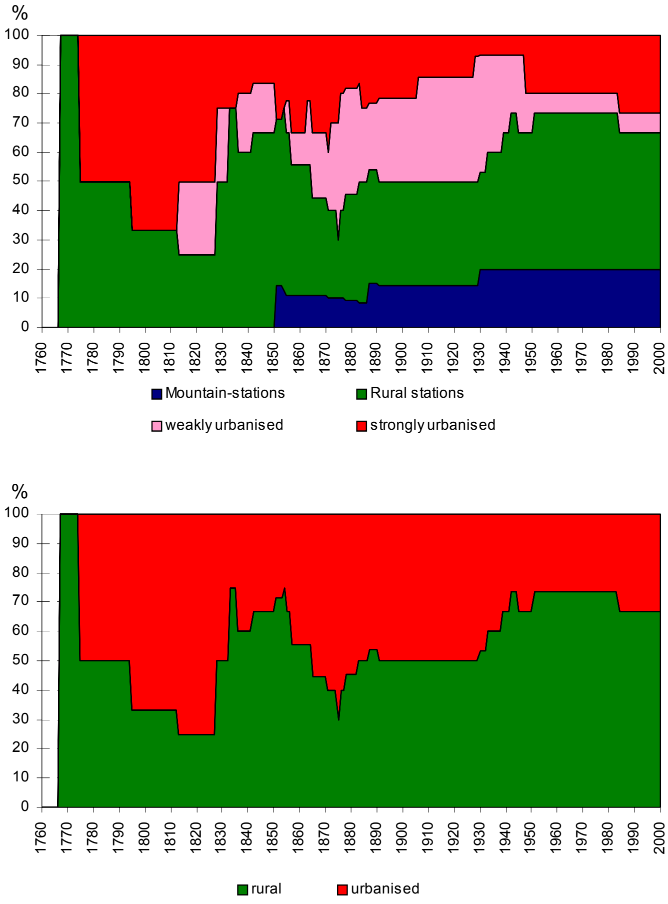


Fig. 4.9. Time series of the urban influence on the ALOCLIM network (upper figure: 4 environmental classes, lower figure: 2 classes)

4.2.5 Observers

Even at the present time, with the increasing automation of the network, observers are of great importance in maintaining the quality of a weather station. Although automatic stations have reached a 70% share of all ALOCLIM stations in the 1990s, none are fully automated and all of them are manned. This is of crucial importance, not only for the continuation of series like cloudiness, but also climate elements like temperature achieve better results if the sensors are inspected daily. Others like precipitation are very sensitive to winter conditions for example, and on mountain stations like Villacher Alpe or Sonnblick an unmanned automatic station is unthinkable given the current state-of-the-art technology. For the ALOCLIM network the majority of data are provided from non-automated sources thanks to the parallel measurements that are still carried out by the observers.

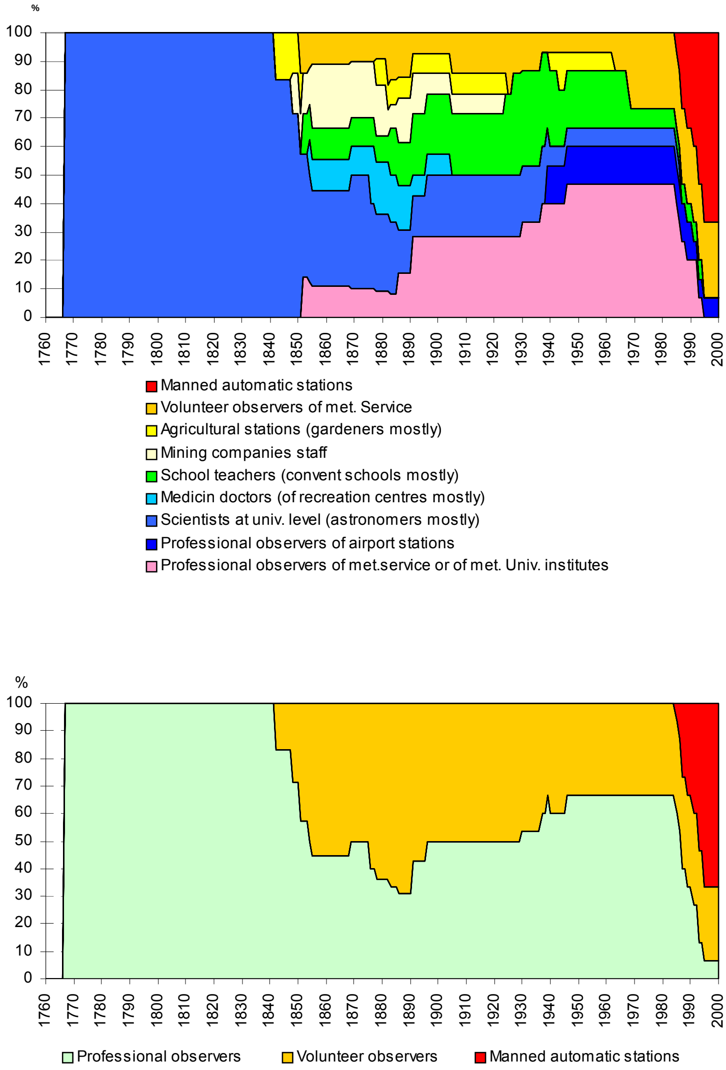


Fig. 4.10. Observers of the ALOCLIM network 1767-2000
(upper figure: 12 classes, lower figure: 3 classes)

Although observing quality is not directly linked to the profession or the intellectual level of the observer, a coarse classification of the ALOCLIM observers showed interesting results (Fig.4.10). During the first 100 years of the ALOCLIM period, observers were dominated by the group which consists of scientists (mainly astronomers), who managed their stations themselves, from the installation of instruments to the publication of the results. They were often members of monasteries, which contributed much to maintain a certain observing tradition, but also secular University Institutes played a role. With the start up of a Weather Service these independent observers at the university level could only be partly replaced by professional observers who were fully paid by the Service. The greater part of observations were carried out by volunteer observers such as physicians in health resorts, school teachers, gardeners, miners or simply interested private individuals. Many devoted their time, parts of their gardens and in many cases their money to create a solid climate database. In the metadata of the single stations it is interesting to learn about personal careers of some long-term volunteer observers, e.g., from a simple salt miner to the mayor of a city or from a young mechanic to the owner of a larger factory. During the late 19th century about 70% of the observations were carried out by volunteer observers. During the following 100 years professional observers slowly replaced them but even today around 30% of observers are volunteers. The recent trend towards automation is mainly occurring at stations with professional observers.

Of extreme interest, concerning breaks in time series, is the frequency of observer changes. The statistical analyses of 15 long-term stations which had 253 single observers and produced 2325 observing years of the ALOCLIM dataset, resulted in a mean observing length of 9.2 years with a strong concentration (43%) occurring in the class of one to five years. Fig.4.11 shows the frequency distribution of observers, Table 4.3 may serve as a “Hall of Fame” for the 8 observers who spent more than 40 years producing climate data at the Austrian long-term stations. The record holders with 52 years are Franz von Zallinger (Innsbruck) and Thaddäus Derfflinger (Kremsmünster), two great old men of the early instrumental period who not only produced the data but also scientifically analysed them on their own.

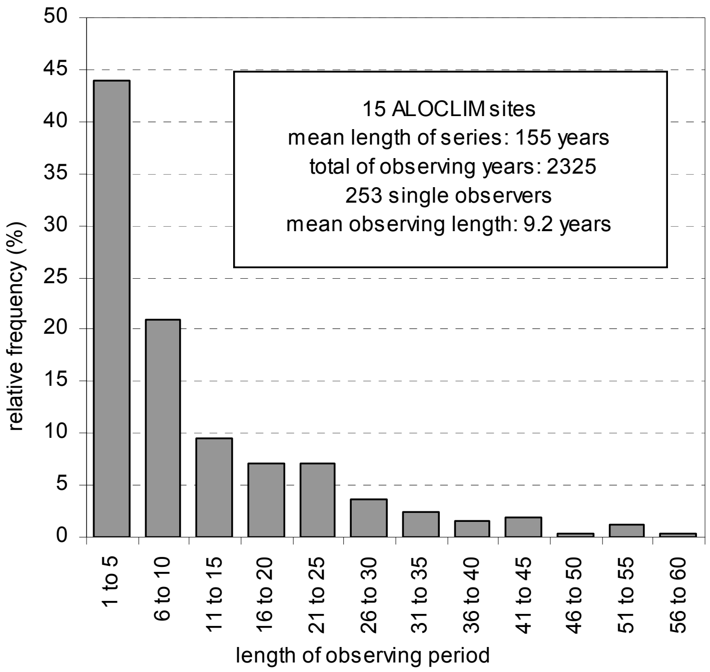


Fig. 4.11. Frequency distribution of observing lengths of the ALOCLIM network

Table 4.3. The 8 longest observing periods of the ALOCLIM network

station	length	time	person
INN	52	1777-1828	Franz von Zallinger, univ.prof. for physics and mathematics
KRE	52	1773-1824	Thaddäus Derfflinger, scientific assistant, later director of the astronomical observatory Kremsmünster
KRE	52	1896-1947	Thiemo Schwarz, scientific assistant, later director of the astronomical observatory Kremsmünster
KRE	48	1947-1994	Ansgar Rabenalt, scientific assistant, later director of the astronomical observatory Kremsmünster
INN	45	1828-1872	Stephan Prandtner, priest and astronomer
BGA	42	1854-1895	Dr.Gustav Pröll, physician
BGA	42	1866-1907	Gustav Rupert Groyer, medical assistant
GRA	42	1851-1892	Andreas Rospini, a man of great interest in meteorology and with self made career from mechanic to the owner of a factory

The time series of the frequency of observer changes in decadal steps (Fig.4.12) shows systematic features that may be of influence concerning the temporal stability of the series. There have been significantly fewer breaks due to observer changes in the earlier parts of the series, a slight increase of changes during the first part of the 20th century, a sudden peak with nearly five changes per decade and per station in the 1940s, and only a slow recovery of observing stability in the recent five decades. The World War II peak in the 1940s was caused not only by direct war casualties, but also by the administrational actions of the German occupational force, such as the liquidation policy against monasteries (see chapter 2). From the point of view of observers the 1940s may be classified as the most unstable period of ALOCLIM.

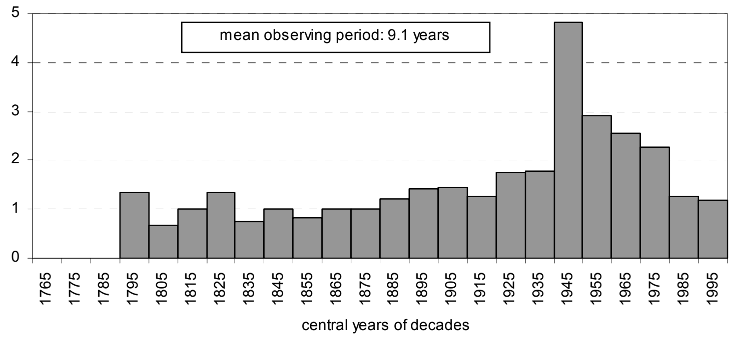


Fig. 4.12. Time series of the number of observer changes per station and per decade in the ALOCLIM network

4.2.6 Instruments

In an ideally managed and maintained Meteorological Service, instruments should play no role in terms of inhomogeneities because they should always measure exactly the physical element they were designed to measure. In reality this is in fact unrealistic in spite of all the instrument checks and quality controls. There are economic considerations that can prevent the purchase of the best (and most expensive) instruments on the market, the human factor also plays a role in the handling of instruments and the design and construction of instruments is also constantly changing. Last but not least, it is also the installation of the instruments that strongly affects the results. Uncertainties regarding thermometer screens, height above ground, windshields of rain gauges and others are treated separately in section 4.2.7. Section 4.2.6 will concentrate on the instruments themselves, based on the respective contents of the single station metadata of the 17 analysed ALOCLIM stations.

4.2.6.1 Barometers

Barometers have always been regarded as the "flagships" of meteorological instruments. Great care has been taken with their maintenance as indicated by comparative measurements, and the station history sources, which are very rich with information about barometers. Five different types of barometers have been identified at the ALOCLIM sites:

Old types of cistern barometers do not allow the adjustment of the mercury level in the cistern or have a contracted scale. For these old types two readings have to be made, one at the upper and one at the lower mercury level. These barometers were sometimes constructed by the observers themselves (e.g. "barometrum Pilgramiano" in Vienna) or built by special mechanics according to the design of the observer (e.g. Barometer "Primavesi" in Wilten-Innsbruck). Some of them did not have a thermometer integrated into the instruments – a source for errors for the reduction to zero deg C.

The next type, which followed the old barometers of the early observing period, was the siphon-type. Here the cistern is reduced to a diameter equal to that of the other mercury column. This allowed a higher resolution of the second (lower) scale and increased the quality of the readings.

The third type of barometer is the "Fortin"-barometer. These are cistern barometers, but with an adjustable level of the mercury in the cistern thanks to a screw which operates against the leather lower surface of the cistern.

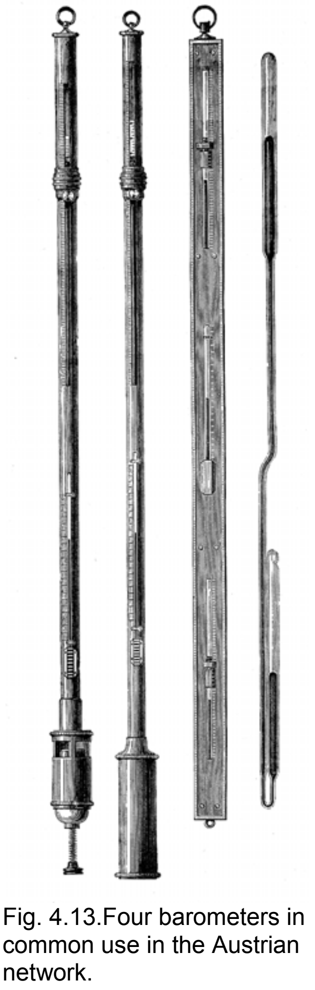


Fig. 4.13.Four barometers in common use in the Austrian network.
From left to right: one Fortin-, one Kew- and two siphon barometers

The fourth class of barometer is the "Kew"-type barometer, also known as "station-barometers" by the Austrian Weather Service (and also in the meta-files). These provide only one reading thanks to a uniformly contracted scale, which takes into account the different diameters of the column and the cistern. Fig. 4.13 shows the four barometers, which were commonly used by the Austrian Weather Service.

The fifth type of barometer is of increasing importance at the moment. It is an electronic sensor based on a temperature compensated aneroid of the type “Meteolabor-GB-1”. Manual aneroid barometers were only very marginal in the ALOCLIM network, only two stations used them for a few years after World War II. Fig.4.14 shows the time series of the use of the types of barometers described in the network. In general the replacement of the different generations of instruments was slow but systematic – it took as many as 80 years, for example, to replace the Fortin-barometers with Kew-barometers and a further 40 years for the two earlier instrument generations. Only the recent change to automatic sensors has been much quicker.

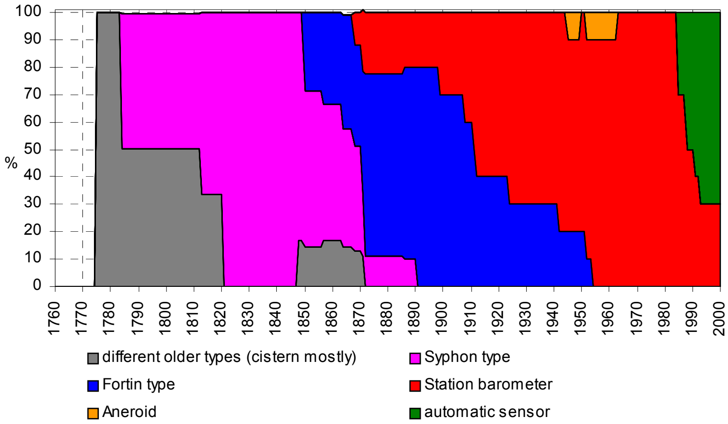


Fig. 4.14. The follow-up of the five generations of barometers in the ALOCLIM network

One of the reasons for the conservatism in instrument types may be the extremely long life-span of a barometer in Austria. The high price of these instruments, and maybe also their image as the leading meteorological instrument, encouraged very delicate handling and maintenance by observers, which resulted in them having the longest active lifetime of all the instruments. They even beat the record period lengths of observers (see section 4.2.5). The three record barometers of the ALOCLIM network were: a Fortin barometer made by Lenoir which was in use at Kremsmünster from 1876 to 1954; a Fortin barometer made by Kappeller at Bregenz (1871-1944); and a Kew-type station barometer at Sonnblick used since 1926 and is still currently in use as a parallel instrument to the modern automatic sensor. The average period of the use of one single barometer is 20.9 years, the frequency distribution of the lengths of use is shown in Fig. 4.15. Fig.4.16 shows the time series of the number of barometer changes per station and per decade. There is no clear trend in the time series, only the early times show more changes in some decades, but also decades without changes at all.

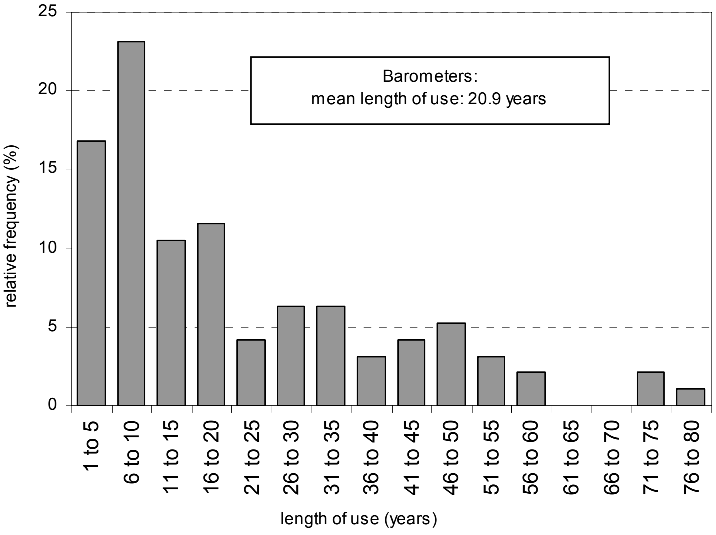


Fig. 4.15. Frequency distribution of lengths of use of barometers in the ALOCLIM network

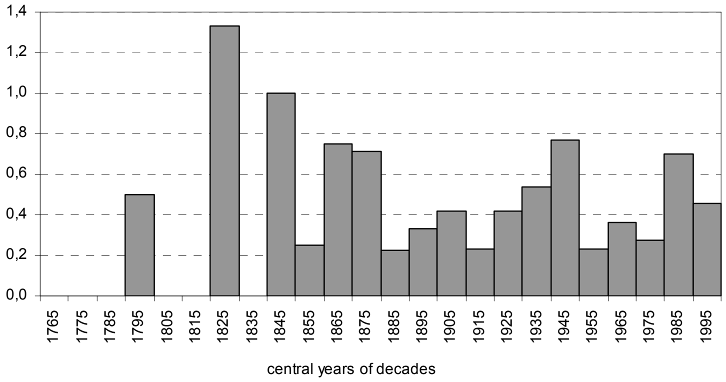


Fig. 4.16. Time series of the number of barometer changes per station and per decade for the ALOCLIM stations

It can be argued that the long-term use of one single instrument may not be regarded as a feature of quality, however, the barometers have been controlled and serviced quite frequently. The complete protocols of comparative measurements were even published in the yearbooks. So it seems that the long-term operation of the barometers is not so much an indication of the use of old fashioned and low quality instruments, but rather of the great care that was taken with them which, from the point of view of series-stability conservatism, is an advantage.

4.2.6.2 Thermometers

Although metadata coverage for station thermometers is less than for barometers (see Fig. 4.3.) this instrument can still be classified as analysable. For maximum and minimum thermometers, the meta situation is worse and meta information was only used during the homogenising procedure for the single series. Quantitative statistics of general trends or breaks in the network cannot be given for these thermometers.

Since the beginning of the instrumental period in Austria a station thermometer has always been part of the equipment of a climate-measuring site. These were originally mercury-in-glass thermometers with a 0.2 deg C Réaumur scale, in the early instrumental period (before 1871). Alcohol-in-glass thermometers were only used as a reserve at mountain stations for the rare cases when temperatures dropped to near the freezing point of mercury. The more expensive method of using an alloy of mercury and thallium (with a freezing point near –60 deg C) was used only for the standard comparative instruments at the Zentralanstalt. In the early instrumental period the majority of maximum-minimum temperature measurements were carried out with SIX-thermometers, which are based on alcohol as the expanding liquid and which usually had a 1 deg C scale. During the second half of 19th century there was a general trend towards separate instruments for maximum and minimum (mercury for maximum with 0.2 deg C scale, alcohol for minimum thermometers with 0.5 deg C scale) which is still the standard at manned stations in Austria. In the 1980s and 90s mechanical thermometers were increasingly replaced by electronic NTC-sensors. All thermometers (station, max. and min.) were frequently compared during station inspections with mobile comparative thermometers and less frequently but at least once every 10 years they were sent to the Zentralanstalt for comparative measurements in a stirred liquid with a low freezing point over the whole range of the scale (-40 to +40 deg C mostly). The scales of thermometers were fixed in most cases at two points, the freezing point and at +20 deg C, a range which expresses the typical temperature distribution of Austrian low-elevation measuring sites. Therefore, the comparative measurements in most cases, showed quite low corrections between 0 and +20 deg C (0 to 2 tenths of a degree), with slightly higher ones at the extreme tails of the scale. Accuracy of station thermometers was highest, maximum thermometers usually ranked second and minimum thermometers showed the lowest accuracy of thermometers in the network. Correction tables were sent out to the stations and should have been used by the observers themselves. Thus, “raw” temperature data should theoretically already contain the instrument correction. In reality this was mostly, but not always done, by the observers, nevertheless the described quality control management of the Zentralanstalt resulted in quite a low number of breaks in the series which were due to instrument changes. This makes the unsatisfactory metadata situation concerning thermometers more tolerable. Much more important, in terms of homogeneity, are specific factors regarding the installation of thermometers (screens, ventilation, height above ground, wall- or free-standing installation, shading) which are better documented and will be described in section 4.2.7.

Some items of the station thermometers are documented well enough to enable some statistical analysis. Fig. 4.17 shows the frequency of instrument changes and Fig. 4.18 shows the time series of instrument changes (both in regard to station thermometers, not to extreme thermometers).

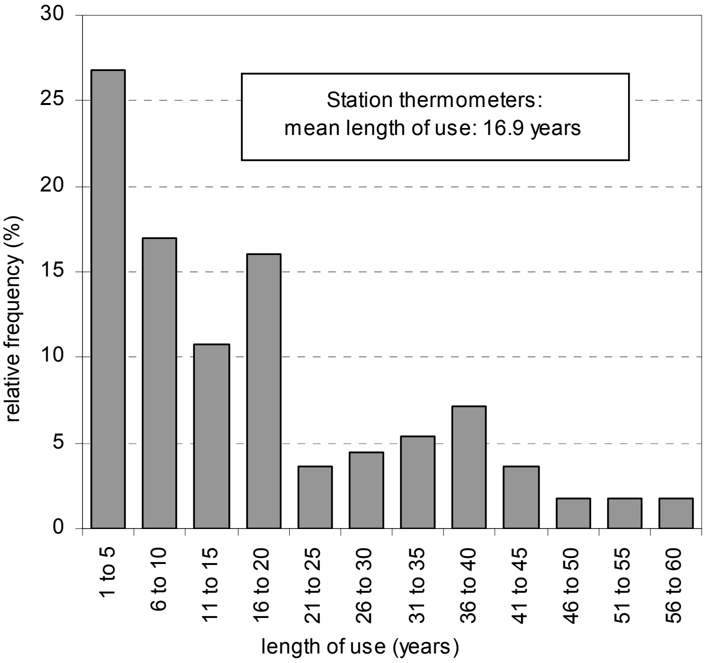


Fig. 4.17. Frequency distribution of lengths of use of station thermometers in the ALOCLIM network

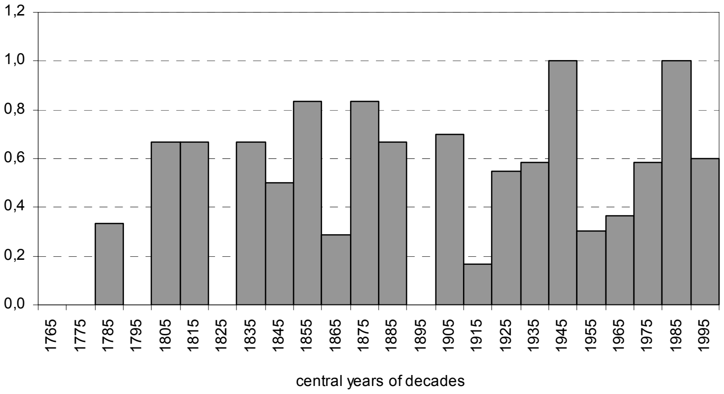


Fig. 4.18. Time series of the number of station thermometer changes per station and per decade for ALOCLIM stations

Compared to barometers, thermometers have a shorter period of use (an average of 16.9 years), a higher concentration in the 1-5 years class (27%) and the record lengths of the operation of one single thermometer is limited between 50 to 60 years. The time series of instrument changes shows a slight long-term trend towards more changes, which are mainly caused by the two main peaks, one in the World War II decade and the other in the 1980s (the start of the change to electronic sensors).

4.2.6.3 Hygrometers

In general, the situation with regard to meta information about hygrometers is poor. Only some unquantified general information can be given. Humidity measurements started much later than those of air pressure and temperature, with first attempts made in Vienna (1829) and Kremsmünster (1833).

Humidity measuring became more frequent in the 1840s and was part of the standard measuring programme of the newly founded Zentralanstalt für Meteorology in 1851. Measuring quality was poor during the first decades and the earliest homogenisable data do not exist before the 1860s. The standard instruments have always been hair hygrometers and since 1848 there are indications that psychrometric measurements were also carried out (see the drawing of a standard temperature screen with a dry and a wet thermometer, published by Kreil, 1848, reference given in Table 3.2). In all observing instructions of the Zentralanstalt, psychrometric humidity measurement was considered to be the more effective method. It was only for mountain stations and for the cold winter months with very low psychrometric differences that measuring with hair hygrometers was regarded to be more accurate. It is however, unclear as to which method was actually used throughout the longest part of the instrumental period (mainly due to the loss of the original lists of the pre WW-II period). The automation period of the 1980s and 1990s has complicated the situation further. The original plan was to replace the manual sensors by highly sophisticated electronic dew-point sensors, these turned out, however, to be too sensitive to environmental influences (pollution, icing etc.). As the continuous recording of wet bulb temperatures is a problem both in winter (with the freezing problem) and also in dry conditions in summer (water supply for the wet bulb), the situation at the moment is not very satisfactory. Most of the Austrian automatic stations use Pernix sensors which are decreasingly accompanied by manual psychrometric measurements.

The lack of high quality metadata means that humidity is the one climate element with a very limited use of metadata for the procedure of homogenising and thus, most cases had to rely on statistical testing.

4.2.6.4 Rain gauges

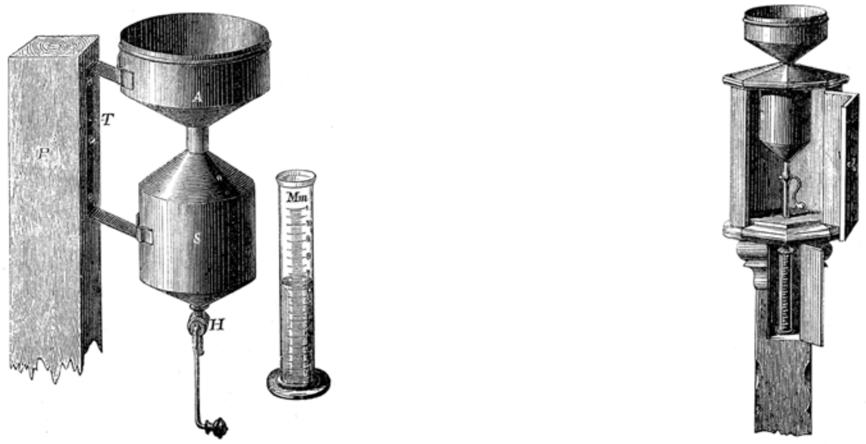
Metadata coverage of instruments for precipitation measurements is slightly better than for humidity, but is still not good enough to perform the quantitative statistic analyses, that can be carried out for thermometers and barometers. Only the general features and evolution can be described. The earliest precipitation measurements started in 1814 at Klagenfurt and 1820 at Kremsmünster. The first information about instrument design is again from Kreil (1848), showing a strangely shaped rain gauge with a ball-like container and a square orifice of one square foot (1055 cm^2). It is the first of a series of six different types of rain gauges, which were used in the network. Figs. 4.19 and 4.20 describe these instruments.

Old Ombrometers of the Austrian network

Oldest (around 1850):
Ombrometer no.1 (Kreil): square orifice, □ 32.5x32.5 cm, 1055 cm²

1860s to 1870s:
Ombrometer no.2 same area of orifice (one Parisian squarefoot), but circular: ○ ,
diameter 36.6 cm, 1055 cm²

1870s:
Ombrometer no.3: according to the regulations of the International Congress in Vienna (1873), based on the metric system ○ , diameter 35.68 cm, 1000 cm²
1870s:
Ombrometer no.4 (Osnaghi): smaller version due to money saving requirements ○ , diameter 25.23 cm, 500 cm²



Older version

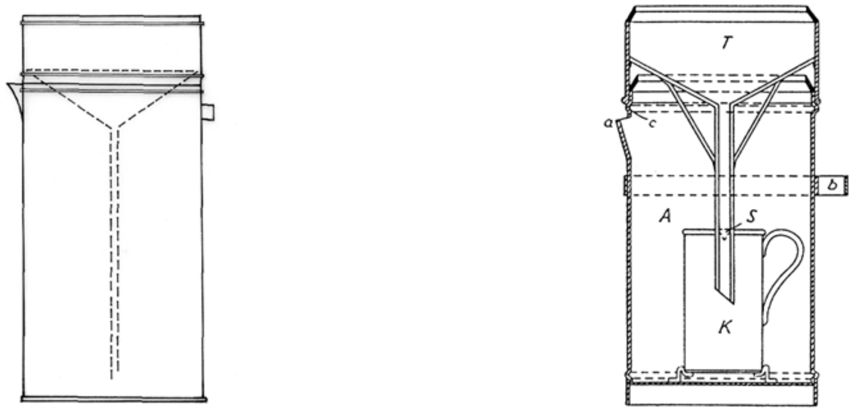
In wooden case

Osnaghi ombrometer

Fig. 4.19. Old types of rain gauges of the Austrian network

Recent ombrometers of the Austrian network

since the 1880s: Big ombrometer 500 cm²
diameter 25.23 cm, 500 cm² in two versions:

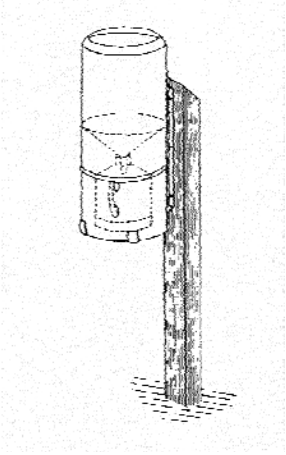


older version (52cm high)

later version (55 cm high)
(also called mountain ombrometer)

Fig. 4.20. Recently used types of rain gauges of the Austrian Network

Small ombrometer (HELLMANN type, 200 cm², first mentioned 1909, more common since the 1940s, in the 1980s mostly replaced again by the 500 cm² type)



tipping bucket (PAAR): 500 cm², unshielded

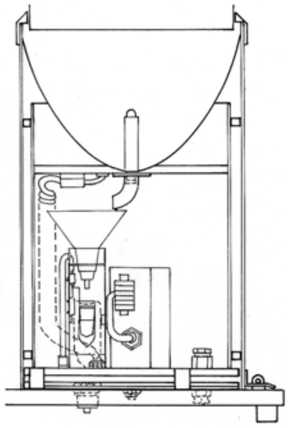


Fig 4.20. – continued

Low elevation rain gauges did not have windshields or snow crosses. Only the three high elevation sites at Sonnblick, Feuerkogel and Villacher Alpe were equipped with windshields. Sonnblick is a special case, where a wind shielded totaliser (one from the high-density small scale network of the region) has produced a homogenisable series (described by Auer, 1992 and Auer and Böhm, 1998). The other rain gauge series of the sites at high elevations were not homogenisable. The form and dimensions of the rain gauges reveal that there is a trend of bigger instruments with orifices of 1055 or 1000cm^2 before the 1870s, followed by three generations of 500cm^2 from the 1870s to the 1940s, then a change to smaller Hellmann type gauges of 200cm^2 from the 1940s which have mostly been replaced again since the 1980s by 500cm^2 gauges. The current trend towards automatic gauges has no impact on the ALOCLIM series because of the comparative manual measurements. There should be no breaks in the series due to changes to the modern tipping bucket and weighing gauges of the automatic network. The individual meta information for each site was used in the homogenising procedure. With regards to the complete network, the warming trend from the 19th to the 20th century could have caused a systematic bias. A decrease of the solid precipitation rate goes along with a reduction of the systematic wind-induced precipitation measurement error. Moreover, the systematic evolution of the size of the gauges might also have had some influence.

4.2.6.5 Sunshine recorders

Sunshine series have good metadata coverage and also a highly conservative instrument evolution. The complete series relies on one type of instrument – the Campbell-Stokes sunshine recorder with one exception, Villacher Alpe, with an automatic sensor and no comparative measurements. Since the 1880s (the start of the earliest sunshine series) the instrument design has remained unchanged. The Campbell-Stokes sunshine recorder was adopted into the Austrian network shortly after the introduction of the second version in 1879 (Helmes, 1982). There was only one documented change at one site (Graz, 1949) from a yellow glass sphere to a clear one. All the instruments came from only two companies both providing the German stripe length (which differs from the French or the English length). Major recording paper changes are not reported and are not evident from the existing original recording stripes. The type of the recording paper has always been very dark blue, which differs greatly from the French type which is a much lighter blue with a higher albedo (Lauscher, 1973). Automation during the 1980s and 1990s introduced for the first time, a new instrument into Austria's sunshine network. This is the photo-electric sensor Haenni-Solar 111. This would cause considerable breaks in the series of ±15% (analysed by Schöner and Mohnl, 1999). As all but one of the ALOCLIM sites still perform parallel recording with the Campbell-Stokes instruments, these breaks are of minor importance for the moment. Fig.4.21 shows the two types of sunshine recorders.

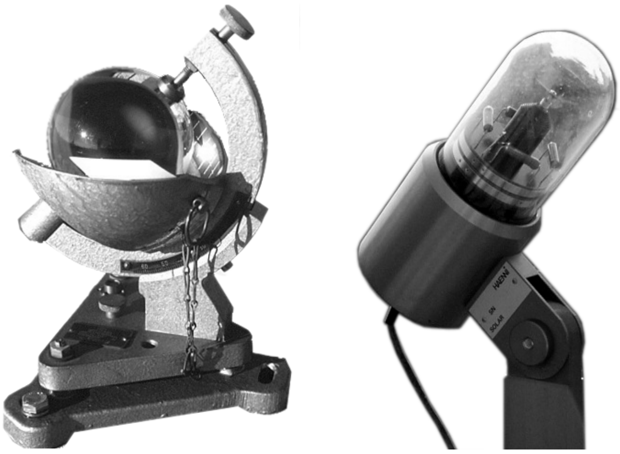


Fig. 4.21. The two types of sunshine recorders of the Austrian network

The mean length of use of a sunshine recorder is 19.8 years. The frequency distribution of Fig.4.22 is similar to that of barometers (Fig.4.15) at the short-term tail of the distribution, and similar to that of thermometers (Fig. 4.17) at the long-term tail.

In general, instruments and instrument changes are not that important for sunshine recorders. Other factors like shadowing-breaks or evaluator-changes influence the homogeneity of the series more. There is no general evolution of these factors and the respective meta information of the individual meta-files was used for homogenising the data (described in chapter 5).

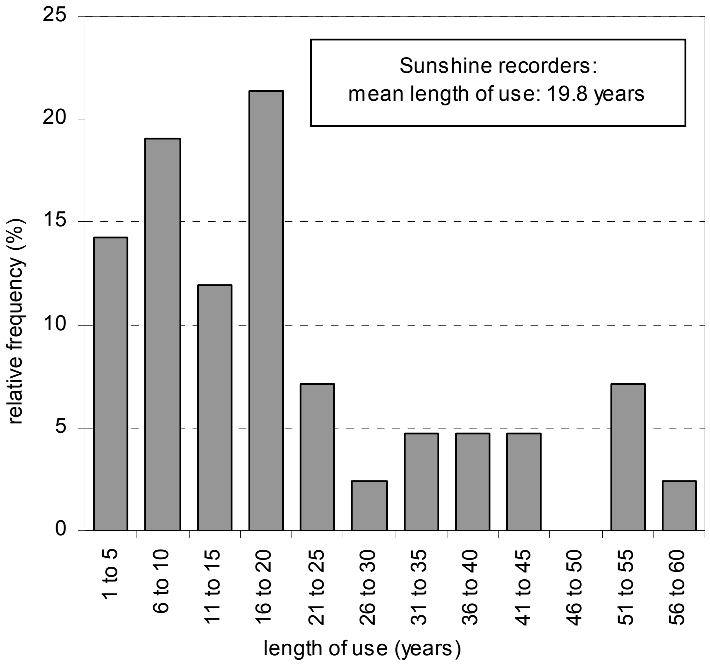


Fig. 4.22. Frequency distribution of lengths of use of sunshine recorders in the ALOCLIM network

4.2.7 Installation of instruments

The installation of instruments is, in general, more important for the homogeneity of a series than the instruments themselves. Factors like height above ground, absolute height, radiation screens, shadowing and others, cause serious breaks if they are not stable in time. The heights of barometers, thermometers and rain gauges as well as the thermometer screens are well documented in the ALOCLIM meta files (see Fig. 4.3) and can be evaluated in statistical terms.

When a station is relocated, altitude changes of some tens of metres are quite common. In the Austrian climate a 10m altitude change causes a systematic change of air pressure of 1.2 hPa (100-500m asl) or 0.9 hPa (in 2500 to 3000m asl). Thus, altitude breaks of only 10m (which also happened frequently without major relocations as a result of the movement of the barometer from one part of a building to another) cause air pressure breaks comparable to the long-term trend of a complete century. Therefore, altitude changes have been treated with much care and could be corrected for 97.4% coverage. Fig. 4.23 shows the results of the analysis of barometer altitudes for the 10 ALOCLIM air pressure series. Most of the altitude breaks have been between 5 and 15m, single breaks have been up to 40m and, most interestingly from the point of view of systematic errors, there has been a systematic mean trend from lower to higher altitudes from the 19th to the late 20th century. Early barometer sites were approximately 10m lower than modern ones. Thus, the original Austrian long-term pressure series have been systematically biased by more than 1 hPa. Most interestingly, this altitude bias is very close to a systematic bias of an international air pressure dataset (Basnett et al., 1997), which was homogenised without metadata information.

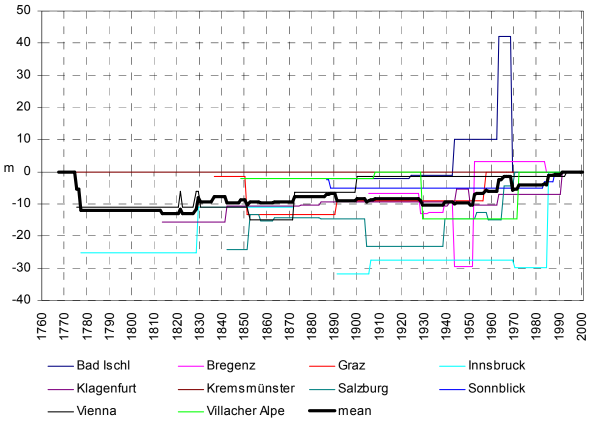


Fig. 4.23. Barometer altitudes relative to actual altitude (old minus new)
Thin: single stations, bold: Austrian mean

Where temperature is concerned, changes in the absolute thermometer height are much less important than those of barometers. Vertical temperature lapse rates in Austria are of the order of –0.5 to –0.6 K/100m (winter above 1500m, summer at all altitudes) and 0.0 to –0.2 K/100m (winter at low altitudes). Fig. 4.24 shows the altitude changes that really happened during the instrumental period. For single stations there were altitude breaks between of 50 to 130m which were relevant for those single events (these were eliminated by homogenisation). Nevertheless, the average altitude curve (the bold line) varies only between +8 and –10m relative to the actual mean height. Thus, the strongest systematic bias of the original ALOCLIM data as a whole, due to altitude changes, has never exceeded 0.1K.

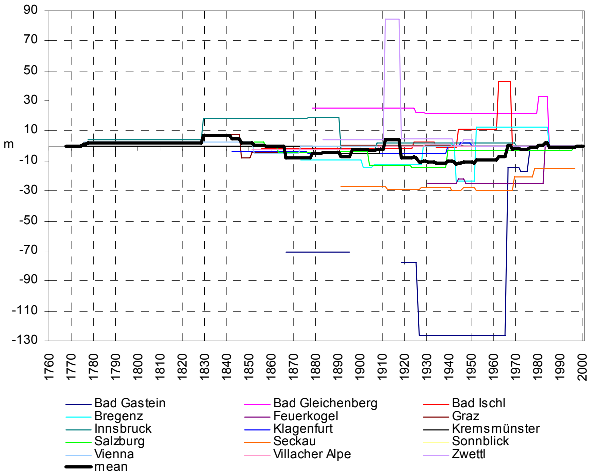


Fig. 4.24. Thermometer altitudes relative to actual altitude (old minus new)
Thin: single stations, bold: Austrian mean

More importantly for temperature, are the heights above ground of the thermometers. Fig. 4.25 shows that there has been a systematic decrease of the height above ground from the early measuring period (15m) to the modern standard of about 2m above ground. This decrease was caused by a change of philosophy regarding the proper installation of a thermometer. The typical installation of a thermometer in the 19th century was in the shadow of a north facing wall in front of a window. There was not much care taken about a standardised height above ground. Most of the old urban sites were in multi-storey buildings and therefore, they were automatically higher than the modern standard of 2m. This general tendency of height reduction went hand in hand with the evolution from small metal screens (also called “window-screens”), installed in front of north-facing windows at high altitudes, to the 2m-above ground free standing double louvered white screens (Stevenson screens) generally above a lawn and remote from buildings (Fig. 4.26). Fig. 4.27 shows the respective time series of the change from N-facing metal screens to modern free standing Stevenson screens. The parallel evolution of thermometer heights and the changes from metal wall-screens to free standing Stevenson screens is evident. It influenced not so much mean temperatures (only a minor negative bias of old summer temperatures and a slight positive one in winter), but also caused a remarkable bias of minimum and maximum temperatures. Original maximum temperatures were lower, minima higher and MDR (mean the daily range) lower in the times of N-facing metal screens than in those of Stevenson screens. The magnitude in the bias is 0.5 to 1K and thus similar to the real climate signal. A quantitative analysis of this bias is given in chapter 5. Homogenisation of the described biases was easy thanks to some comparative measurements and also due to the slowness of the evolution. The change from the old to the new temperature sites took nearly 80 years, leaving enough time to provide sub-periods with reference series for each of the single station breaks.

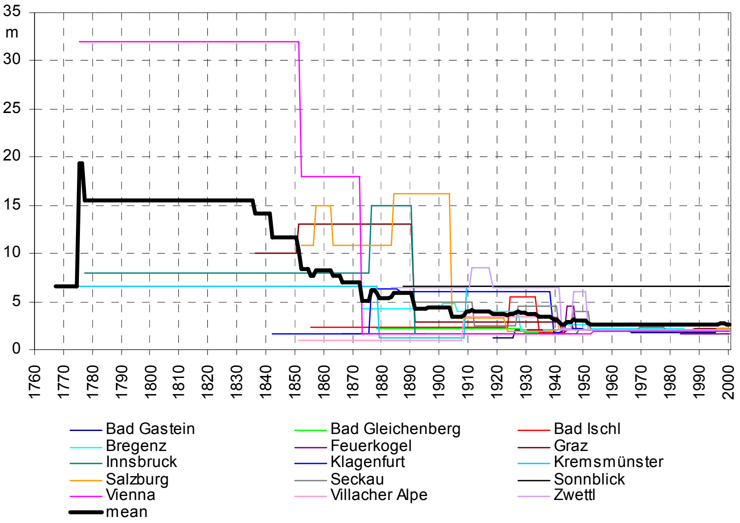
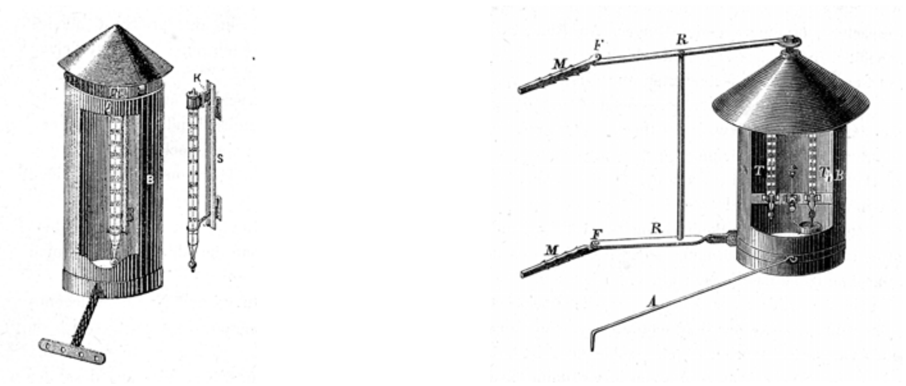


Fig. 4.25. Heights above ground of ALOCLIM thermometers
Thin: single stations, bold: Austrian mean

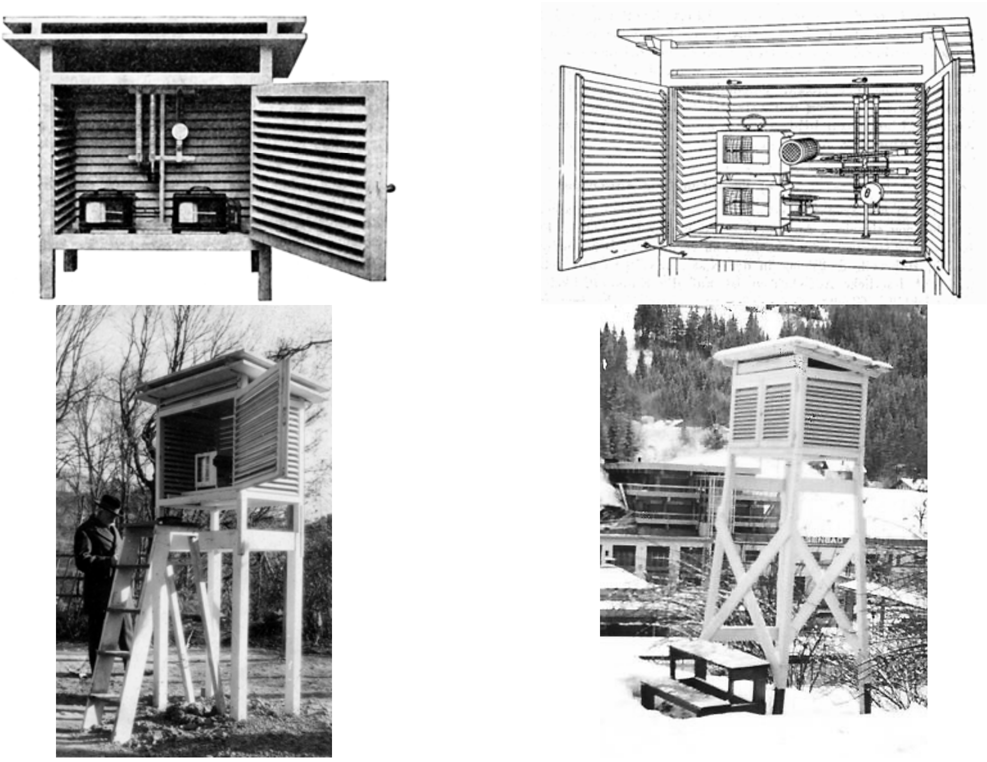


Small metal screen

Big metal screen

Typical N-wall window equipment

Double blinded wooden screen types used in the Austrian network



Old standard model

Modern standard model

Fig. 4.26. Old and new types of thermometer screens in Austria

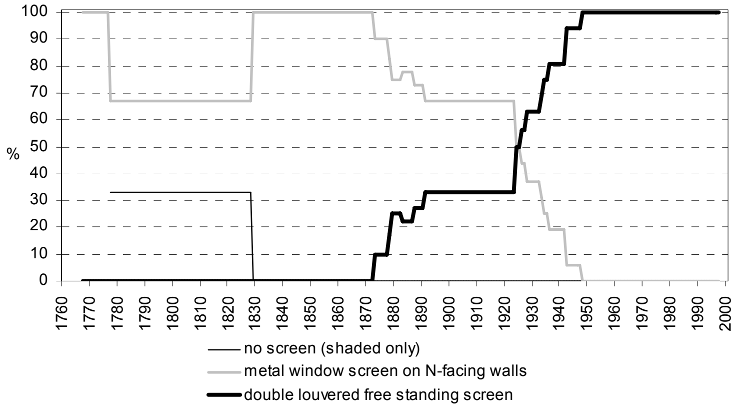


Fig. 4.27. Time series for the follow-up of different types of thermometer screens used in the ALOCLIM-network

Similiarly for rain gauges, an evolution from higher to lower installations of the instruments could also be detected (Fig. 4.28). In the early instrumental period the installation of these instruments was considered to be better when located in open areas remote from obstacles. Together with the higher number of urban sites in towns and cities, where such places often were not easy to find at near to ground level – this philosophy resulted in rain gauge sites on exposed platforms or flat rooftops 10 to 50m above ground. After the findings of some international rain gauge inter-comparison projects the wind speed factor is now considered to be the main cause of the biases found in precipitation measurements. Therefore, some moderate shading with obstacles in the surroundings of a rain gauge is regarded to be an advantage rather than a disadvantage. Thus, modern ALOCLIM sites tend to be situated nearer to ground (actual mean for gauge orifice height = 1.3 m above ground) than the early ones with a typical height of 18 to 20 m above ground in the 1810s to 1840s. Together with the lower temperatures of the 19th century, this might have negatively biased the early precipitation measurements although the higher number of sites in the urban environment (with lower wind speeds due to higher surface roughness) could have balanced that effect. Of some interest is the special habit of the Fathers of the Kremsmünster monastery who were obviously already aware of the dangers of wind speed especially concerning the measurement of solid precipitation. They used a 48m high observing platform for measuring in summer. In winter they moved the rain gauge down to the garden to a height of only 1.3 m. As with the parallel evolution of thermometer sites, the decrease of rain gauge orifice heights was also slow and did not happen simultaneously at all sites. Thus it was not difficult to find undisturbed comparative sub-series for homogenisation in each single case of height changes of the gauges.

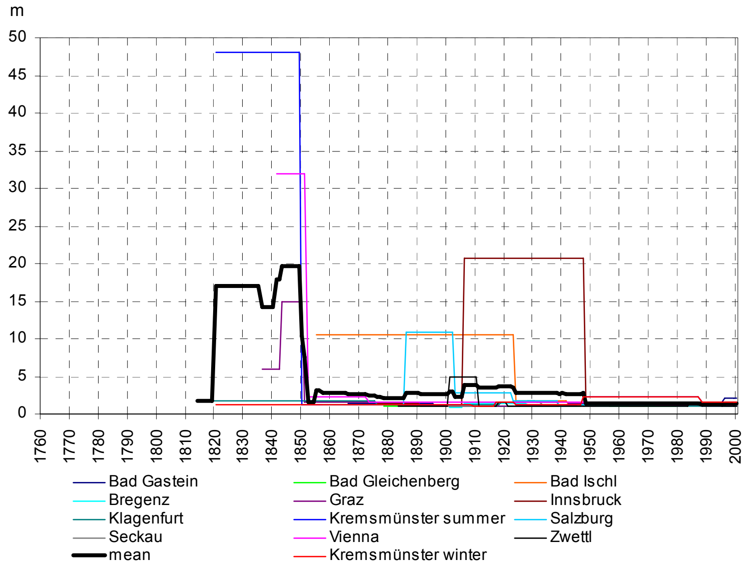


Fig. 4.28. Heights above ground of ALOCLIM rain gauges
Thin: single stations, bold: Austrian mean

5 Homogenisation

All of the ALOCLIM series (see chapter 3) have been checked for non-climatic inhomogeneities and adjusted (to the most recent homogeneous sub-interval) using metadata information (see chapter 4) and mathematical homogeneity tests, which are described in general in section 5.1. Section 5.2 discusses the homogenising tools that were used in the project and sections 5.3, 5.4 and 5.5 describe their practical application to the monthly ALOCLIM series of the nine main climate elements (see chapter 3). A short section, 5.6, deals with the remaining problems – mainly concerning the homogenisation of derived elements – and suggests a likely solution via the homogenisation of daily data. Finally, section 5.7 analyses the homogenised series versus the original data and discusses the randomness or the systematic biases of the adjustments for single series and for the regional mean of the study area.

Homogeneity testing and adjusting was performed before the closing of gaps in the time series. One of the advantages of the software used for this study (HOCLIS, see section 5.2) is that homogeneity testing and adjusting is possible for an incomplete series. If the gaps have to be closed before homogenisation there are problems as the locations of homogeneity breaks have not yet been identified. Thus, the closure of smaller gaps (see chapter 3) was carried out as the final step.

5.1 General remarks

In general each climate time series can be split in the following way

$$x(t) = c(t) + i(t) + \varepsilon(t)$$

with: c(t) … climate signal function (of time)

i(t) …. inhomogeneity function (of time)

ε(t) … white noise function (of time)

For a theoretically perfect homogenous time series $i(t) = 0$. However, in practice $i(t) \neq 0$ and is either a step function, for example, change of instrument, station relocation or a trend function for example, a growing tree. However, it should be remembered that the definition of inhomogeneity trends is particularly related to the definition of the problem, for example, the scale of climate investigation. A growing tree is defined as an inhomogeneity for the investigation of regional climate change but is not an inhomogeneity in micro-climate studies.

$\varepsilon(t)$, the white noise function, is assumed to be normally distributed. $c(t)$, the climate signal function has to be removed for statistical evaluations of non-climatic inhomogeneities (break points or trends). This can be done very simply by the computation of difference series (additive model) or ratio series (cumulative model) with a neighbouring climate station.

$$z(t) = x_1(t) - x_2(t) \quad \text{additive model}$$

$$z(t) = x_1(t) / x_2(t) \quad \text{cumulative model}$$

However, it is very important to point out that this computation is possible only if both series have the same climate signal function (assumption of same climate region). If such a neighbouring station is not available, one has to work with so called absolute homogeneity tests. These tests are well known from the statistic literature (e.g., Sneyers, 1990 or Kundzewicz and Robson, 2000). From our experience we strongly recommend the use of relative homogeneity tests where possible, as they are more powerful in detecting break points. Absolute tests are strongly limited in their capacity to separate $c(t)$ from $i(t)$.

Relative homogeneity tests are based, in many cases, on the same assumptions and on similar theory. These are:

a) the assumption of normal distribution or at least randomness

b) the weighting of test statistics with a measure of variance (significance)

c) the test of change in the mean or change in the variance of series sub-sets

d) computation of difference (ratio) series to a weighted reference series

e) a (maximum) likelihood principle of test statistic

If the assumption of randomness is not fulfilled one has to work with distribution free tests (rank test) such as the Mann-Kendall test. Tests of randomness include the Wald-Wolfowitz test and the Neumann-ratio test (Sneyers, 1999), for example.

The following discussion of homogeneity tests is limited to the methods used within ALOCLIM. Useful reviews of homogeneity tests and methods can be found in Peterson et al. (1998), HMS-WMO (1997) and HMS-WMO (1999). General requirements of homogenisation tools can be defined as:

a) a good combination of mathematics and software

b) the possibility to consider metadata

c) no assumption that any series is homogenous

5.1.1 Break point detection

The Craddock method (Craddock, 1979) for break point detection has the following formula:

$$S(j) = \sum_{t=1}^{j} \left(z_{(t)} - \bar{z} \right)$$

$$\bar{z} = \frac{1}{n} \sum_{t=1}^{n} z(t)$$

with n =series length

As this method includes no measure of significance it is not a real statistical test. Determination of break points is subjective and based on the choice of the analyser. Within ALOCLIM, this method was reworked and extended to a multiple Craddock-curve inter-comparison method (comparison of a matrix of up to 5 diagrams with up to ten comparison series each). Our experiences show that this Craddock method is powerful enough (possible undetected breaks are of very low significance) if the analyser is experienced with the method. The main advantage of the method is its speed. The pre-eminent applicability of the Craddock method is supported by other investigators such as Aschwanden et al. (1996).

The statistics for the MASH test (Szentimrey, 1999) are formulated as:

$$S_{(i,\,p,\,j)} = \frac{(p-i+1)(j-p)}{(j-i+1)} \frac{(z_{(i,\,p)} - Z_{(p\,+\,1,\,j)})^2}{S^2(z_{(t)})}$$

$(1 \le i \le p < j \le n)$

with:

$z_{i,p}$,$z_{p+1,j}$ … means above respective intervals [i,p] and [p+1,j]

$S^2(z(t))$ … standard deviation of series z(t)

$$INH_{(k,\,l)} = \max(S_{(i,\,p,\,j)})$$

MASH uses an optimal weighting procedure for the computation of reference series similar to a multiple linear regression. It works with either an additive or cumulative model. INH(k,l) has to be compared with the critical value. In essence, this means that the test value is the standardised difference of neighbouring means where all possibilities are examined. The new software method of MASH version 2.0 is a very powerful tool which allows the homogenisation of monthly values of climate time series with the possibility of also considering metadata (Szentimrey, pers. comm.).

5.1.2 Adjustment of inhomogeneous series

Within ALOCLIM the adjustment of an inhomogeneous series was applied in three different ways: the shift method, the ratio method and the linear regression method. The adjustment of the examined series has always been done for homogenous sub-periods of a reference series. This method worked for all climate elements and all periods (there was never a point when an examined series could not be homogenised due to any missing reference series). As a result of the unsolved problem of homogenisation of monthly values, as well as the non-existent possibility of considering metadata at the time of ALOCLIM homogenisation, MASH was not used for adjusting time series.

Within ALOCLIM, there was some discussion about the linear regression method of homogenisation. The use of this method was supported by the fact that break points in climate time series are not only break points of the mean but also break points of the variance. Szentimrey (1999) discussed the linear regression model for homogenisation in detail. He concluded that the model is a “self-contradiction” as this method adjusts the climate signal function. However, this conclusion results mainly from the assumption that one can split each series in the climate signal function, the inhomogeneity function and the white noise function with the same climate signal function of neighbouring stations. This assumption is not valid, as the homogenisation of an examined series with a reference series with different variance also has to homogenise the climate signal function. In other words, the above mentioned method is only valid if one works with normalised series or more precisely, with normalised homogenous sub-periods of series. From a practical point of view, we can summarise that the contribution from the difference in method to the climate signal is rather small. Application of the regression method within ALOCLIM homogenisation was possible only in a small number of cases.

5.2 The ALOCLIM method of homogenisation of monthly data (HOCLIS)

HOCLIS (Homogenisation of Climate Series) is a DOS-based set of FORTRAN programmes. As it was the aim of the ALOCLIM project to homogenise a comprehensive climate data set, rather than to develop user friendly and mathematically sophisticated homogenisation software, the operation of HOCLIS requires some introduction. The following paragraphs describe HOCLIS very briefly.

a) The HOCLIS data format of input files

To run the programmes of HOCLIS the following data format for input files (FORTRAN format) has to be used:

Header:	2 lines of free format file information (name of station, element, etc.)
Column 1:	year (I4)
Column 2:	free space (4X)
Column 3 to 14:	monthly values of climatological element (12I6)
Column 15 to 18:	seasonal values of climatological element (4I6)
Column 19:	annual values of climatological element (I6)

b) *Programme* ALLVALUES

The programme computes annual means and seasonal means, annual sums and seasonal sums or annual extremes and seasonal extremes of the selected series.

1 Input file: Examined series named ”name.*“

1 Output file: File including seasonal and annual values named “name.adj“

c) *Programme* ADJUSTMENT

This programme adjusts the examined series due to documented inhomogeneities (e.g., change in observation time, relocation with overlapping time series, change in unit system, etc.). The programme asks for the monthly shifts (e.g., temperature) or monthly ratios (e.g., precipitation).

1 Input file: Examined series named ”*name*.*“

1 Output file: Adjusted series named ”*name*.adj“

To make several adjustments for one examined series, by running ADJUSTMENT several times, the programme asks if previous output files should be saved. In the case of saving the old versions of output files the ADJUSTMENT programme renames the previous output file to ”*name*.adj1“ and in the next step to ”*name*.adj2“ and so on (up to *name*.adj99). That means:

”*name*.adj“:	is the output file of the last step of adjustment
”*name*.adj*“:	is the output file of the * step of adjustment.

d) *Programme* CRADDOCK

Programme CRADDOCK computes multiple Craddock-curves for break point detection. Multiple means that one examined series is compared with up to 10 reference series. The reference series are not assumed to be homogeneous. Missing values of the reference series and the examined series are allowed. In case of missing values no test quantity will be computed.

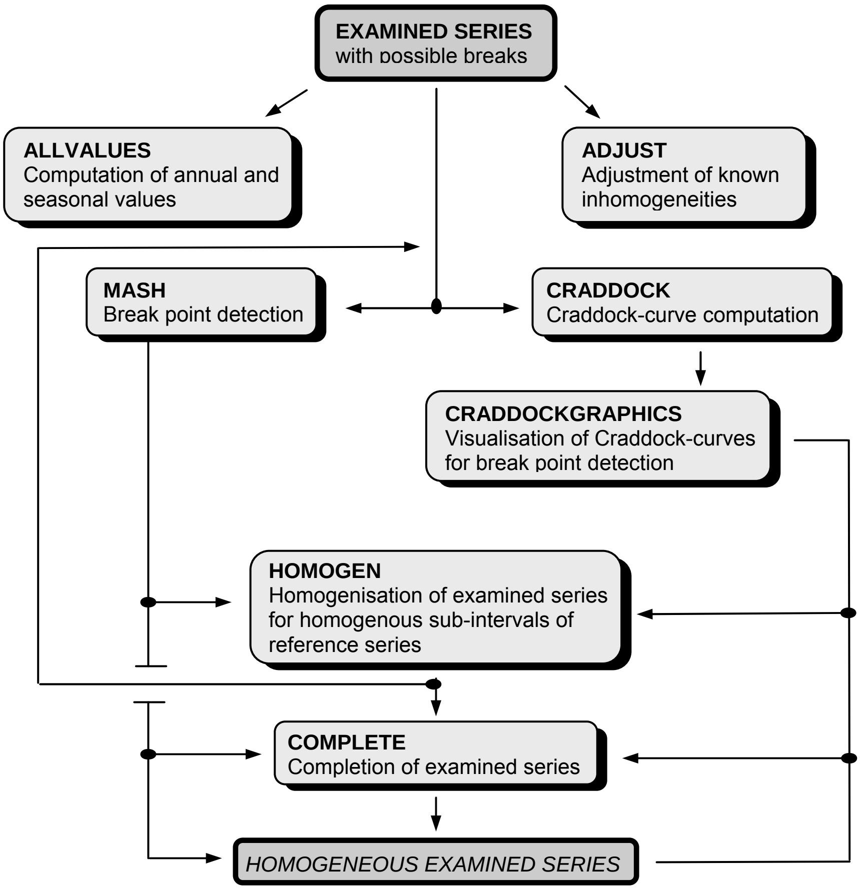


Fig. 5.1. Scheme of the HOCLIS procedure

Running the CRADDOCK programme offers two options for Craddock-curves computation:

1. Compare one examined series with up to ten reference series
2. Compare for a set of up to 11 series each series with each other

Up to 11 input files:	1 examined series named ”*name*.*“ up to 10 reference series (or 11 series each as examined series (in one step of the loop) and as reference series (in all other steps of the loop)
1 - 11 output file(s):	series of test quantities named ”*name*.cra“

When running CRADDOCK several times for the same examined series, the programme offers the possibility of keeping the old versions of output file. As for the output of ADJUSTMENT new file names are applied:

”*name*.cra“:	is the output file of the last step of Craddock-test
”*name*.cra*“:	is the output file of the * step of Craddock-test.

e) *Excel-Macro* CRADDOCKGRAPHICS

With the Excel-Macro, CRADDOCKGRAPHICS, one can visualise the output of programme CRADDOCK (Craddock-curves). There are up to 5 diagrams each including up to 10 Craddock-curves drawn on one

A4-page (see Fig. 5.2). Missing data in the data series of Craddock-curves are set to 999999 by programme CRADDOCK. The gaps can easily be seen in the diagrams produced by CRADDOCKGRAPHICS as vertical lines. As the “Craddock-test” is not really a test in a statistical sense, one has to choose subjectively which breaks have to be homogenised. A break is most likely in a series if signals appear at the same point in time for several comparative series. Signals appearing only once belong most likely to the corresponding comparative series (see the example in Fig.5.2).

f) *Programme* HOMOGEN

By running programme HOMOGEN, one can homogenise a period of the examined series on a monthly basis using a homogeneous sub-period of a reference series. The programme asks for the year and month of the break (known from metadata, Craddock-curves or the MASH-test) as well as the period of homogenisation (previous to the break or after the break).

HOMOGEN offers the option of three homogenisation methods: linear regression, shift or ratio. If the computed linear regression is outside the limit permitted by programme HOMOGEN (coefficient of regression between 0.5 and 2.0) the programme asks again for the method of homogenisation i.e., linear regression using values outside the limit / shift / ratio.

2 Input files:	Examined series named „*name*.*“
	Reference series with homogeneous reference period
2 Output files:	Homogenised examined series named ”*name*.hom“
	Information file of monthly regression / shifts / ratios named ”*name*_hom.inf“

Similar to ADJUST and CRADDOCK, the programme offers the opportunity to keep older versions of homogenisation (up to 99) of the examined series with:

”*name*.hom“:	the output file of the last step of homogenisation
”*name*.hom*“:	the output file of the * step of homogenisation.

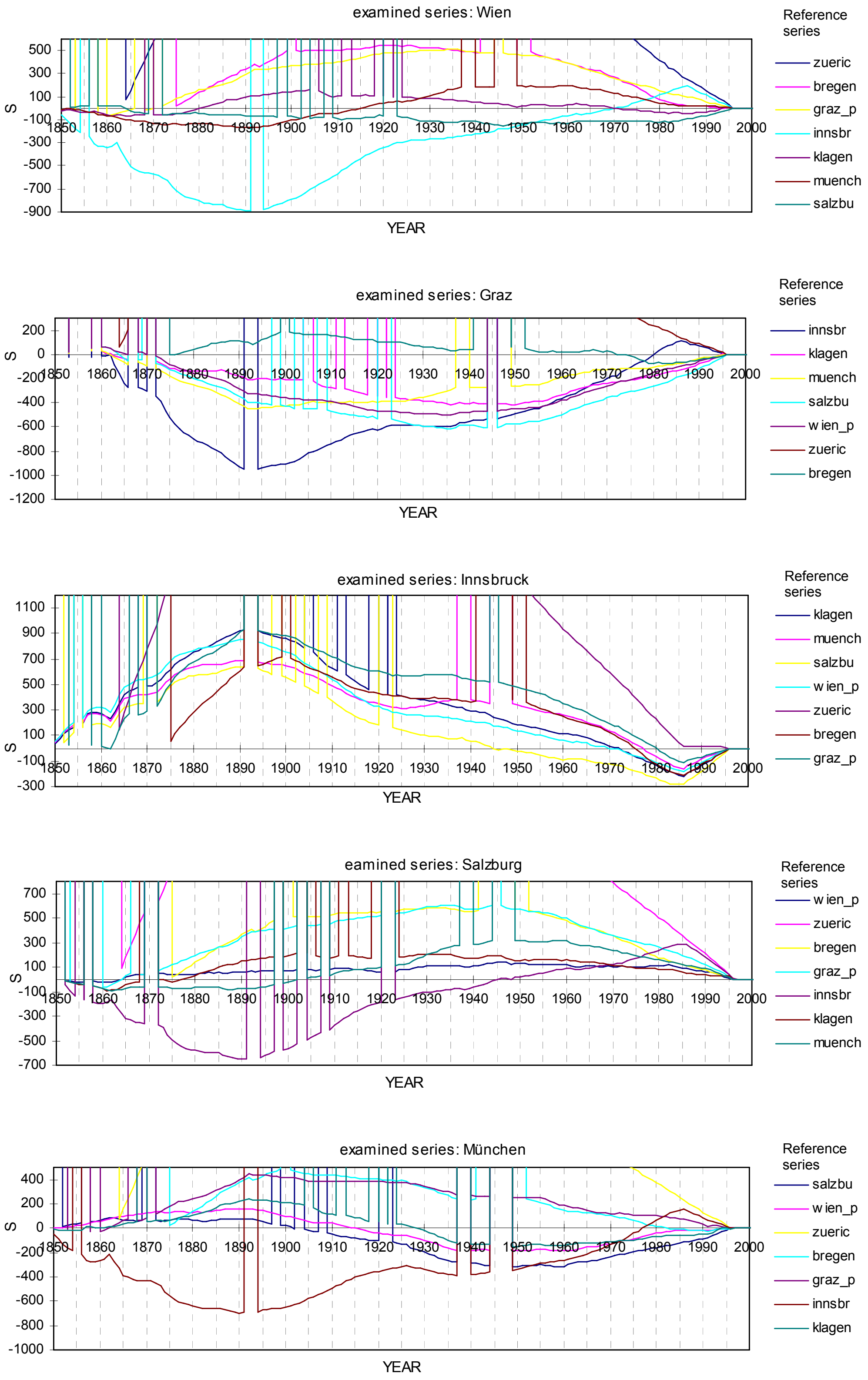


Fig. *5.2.* Example of Craddock-curve visualisation for air pressure series with break points for Vienna, Graz and Innsbruck

g) *Programme* COMPLETE

Programme COMPLETE is used to close a gap of an examined series on a monthly basis by means of an homogenous sub-period of a reference series.

To fill a gap in a time series the programme COMPLETE offers three choices: linear regression, shift or ratio. Linear regression is always the first choice for completing the series in order not to extinguish existing differences in high frequency variability between the compared series.

The procedure is the same as for HOMOGEN:

2 Input files:	Examined series named ”*name*.*“
	Reference series with complete reference period
2 Output files:	Completed examined series named ”*name*.cpl“
	Information file of monthly regression / shifts / ratios named ”*name*_cpl.inf“

As for ADJUST, CRADDOCK and HOMOGEN the programme can keep older versions of the completed examined series with:

”*name*.cpl“:	the output file of the last step of completion
”*name*.cpl*“:	the output file of the * step of completion.

h) The use of MASH within the HOCLIS procedure

The version of MASH (MASH v1.02) available within ALOCLIM, allows testing and homogenisation of annual values only. This fact contradicts the aim of ALOCLIM, which is to homogenise monthly data. In spite of this limitation, MASH was used within ALOCLIM as a very powerful tool for break point detection. However, our experiences show that MASH should be used very carefully as its high level of automation results in a risk of biased homogenisation. This is especially the case if pre-homogenised or pre-processed time series, as well as series of slightly different climate regions, are investigated. In fact, it has to be mentioned that in the case just mentioned the statistical assumptions of MASH are not really fulfilled. As an example, Figure 5.3 shows the influence of station selection on homogenisation results for mean cloudiness.

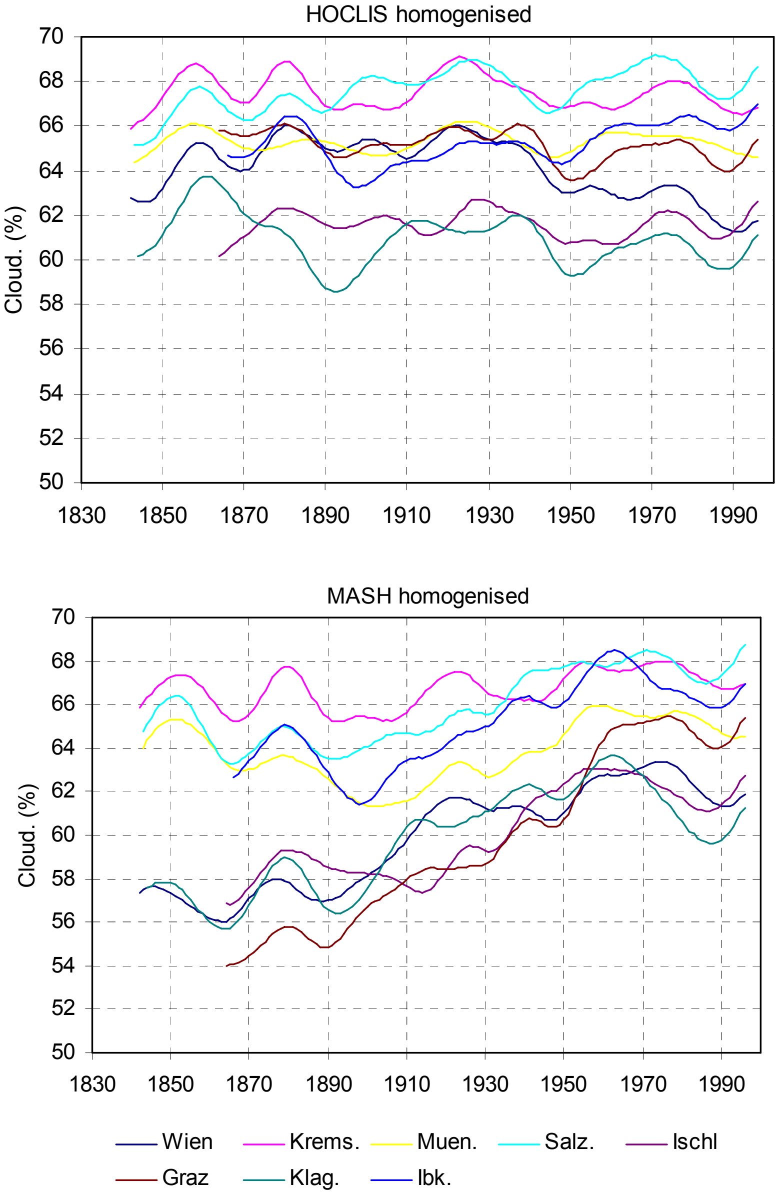


Fig. 5.3. Influence of station selection (homogenisation of all stations at once for MASH, homogenised subregions for HOCLIS) on MASH homogenisation result

5.3 Homogenisation of quantitatively documented breaks

The most advantageous metadata are those which not only provide information about the time and the qualitative nature of a break, but also about its magnitude. In theory, most of the breaks in time series should be documented quantitatively. If relocation cannot be avoided comparative measurements of reasonable length should be carried out. New instruments should be tested and compared before being integrated into the network. New observers should be well trained before they take over the job from their predecessors. Only changes in the environment, such as increasing urbanisation, deforestation and others, are sometimes unavoidable. The precautions described are usually mentioned in observing manuals of the Meteorological Services and should make it easy to adjust climate time series without any statistical testing of the series. In reality, however, a break is usually not carefully planned, but comes suddenly and unexpectedly. An observer dies or moves to another place, a thermometer breaks, the glass sphere of a sunshine recorder is stolen, etc. These, and a number of other reasons, make it impossible to document a break quantitatively, making statistical testing necessary.

Nevertheless, in spite of the difficulties of running a network according to the theoretical demands, quantitatively documented breaks do sometimes exist and are a great help in homogenising a climate time series. Three examples will be given here – one for the relocation of a temperature site, one for changes of observation hours and one for the introduction of a new observing technique.

5.3.1 Comparative measurements during a relocation

This example deals with the relocation of the thermometer screen within the Wien-Hohe Warte site. The relocation was really only a small horizontal shift of only 50m at nearly unchanged height above the ground. However, it also moved from a shaded position 1m north of the Institute building to an open position further away from the building. The excerpt from the meta file of Vienna (included in the CD-ROM) provides the following details:

1872-04 to 1899-12: Hannhütte 1 (Big Stevenson screen, 5.5m N from institute's building, ht = 1.9m above ground)

1900-01 to 1987-12: Hannhütte 2 (Same screen, distance to the N-wall of the building now only 1m), some instrument-rearrangements within the big screen: 1900 to 1937-12: ht=1.9m, 1938-01 to 1946-12: ht=1.5m, 1947-01 to 1987-12: ht=1.6m

1947-12 to 1992-12: Freilandhütte 1 (Austrian standard screen (Stevenson - screen), in a mostly unshaded position in the garden (smallest distance to building 20m), ht=1.9m

The change from "Hannhütte 2" to "Freilandhütte 1" was accompanied by long-term comparative measurements. The mean temperature differences between the two sites are shown in Fig. 5.4. They are rather small for the mean, the new open site is less than 0.1K warmer for the annual mean. There was, however, a considerable cooling, up to 0.6K in the summer, of the mean minima and a warming up to 0.8K for the mean maxima. This single break due to a minimal on-site relocation would have caused a mean annual break of the mean daily temperature range of 1.0K (1.5K in summer, 0.6K in winter).

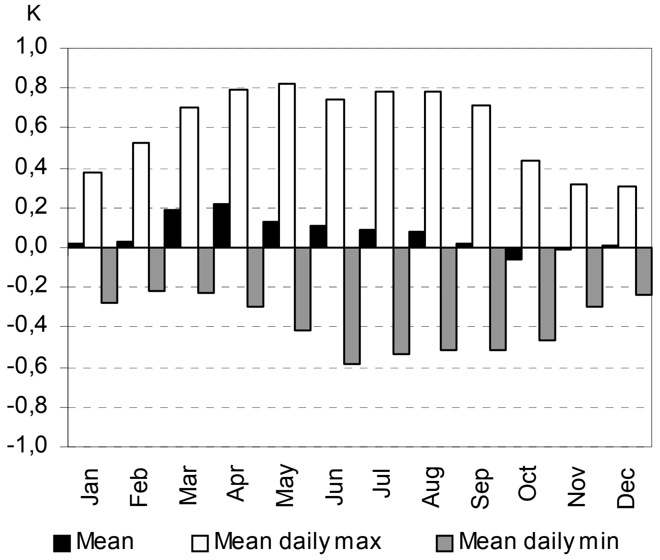


Fig.5.4. Temperature differences of two measuring sites (Freilandhütte 1 minus Hannhütte 2) of the station Wien-Hohe Warte. (Horizontal distance 50m, both thermometers in Stevenson-screens, similar altitude above ground) Sample: 1980-1986

5.3.2 Adjusting for breaks due to changes of observing time

Comparative long-term measurements, like the one for the Vienna relocation from Hannhütte to Freilandhütte, are rare and could be applied for the homogenisation of a few single cases only. For changes in observing hours, which frequently occurred in the early times of the instrumental period, a reconstruction of the mean errors based on a 10 year dataset of the automatic network could be used to adjust all “observing time” biases for the elements temperature, relative humidity, vapour pressure and air pressure. A spatial analysis of a 50-stations hourly dataset (1986-1995) resulted in mean daily courses for each month of the four climate elements for six significantly different sub-regions (extra-Alpine-rural, extra-Alpine-urban and four inner-Alpine sub-regions in 500m-altitude bands.) For one site, Vienna, a 100 year analysis showed that the mean daily course is rather stable in time. Thus, the information from the recent 10 year dataset was also assumed to be representative of earlier periods. Any estimation algorithm used during the instrumental period could thus easily be derived from the mean daily courses and used to adjust the breaks due to observing time changes. Figs.5.5 to Fig.5.8 show examples of the mean daily courses for the four elements together with the resulting breaks from some typical observing time changes. The full data of daily courses of the four climate elements for each month and for each sub-region are included in the CD-ROM (directory “METADATA”).

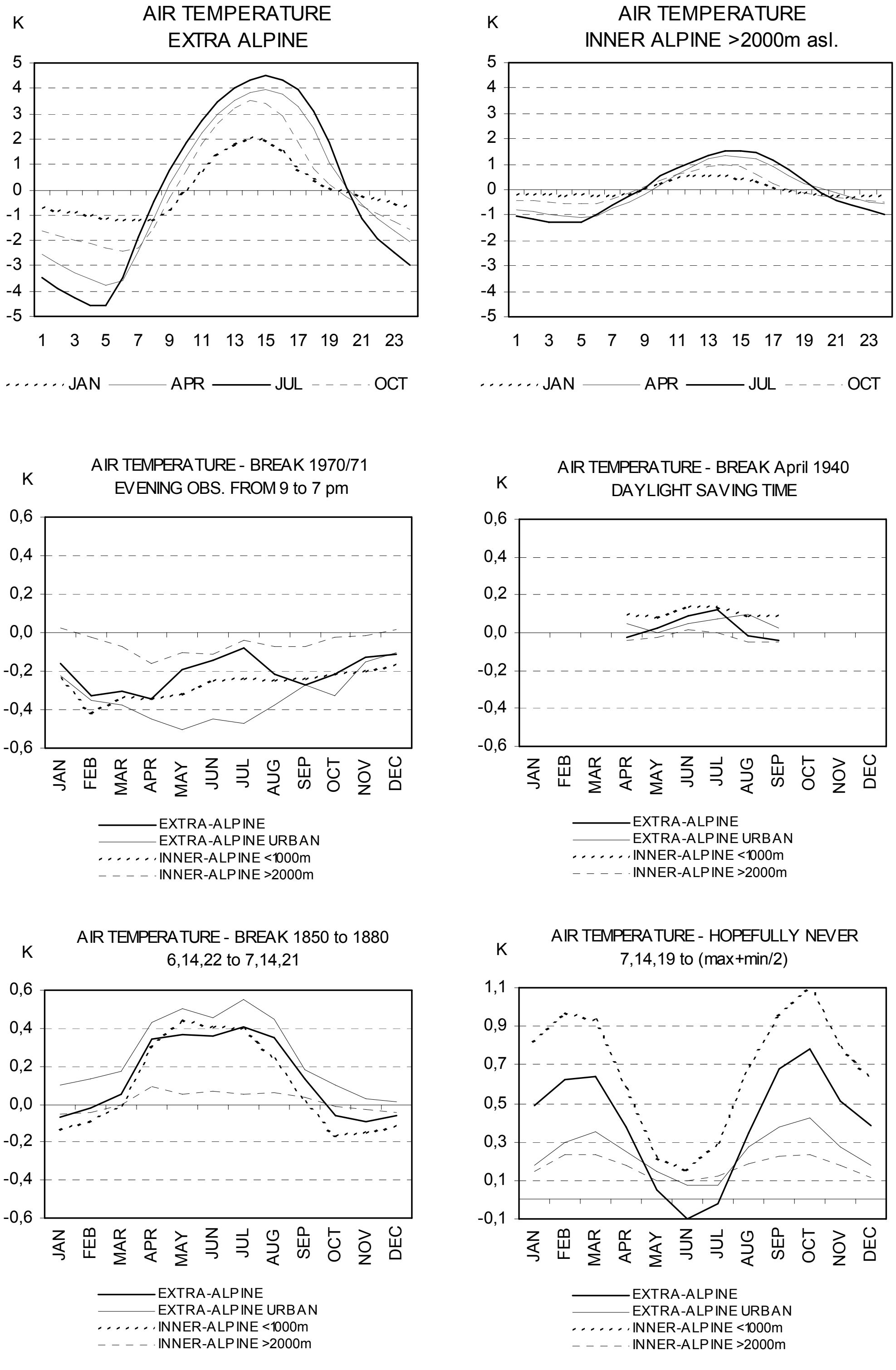


Fig.5.5. Mean daily variation of air temperature in two sub-regions of Austria for Jan, Apr, Jul, and Oct (the two Figs. top) and four typical breaks in temperature time series (new minus old) due to observing time changes for four Austrian sub-regions (the four Figs. below). Data base: Spatial analysis of a 10 years sample of hourly data of 50 automatic recording stations 1986-1995

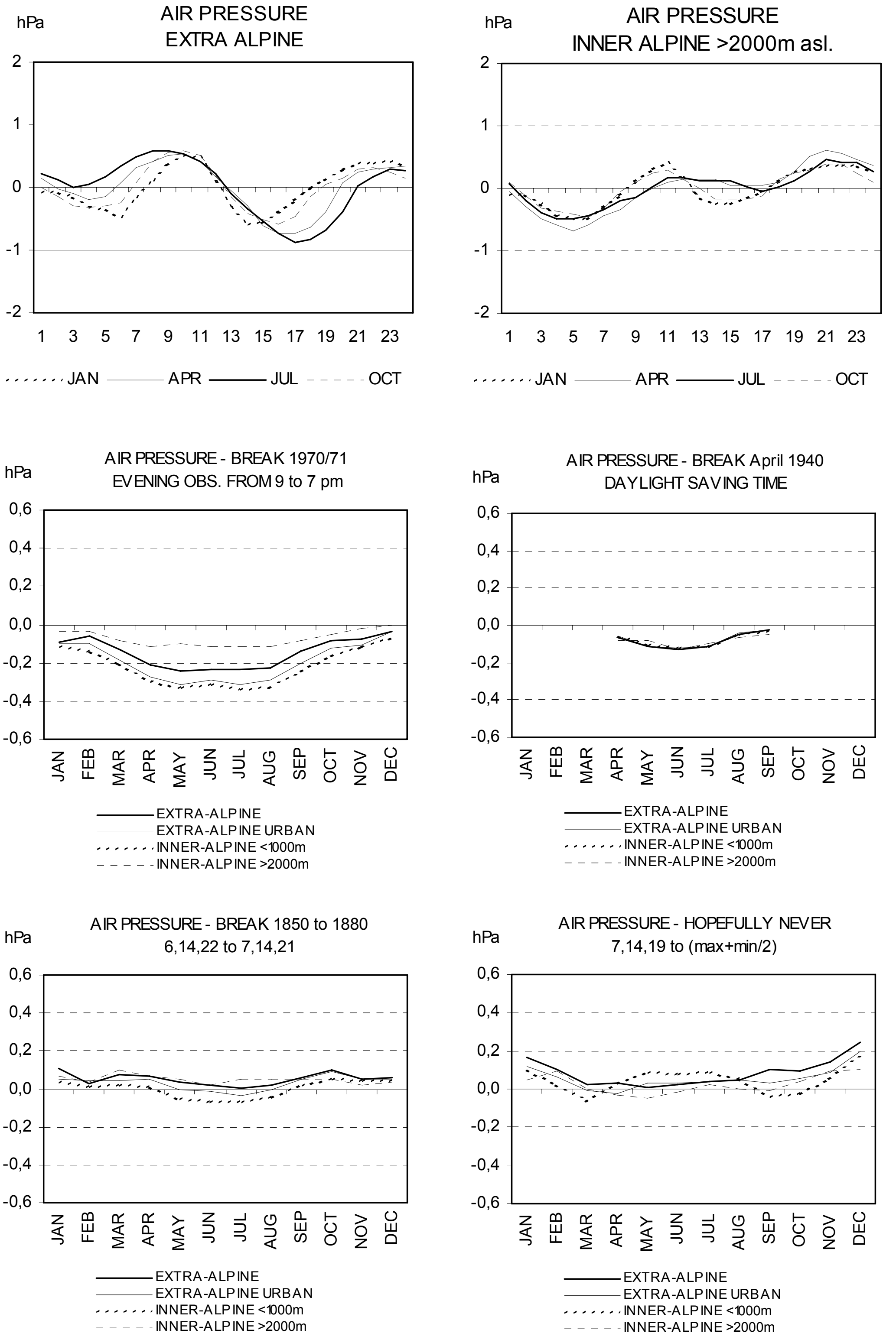


Fig.5.6. Mean daily variation of air pressure in two sub-regions of Austria for Jan, Apr, Jul, and Oct (the two Figs. top) and four typical breaks in air pressure time series (new minus old) due to observing time changes for four Austrian sub-regions (the four Figs. below). Data base: Spatial analysis of a 10 years sample of hourly data of 50 automatic recording stations 1986-1995

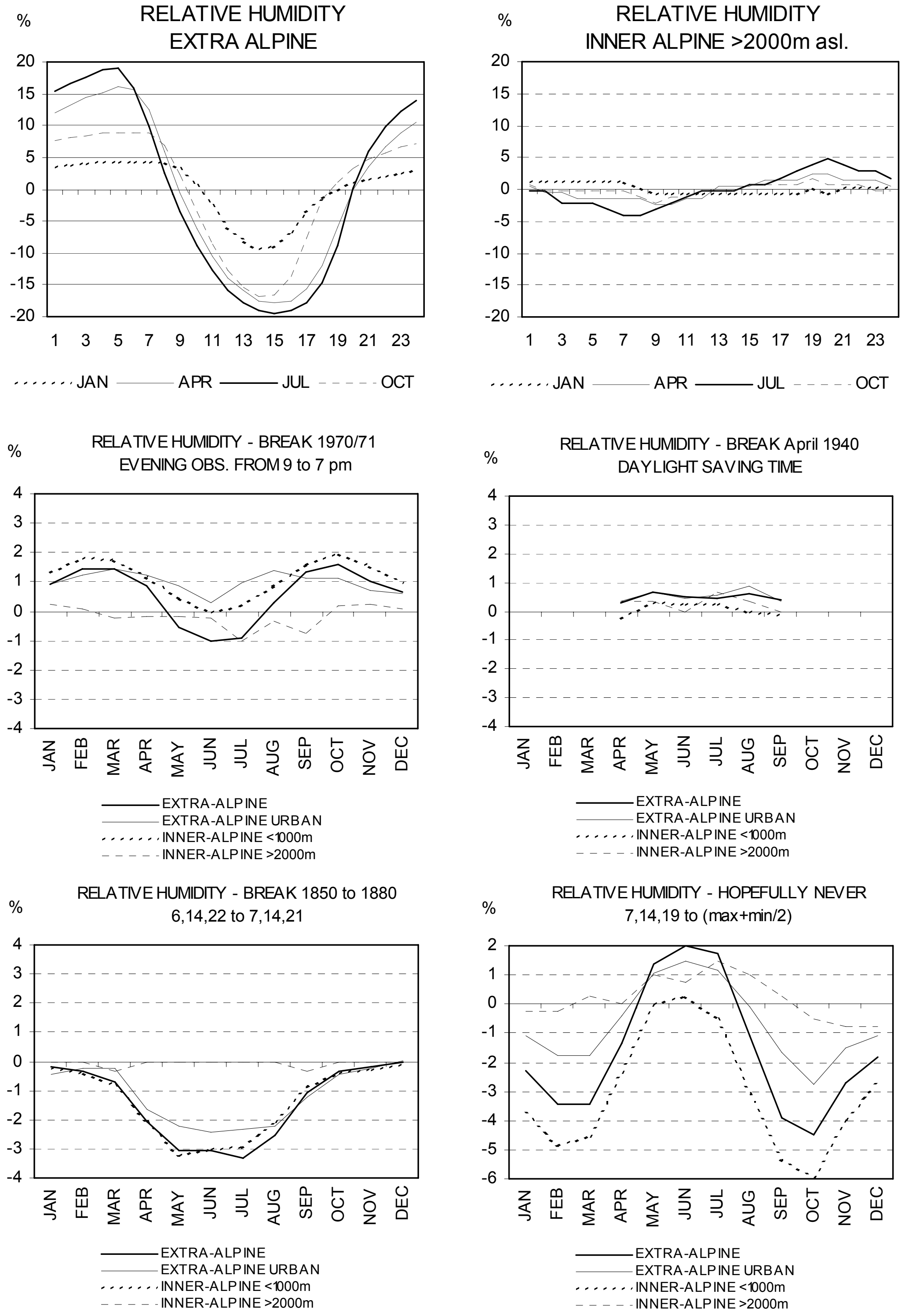


Fig.5.7. Mean daily variation of relative humidity in two sub-regions of Austria for Jan, Apr, Jul, and Oct (the two Figs. top) and four typical breaks in relative humidity time series (new minus old) due to observing time changes for four Austrian sub-regions (the four Figs. below). Data base: Spatial analysis of a 10 years sample of hourly data of 50 automatic recording stations 1986-1995

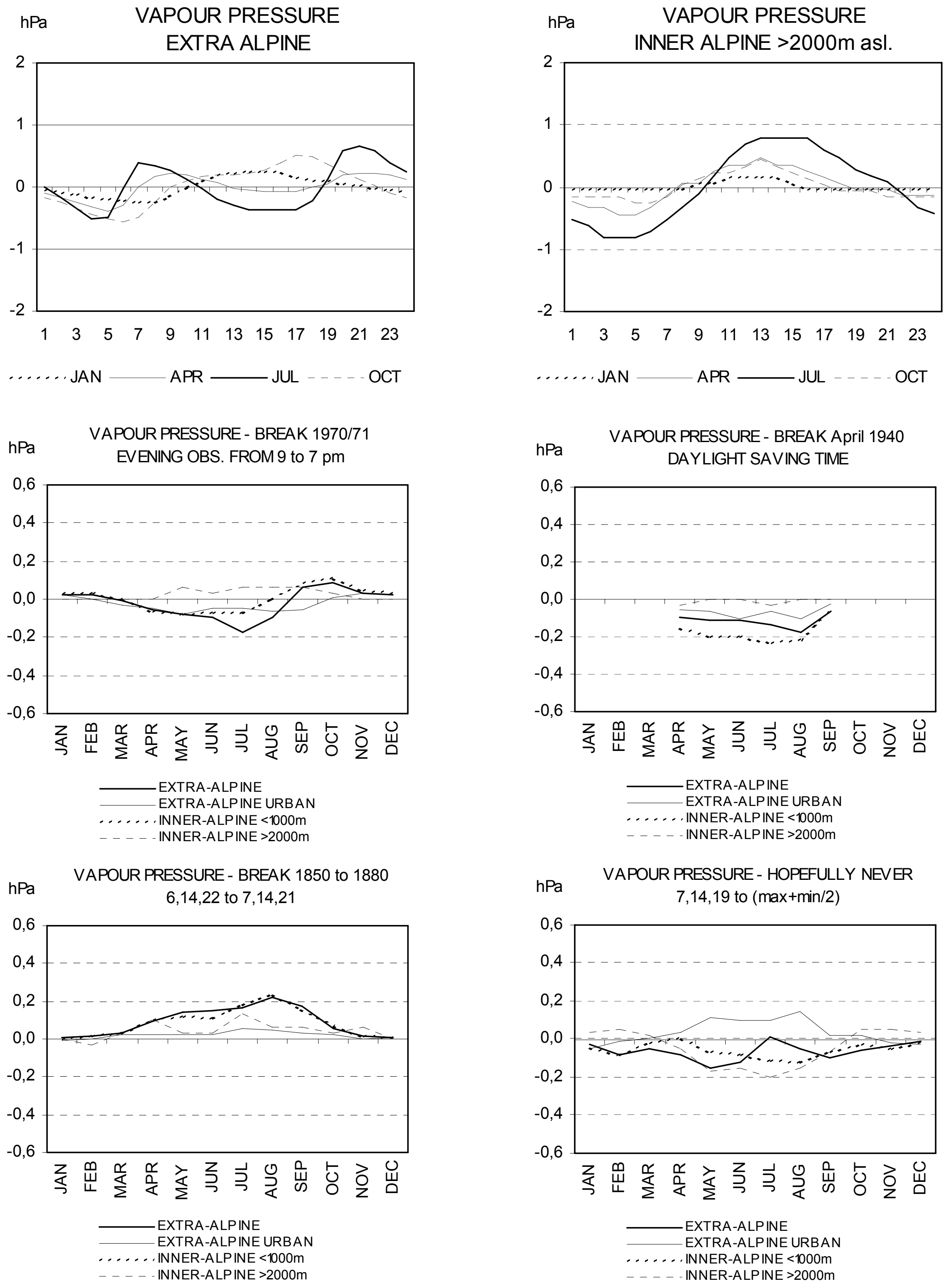


Fig.5.8. Mean daily variation of vapour pressure in two sub-regions of Austria for Jan, Apr, Jul, and Oct (the two Figs. top) and four typical breaks in vapour pressure time series (new minus old) due to observing time changes for four Austrian sub-regions (the four Figs. below). Data base: Spatial analysis of a 10 years sample of hourly data of 50 automatic recording stations 1986-1995

Mean daily courses of temperature and humidity are characterised by single waves with the strongest amplitudes at inner Alpine valleys (below 1000m asl) and the extra Alpine lowlands. The amplitudes are slightly reduced at urban sites and decrease considerably with increasing altitude. The amplitudes are strongest in summer and weakest in winter for each sub-region. Consequently, the breaks due to changes in observing time are highest in low-elevation summers, are slightly reduced for urban sites and decrease with increasing altitude. The four typical breaks shown in the Figures are:

1) 1970 to 1971 (evening observation changed from 9 to 7pm) simultaneously for the whole network;
2) April 1940 (introduction of daylight saving time) for most of the stations (some did not use DST);
3) a frequent break occurring in the late 19th century (0600h,1400h,2200h to 0700h,1400h,2100h) for many stations, but some had a different older standard;
4) a change to (max+min)/2 which did not happen (yet) for climate monthly means in Austria, but is used in some other Weather Services. (e.g. in Italy, see Servizio Idrografico, 1924-1998).

For temperature, the 1970/71 break (mean of 0700h, 1400h, 2*2100h to mean of 0700h, 1900h, max, min) caused a cooling of 0.2 to 0.4K for low level sites (strongest at urban sites), and a smaller one (less than 0.1K) at high-Alpine sites. For relative humidity, the changes were of the order of ±1%. The daylight saving time break of 1940 (only for summer months) was much less important (near 0.1K for temperature, less than 1% for relative humidity). The change to the new standard based on 0700h, 1400h and 2100h in the second part of the 19th century caused strong breaks for all low-level regions both for temperature and relative humidity, especially in summer. The new summer means were about 0.4K warmer and some 3% drier than before, in winter the changes were much smaller. At high-level sites there was nearly no break at all. The last break is a hypothetical one for Austria and may serve as a warning to avoid such a break in the future by changing to the (max+min)/2 formula for the calculation of means. A strong break in the climate time series would be the consequence with higher temperatures of more than 1K in some regions and months, and a reduction in relative humidity of up to 6%.

The mean daily variation of air pressure is characterised by a double wave structure with rather small amplitudes of 1hPa or less. The reduction of amplitude from low-level to high-level sites is less distinct than for temperature or relative humidity and also the winter-summer differences are smaller. Consequently the breaks, due to observing time changes, are also smaller. Only the 1970/71 change caused a reduction in air pressure of 0.1 to 0.3 hPa (stronger in summer, less significant in winter). The three other breaks do not exceed 0.1hPa and can be ignored. Even the (max+min)/2 formula is tolerable for air pressure.

The daily variations in vapour pressure are also small. They show interesting features with double waves in low-level summers and single waves in low-level winters and at high-level sites in all seasons. Vapour pressure is the only one of the four climate elements, which has stronger daily variations at higher altitudes. This effect (which is strongest in summer) is due to convective uplift which is the main water vapour source at high altitudes. As the amplitudes of the daily variations always remain within a band of ±1hPa the resulting breaks due to observing time changes are also small and never exceed 0.2 hPa. This is only slightly more than for air pressure, but taking into account the small short- and long-term variability of that climate element, the breaks should not be ignored.

5.3.3 Comparative measurements with different sensors

A general problem that affects climate series worldwide at the moment, is the tendency to change from manned stations to automatic networks. In Austria, automation has been rapidly developing since the mid-1980s and the day will come, sooner or later, when there will be no more manual measuring at all. Luckily, some care has been taken to reduce the influence of automation on long-term climate time series. The new temperature and humidity sensors are installed in Stevenson screens and not in new and smaller screens like in other Meteorological Services. This strongly reduces the automation breaks for these elements. For precipitation there are comparative daily manual measurements at most of the climate stations (and at each long-term ALOCLIM site). The results of the automatic sensors are not the best and there is hope that the comparative measurements will not be stopped too soon. Where air pressure is concerned the situation is not quite clear yet. Comparisons have shown rather satisfying results for certain automatic sensors, but the long-term stability of the new sensors is still in question.

For sunshine series a detailed analysis was carried out by Schöner and Mohnl (1999) based on hourly datasets of 14 sites with comparative measurements and samples of 5 to 15 years length. The traditional instrument in the Austrian service, since the 1880s, has been the Campbell-Stokes sunshine recorder. The new sunshine sensors of the automatic network are opto-electronic sensors Haenni-Solar 111B. Except for one site, Villacher Alpe, all ALOCLIM sunshine sites still use the traditional Campbell-Stokes sensors, so the described problems concerning breaks due to instrument changes, do not yet affect homogeneity. The new electronic sensors are supposed to produce better results by reducing the effects of “overburning” during intermittent cloudiness and also the losses of sunshine duration due to wet paper after foggy or rainy conditions. There are in fact, stronger differences between the two instruments, but they are not stable in either space or time. As Fig. 5.9 shows there is a distinct annual course in the inter-comparison of the two instruments with more positive values (higher sunshine totals from the new sensor) in winter and less positive or negative values in summer. The monthly breaks generally shift from mostly positive values at low level sites to more negative values with increasing altitude. The two main effects mentioned, overburning and wetting, explain well the characteristics of the breaks in Austrian climate (see Schöner and Mohnl, 1999).

In general, the breaks in sunshine series due to automation are large and far from tolerable. The range is from +20% to minus 15% and clearly exceeds the true climatic signal of the last 100 years.

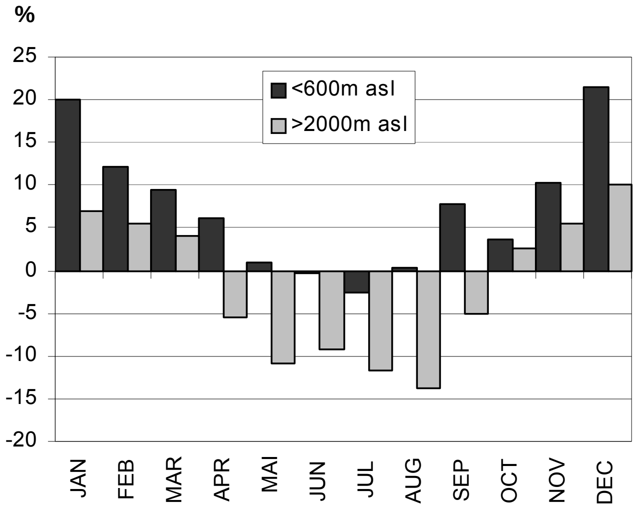


Fig. 5.9. Mean annual course of the breaks in Austrian sunshine series due a change from the traditional Campbell-Stokes recorders to the Haenni-Solar sensors of the automatic network (new minus old in %, sample 1986-1999, dark: mean of 4 low-level sites, light: mean of 3 high-level sites)

5.4 Homogenisation of non-documented break points

The following section gives some details of the homogenisation of individual climate elements.

5.4.1 Homogenisation of monthly temperature data (monthly means, mean daily extremes)

The homogenisation of air temperature series was possible back to 1767, when continuous air temperature measurements in Austria began. The high spatial persistence of air temperature results in clear break signals. As a result of the annual course of the adjustments, monthly values are necessary for homogenisation. Possible sources of inhomogeneities are:

- station relocations,
- changes of instrumentation (mercury-in-glass, liquid-in-glass, NTC, PTC),
- changes of sheltering,
- changes of height above ground, ventilation (yes or no),
- changes in observation hours, changes in calculation of means,
- changes of the surroundings (micro- to meso- scale),
- insecurities about the application of corrections, and
- mistakes in writing or typing.

Within ALOCLIM, homogenisation of air temperature was done for monthly means and monthly means of the extremes.

5.4.2 Homogenisation of monthly air pressure data (monthly means)

Homogenisation of air pressure data profited from the detailed metadata as well as the high inter-station correlation. Signals from the Craddock-curves were very clear and homogenisation was possible back to 1781 for monthly means of air pressure. Earlier measurements could not be homogenised due to the unknown temperature correction. Homogenisation values show a clear annual course. Therefore, the computation of monthly adjustment values seems to be the appropriate tool for the homogenisation of air pressure data. The main possible sources of inhomogeneities are station relocations, changes of instrumentation (correction value), changes of observation hours, changes in mean calculation, missing corrections and insecurities about corrections.

5.4.3 Homogenisation of monthly precipitation data (totals)

In contrast to air temperature and air pressure, the homogenisation of precipitation is affected by more problems. On one hand, precipitation measurements are biased by much higher measurement errors especially at high elevated sites (e.g., Auer, 1993), on the other hand, due to the high variability, the spatial correlation is much lower for precipitation compared to other climate elements. Therefore, a much denser network is necessary for homogenisation, which was available for ALOCLIM monthly precipitation sums from the pre-ALOCLIM study of Auer (1993). Based on this dataset, monthly precipitation sums could be homogenised back to 1845. The now available additional and longer comparative series from the ALPCLIM dataset (Auer et al., 2001) enabled the extension of the ALOCLIM precipitation series back to 1814. From our experience we can conclude that only lowland stations (up to 1000m asl) showed reliable results for a mountainous country like Austria. There was one exception however, which could be homogenised successfully (Auer, 1992a) – the high Alpine site Sonnblick with a dense network of wind-shielded totalisers in operation since 1927.

Metadata have been very helpful in the homogenisation of precipitation sums, however, various breaks could not be explained by the metadata. For the homogenisation of precipitation sums annual adjustments turned out to be more effective. Possible sources of inhomogeneities have been:

- station relocations (also within small distances),
- changes in surroundings (micro- to meso- scale),
- changes of instruments (shape, height above ground, heating, wind shield, single readings or recorder),
- changes of observation time, and
- mistakes in writing or typing.

Changes of other meteorological parameters, which influence precipitation measurements (e.g., wind, amount of solid precipitation), still present an unsolved problem (Forland et al., 2000).

5.4.4 Homogenisation of monthly totals of bright sunshine

Only a small number of stations with long-term series of bright sunshine in Austria exist. However, compared to other countries, Austria is in a very good position with series of bright sunshine back to 1881 - the beginning of continuous sunshine duration records in Austria. Our experience is that sunshine duration data should be homogenised by monthly adjustment values. The spatial persistence of sunshine duration is somewhat less than for air temperature but still high enough to homogenise stations which are scattered in distances of about 100km. Possible sources of inhomogeneities are:

- station relocations,
- changes of instrumentation,
- changes in the surroundings.

For the Campbell-Stokes instrument in particular (the most widely used instrument), the following inhomogeneities are possible: different types (colours) of paper (differences up to 10%), different diameter of glass-sphere, different colour of the glass-sphere, accuracy of the interpreter, accuracy of set up, servicing of instrument (rime, hoar...), and shadowing of the instrument.

5.4.5 Homogenisation of monthly cloudiness data (means)

It is a very interesting outcome of project ALOCLIM, that breaks in cloudiness data of an examined series can be found with a reference series far away from the examined series (about 100 km). This result agrees well with the finding mentioned above concerning homogenisation of sunshine duration. Records of cloudiness data go back to the earliest part of the instrumental period (about 1763). However, prior to 1840, cloudiness data were derived from the number of clear and overcast days in Austria. Thus, the accuracy of the earliest data is not satisfactory and the series had to be truncated. Breaks have been most commonly related with changes of the observers, which were well documented in metadata. Possible sources of inhomogeneities have been:

- changes of observers,
- station relocations,
- changes of the station surroundings,
- changes in observation time,
- changes of observation units (1/4, 1/8, 1/10),
- mistakes in writing or typing, and
- changes in the observation guidelines.

5.4.6 Homogenisation of monthly relative humidity data (means)

In general there have been two different methods of measuring relative humidity, namely, psychrometric and non-psychrometric systems. From metadata it is not clear when the psychrometric measurements started (see also section 4.2.6.3). However, from metadata it can be derived that, in general, humidity was measured at low level sites by psychrometers, and by hair-hygrometers at high level sites. Due to the ongoing replacement of many stations by automatic weather stations, humidity will, increasingly, be measured by non-psychrometric instruments. It was possible to homogenise relative humidity back to the 1860s. Similar to air temperature, possible reasons for breaks in the series have been:

- station relocations,

- change of measuring system (psychrometric to non-psychrometric),
- changes of instrumentation (e.g. replacements of hair –hygrometer, thermometer with mercury-in-glass or liquid-in-glass, NTC, PTC),
- changes of sheltering,
- changes of height above ground,
- ventilation (yes or no),
- changes of observing hours,
- changes in the rules for the calculation of means,
- changes of the surroundings (micro- to meso- scale),
- insecurities about the application of corrections, and
- mistakes in writing or typing.

5.4.7 Homogenisation of monthly vapour pressure data (means)

Due to the fact that vapour pressure is not directly measured, but calculated by formulae, the problems and preconditions for homogenisation of vapour pressure are the same as for relative humidity.

5.5 Possibilities of final internal homogeneity testing of monthly values

The method described uses the advantage of a multiple climate dataset. Some of the climate elements are inter-related by the laws of physics. This fact can be used for a check of homogenisation results. However, this method is based on the precondition that each climate element has been homogenised independently of the others. Two examples are selected for this kind of final homogeneity testing within this paper.

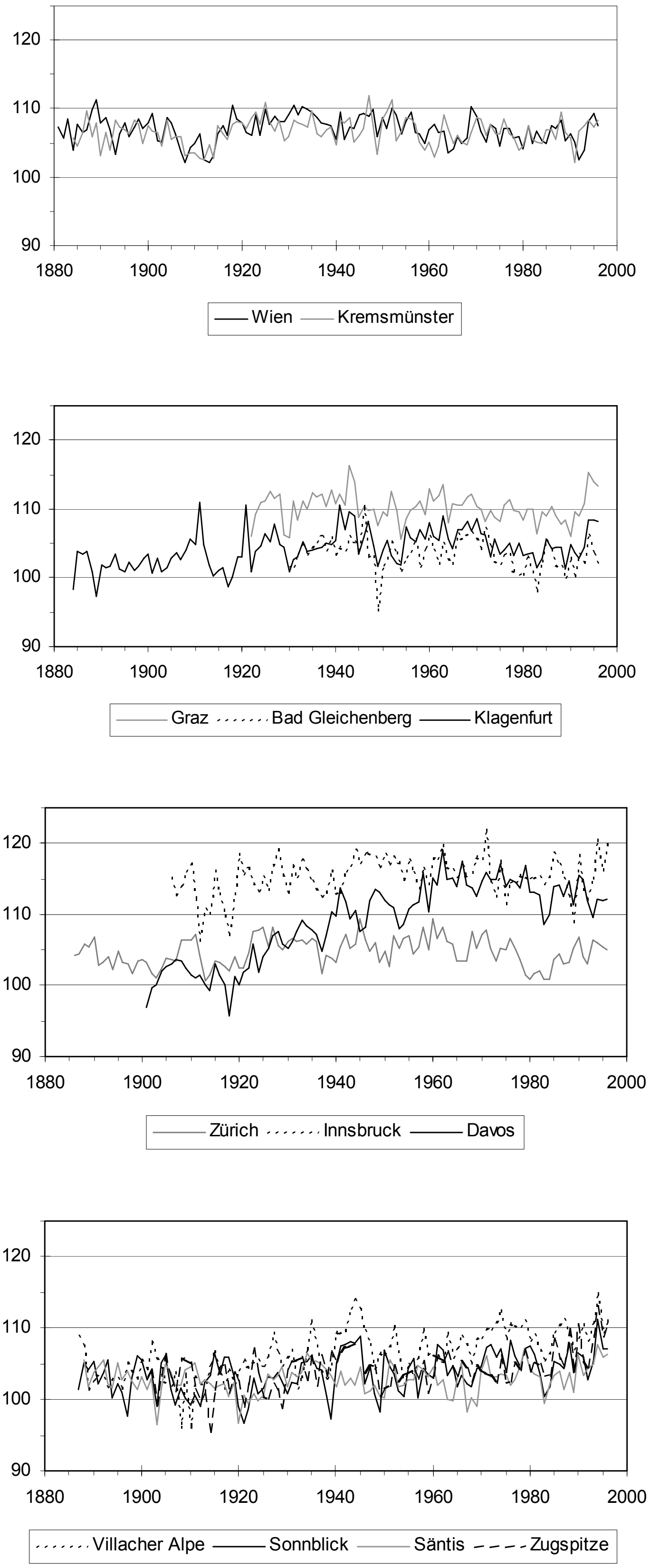


Fig. 5.10. Sum of cloudiness plus relative sunshine duration for selected ALOCLIM stations (both in percent)

Example 1 deals with the relationship between sunshine duration and cloudiness. As long as turbidity is constant, the sum of cloudiness (in percent) and relative sunshine duration should also stay constant (about 100%) (Lauscher, 1957). This kind of homogeneity testing is of special interest when referring to the question regarding the underestimation of high cloudiness at the turn of the century, for which no clear information was found in the metadata (see e.g., Schuepp, 1963, Lauscher, 1989). In Figure 5.10 the sum of cloudiness and relative sunshine duration is documented for selected ALOCLIM stations. Whereas the sum of sunshine duration and cloudiness is quite constant in time for most of the series, a strong increase can be observed for Davos during the period 1900 to 1960. Due to the special local climate of Davos and the absence of a comparable reference series, homogenisation has to be considered unsatisfactory. If examined closely, a very slight decrease in the sum-curve for low level sites since the 1940s can be seen. This fact may result from the unrealistic assumption of a constant turbidity level. For city sites in particular, turbidity increased from the 1940s (see e.g. Auer et al., 1998). Moreover, Figure 5.10 shows very clearly that there is no evidence for the underestimation of cloudiness within the period 1880 to 1997.

In example 2 (Figure 5.11) the difference between the measured and computed relative humidity is shown for the example of Sonnblick. The computed values of relative humidity were derived by the Magnus formula using homogenised temperature and vapour pressure data. All 3 elements (air temperature mean, vapour pressure mean and relative humidity mean) were homogenised independently from each other. The columns of differences between the measured and the computed value of relative humidity show, however, a clear break from 1931 to 1932. Consequently, the homogenised air temperature, humidity and vapour pressure data of Sonnblick had to be reassessed.

It should be mentioned that, in addition to these two examples, several other possibilities do exist for this kind of homogeneity testing (e.g., test of air temperature mean against mean daily maximum temperature or against mean daily minimum temperature).

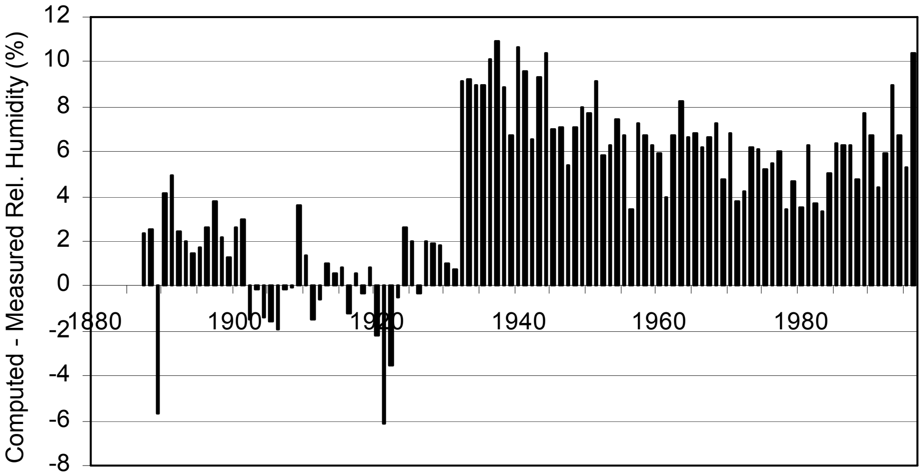


Fig. 5.11. Differences between the measured and computed relative humidity for station Sonnblick (example 2 of final homogeneity testing)

5.6 Remarks on homogenisation of daily data and monthly values derived from daily data

Within ALOCLIM, a certain amount of work was put into the homogenisation of daily data. There were some experiences from other investigations (e.g., Herzog and Müller-Westermeier, 1997). From these studies one can summarise that most investigators used the very simple method to homogenise daily values by applying monthly adjustments. We used the same method for the homogenisation of daily values of air temperature, precipitation and cloudiness with some extensions for a limitation of homogenised values. However, the final derived time series were questionable in several cases and we concluded that the method selected was too simple. As it was outside the scope of ALOCLIM to develop a more sophisticated method for the homogenisation of daily data, we adjusted the daily values of temperature, precipitation and cloudiness for six ALOCLIM stations, namely Wien Hohe Warte, Kremsmünster, Innsbruck University, Salzburg, Graz-University and Sonnblick (for Sonnblick only temperature and cloudiness). As the quality levels of the homogenised daily data do not reach those of the monthly values, continuing investigations on this topic will be necessary.

At present other research groups are progressing with the homogenisation of daily data. For example, Steinacker et al. (2000) use daily spatial data fields of climate elements (a cross validation method) for the determination of break points and adjustments. However, this method is restricted in Austria to the period since World War II when a dense network of daily data existed. As mentioned in chapter 2, most of the original daily data in Austria prior to World War II, were destroyed with the exception of the above mentioned six stations.

5.7 Analysis of adjustments

A comparison of homogenised and original series shall demonstrate what has been changed by the procedure of homogenisation and why it had to be changed. This analysis has been performed on 15 Austrian stations for 9 climate elements shown in Table 5.1. For each of these stations and elements original data and metadata are available (see chapters 3 and 4). For the non-Austrian sites there was no full metadata information and the data received from the neighbouring Weather Services were not, in each case original, but already fully or partly homogenised. Therefore they could not be included in the analysis of adjustments. The monthly adjustment values of all single breaks detected at the 15 stations are collected in the CD-ROM together with the respective causes found in their station history files (directory “DETECTED BREAKS”)

Table 5.1. Sites and climate elements used for the quantitative analysis of adjustments

		air pressure	mean temperature	mean daily max temp.	mean daily min temp	sunshine	cloudiness	precipitation	rel.humidity	vapour pressure
Bad Gastein	BGA		X	X	X		X	X	X	
Bad Gleichenberg	BGL		X	X	X	X	X	X	X	X
Bad Ischl	BIL	X	X	X	X		X	X	X	X
Bregenz	BRE	X	X	X	X		X	X	X	X
Feuerkogel	FEU		X	X	X				X	X
Graz	GRA	X	X	X	X	X	X	X	X	X
Innsbruck	INN	X	X	X	X	X	X	X	X	X
Klagenfurt	KLA	X	X	X	X	X	X	X	X	X
Kremsmünster	KRE	X	X	X	X	X	X	X	X	X
Salzburg	SAL	X	X	X	X		X	X	X	X
Seckau	SEK		X	X	X		X	X	X	X
Sonnblick	SON	X	X	X	X	X	X	X	X	X
Villacher Alpe	VIA	X	X	X	X	X	X			X
Vienna	VIE	X	X	X	X	X	X	X	X	X
Zwettl	ZWE		X	X	X		X	X	X	X

5.7.1 Causes for homogeneity breaks

Each adjusted break was compared with the metadata (see section 4.1). If a break indicated by metadata was within a range of 2 years of an adjusted break, the meta information was classified as “the cause” (or better as “one of the causes”) of the respective break in the series. A great portion of the breaks showed multiple causes. The relocation of a station for example often coincides with a change of the observer, of instruments, of altitude and others. In these cases it is not possible to determine which of the potential causes has created the break. In fact, multiple causes are common and a break is generally produced by more than one factor. Mono-causal cases have been rare, only changes in the observation hours occurred frequently as single factors. The dominant feature is that homogeneity breaks coincide with a number of simultaneous reasons.

Table 5.2 shows the analysis of 17056 years of climate series for the 15 stations and the nine climate elements. Seven hundred and ninety breaks could be detected which results in a mean length of a homogeneous sub-interval of 23.3 years. The homogeneous sub-intervals are shortest for air pressure (12.3 years) and relative humidity (14.1 years), longest for precipitation (32.7 years) followed by sunshine duration (30.7 years). Of the detected breaks, 72% can be explained by metadata and 28% are based on statistical test results only. The best metadata verification is given for air pressure, temperature and precipitation (some 80%), with a coverage of only 52%, sunshine series have the poorest metadata (but this caused no major problems in homogenising due to clear statistic test signals).

The last line of Table 5.2. underlines the fact that the most common breaks are not mono-causal but coincide with more than one “meta-break”. The average is 1.9 “metadata explanations” per data-break (minimum 1.2 for cloudiness, maximum 2.3 for mean temperature).

Table 5.2. Quantitative analysis of breaks and their causes documented in meta data files

	air pressure	mean temperature	mean daily max temp.	mean daily min temp	sunshine	cloudiness	precipitation	rel.humidity	vapour pressure	**total**	**mean**	
no. of analysed series	10	15	15	15	8	14	13	14	14	**118**		series
no. of analysed years	1992	3405	1860	1860	832	1890	1703	1708	1806	**17056**		years
mean homogeneous sub-interval	12,3	22,4	25,5	29,5	30,7	21,8	32,7	14,1	20,5		**23,3**	years
detected breaks	127	152	73	63	27	87	52	121	88	**790**		breaks
breaks explained by meta data	80	79	81	76	52	66	79	69	70		**72,4**	%
not explained	20	21	19	24	48	34	21	31	30		**27,6**	%
change of:												
location	27	39	41	41	22	22	44	22	26		**31,6**	%
observer	37	48	42	51	30	55	60	37	48		**45,3**	%
observing time	26	32				12		19	14		**20,6**	%
altitude above sealevel (>10m)	35	13	16	14			21	10	10		**17,0**	%
altitude above ground (>1m)		31	33	25			27	14	22		**25,3**	%
instrument	35	26	37	40	18		44	38	43		**35,1**	%
screen		21	30	27				16	22		**23,2**	%
shading					11							%
calibration	6											%
observing rules						2						%
%...percent of all breaks (including not explained breaks), multiple causes of one break possible												
no. of explanations per break	1,86	2,31	2,18	2,22	1,29	1,23	2,17	1,87	2,15		1,92	

The highest rate of coincidence with breaks is given for observer changes, but these 45% (min. 30% for sunshine, max. 60% for precipitation) have to be considered with great care. The 55% for cloud observation may be real causes for breaks, but for most of the other climate elements observer changes should be regarded as a complementary factor of minor importance.

If metadata are used at all as part of the homogenising procedure, the most common factor mentioned is the relocation of a site. The problem with this simple explanation is that the real factors are more diverse. Some are direct environmental changes (urban-rural, shading, altitude above sea-level etc.), others are a number of “artificial” changes in combination with a site relocation as there are new instruments, alterations in the installation of instruments (new screen, new installation height above ground…), and in most of the cases the cause of a relocation is an observer change which complicates the situation even more. Therefore, a number of the following factors often coincide with the 32% of relocations (max. 44% for precipitation, min. 22% for sunshine, cloudiness and relative humidity).

Changes of absolute height are most important for air pressure. A few meters change in altitude exceeds the accuracy of the instrument, a 8m change causes a 1hPa break (which equals the long-term centennial trend in the region). Therefore, the threshold for the metadata height statistics for air pressure was defined as 1m, for the other climate elements a 10m change was considered as the lower effective threshold. The 35% of documented altitude changes greatly assisted the homogenisation of air pressure series.

More importantly for the three temperature elements and for precipitation, is the altitude above ground (with a change threshold of 1m). For all of the breaks 27% to 33% are connected with the vertical distance of the instruments to the ground. The only problem is the frequently occurring combination of such relative height changes with changes of the temperature screen (see the respective Figures in section 4.2.7). There has been a co-evolution in the network from old metal screens fixed high above ground on shaded north-walls of buildings to free-standing Stevenson screens with thermometers 2m above ground. For relative humidity and for vapour pressure, relative height is less important, for sunshine, cloudiness and air pressure it was a priori excluded from the analysis as an obviously ineffective factor.

An interesting group is that of instrument changes. In an ideally managed network it should be of very low importance. Instrument quality should always be checked before use, corrections should be applied before data storage and the instruments should be re-checked frequently. Thus, breaks due to instrument changes should happen very rarely, only in cases of technological advance are they inevitable. There is an unpleasantly high rate of coincidence between instrument changes and inhomogeneities in the series of 35%. Sunshine series (18%) are the least sensitive in this respect, precipitation and humidity (38 to 43%) rank at the top of this scale. The statistics of instrument changes is a good example of the gap between theory and practise that is obvious in a field such as natural science measurements where the gap is expected to be extremely small.

A positive example on the other hand, is the handling of the problems due to observing time changes. They are, in most of the cases, single events not combined with other changes. Although they unfortunately exist and affect a number of climate elements (only the cumulative elements precipitation and sunshine duration and the temperature extremes are not affected), they are very well documented (see Fig.4.3) and could be removed with the simple procedure described in section 5.3.2.

The rest of the documented causes for breaks (shading, calibration and changes of observing regulations) affected single elements only and helped to explain only a few inhomogeneities, although there were some quite important ones among them.

The following points can serve as a summary to underline once more, the importance but also the problems of the time consuming step of analysing the causality of inhomogeneities in climate time series:

- The great number of non-climatic inhomogeneities clearly shows the absolute necessity of using only carefully homogenised data for long-term climate analyses. With a mean homogeneous sub-interval of not more than 23 years, centennial series are normally affected by a number of breaks – priori homogeneous series do not exist.

- In spite of the existing troubles in the special case of Austria with a considerable loss of station history information during World War II (see chapter 2), it is possible to explain more than 70% of the detected breaks from the coinciding metadata information.
- The assignment of breaks to single causes is not easy and in fact rarely exists. The typical case is the multi-causal explanation of a break. Simple explanations like “station relocation” hide a number of other causes that are the actual forcing factors in the sense of physical laws.

5.7.2 Quantitative comparison of original and homogenised series

As the adjustments of the series were applied to every single month (see section 5.1) not only the annual but also seasonal breaks and the annual course of breaks can be analysed. From the collection of all monthly adjustment values on the CD-ROM (directory “detected breaks”) some typical examples shall illustrate the annual variation and also the magnitude of such breaks.

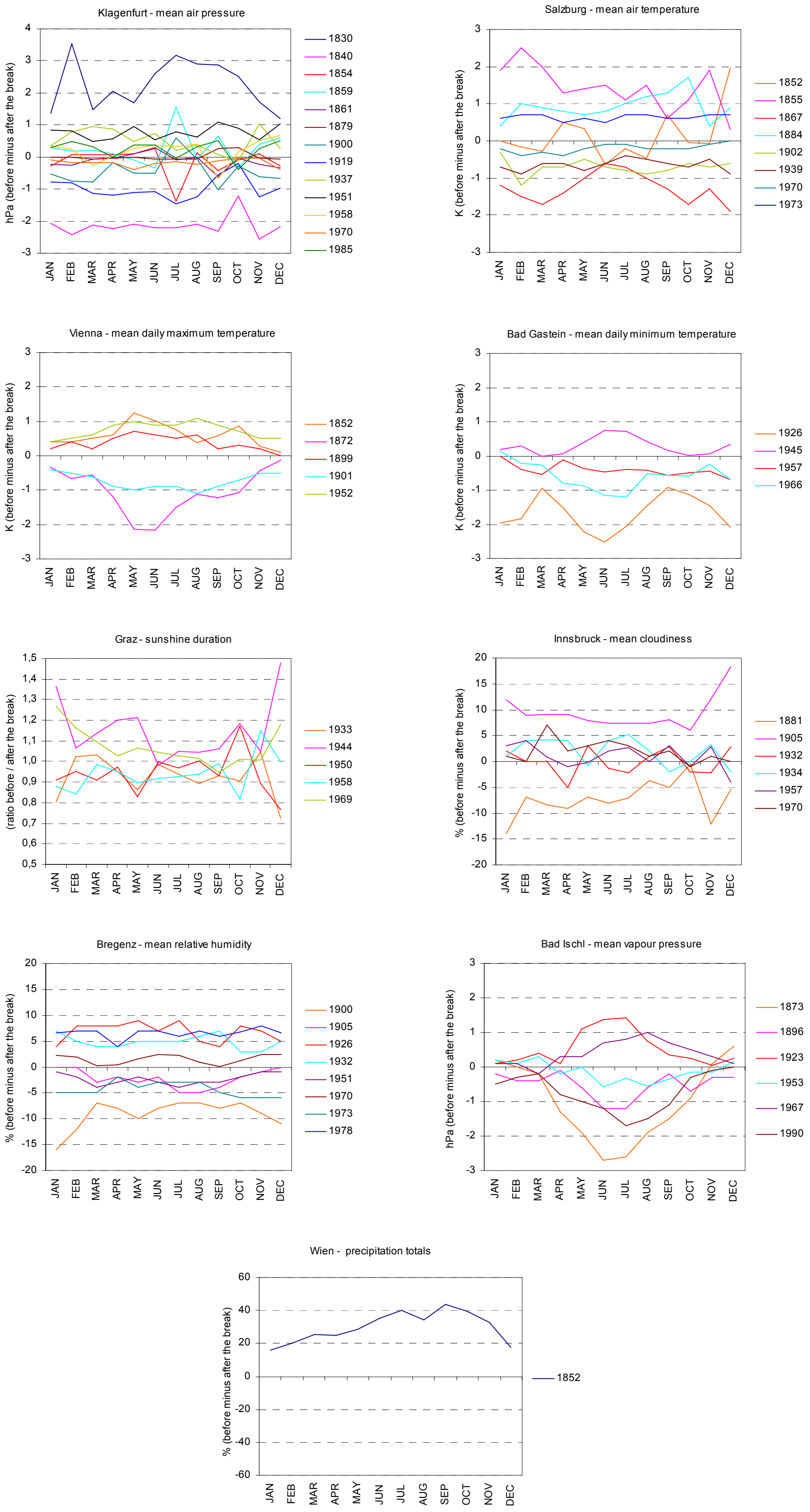


Fig. 5.12. Typical annual variation of breaks in ALOCLIM time series – one example for each climate element

The example for air pressure breaks of the Klagenfurt series illustrates the common features of that element. There are many breaks, the annual variation is low, most of the breaks are within the range of 1 hPa but some single events are near the 2 hPa margin.

The breaks in mean temperature at Salzburg show some cases with a higher annual variation compared to air pressure. There are double wave structures (1867, 1902) but also quite chaotic variations with stronger single month extremes. The breaks of the mean daily extreme temperatures of Wien and Bad Gastein are more regular than those for mean temperature. There are no cases with constant monthly breaks through the year, the typical structure is again the double wave, but single waves also occur. A good example of the latter, is the 1872 break in Vienna. This is the result of a relocation from the city centre to the recent site in the northern suburbs of the town which caused a reduction of the daily maxima of 0.5 to 1K in the cold season, up to 2K in May and June.

The typical annual course of sunshine breaks (ratios not differences) is that of lower summer and higher winter values but also a certain amount of chaotic ups and downs. Most of the breaks are within a ±10% margin but single winter months show rather strong breaks of ±20% or more. The typical annual course of cloudiness breaks is that of more or less constant values through the year within the range of 5% sky coverage. However, there are also single cases with stronger breaks of 10 to 15% and an unusual annual cycle.

It was astonishing that the two humidity elements did not exhibit as many problems as precipitation. The typical break in relative humidity series is well illustrated by the example of Bregenz with very stable but rather high adjustment factors. Five to 10% of the breaks in the series occur frequently, which again underlines the absolute necessity to homogenise the series. The homogenisation of the vapour pressure series was also based on astonishingly clear test signals. The annual cycle is always a single wave with high values in summer and low ones in winter due to the strong respective annual cycle of vapour pressure. Summer breaks often exceed 1 hPa, which is rather high compared to the typical mean summer values of vapour pressure in the Austrian climate. Winter breaks of less than 1 hPa are not negligible in relation to low vapour pressure in winter.

The annual course of precipitation breaks is the most erratic, with chaotic ups and downs from month to month, of all the climate elements. The typical magnitude is ±10% but single months with more than 20% breaks also occur frequently. Precipitation is the only climate element where the concept of monthly adjustments should be reconsidered and may be replaced by seasonal adjusting in order to smooth the monthly outliers. They are caused by the strong variability of this climate element both in space and in time which makes the limited length of homogeneous sub-intervals often too short to derive statistically stable mean adjustment factors based on the poorly correlated comparative series.

The conclusions of the analysis of the annual courses of breaks are quite clear. The necessity of homogenising could be quantitatively confirmed. The breaks equal or exceed the typical magnitude of the climate signal itself (which will be shown and discussed in chapter 6). For most of the climate elements seasonal testing is advisable in order to avoid overlooking the “masked inhomogeneities” with summer and winter breaks of opposite sign which results in a zero-break for the annual mean (or the annual total). The system of seasonal testing and monthly adjusting which was performed in ALOCLIM has quite reasonable results, only for precipitation does a smoothing of the highly variable annual course seems to be advisable for the future.

The single breaks described were removed, (as detailed earlier in this chapter) which finally resulted in homogenised time series. To describe regional to local climate variability it is currently evident that homogenisation is necessary. For larger regions it is sometimes argued that simple spatial averaging of a number of time series alone can eliminate the non-climatic inhomogeneities (which are argued to be random). The permissibility of this assumption shall be tested here for the sample of 15 ALOCLIM stations. Fig.5.13 shows the annual difference series “homogenised minus original” (or the respective ratio series for the cumulative elements) for each of the 9 climate elements and for each individual station. Fig.5.14 shows blow-ups (with enlarged vertical axis) of the summer, winter and annual spatially averaged Austrian means of the hom-ori difference (ratio) series.

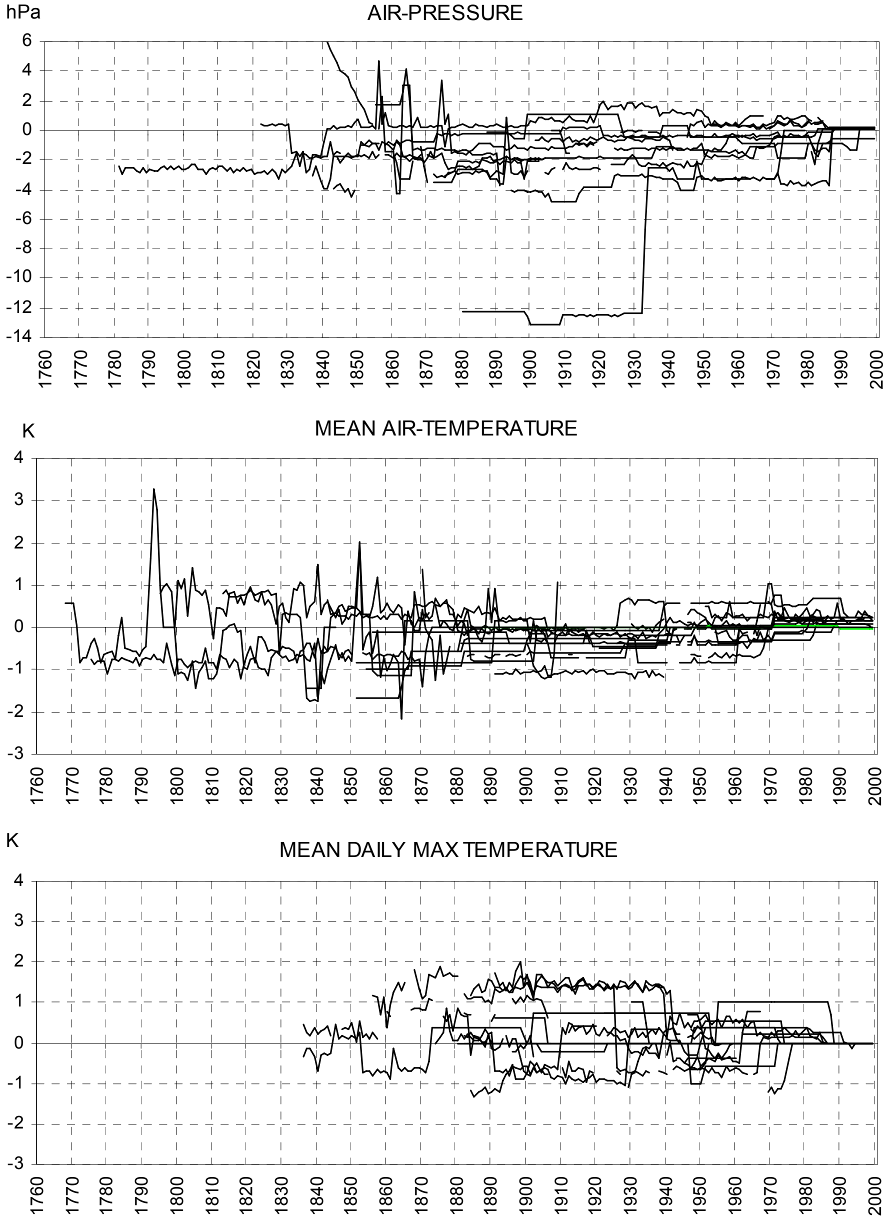


Fig. 5.13. Annual difference (ratio) series homogenised minus original for the nine climate elements of the single stations for the sample of ALOCLIM sites
(for the sample size of each element compare Table 5.1)

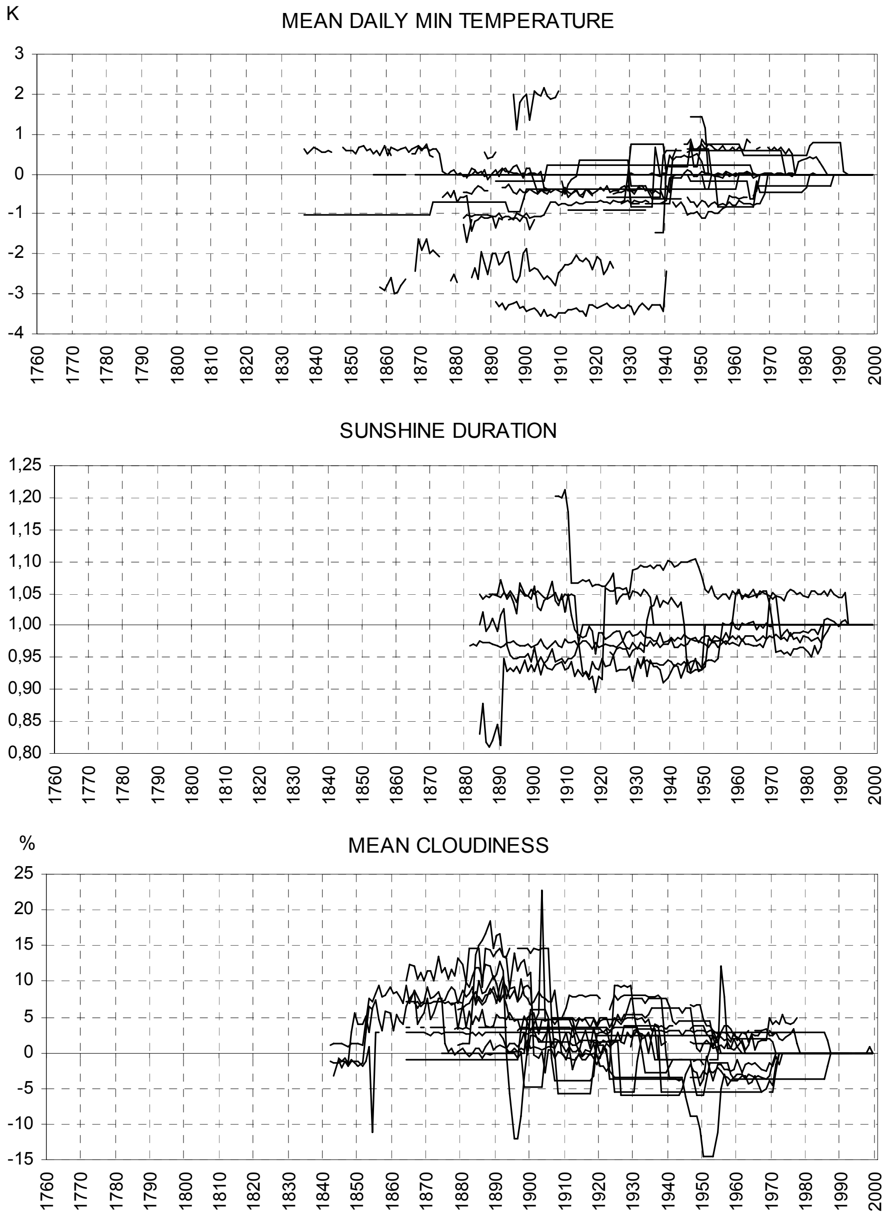


Fig 5.13. – continued

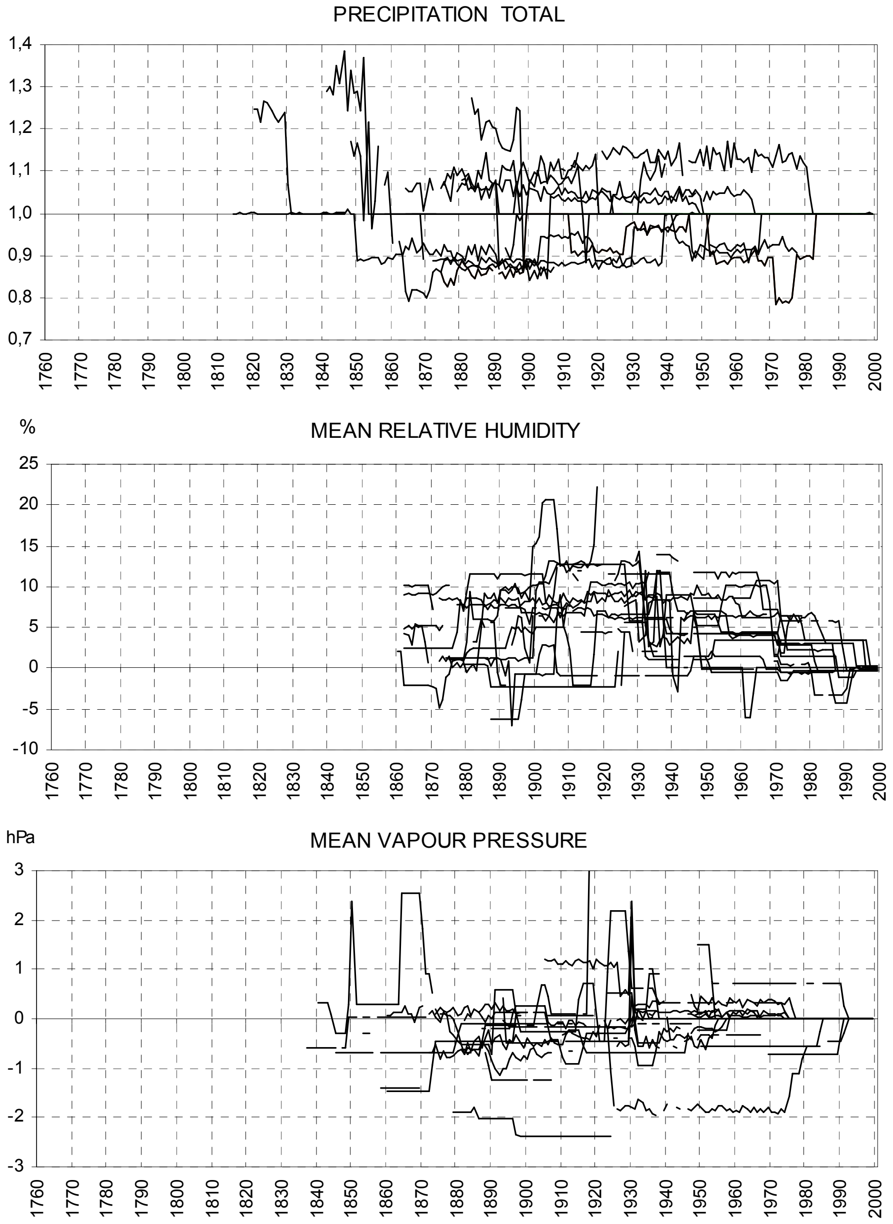


Fig 5.13. - continued

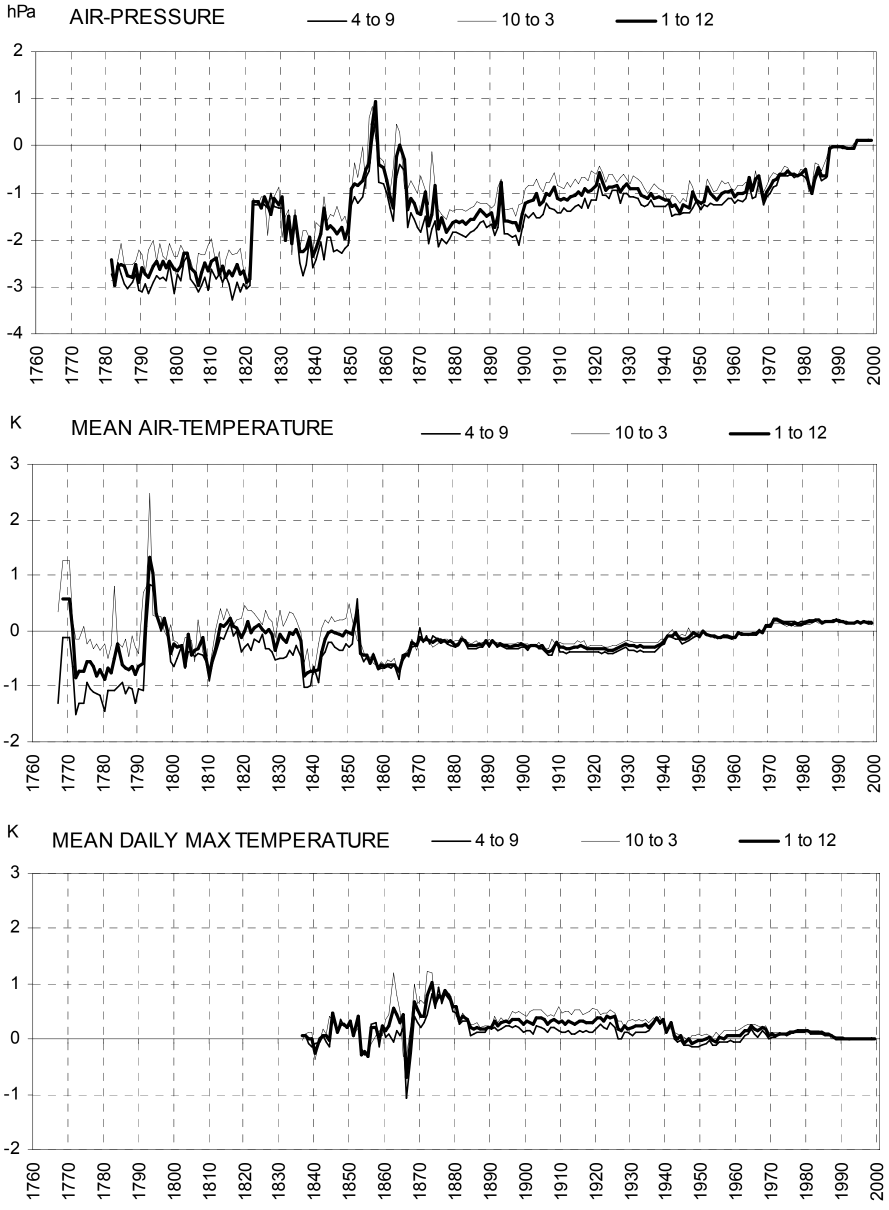


Fig. 5.14. Annual and seasonal differences (ratio) of series homogenised minus original for the nine main climate elements averaged over the sample of ALOCLIM sites
bold…annual (months 1 to 12), medium… summer half year (4 to 9), thin...winter half year (10 to 3),
(for the sample size of each element compare Table 5.1)

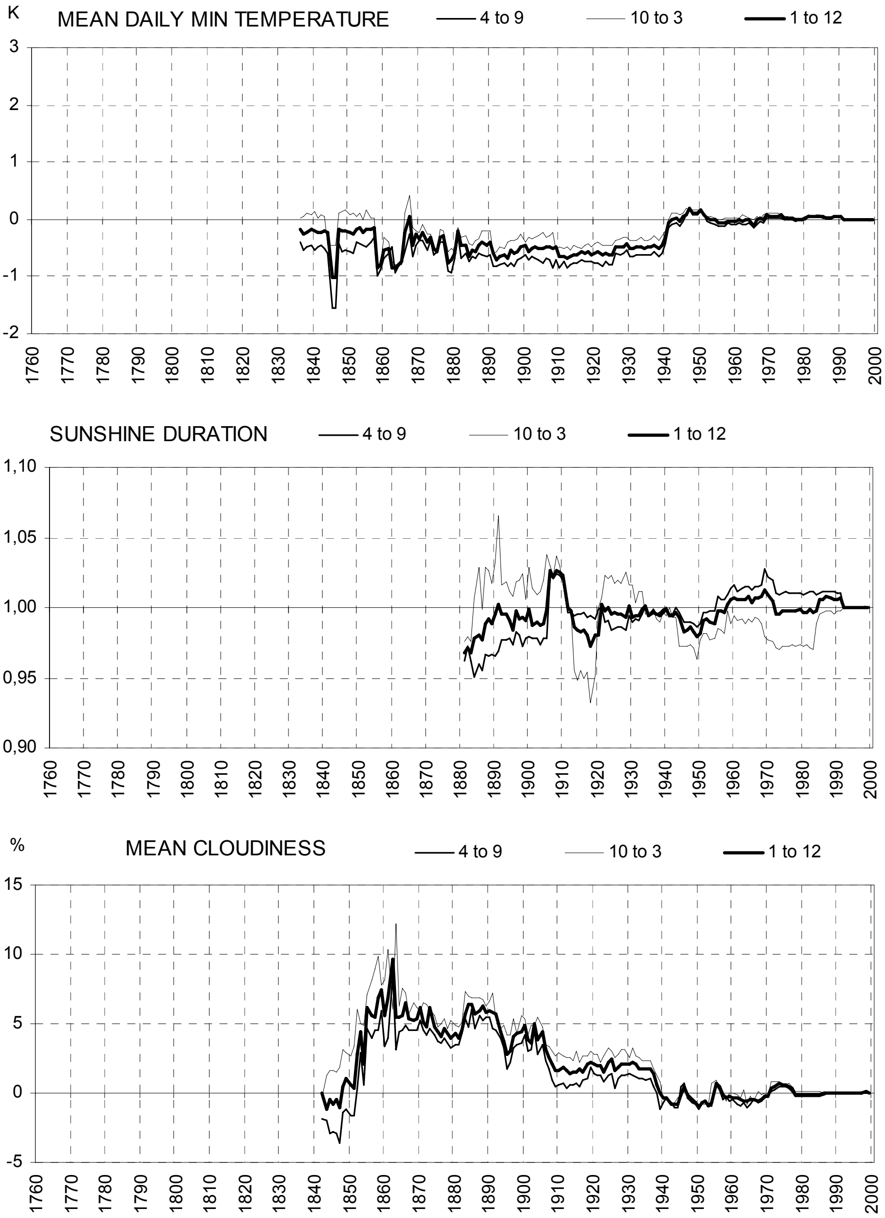


Fig. 5.14. - continued

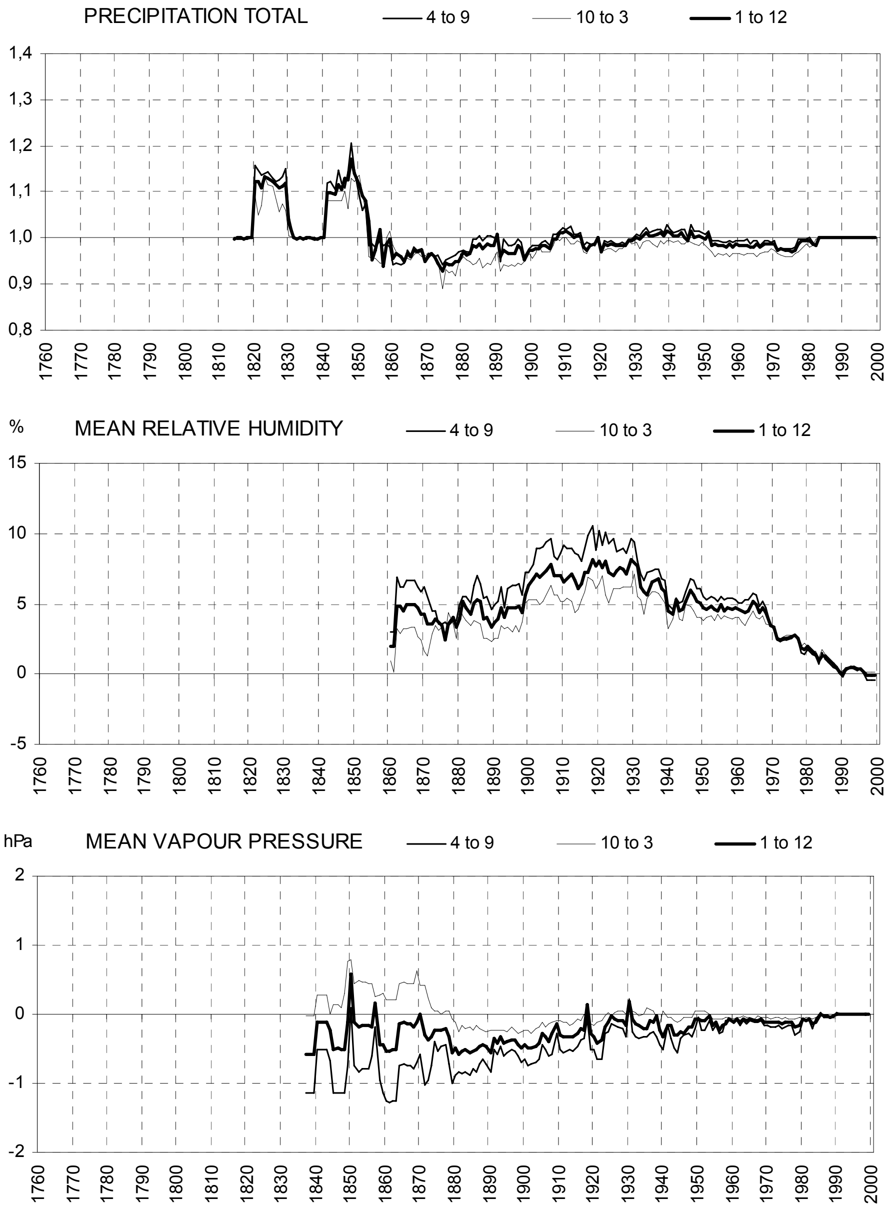


Fig 5.14. - continued

A first glance the single station series of Fig.5.13 strongly confirms, once more, the necessity to homogenise in order to acquire information about real climate variability. For each element the single breaks accumulate to provide error series which strongly deviate from zero (strong short-term outliers due to writing, typing or digitising errors were eliminated in order to avoid an unsuitably enlarged vertical axis and damped curves). The strong station to station variability of the curves seems to confirm the assumption of the randomness of the inhomogeneities. A closer look at the blow-ups of the spatial averages of Fig.5.14 however, shows that not only the individual station series but also the averages of all ALOCLIM stations are systematically biased both for shorter sub-intervals and in some cases also for the long-term trend.

A good example of a biased trend is the air pressure series in Fig.5.14. The original Austrian mean air pressure data are systematically too low at the start of the record. There are no significant seasonal differences, the bias accumulates to more than 1.5 hPa back to the 1870s and the earliest part of the series has an even greater bias, but is statistically less significant due to the limited sample size. The systematic trend of the error series back to the 1870s is climatologically of high interest because it has caused a reversal of the long-term air pressure trend from a slightly negative one in the original series, to a positive one in the homogenised series. Thus, the issue over whether the most appropriate adjustments have been applied is very sensitive. This is a point where metadata are helpful in order to confirm such systematic changes due to homogenisation. Due to the great care that has always been taken in respect to the documentation of air pressure measurements it was possible to find the most likely reason for the described effect. By chance, or due to a long-term development towards higher buildings in general, the Austrian air pressure measuring sites systematically changed their absolute altitudes during the 130 years of the series (see Fig. 4.23). The old barometers of the ALOCLIM sites were installed, on average, 10m lower than today which is, in quantitative terms, not far from the 1.5 hPa trend of the mean air pressure error curve in Fig. 5.14.

The temperature series, including the mean curves and the mean daily maxima and minima, also turned out to be systematically biased. The respective curves in Fig.5.14 show mean temperatures in the mid-19th century that are too low, and an increase to the recent values mainly in two steps which are confirmed by metadata (the early part of the series is again, not that interesting in respect to systematic effects due to the limited station number). One step occurred around 1940, the reason can be found in a number of city airport relocations (caused by the needs of World War II). World War II also caused a similar step in the degree of urbanised environment in the network (see Fig.4.9). The second step happened from December 31st 1970 to January 1st 1971 due to the change of the evening observing hours from 9pm to 7pm which was a quantitatively well documented break thanks to the existence of a dataset of continuously recording stations (see section 5.3). Both steps together caused an increase of the long-term Austrian temperature trend of approximately 0.5K which interestingly is not far from the trend difference between the (stronger increasing) Austrian temperatures and the mean global ones (for example Jones, 1994 and others).

Mean daily maximum temperatures (Fig.5.14) show original temperatures in the late 19th century that are too high and a more or less single step adjustment to the situation around the year 1940. Mean daily minima show a stronger reverse effect at the same time. Both effects were caused by the mentioned city airport relocations (from urban influenced to more rural sites) and make sense in terms of the underlying physics. Minima temperatures are warmer in the urban heat island and maxima in the urban canopy are not so high – an effect that is well known and documented by a great number of studies (for example, for the city of Vienna see Auer et al., 1989). Also, the quantity of the effect is reasonable, the minima are more strongly affected by the urban heat island than the maxima and also the 1940 step of the minima is twice as strong as that of the maxima. Both effects together (the minima values which are too low and the maxima values which are too low in the older parts of the series) caused a cumulative effect on mean daily temperature range (DTR) series. Original DTR series were too high in the early parts and would have produced a decreasing centennial DTR-trend in Austria, whereas the homogenised DTR-series show no centennial trend.

The sunshine series show a weak centennial trend of rising ratios (hom/ori), which is based on summer and mainly caused by a slight systematic under-estimation of summer sunshine in the earlier decades. Since 1970, a slight reversion of this effect can be seen. There is no evidence of the cause of this effect in metadata which may be due to the fact that sunshine metadata are the poorest of all climate elements (see Table 5.2). The lower quality of the glass spheres in the early years could be a reason for this effect but there are only a few hints about this problem in the station history files. -Yellow glass instead of the modern clear one, a less exact focus, the open question of the quality of the recording paper, could all serve as factors to reduce the efficiency of the old sunshine recorders. But the effect is very weak and, taking into account the small sample, could well be random.

Cloudiness is one of the elements with a strong long-term trend in the hom-ori difference series. If the 1840s and 50s are excluded (low station density) there is a general tendency for values to be 5% too low in the original series in the mid-19th century. There then followed a reduction in these differences and a vanishing of the effect in the mid-20th century. Again, the metadata situation is not clear enough to explain the systematic under-estimation in the first part of the series. But there are some hints that in the 19th century some strange observing rules existed concerning the estimation of high clouds. There were some discussions by Weather Service directors during the 19th century regarding whether or not to divide the observed sky coverage by high clouds by two and then add this to the medium and low clouds. It was never quite clear whether this rule was ever used in practice. If it was used, even by relatively few observers, it would qualitatively explain the strong bias of 19th century cloud series seen in Fig.5.14.

In spite of the rather strong adjustments of single station series (Fig.5.13), the average precipitation series of Austria (Fig.5.14) has not been altered systematically through homogenisation for the majority of the time series. After the strong break in the 1850s, only a slight increase of the hom/ori series from the 1860s to 1910 can bee seen which increased the hom/ori ratio from 0.95 to 1.0. The earlier part of the series (before 1853) shows the typical biases caused by two sites with precipitation gauges on high elevated platforms.

Relative humidity on the other hand belongs to the climate elements with a strong bias of the Austrian mean adjustments. For the period 1860 to the 1970s, original values were too high and had to be reduced by some 5% (with peak values of 7% in the first decades of the 20th century). Metadata coverage is not of the highest quality for this climate element and a satisfactory explanation for the under-estimation of relative humidity could not be found. Only a small part is due to the observing time change from 1970 to 1971.The automation of the network (beginning in the 1980s) may have also played a role in the case of relative humidity. Unlike other climate elements, humidity data from automatic stations had to be included in the long-term series due to an increasing lack of conventional data based on psychrometric measurements. There is therefore, no alternative other than to accept the mathematical test results as they are and to use the relative humidity series with less confidence than those elements with better metadata support.

It is surprising that the vapour pressure series do not show a similar bias as the relative humidity series. These data are only slightly biased in the first part of the series (max. 0.5 hPa in the annual mean) and has the opposite sign to the relative humidity bias. The original vapour pressure data were systematically too low, the hom-ori differences continuously increased up to zero, a point that was reached in the mid-20th century. This apparent contradiction can be explained by the fact that vapour pressure (as a measure for absolute humidity) is strongly linked to temperature and therefore, it is acceptable that the hom-ori difference series of vapour pressure are similar to those of temperature (shown in the first diagram of Fig.5.14).

Table 5.3. summarises the results of the quantitative analysis of the changes that resulted from homogenisation. It is not necessary to underline again the necessity of homogenising single series but the Table, together with what has been discussed in this chapter, shows that even spatially averaged climatic trends for larger regions may well be systematically biased due to non-climatic inhomogeneities. Several Austrian spatial mean series have been biased before homogenisation: most strongly for air pressure, cloudiness and relative humidity, and weaker for temperature and vapour pressure. Only the adjustments of the sunshine and precipitation series are random, if averaged over the whole study area. In most of the cases, reasonable explanations for the systematic biases could be found in the metadata. This makes us believe that the systematic homogenising adjustments have increased the value of the climatic series which now better describe the real climate variability and which are now considerably less disturbed by non-climatic noise.

Table 5.3. Summary of the detected systematic biases of the original ALOCLIM dataset

	element								
	air pressure	mean temperature	mean daily max temp.	mean daily min temp	sunshine	cloudiness	precipitation	rel.humidity	vapour pressure
systematic bias	yes	yes	yes	yes	no	yes	no	yes	yes
strenght of bias	***	*	*	**		***		***	*
sign of bias	+	+	-	+		-		-	+
meta data explanation	good	good	good	good	moderate	weak	moderate	weak	weak

6 Long-term climate variability of Austria described by regional time series

Since the release of the first homogenised ALOCLIM series several studies have been published by the members of ZAMG's working group on climate variability (Auer and Böhm, 1996, Auer et al., 1996 a and b, 1998 a and b, 1999 a and b, Böhm, 1998 a and b, Böhm et al., 1998 a and b, Böhm, 1999 a and b, Böhm, 2000, Brazdil et al., 1996, Schöner et al., 2000 a and b, Weber et al., 1997, Auer et al., in press). This chapter will present the final results of the homogenisation attempts comprehensively (chapters 1 to 5) for the main climate elements in the ALOCLIM region, updated to March 2000. Table 6.1 contains the names, locations, the sub-regions and the starting years of the available homogenised series. From the 485 original single element series of 86 sites and 20 climate elements, the 208 homogenised series of 56 sites and 9 main climate elements shown in Table 6.1 will be the subject of the regional climate variability presentation of chapter 6. The bold faced sites in the table are termed "multiple files" which contain 5 to 9 climate elements. Additional sites containing 2 to 4 elements, have been used to increase spatial density for the calculation of regional and sub-regional means. The series of grey shaded sites can be found on the accompanying CD-ROM, the other series are available after approval from the respective data holders.

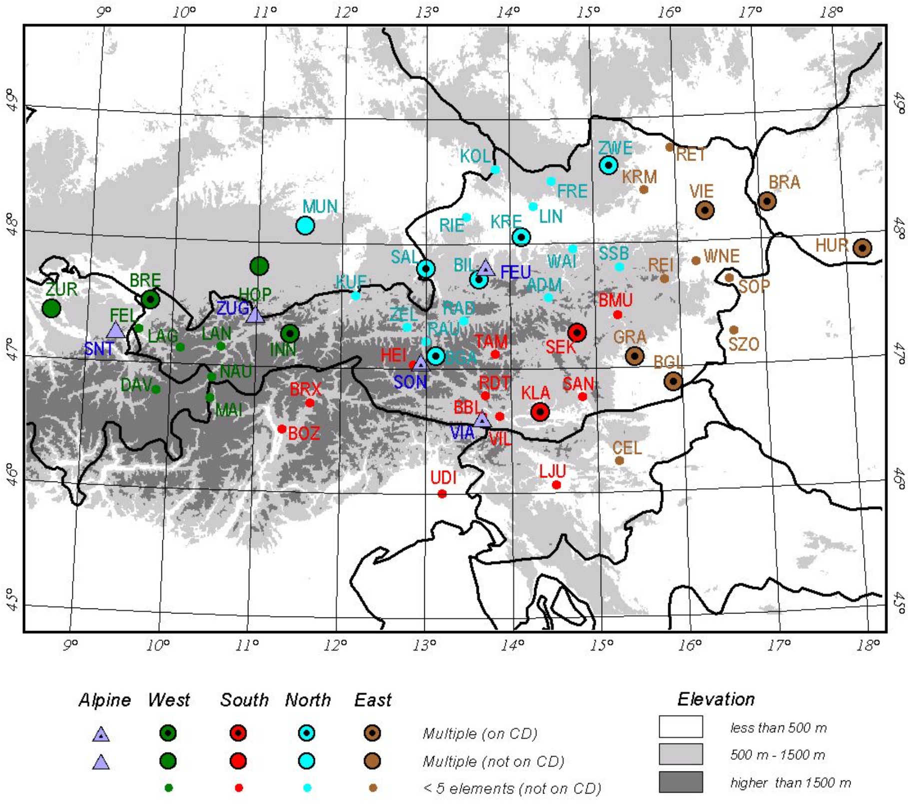


Fig. 6.1. Spatial distribution and sub-regional classification of the homogenised ALOCLIM series

Table 6.1. Starting years of the available homogenised monthly time series of nine main climate elements in the ALOCLIM region

ALOCLIM - homogenised monthly series

Name	abbreviation	country	longitude	latitude	altitude (m asl)	region	mean air pressure	mean temperature	mean daily max. temp.	mean daily min. temp.	precipitation totals	hrs. of bright sunshine	mean cloudiness	mean relative humidity	mean vapour pressure
Admont	ADM	A	14° 27'	47° 34'	646	N		1883							
Bad Bleiberg	BBL	A	13° 40'	46° 37'	907	S					1874				
Bad Gastein	**BGA**	**A**	**13° 07'**	**47° 06'**	**1100**	**N**		**1854**	**1855**	**1855**	**1858**		**1864**	**1913**	
Bad Gleichenberg	**BGL**	**A**	**15° 54'**	**46° 52'**	**303**	**E**		**1881**	**1882**	**1882**	**1879**	**1930**	**1879**	**1879**	**1879**
Bad Ischl	**BIL**	**A**	**13° 38'**	**47° 43'**	**469**	**N**	**1855**	**1855**	**1882**	**1882**	**1858**		**1864**	**1860**	**1860**
Bozen/Bolzano	BOZ	I	11° 20'	46° 30'	272	S		1850			1871				
Bratislava	**BRA**	**SK**	**17° 06'**	**48° 17'**	**280**	**E**	**1852**	**1850**	**1891**	**1891**	**1857**	**1934**		**1871**	**1873**
Bregenz	**BRE**	**A**	**09° 44'**	**47° 30'**	**424**	**W**	**1875**	**1869**	**1880**	**1880**	**1873**		**1872**	**1874**	**1874**
Brixen/Bressanone	BRX	I	11° 39'	46° 43'	569	S		1865			1878				
Bruck an der Mur	BMU	A	15° 16'	47° 25'	482	S					1876				
Celje	CEL	SLO	15° 15'	46° 15'	244	E		1900							
Davos	DAV	CH	09° 51'	46° 47'	1590	W		1901				1886			
Feldkirch	FEL	A	09° 37'	47° 16'	440	W		1875			1875				
Feuerkogel	**FEU**	**A**	**13° 43'**	**47° 49'**	**1618**	**H**		**1930**	**1930**	**1930**				**1931**	**1931**
Freistadt	FRE	A	14° 30'	48° 30'	548	N		1876			1877				
Graz-University	**GRA**	**A**	**15° 27'**	**47° 05'**	**366**	**E**	**1837**	**1837**	**1881**	**1881**	**1864**	**1922**	**1864**	**1862**	**1856**
Heiligenblut	HEI	A	12° 51'	47 02'	1315	S					1896				
Hohenpeissenberg	**HOP**	**D**	**11° 01'**	**47° 48**	**986**	**W**	**1781**	**1781**	**1880**	**1880**		**1886**		**1879**	**1880**
Hurbanovo	**HUR**	**SK**	**18° 12'**	**47° 52'**	**124**	**E**	**1872**	**1872**	**1877**	**1877**	**1871**	**1934**		**1872**	**1873**
Innsbruck-University	**INN**	**A**	**11° 24'**	**47° 16'**	**577**	**W**	**1830**	**1777**	**1891**	**1891**	**1866**	**1906**	**1866**	**1883**	**1893**
Klagenfurt	**KLA**	**A**	**14° 20'**	**46° 39'**	**447**	**S**	**1844**	**1813**	**1860**	**1860**	**1814**	**1884**	**1844**	**1860**	**1845**
Kollerschlag	KOL	A	13° 50'	48° 36'	725	N		1886							
Krems	KRM	A	15° 37'	48° 25'	203	E					1867				
Kremsmünster	**KRE**	**A**	**14° 08'**	**48° 03'**	**383**	**N**	**1822**	**1767**	**1836**	**1836**	**1820**	**1884**	**1842**	**1862**	**1840**
Kufstein	KUF	A	12° 10'	47° 35'	495	N		1896							
Landeck	LAN	A	10° 35'	47° 09'	785	W					1887				
Langen am Arlberg	LAG	A	10° 07'	47° 08'	1218	W					1881				
Linz	LIN	A	14° 17'	48° 18'	263	N					1852				
Ljubljana	LJU	SLO	14° 31'	46° 04'	299	S		1876							
Marienberg/Mte.Maria	MAI	I	10° 29'	46° 44'	1323	W		1858			1858				
München	**MUN**	**D**	**11° 33'**	**48° 08'**	**535**	**N**	**1825**	**1825**	**1880**	**1880**	**1879**		**1843**		**1842**
Nauders	NAU	A	10° 30	46° 54'	1360	W					1896				
Radenthein	RDT	A	13° 42'	46° 47'	685	S		1892							
Radstadt	RAD	A	13° 27'	47° 23'	858	N		1896							
Rauris	RAU	A	13° 00'	47° 13'	934	N					1876				
Reichenau an der Rax	REI	A	15° 50'	47° 42'	486	E		1865							
Retz	RET	A	15° 57'	48° 45'	256	E		1896							
Ried im Innkreis	RIE	A	13° 29'	48° 13'	435	N		1872			1872				
Salzburg-Airport	**SAL**	**A**	**13° 00'**	**47° 48'**	**430**	**N**	**1842**	**1842**	**1876**	**1876**	**1864**		**1843**	**1862**	**1853**

Table 6.1. – continued

Name	abbreviation	country	longitude	latitude	altitude (m asl)	region	mean air pressure	mean temperature	mean daily max. temp.	mean daily min. temp.	precipitation totals	hrs. of bright sunshine	mean cloudiness	mean relative humidity	mean vapour pressure
Säntis	**SNT**	**CH**	**09° 21'**	**47° 15'**	**2500**	**H**	**1883**	**1864**				**1888**	**1883**		**1901**
St. Andrä i. Lav.	SAN	A	14° 50'	46° 46'	404	S		1852							
St. Sebastian	SSB	A	15° 18'	47° 48'	872	N					1884				
Seckau	**SEK**	**A**	**14° 47'**	**47° 17'**	**874**	**S**		**1891**	**1891**	**1891**	**1891**		**1891**	**1891**	**1891**
Sonnblick	**SON**	**A**	**12° 57'**	**47° 03'**	**3105**	**H**	**1887**	**1887**	**1887**	**1887**	**1927**	**1887**	**1887**	**1887**	**1887**
Sopron	SOP	HU	16° 36'	47° 41'	234	E		1871							
Szombathely	SZO	HU	16° 38'	47° 16'	221	E		1874							
Stift Zwettl	**ZWE**	**A**	**15° 12'**	**48° 37'**	**505**	**N**		**1883**	**1883**	**1883**	**1883**		**1883**	**1883**	**1883**
Tamsweg	TAM	A	13° 49'	47° 07'	1012	S					1893				
Udine	UDI	I	13° 12'	46° 00'	51	S					1803				
Villach	VIL	A	13° 52'	46° 37'	493	S					1888				
Villacher Alpe/Obir	**VIA**	**A**	**13° 40'**	**46° 36'**	**2140**	**H**	**1880**	**1851**	**1882**	**1882**		**1884**	**1879**		**1881**
Waidhofen/Ybbs	WAI	A	14° 45'	47° 57'	421	N		1896							
Wien - Hohe Warte	**VIE**	**A**	**16° 21'**	**48° 14'**	**203**	**E**	**1781**	**1775**	**1836**	**1836**	**1845**	**1881**	**1842**	**1862**	**1837**
Wiener Neustadt	WNE	A	16° 13'	47° 50'	285	E					1857				
Zell am See	ZEL	A	12° 47'	47° 20'	766	N		1875			1875				
Zugspitze	**ZUG**	**D**	**10° 59'**	**47° 25'**	**2962**	**H**	**1901**	**1901**	**1901**	**1901**		**1901**	**1901**	**1901**	**1901**
Zürich	**ZUR**	**CH**	**08° 34'**	**47° 23'**	**569**	**W**	**1864**	**1864**			**1858**	**1886**	**1864**	**1901**	**1901**
number of series (all): 210			**series per element:**				**17**	**43**	**20**	**20**	**37**	**15**	**18**	**19**	**21**

bold: multiple series (5 climate elements at least) shaded: data on CD-rom

low level regions: W...West, E...East, N...North, S...South, high-level: H

Figure 6.1 shows the spatial distribution of the sites. In addition to the site information already given in Table 6.1, the map also provides information about the geographical sub-regions that will be used in this chapter. There are five sub-regions, one high elevation group (violet triangles) consisting of the 5 mountain sites and four low level regions. The pair of regions West (green) and East (brown) may display Atlantic versus continental features. The climatic differences between the groups North (blue) and South (red) - the border is the main Alpine divide – should be due to the climatic barrier of the Alps. Although there may be other arrangements of sub-regions more suitable for different climate elements, the geographical sub-division was kept constant for all elements, in order to enable comparative analysis of the different elements. A study on a more extended Alpine wide dataset based on principal component analysis (Böhm, et al., 2001) confirmed the ALOCLIM classification for temperature. It could show that for monthly temperature means, the main Alpine divide is in fact a distinct climatic border and that there does, in fact, exist a more gentle transition from Atlantic to continental climate within the ALOCLIM study region.

The following two sections summarise the climate variability of the instrumental period in the study region. This summary is based on mean seasonal and annual time series of the nine main climate elements separately (section 6.1), and combined for groups of elements with interesting interconnections (section 6.2). The basis for spatial averaging are relative series, all refer to 1961-1990 normals. This avoids breaks in the average series due to different lengths of the single series. The number of series available for each sub-regional average is given in Table 6.2. The low level group is covered by 11 to 36 single series for each climate element. The coverage of the sub-regional low-level groups is satisfactory in most of the cases. Only sub-group South (S) is covered by only one or two series for air pressure, sunshine, cloudiness, relative humidity and vapour pressure. To avoid a biased mean of the combined sub-group "low-level" due to the different number of series, the low level average was not calculated from all single series but as the average of the four sub-regional low level means. The high level sub-group is based on three to five series of the well-kept mountain observatories of the region. Only for precipitation are there no homogenised high level series available due to their unsolvable homogeneity problems (see chapter 5).

Table 6.2. Number of homogenised single series available for averaging sub-regional means

	sub-regions					
elements	W	E	N	S	low level	high level
mean air pressure	4	4	4	1	13	4
mean temperature	7	10	14	7	38	5
mean daily max. temperature	3	5	6	2	16	4
mean daily min. temperature	3	5	6	2	16	4
precipitation totals	7	7	11	10	35	0
totals of bright sunshine	3	5	2	1	11	4
mean cloudiness	3	3	6	2	14	4
mean relative humidity	4	5	6	2	17	3
mean vapour pressure	4	5	5	2	16	5

6.1 Single element series

All sub-regional and regional average series are shown in Figures 6.2 to 6.19 for the summer half year (months 4 to 9), winter half year (months 10 to 3) and entire year (months 1 to 12) as smoothed curves. Smoothing is performed by a 30-year Gaussian low pass filter with continuously decreasing filter width at the beginning and the end of the series. This technique has the advantage of not cutting the tails off the smoothed curves (for example the highly interesting, most recent years) but there are also certain disadvantages in comparing smoothed curves of different lengths. If, for example, a series starts in the middle of a minimum period, the smoothed starting tail of the curve will exaggerate the minimum compared to a longer series for which the years prior to the minimum are also included in the calculation of the smoothed value. Another effect which should be kept in mind when studying Figures 6.2 to 6.19, is caused by the fact that all series are deviations from the 1961-1990 average, the recent climatic normal period defined by WMO. This makes the curves appear to be tied together in that period and a slightly wider range among the sub-regional mean curves in the early parts of the series. This does not necessarily reflect stronger regional differences.

For each climate element two figures are shown, one for the seasonal and annual series of the four low level sub-regions and one for the respective seasonal and annual series of sub-region “low level” versus sub-region “high level”. A single year’s unsmoothed series can be found in the relevant directory of the CD-ROM.

Mean air pressure (Figs. 6.2 and 6.3)

Air pressure series are, along with mean temperature, the longest series of the region, some of them starting as early as 1781. The fluctuations of the annual low elevation series are similar throughout the whole region but some interesting contrasts become evident at higher altitudes. Air pressure series of stations below 700 m asl show two maxima with positive deviations of 0.9 hPa around 1800 and 1.0 hPa around 1990. The mean air pressure increase of the high elevation series since 1880 exceeds that of the low elevation series by far, with 1.48 hPa per 100 years for the high Alpine region and only 0.7 hPa for the lowlands. This asymmetric increase of low and high elevation air pressure has been used as a measure for the increasing temperature of the air column in between (Böhm et al., 1998). In the seasonal series, there is a distinct difference in the strength of the two main maxima. In summer the dominant air pressure maximum is the earlier one around 1800, whereas in winter the recent maximum of the 1990s far exceeds the earlier one.

Mean air temperature (Figs. 6.4 and 6.5)

Most of the regional series of mean air temperature start in the late 18th century, only the high level sub-group is shorter (1851). Horizontal low elevation groups and the two vertical sub-groups show similar features in timing dominated by a bicentennial wave with a first maximum in the early 19th century, a minimum around 1890 and the main maximum in the 1990s. The coldest periods were approximately 1 K below the 1961-1990 average, the warmest 0.7 K (in the 1990s) and 0.3 K (early 19th century) above normal. Similar to the seasonal features of air pressure, temperature also shows different weighting of the two main maxima. In summer, the main maximum in the early period (around 1800) is as high as the recent one of 1990 whereas the dominant winter maximum is the more recent one of the 1990s. Also, the main minimum is shifted from 1890 (winter and year) to the summer minimum of the 1910s.

Mean daily maximum and minimum temperature (Figs. 6.6 to 6.9)

Series of temperature extremes start as early as the 1830s. In general, both minimum and maximum series are similar to the series of mean temperature but there are some slight but systematic peculiarities. The summer maximum curves have slightly stronger amplitudes on the decadal scale than summer minimum curves and a similar but weaker, effect is given for the winter minimum vs. the winter maximum curves. In general, there are only minor regional differences concerning horizontal as well as vertical subgroups, with the one exception, a smaller long-term increase of mean daily maximum temperatures in the West (W) region. The question about eventual trends of the difference series (the mean daily temperature range) is will be discussed in section 6.2 of this chapter.

Precipitation totals (Figs. 6.10 and 6.11)

Homogenisable precipitation series start in the early 19th century in the study region (Klagenfurt 1814, Kremsmünster 1820, Udine 1803). Regional means have been calculated since 1814. In contradiction to air pressure and temperature, precipitation series show significant sub-regional differences. The “Atlantic” sub-region West (W) shows a long-term increase of precipitation in summer and in winter. In region North (N), there is a high precipitation level prior to the 1860s in summer, a weaker maximum in winter and a strong drying towards the 1860s, which are the driest summer years in all four sub-regions. The first part of the 18th century was very wet in the South (S) in winter, but less so in summer. After the mid-19th century minimum, the “Atlantic” sub-regions, West and North, are characterised by a long-term increase of annual precipitation totals which is mainly caused by winter precipitation. The more continental subgroups, East (E) and South, also start with low precipitation amounts in the 1860s, and quickly increase in the subsequent year, and remain at a high level for more than 5 decades followed by a drying trend until the 1980s (followed by first signs of a recovery since then). The regional differences are more pronounced in the winter half of the year and there are also some local short-term variations superimposed over the described long-term trends. Vertical differences cannot be studied systematically due to the described problems in homogenising high level precipitation series (see chapter 5). Only one site with a short series, the high-level Sonnblick totaliser network starting in 1927 (Auer, 1992b), could show that in this specific case there were no significantly different precipitation trends of the high elevation series versus the surrounding valley series.

Totals of bright sunshine (Figs. 6.12 and 6.13)

The most striking feature of the sunshine series is a difference between the long-term evolution of the high level and the low level series. Although the features of the low elevation stations show only minor differences among them, the high elevation curves do differ significantly from the low elevation sites. With their centennial increasing trend of bright sunshine hours, high elevation stations show a strong parallel with temperature curves. In contrast, this similarity is not true for low elevation records. The second half of the recent century is especially characterised by a reduction of sunshine at low elevation sites, a significant trend of 1.6 hours per year of the difference series of high and low elevation stations becomes obvious. The effect is similar in winter and in summer. This effect has been the subject of a study (Auer et al., 1998a) which discusses an increase of boundary layer turbidity as a potential cause.

Mean cloudiness (Figs. 6.14 and 6.15)

Initially, the cloudiness and sunshine series seem to be anticyclical elements and thus the subjectively estimated cloudiness series could provide needless repetition of information already acquired by the more precise instrumentally measured sunshine series. These arguments are only partly true. Concerning quality in terms of homogeneity, the problems concerning the cloudiness series were not substantially greater than those of the sunshine series. Moreover, there are also differences concerning different observing times (three times a day constantly throughout the year for cloudiness, and totals over a variable day length for sunshine) and concerning the length of the series (which are considerably longer for cloudiness).

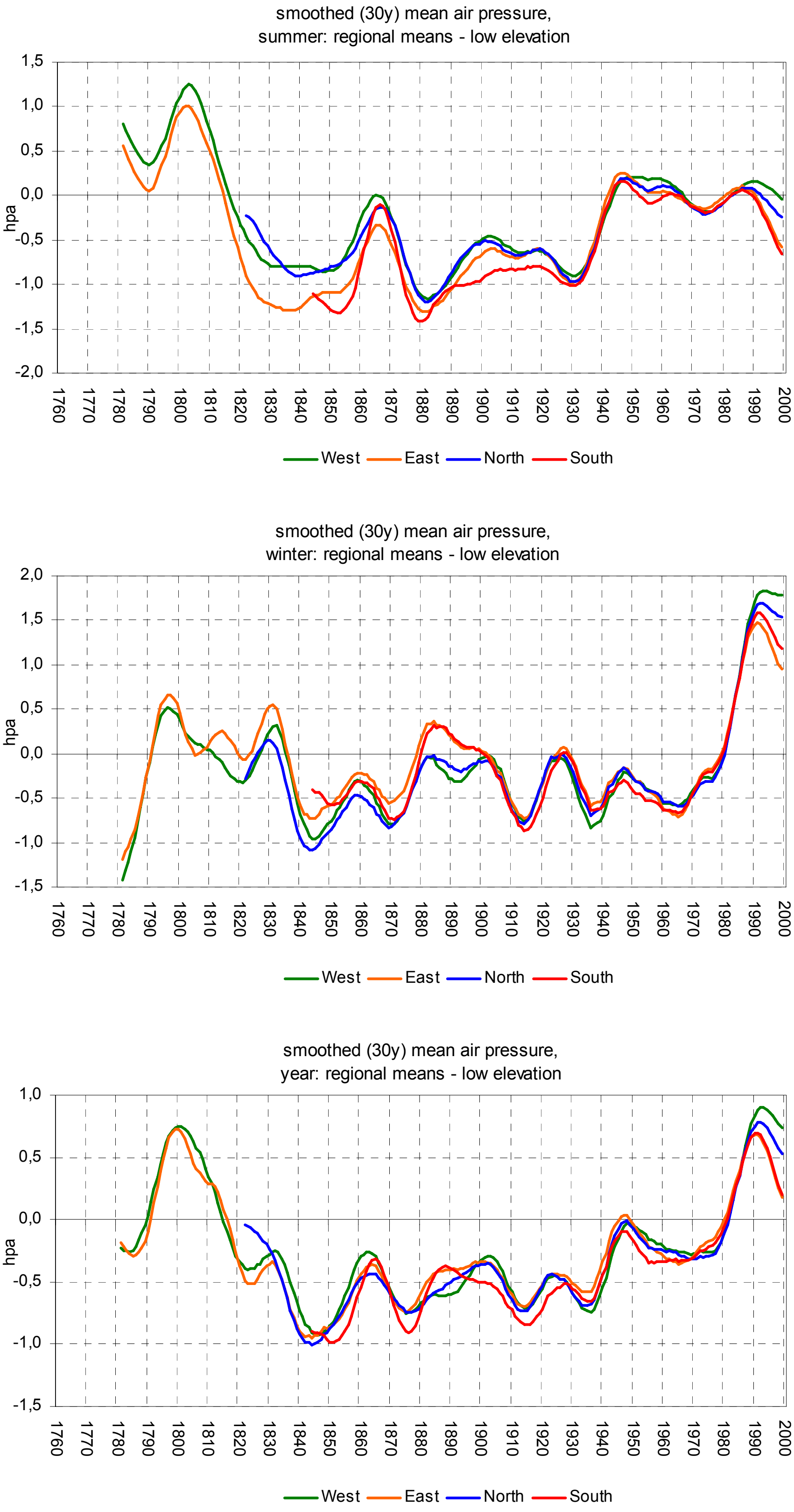
Homogenised cloudiness series start before 1850 in most of the sub-regions. There are some interesting regional differences with a long-term increasing trend of the annual means in the West, no trend in the North and decreasing cloudiness in the continental sub-regions, East and South. These regional features are more pronounced in winter than in summer and there are of course a number of superimposed short-term oscillations on a decadal scale. The vertical structure of the time series is less clear than it is for the sunshine series and cannot be used to explain the described relative increase of high level versus low level sunshine series.

Mean relative humidity (Figs. 6.16. and 6.17)

Since the 1860s, the starting decade of most of the regional series, the main feature of relative humidity is a decreasing long-term trend of the annual low level means with local differences in strength – weaker in the West, stronger trends in the South, East and West. This decrease occurs in summer where it oscillates and in winter where it is steadier – with greater regional differences in summer. Concerning the vertical structure, there is a remarkable deviation of the high level series which show no long-term decrease of relative humidity neither for the annual means nor for the single seasons. The deviation from the low level decreasing trend is strongest in summer and less pronounced in winter.

Mean vapour pressure (Figs. 6.18 and 6.19)

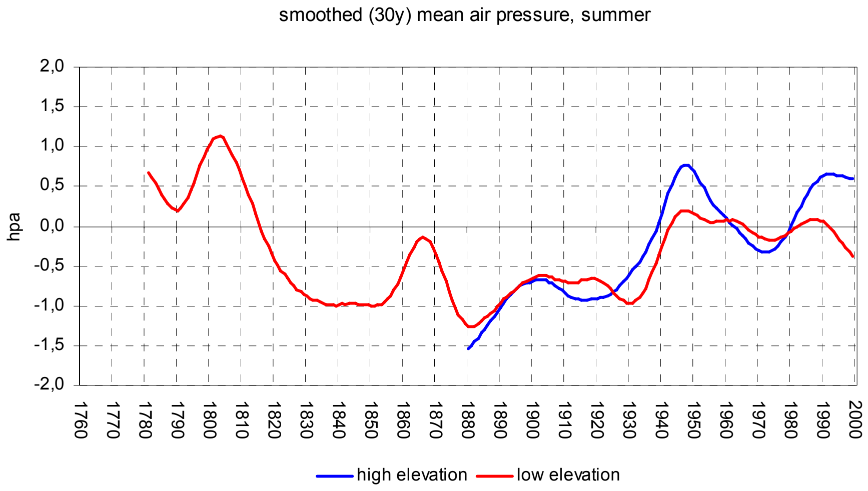
Vapour pressure – a measure of absolute humidity – shows a general increasing long-term trend that is mainly visible in the annual and summer series. As a result of the distinctive annual cycle (with near to zero values in winter) the variations and trends of the winter curves are much smaller and the annual curves mostly reflect summer vapour pressure. The general increasing trend in summer and for the year as a whole, is superimposed by two and a half rather regular oscillations with relative minima in the 1850s, the 1910s and near 1980, and the respective relative maxima are found in the 1870s and 80s, the 1950s. In absolute values (hPa) there are no vertical differences between the low level and the high level series. Considering the much lower vapour pressure in the colder mountain air of the high level observatories, the similar increase in absolute values in fact means a much stronger relative increase of the high level versus the low level vapour pressure.

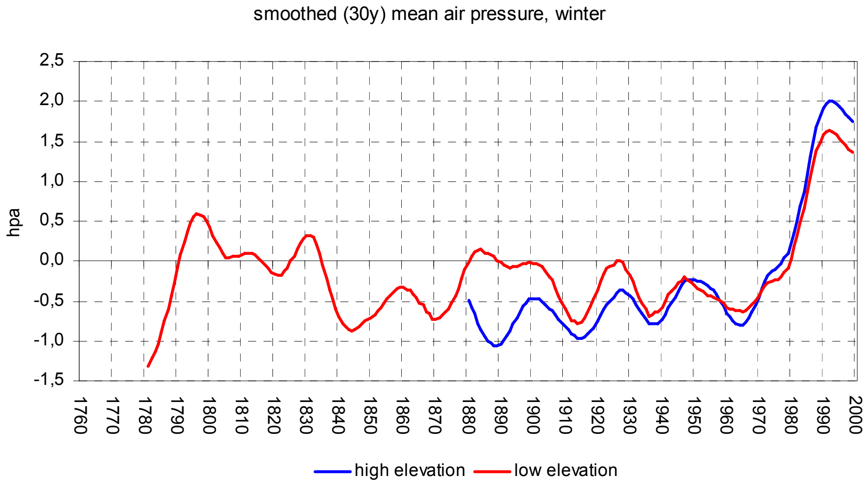

smoothed (30y) mean air pressure,
summer: regional means - low elevation

smoothed (30y) mean air pressure,
winter: regional means - low elevation

smoothed (30y) mean air pressure,
year: regional means - low elevation

Fig.6.2. Smoothed seasonal and annual mean air pressure series for the ALOCLIM low level sub-regions. Summer half year (months 4 to 9), winter half year (months 10 to 3, displayed at the year with 10 to 12), year (months 1 to 12), smoothing with a 30-years Gaussian low-pass filter, relative to 1961-1990 average


smoothed (30y) mean air pressure, summer


smoothed (30y) mean air pressure, winter

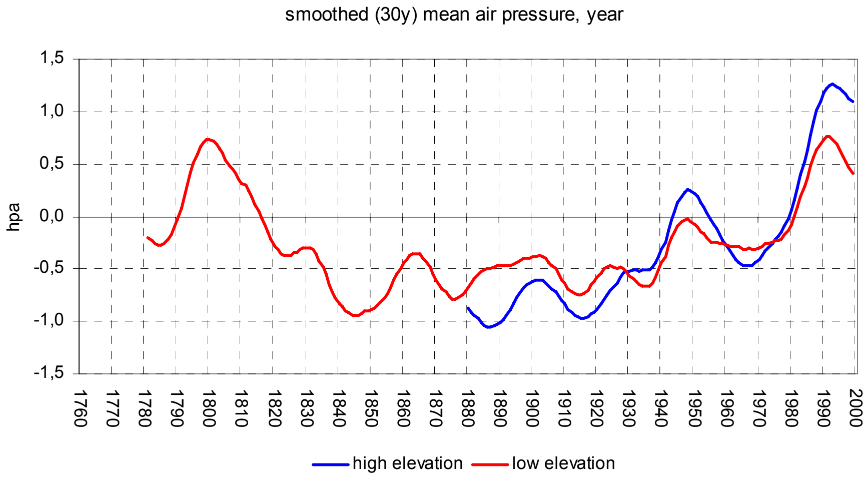
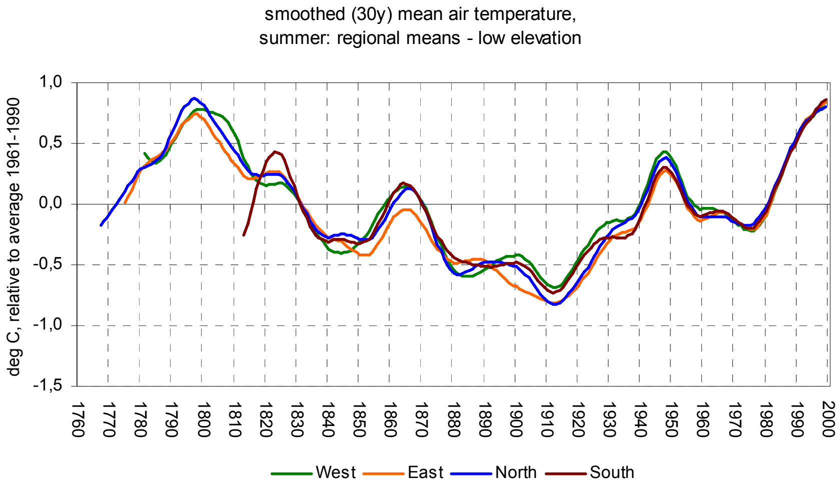
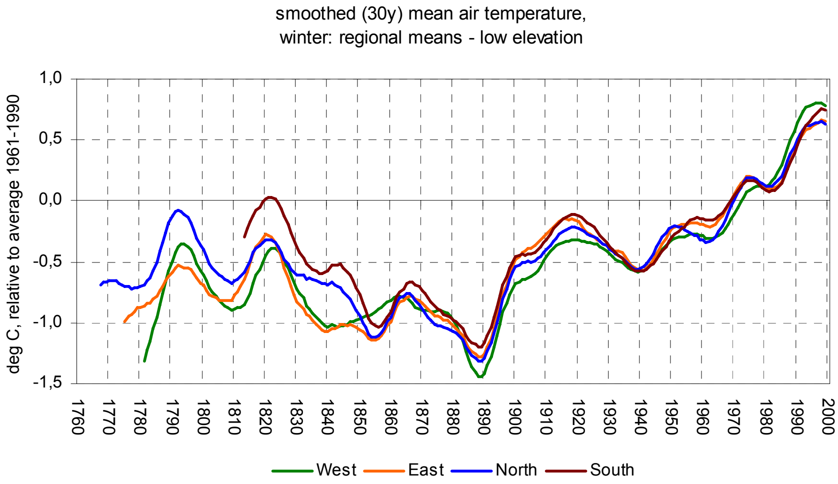

smoothed (30y) mean air pressure, year

Fig.6.3. Smoothed seasonal and annual mean air pressure series for the ALOCLIM low level mean and the ALOCLIM high level mean. (Seasons, smoothing and reference period according to Figure 6.2)


smoothed (30y) mean air temperature,
summer: regional means - low elevation


smoothed (30y) mean air temperature,
winter: regional means - low elevation

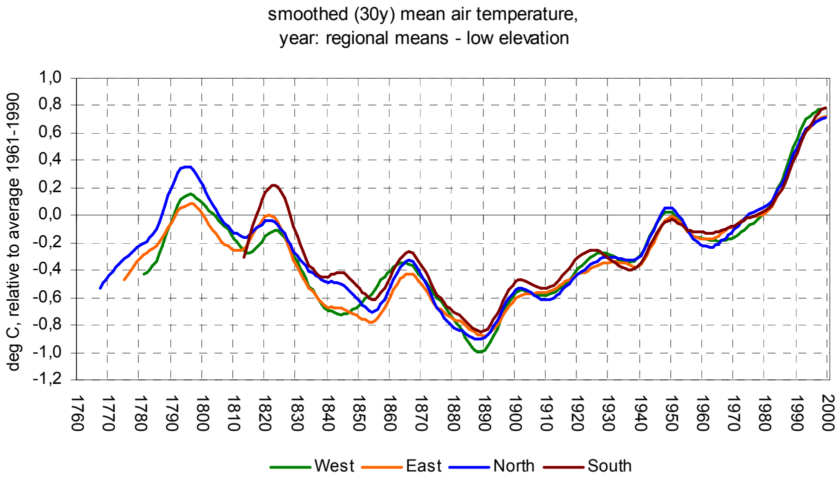

smoothed (30y) mean air temperature,
year: regional means - low elevation

Fig.6.4. Smoothed seasonal and annual mean air temperature series for the ALOCLIM low level sub-regions. (Seasons, smoothing and reference period according to Figure 6.2)

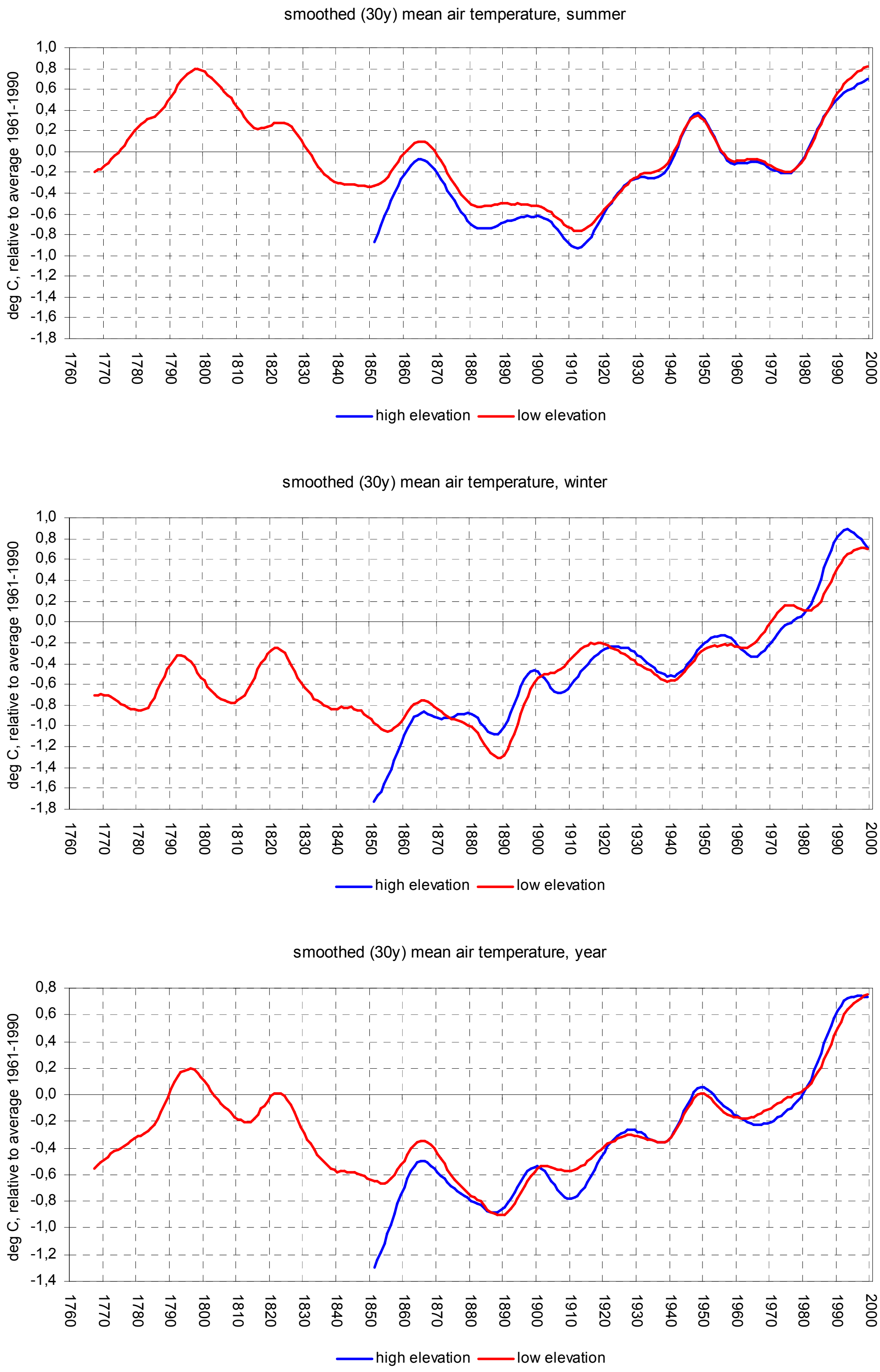
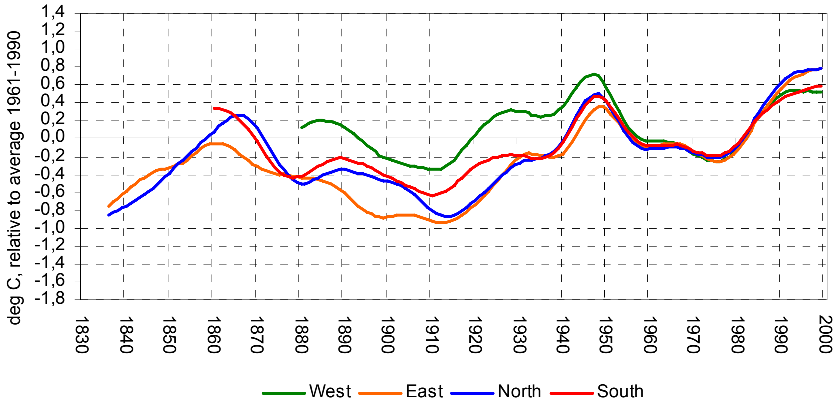
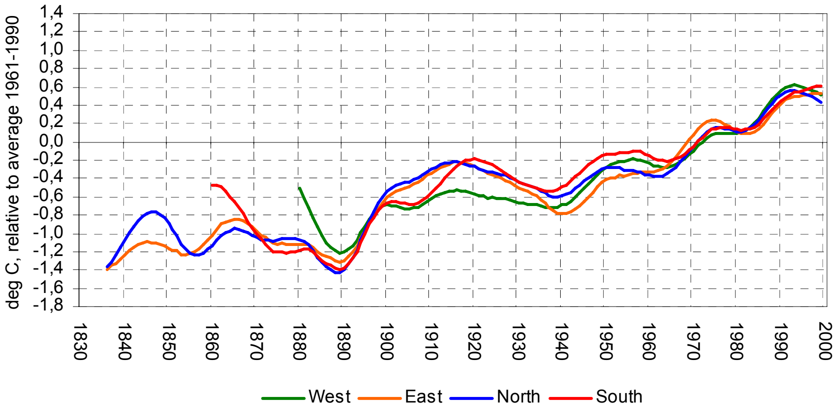


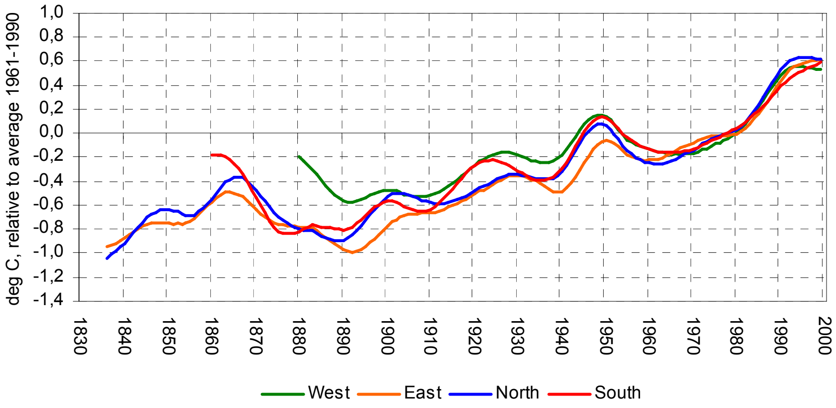
Fig.6.5. Smoothed seasonal and annual mean air temperature series for the ALOCLIM low level mean and the ALOCLIM high level mean. (Seasons, smoothing and reference period according to Figure 6.2)



smoothed (30y) mean daily maximum air temperature, summer: regional means - low elevation

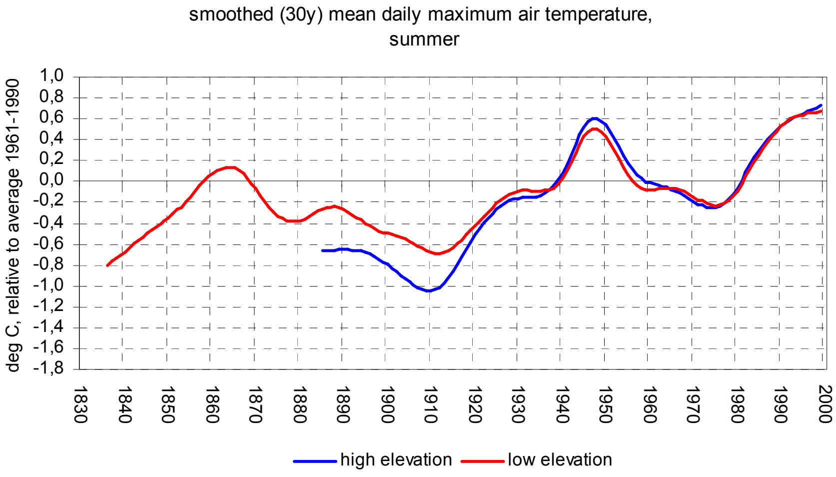


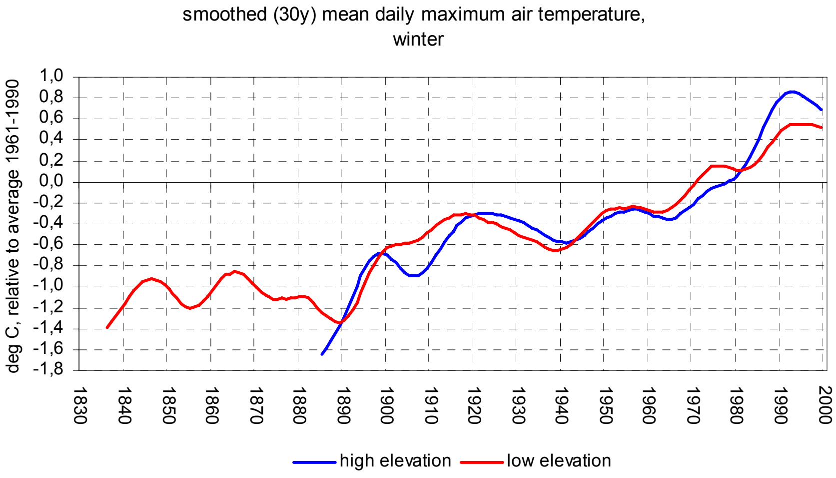
smoothed (30y) mean daily maximum air temperature, winter: regional means - low elevation



smoothed (30y) mean daily maximum air temperature, year: regional means - low elevation

Fig.6.6. Smoothed seasonal and annual mean daily maximum temperature series for the ALOCLIM low level sub-regions. (Seasons, smoothing and reference period according to Figure 6.2)





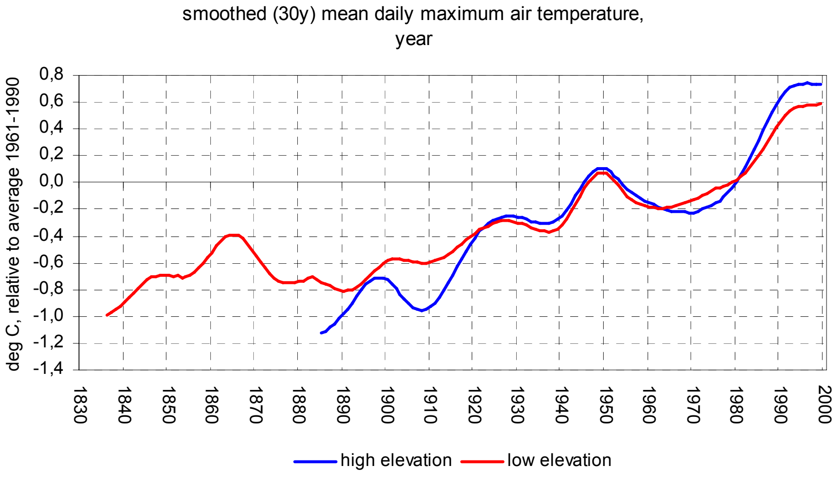
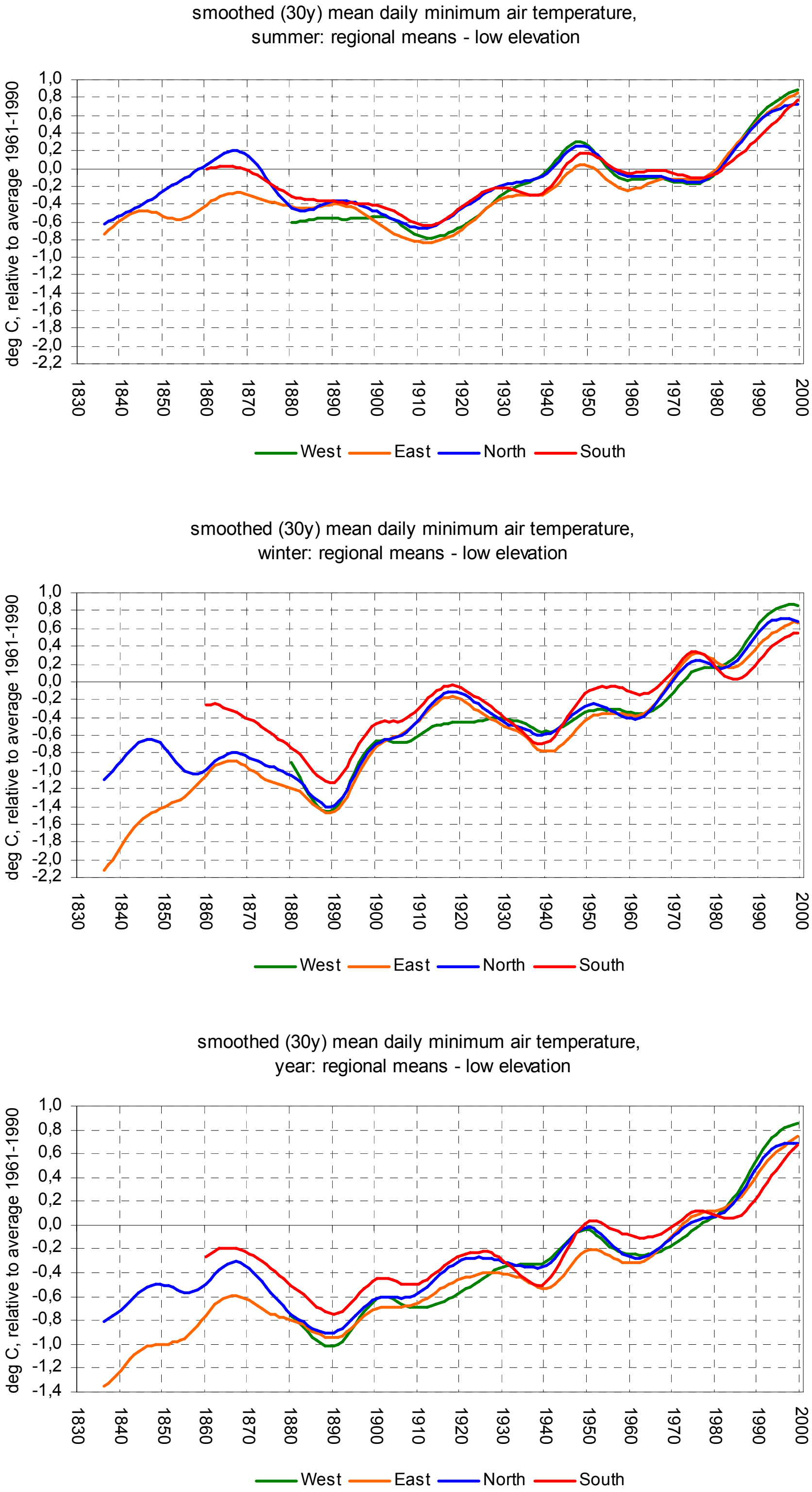


Fig.6.7. Smoothed seasonal and annual mean daily maximum temperature series for the ALOCLIM low level mean and the ALOCLIM high level mean. (Seasons, smoothing and reference period according to Figure 6.2)

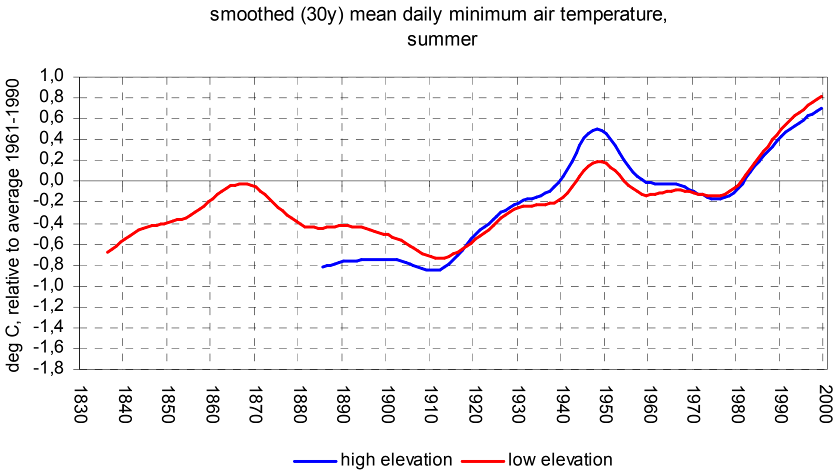


smoothed (30y) mean daily minimum air temperature, summer: regional means - low elevation

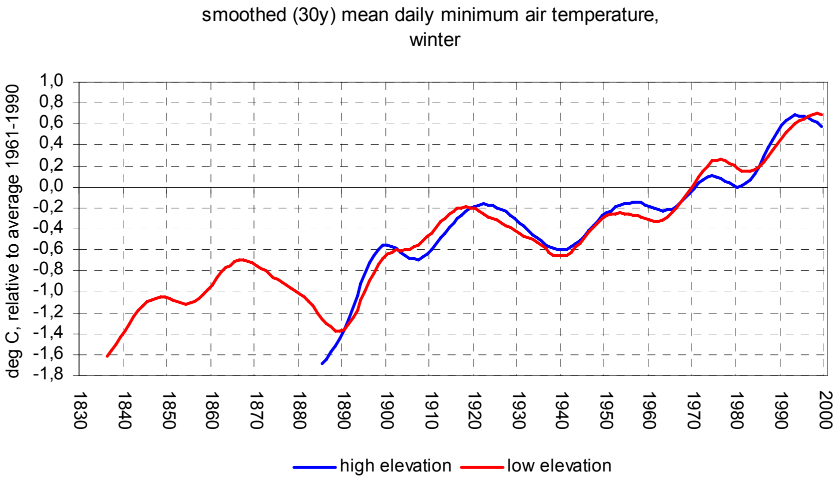
smoothed (30y) mean daily minimum air temperature, winter: regional means - low elevation

smoothed (30y) mean daily minimum air temperature, year: regional means - low elevation

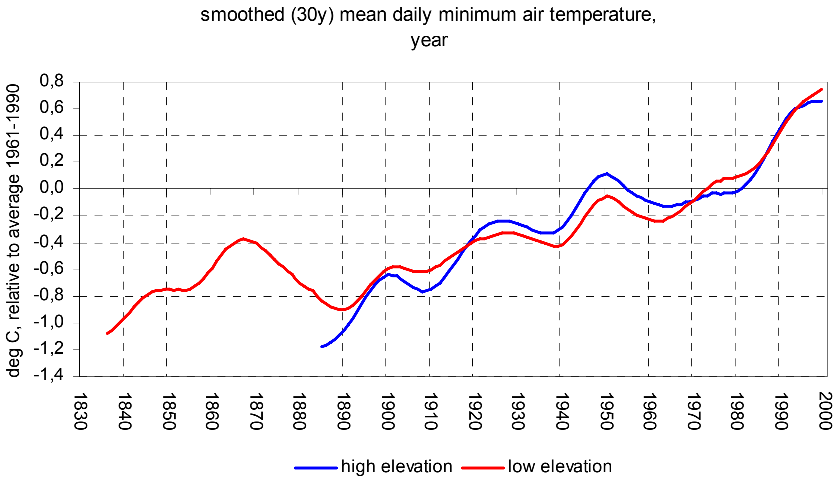
Fig.6.8. Smoothed seasonal and annual mean daily minimum temperature series for the ALOCLIM low level sub-regions. (Seasons, smoothing and reference period according to Figure 6.2)



smoothed (30y) mean daily minimum air temperature, summer

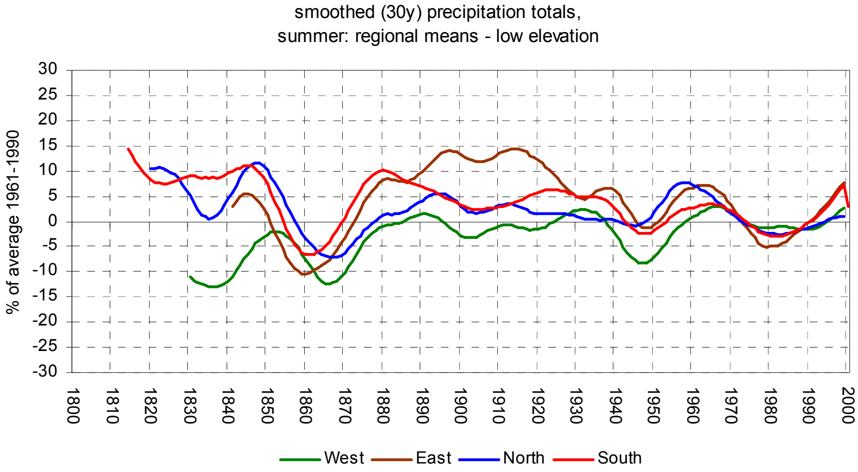


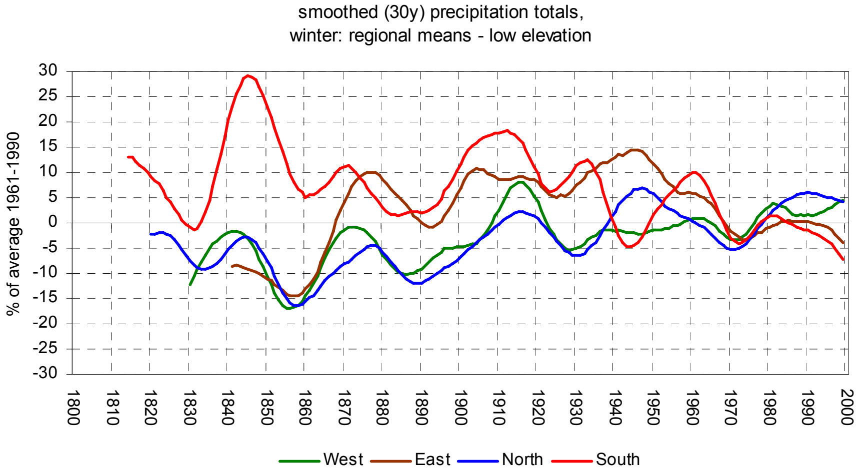
smoothed (30y) mean daily minimum air temperature, winter



smoothed (30y) mean daily minimum air temperature, year

Fig.6.9. Smoothed seasonal and annual mean daily minimum temperature series for the ALOCLIM low level mean and the ALOCLIM high level mean. (Seasons, smoothing and reference period according to Figure 6.2)





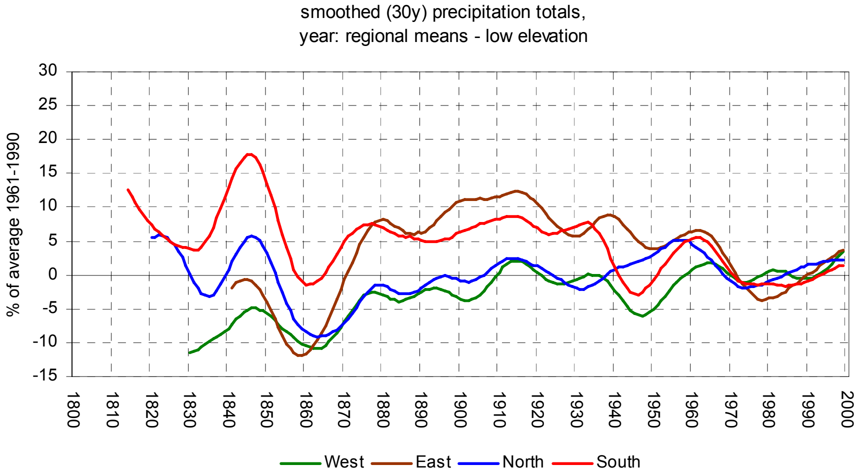
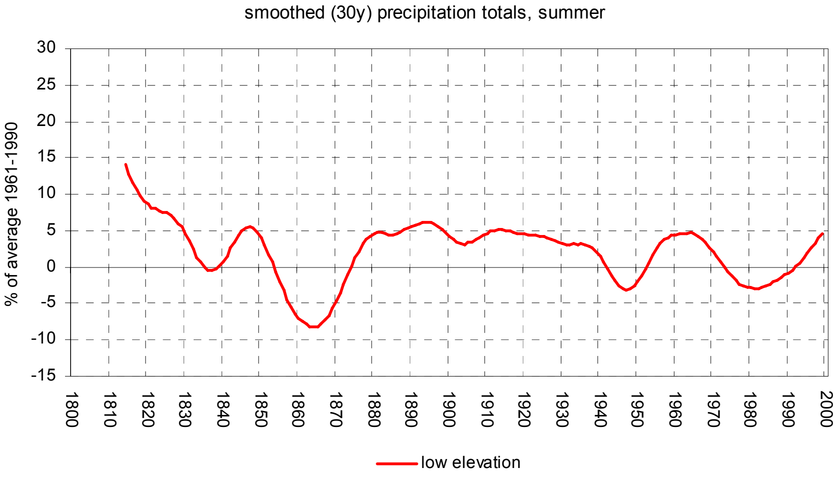
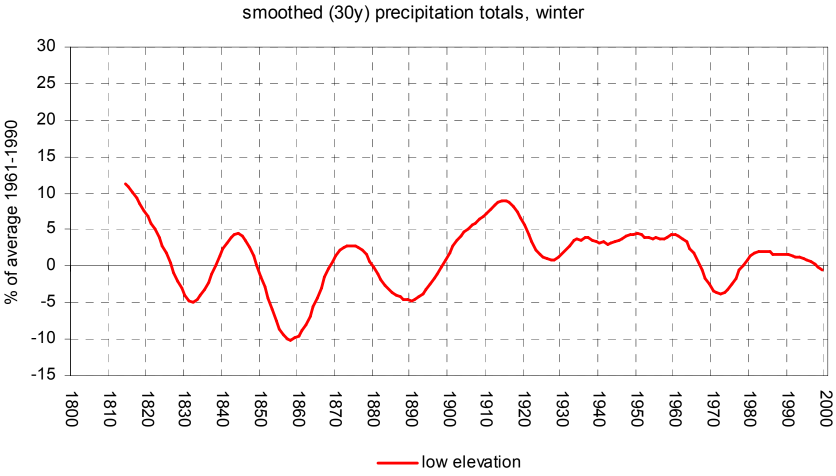


Fig.6.10. Smoothed seasonal and annual series of precipitation totals for the ALOCLIM low level sub-regions. (Seasons, smoothing and reference period according to Figure 6.2)





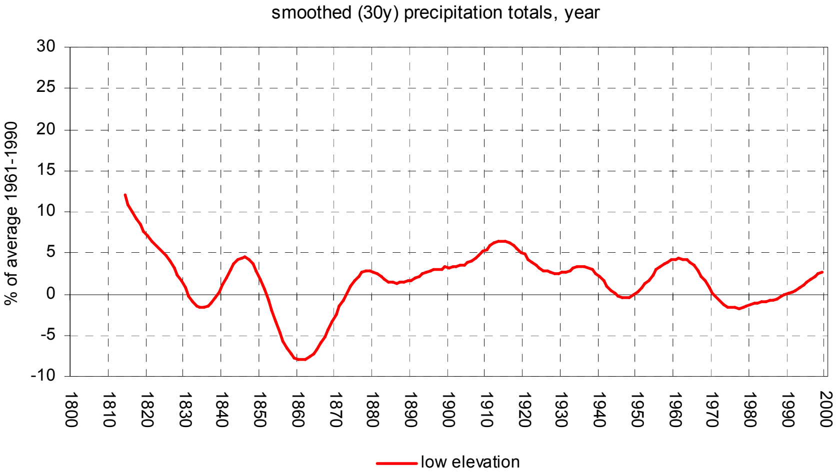
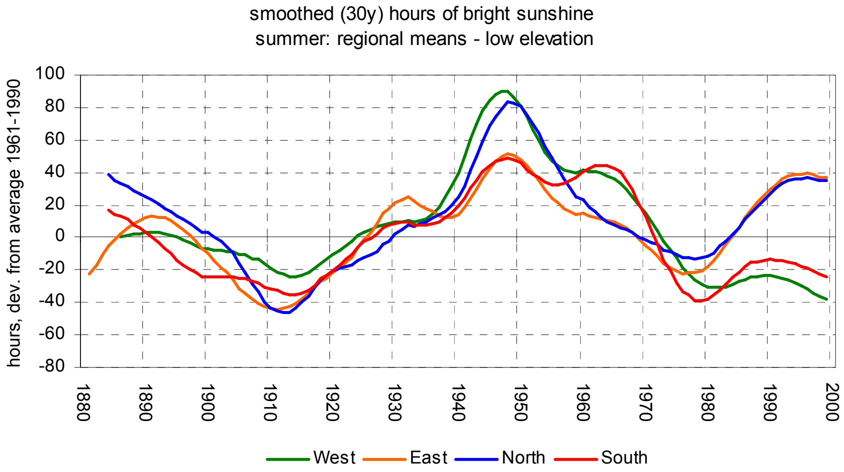
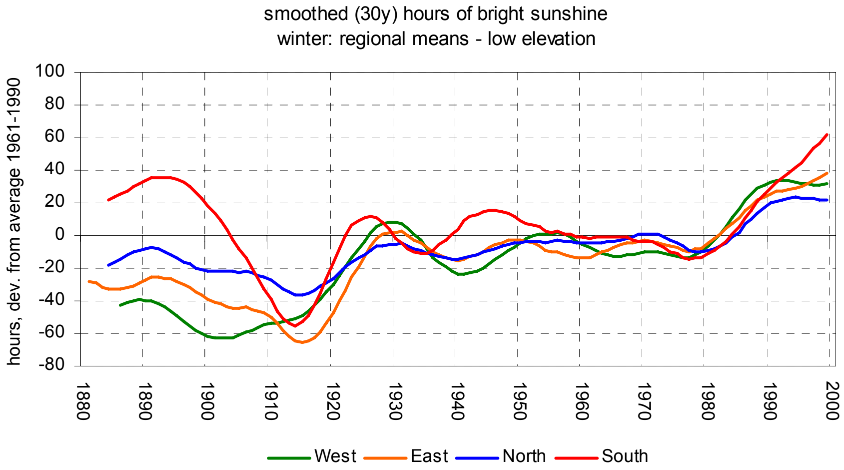


Fig.6.11. Smoothed seasonal and annual series of precipitation totals for the ALOCLIM low level mean. (Seasons, smoothing and reference period according to Figure 6.2)


smoothed (30y) hours of bright sunshine
summer: regional means - low elevation


smoothed (30y) hours of bright sunshine
winter: regional means - low elevation

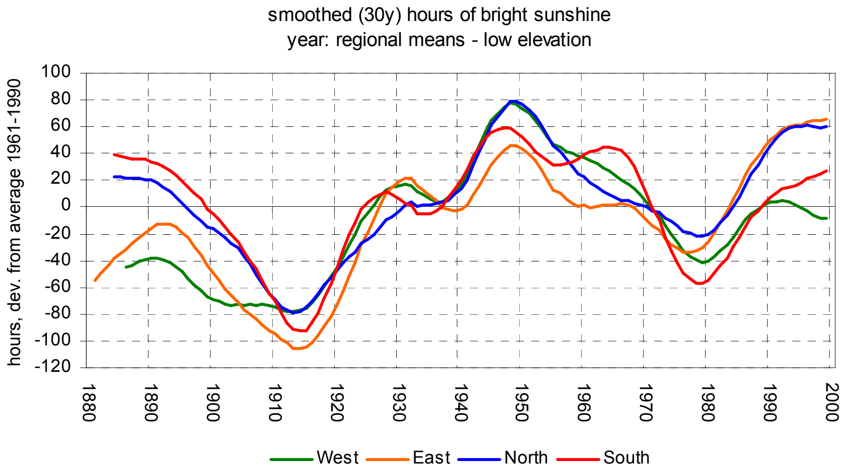

smoothed (30y) hours of bright sunshine
year: regional means - low elevation

Fig.6.12. Smoothed seasonal and annual series of totals of bright sunshine for the ALOCLIM low level sub-regions. (Seasons, smoothing and reference period according to Figure 6.2)

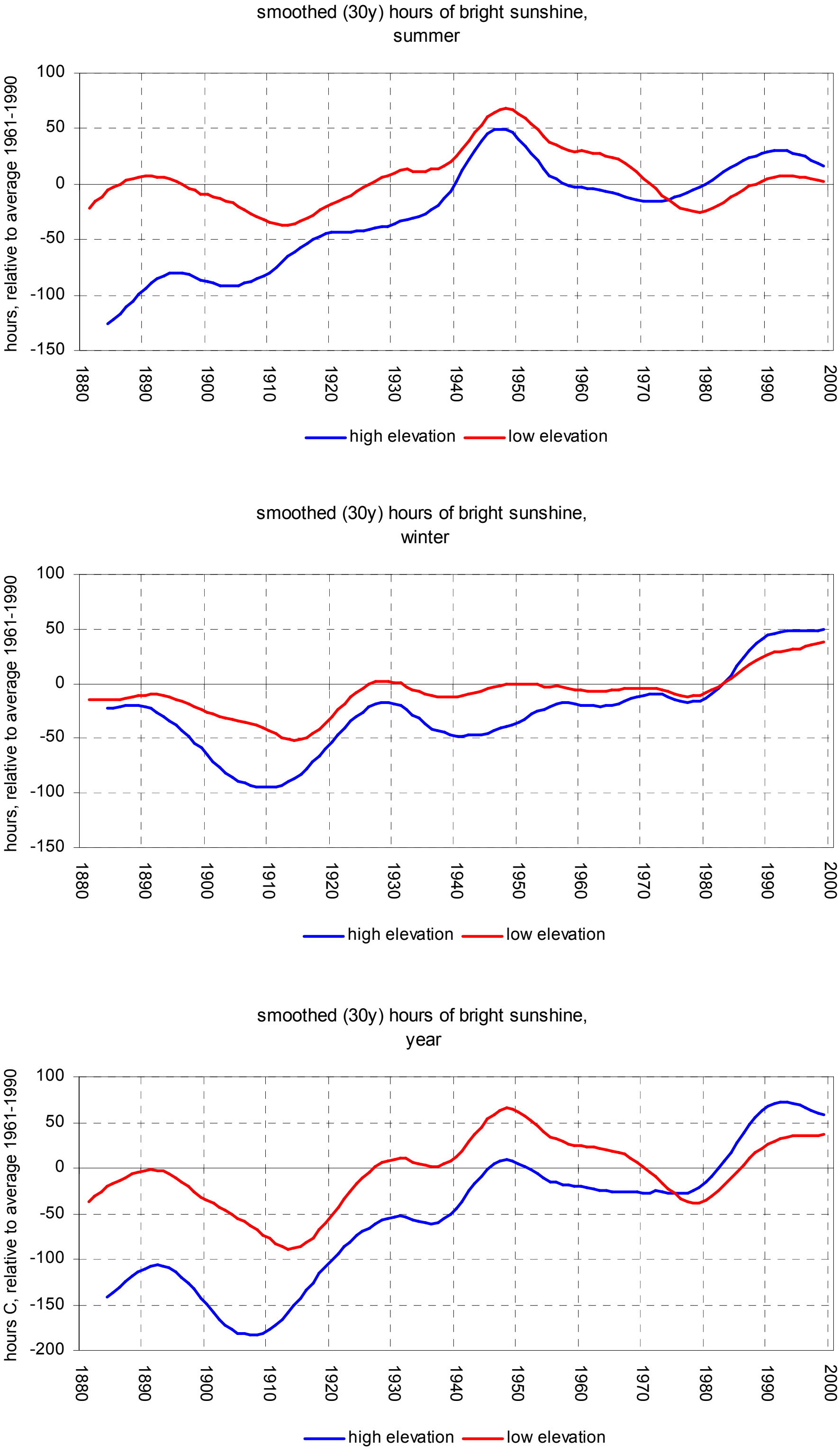


Fig.6.13. Smoothed seasonal and annual series of totals of bright sunshine for the ALOCLIM low level mean and the ALOCLIM high level mean. (Seasons, smoothing and reference period according to Figure 6.2)

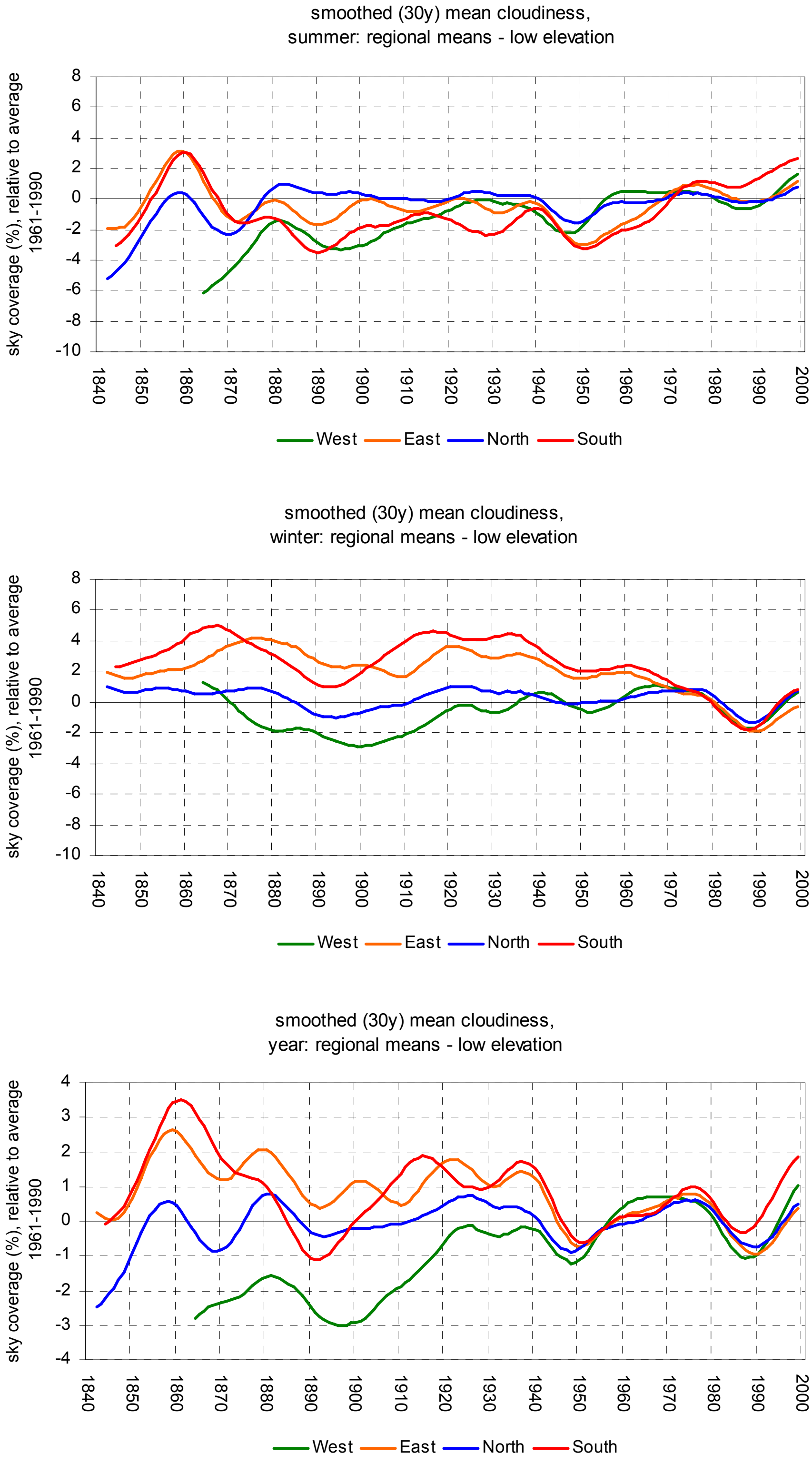
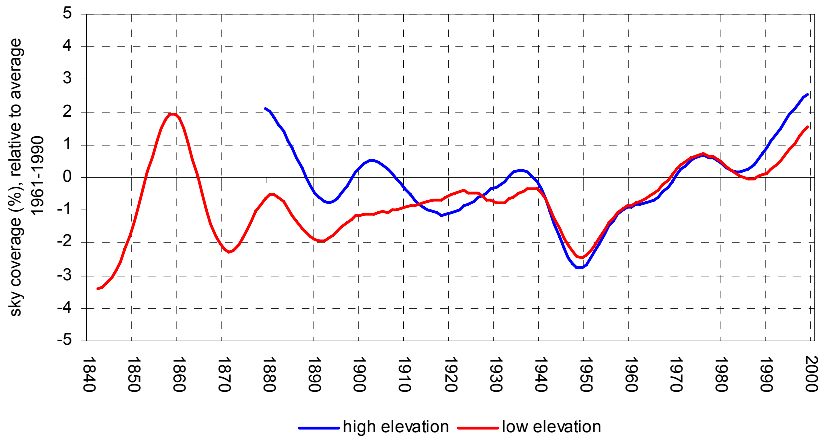
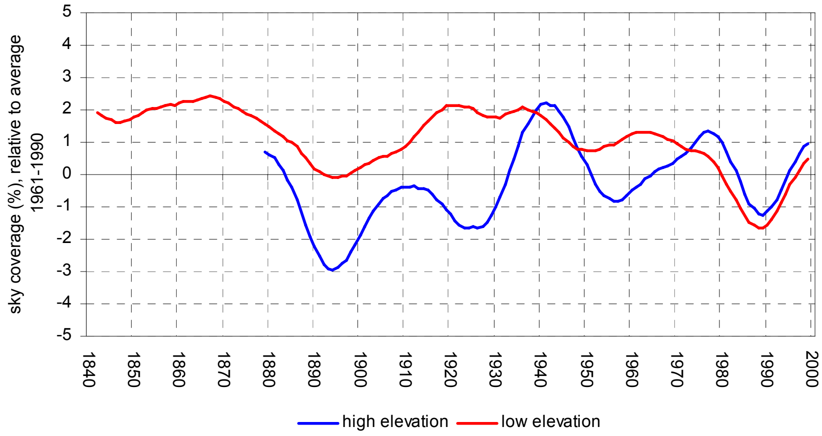


Fig.6.14. Smoothed seasonal and annual mean cloudiness series for the ALOCLIM low level sub-regions. (Seasons, smoothing and reference period according to Figure 6.2)

smoothed (30y) mean cloudiness, summer



smoothed (30y) mean cloudiness, winter



smoothed (30y) mean cloudiness, year

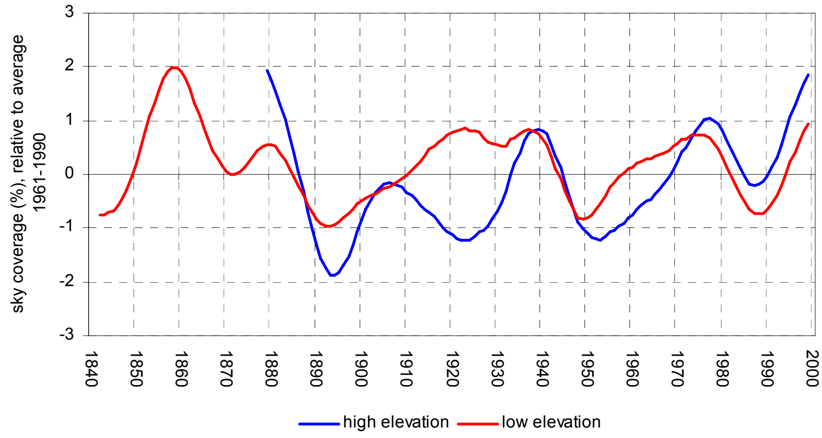
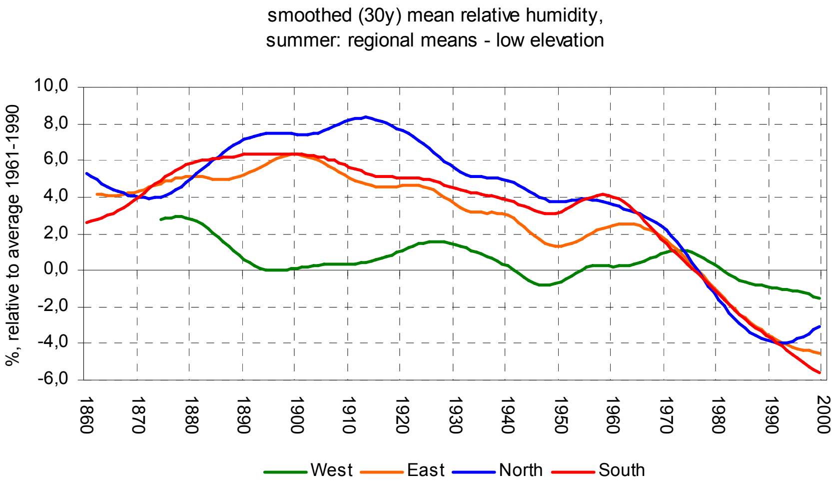
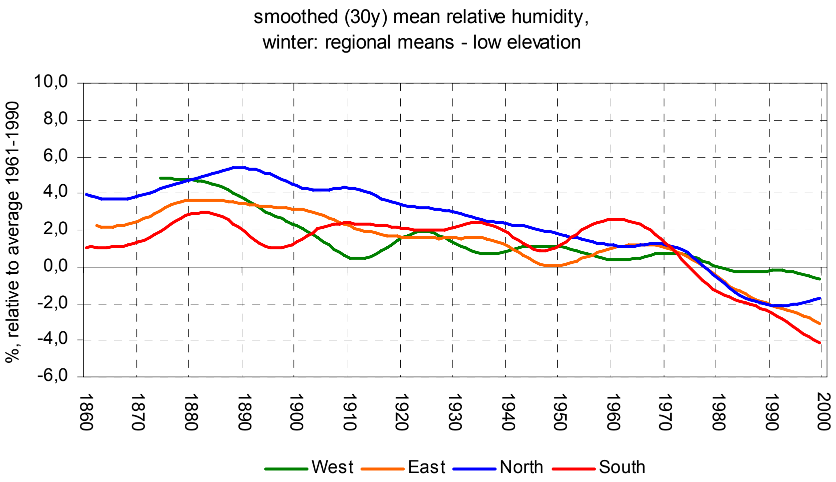


Fig.6.15. Smoothed seasonal and annual mean cloudiness series for the ALOCLIM low level mean and the ALOCLIM high level mean. (Seasons, smoothing and reference period according to Figure 6.2)





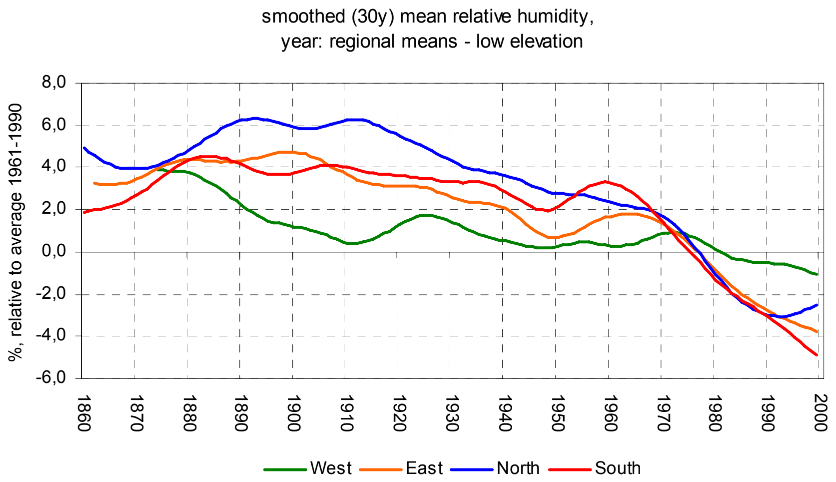
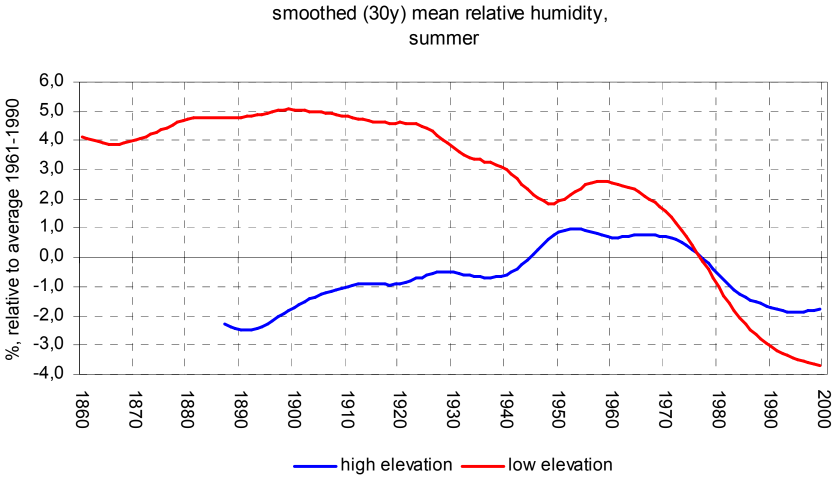
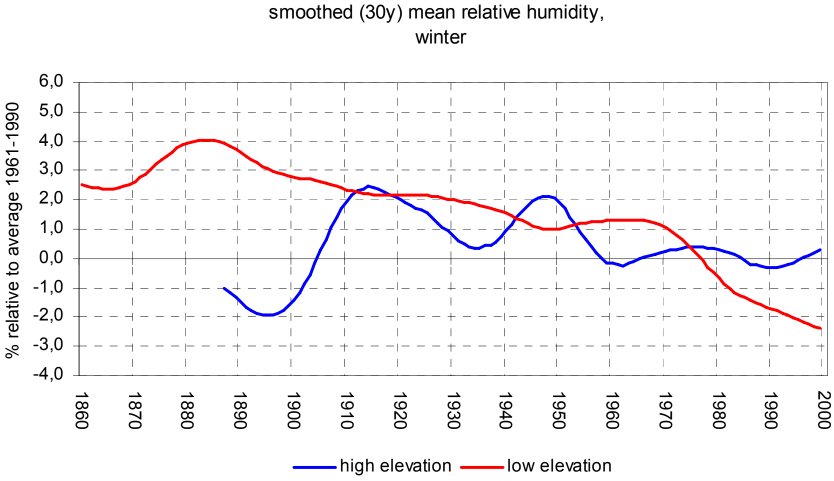


Fig.6.16. Smoothed seasonal and annual mean relative humidity series for the ALOCLIM low level sub-regions. (Seasons, smoothing and reference period according to Figure 6.2)





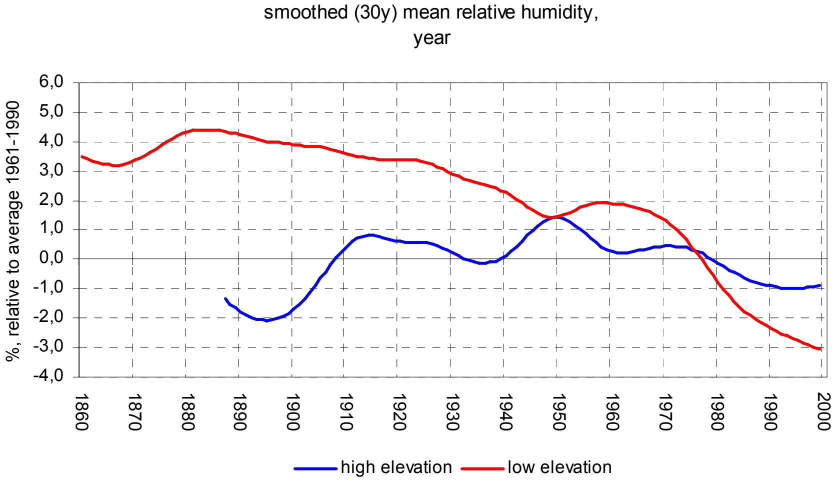
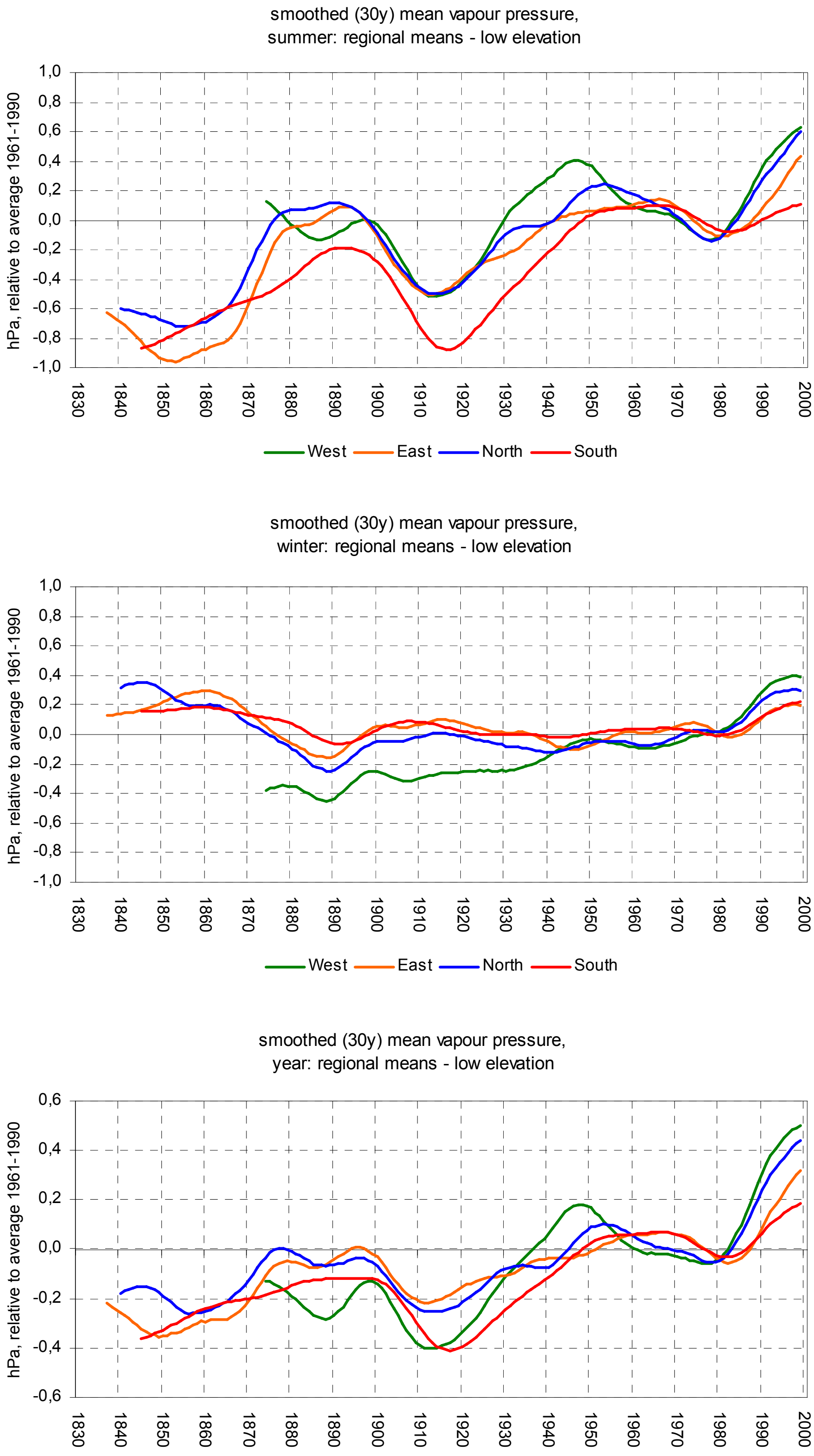


Fig.6.17. Smoothed seasonal and annual mean relative humidity series for the ALOCLIM low level mean and the ALOCLIM high level mean. (Seasons, smoothing and reference period according to Figure 6.2)



smoothed (30y) mean vapour pressure, summer: regional means - low elevation

smoothed (30y) mean vapour pressure, winter: regional means - low elevation

smoothed (30y) mean vapour pressure, year: regional means - low elevation

Fig.6.18. Smoothed seasonal and annual mean vapour pressure series for the ALOCLIM low level sub-regions. (Seasons, smoothing and reference period according to Figure 6.2)

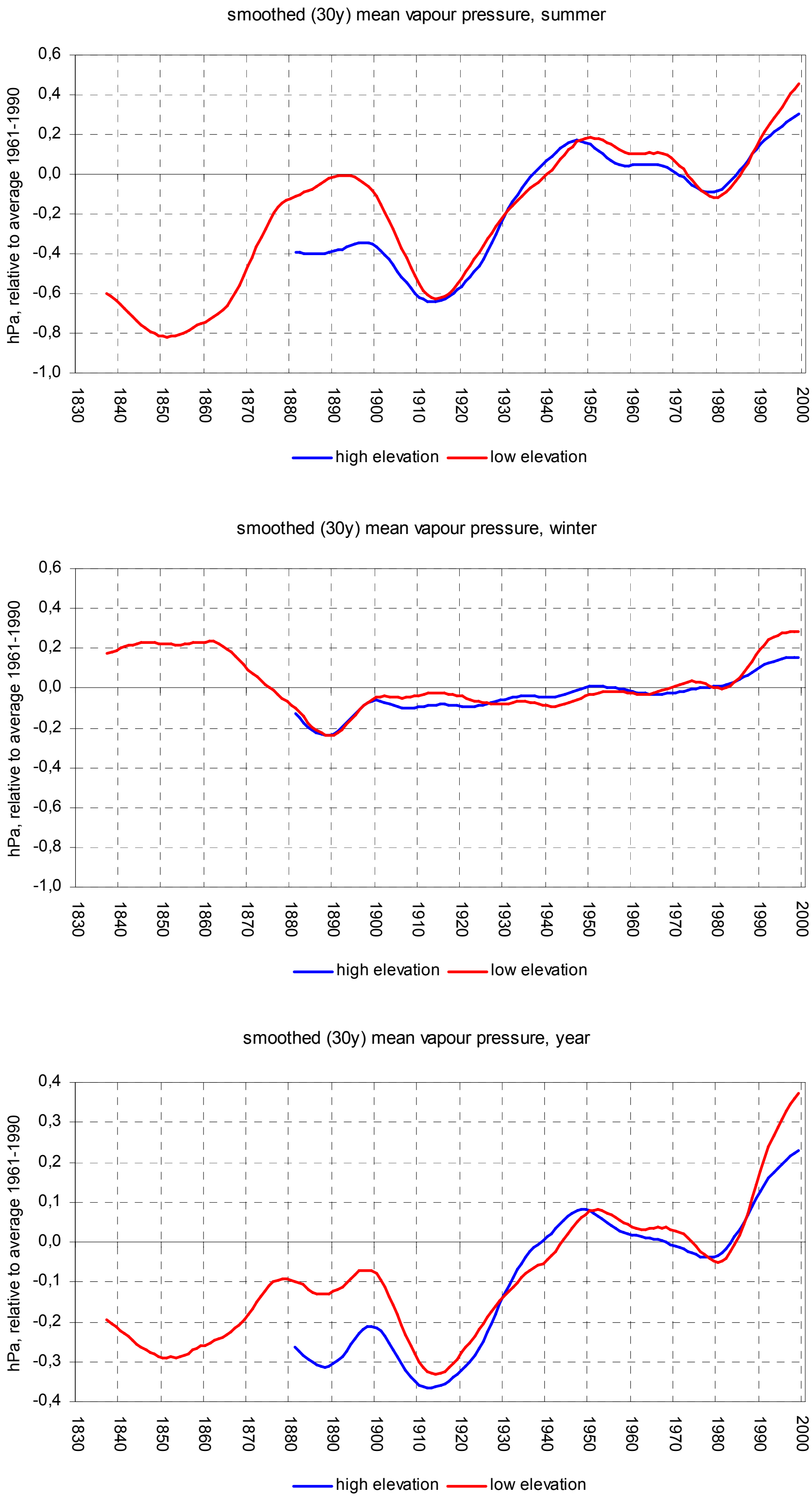


Fig.6.19. Smoothed seasonal and annual mean vapour pressure series for the ALOCLIM low level mean and the ALOCLIM high level mean. (Seasons, smoothing and reference period according to Figure 6.2)

6.2 Combined series

The full value of the new multiple climate series becomes evident if the single element series are studied together to obtain information regarding their interactions.

6.2.1 The short term aspect

One way to study interconnections between different climate elements is correlation analysis. Correlations are a good measure of the similarity between time series at short time scales. However, this type of analysis has limitations when comparing climate time series at longer time scales because the long-term signal in the series may be too small. Nevertheless, correlation analysis provides basic information about the interactions among the different climate elements. Table 6.3 shows the results of an analysis of the seasonal and annual series of the nine climate elements. Each climate element has been compared with each other element, only mean daily minimum and maximum temperature has been compared with mean temperature alone. The high correlation of the min- and max-series with mean temperature makes them negligible. Only their difference, the mean diurnal temperature range (DTR) series are highly interesting because of their frequent use as a detection criteria for anthropogenic climate change. The marking of “correlation coefficients significantly different from zero” (bold) and of “strong” correlations ($r \geq 0.5$, shaded) helps to concentrate on the essential interactions.

Table 6.3. Correlation table of the regional mean series of different climate elements for summer half year (SUN), winter half year (WIN) and for the year (YEAR).
Sample: Single seasonal and annual values 1886-1999

PP	WEST			EAST			NORTH			SOUTH			HIGH LEVEL			LOW LEVEL		
	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR
TM	**0,48**	0,21	**0,47**	**0,29**	-0,06	0,23	**0,32**	0,10	**0,36**	**0,44**	0,08	**0,35**	**0,79**	**0,70**	**0,81**	**0,41**	0,10	**0,38**
DTR	0,03	**0,25**	0,14	**0,39**	**0,32**	**0,41**	**0,38**	**0,30**	**0,49**	**0,35**	**0,34**	**0,37**	**0,33**	0,16	**0,25**	**0,36**	**0,40**	**0,46**
PREC	**-0,44**	-0,20	**-0,42**	**-0,39**	**-0,62**	**-0,55**	**-0,32**	-0,19	**-0,34**	**-0,40**	**-0,49**	**-0,43**				**-0,47**	**-0,52**	**-0,59**
SUN	**0,50**	**0,62**	**0,53**	**0,46**	**0,47**	**0,50**	**0,36**	**0,44**	**0,46**	**0,43**	**0,49**	**0,44**	**0,70**	**0,67**	**0,69**	**0,50**	**0,62**	**0,56**
CLOUD	**-0,42**	**-0,54**	**-0,45**	**-0,40**	**-0,53**	**-0,57**	**-0,41**	**-0,57**	**-0,65**	**-0,23**	**-0,62**	**-0,55**	**-0,40**	**-0,55**	**-0,41**	**-0,43**	**-0,67**	**-0,65**
R.HUM	**-0,45**	-0,20	**-0,37**	**-0,35**	**-0,39**	**-0,41**	**-0,34**	**-0,28**	**-0,38**	**-0,29**	**-0,30**	**-0,25**	-0,21	**-0,43**	**-0,30**	**-0,41**	**-0,38**	**-0,41**
VAP	**0,26**	0,10	**0,34**	0,00	**-0,28**	-0,04	0,12	0,05	**0,29**	0,20	-0,10	0,22	**0,74**	**0,29**	**0,59**	0,17	-0,07	0,23

TM	WEST			EAST			NORTH			SOUTH			HIGH LEVEL			LOW LEVEL		
	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR
PP	**0,48**	0,21	**0,47**	**0,29**	-0,06	0,23	**0,32**	0,10	**0,36**	**0,44**	0,08	**0,35**	**0,79**	**0,70**	**0,81**	**0,41**	0,10	**0,38**
TMMAX	**0,90**	**0,97**	**0,94**	**0,96**	**0,97**	**0,97**	**0,97**	**0,97**	**0,97**	**0,91**	**0,94**	**0,92**	**0,98**	**0,98**	**0,98**	**0,96**	**0,98**	**0,97**
TMMIN	**0,93**	**0,97**	**0,96**	**0,92**	**0,97**	**0,96**	**0,95**	**0,98**	**0,96**	**0,88**	**0,94**	**0,91**	**0,97**	**0,98**	**0,98**	**0,95**	**0,98**	**0,97**
DTR	0,18	-0,02	-0,11	**0,53**	0,03	0,18	**0,68**	0,09	**0,32**	**0,37**	0,07	0,16	**0,35**	-0,08	0,14	**0,51**	0,07	0,18
PREC	**-0,40**	0,19	-0,18	**-0,42**	-0,03	-0,16	**-0,52**	0,22	-0,12	**-0,31**	0,07	-0,19				**-0,48**	0,12	-0,19
SUN	**0,58**	**0,25**	**0,34**	**0,61**	**0,27**	**0,40**	**0,66**	0,14	**0,36**	**0,48**	0,06	0,20	**0,68**	**0,44**	**0,62**	**0,62**	0,19	**0,35**
CLOUD	**-0,41**	-0,03	-0,10	**-0,41**	-0,20	**-0,25**	**-0,54**	-0,03	**-0,26**	-0,23	-0,02	-0,04	**-0,41**	**-0,30**	**-0,31**	**-0,42**	-0,10	-0,18
R.HUM	**-0,57**	**-0,55**	**-0,50**	**-0,67**	**-0,35**	**-0,57**	**-0,65**	**-0,35**	**-0,59**	**-0,57**	**-0,34**	**-0,56**	**-0,27**	**-0,25**	**-0,25**	**-0,68**	**-0,47**	**-0,62**
VAP	**0,77**	**0,91**	**0,81**	**0,54**	**0,86**	**0,65**	**0,72**	**0,92**	**0,77**	**0,57**	**0,73**	**0,59**	**0,83**	**0,72**	**0,77**	**0,74**	**0,91**	**0,79**

DTR	WEST			EAST			NORTH			SOUTH			HIGH LEVEL			LOW LEVEL		
	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR
PP	0,03	**0,25**	0,14	**0,39**	**0,32**	**0,41**	**0,38**	**0,30**	**0,49**	**0,35**	**0,34**	**0,37**	**0,33**	0,16	**0,25**	**0,36**	**0,40**	**0,46**
TM	0,18	-0,02	-0,11	**0,53**	0,03	0,18	**0,68**	0,09	**0,32**	**0,37**	0,07	0,16	**0,35**	-0,08	0,14	**0,51**	0,07	0,18
PREC	**-0,32**	-0,24	**-0,39**	**-0,68**	**-0,43**	**-0,52**	**-0,63**	**-0,29**	**-0,51**	**-0,50**	**-0,39**	**-0,44**				**-0,66**	**-0,38**	**-0,56**
SUN	**0,64**	**0,52**	**0,56**	**0,80**	**0,68**	**0,74**	**0,84**	**0,71**	**0,72**	**0,63**	**0,67**	**0,57**	**0,53**	**0,30**	**0,42**	**0,86**	**0,78**	**0,79**
CLOUD	**-0,63**	**-0,62**	**-0,59**	**-0,78**	**-0,76**	**-0,79**	**-0,82**	**-0,76**	**-0,77**	**-0,61**	**-0,68**	**-0,57**	**-0,48**	-0,19	**-0,26**	**-0,85**	**-0,82**	**-0,80**
R.HUM	**-0,32**	-0,22	-0,12	**-0,48**	**-0,31**	**-0,33**	**-0,40**	-0,15	-0,21	-0,16	**-0,38**	**-0,25**	**-0,34**	**-0,26**	**-0,27**	**-0,28**	**-0,36**	-0,21
VAP	-0,09	-0,15	-0,23	-0,17	-0,14	-0,23	**0,29**	0,01	0,16	-0,03	-0,13	-0,02	0,18	-0,24	0,10	0,06	-0,09	-0,02

PREC	WEST			EAST			NORTH			SOUTH			HIGH LEVEL			LOW LEVEL		
	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR
PP	**-0,44**	-0,20	**-0,42**	**-0,39**	**-0,62**	**-0,55**	**-0,32**	-0,19	**-0,34**	**-0,40**	**-0,49**	**-0,43**				**-0,47**	**-0,52**	**-0,59**
TM	**-0,40**	0,19	-0,18	**-0,42**	-0,03	-0,16	**-0,52**	0,22	-0,12	**-0,31**	0,07	-0,19				**-0,48**	0,12	-0,19
DTR	**-0,32**	-0,24	**-0,39**	**-0,68**	**-0,43**	**-0,52**	**-0,63**	**-0,29**	**-0,51**	**-0,50**	**-0,39**	**-0,44**				**-0,66**	**-0,38**	**-0,56**
SUN	**-0,54**	**-0,38**	**-0,59**	**-0,62**	**-0,54**	**-0,54**	**-0,65**	**-0,30**	**-0,54**	**-0,49**	**-0,48**	**-0,45**				**-0,68**	**-0,51**	**-0,63**
CLOUD	**0,60**	**0,34**	**0,57**	**0,58**	**0,54**	**0,54**	**0,64**	**0,47**	**0,54**	**0,41**	**0,51**	**0,38**				**0,66**	**0,52**	**0,61**
R.HUM	**0,51**	-0,10	0,20	**0,60**	**0,35**	**0,52**	**0,42**	-0,11	0,20	**0,31**	**0,27**	**0,35**				**0,53**	0,11	**0,37**
VAP	-0,06	**0,26**	-0,05	**0,25**	0,13	0,23	-0,12	**0,27**	0,01	0,04	**0,30**	0,06				-0,05	0,21	-0,02

Table 6.3. – continued

SUN	WEST			EAST			NORTH			SOUTH			HIGH LEVEL			LOW LEVEL		
	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR
PP	**0,50**	**0,62**	**0,53**	**0,46**	**0,47**	**0,50**	**0,36**	**0,44**	**0,46**	**0,43**	**0,49**	**0,44**	**0,70**	**0,67**	**0,69**	**0,50**	**0,62**	**0,56**
TM	**0,58**	**0,25**	**0,34**	**0,61**	**0,27**	**0,40**	**0,66**	0,14	**0,36**	**0,48**	0,06	0,20	**0,68**	**0,44**	**0,62**	**0,62**	0,19	**0,35**
DTR	**0,64**	**0,52**	**0,56**	**0,80**	**0,68**	**0,74**	**0,84**	**0,71**	**0,72**	**0,63**	**0,67**	**0,57**	**0,53**	**0,30**	**0,42**	**0,86**	**0,78**	**0,79**
PREC	**-0,54**	**-0,38**	**-0,59**	**-0,62**	**-0,54**	**-0,54**	**-0,65**	**-0,30**	**-0,54**	**-0,49**	**-0,48**	**-0,45**				**-0,68**	**-0,51**	**-0,63**
CLOUD	**-0,78**	**-0,67**	**-0,64**	**-0,84**	**-0,84**	**-0,83**	**-0,87**	**-0,80**	**-0,77**	**-0,76**	**-0,75**	**-0,74**	**-0,73**	**-0,82**	**-0,67**	**-0,89**	**-0,84**	**-0,82**
R.HUM	**-0,60**	**-0,43**	**-0,47**	**-0,51**	**-0,66**	**-0,55**	**-0,36**	**-0,38**	**-0,36**	-0,18	**-0,41**	-0,20	**-0,42**	**-0,70**	**-0,50**	**-0,39**	**-0,55**	**-0,42**
VAP	**0,25**	0,14	0,20	0,00	-0,05	0,00	**0,31**	-0,01	0,21	0,09	-0,11	0,10	**0,49**	-0,08	**0,40**	**0,26**	-0,01	0,20

CLOUD	WEST			EAST			NORTH			SOUTH			HIGH LEVEL			LOW LEVEL		
	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR
PP	**-0,42**	**-0,54**	**-0,45**	**-0,40**	**-0,53**	**-0,57**	**-0,41**	**-0,57**	**-0,65**	-0,23	**-0,62**	**-0,55**	**-0,40**	**-0,55**	**-0,41**	**-0,43**	**-0,67**	**-0,65**
TM	**-0,41**	-0,03	-0,10	**-0,41**	-0,20	**-0,25**	**-0,54**	-0,03	**-0,26**	-0,23	-0,02	-0,04	**-0,41**	**-0,30**	**-0,31**	**-0,42**	-0,10	-0,18
DTR	**-0,63**	**-0,62**	**-0,59**	**-0,78**	**-0,76**	**-0,79**	**-0,82**	**-0,76**	**-0,77**	**-0,61**	**-0,68**	**-0,57**	**-0,48**	-0,19	**-0,26**	**-0,85**	**-0,82**	**-0,80**
PREC	**0,60**	**0,34**	**0,57**	**0,58**	**0,54**	**0,54**	**0,64**	**0,47**	**0,54**	**0,41**	**0,51**	**0,38**				**0,66**	**0,52**	**0,61**
SUN	**-0,78**	**-0,67**	**-0,64**	**-0,84**	**-0,84**	**-0,83**	**-0,87**	**-0,80**	**-0,77**	**-0,76**	**-0,75**	**-0,74**	**-0,73**	**-0,82**	**-0,67**	**-0,89**	**-0,84**	**-0,82**
R.HUM	**0,64**	0,24	**0,39**	**0,31**	**0,63**	**0,46**	**0,30**	0,20	0,20	-0,10	**0,48**	0,14	**0,42**	**0,73**	**0,57**	0,21	**0,48**	**0,27**
VAP	-0,05	0,15	0,07	0,13	0,10	0,15	-0,15	0,08	-0,09	0,00	0,19	-0,07	-0,10	0,25	0,09	-0,05	0,09	-0,01

R.HUM	WEST			EAST			NORTH			SOUTH			HIGH LEVEL			LOW LEVEL		
	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR
PP	**-0,45**	-0,20	**-0,37**	**-0,35**	**-0,39**	**-0,41**	**-0,34**	**-0,28**	**-0,38**	**-0,29**	**-0,30**	**-0,25**	-0,21	**-0,43**	**-0,30**	**-0,41**	**-0,38**	**-0,41**
TM	**-0,57**	**-0,55**	**-0,50**	**-0,67**	**-0,35**	**-0,57**	**-0,65**	**-0,35**	**-0,59**	**-0,57**	**-0,34**	**-0,56**	**-0,27**	**-0,25**	**-0,25**	**-0,68**	**-0,47**	**-0,62**
DTR	**-0,32**	-0,22	-0,12	**-0,48**	**-0,31**	**-0,33**	**-0,40**	-0,15	-0,21	-0,16	**-0,38**	**-0,25**	**-0,34**	**-0,26**	**-0,27**	**-0,28**	**-0,36**	-0,21
PREC	**0,51**	-0,10	0,20	**0,60**	**0,35**	**0,52**	**0,42**	-0,11	0,20	**0,31**	**0,27**	**0,35**				**0,53**	0,11	**0,37**
SUN	**-0,60**	**-0,43**	**-0,47**	**-0,51**	**-0,66**	**-0,55**	**-0,36**	**-0,38**	**-0,36**	-0,18	**-0,41**	-0,20	**-0,42**	**-0,70**	**-0,50**	**-0,39**	**-0,55**	**-0,42**
CLOUD	**0,64**	0,24	**0,39**	**0,31**	**0,63**	**0,46**	**0,30**	0,20	0,20	-0,10	**0,48**	0,14	**0,42**	**0,73**	**0,57**	0,21	**0,48**	**0,27**
VAP	-0,09	**-0,36**	-0,19	0,01	0,07	0,02	**-0,27**	-0,13	**-0,30**	-0,09	0,10	-0,07	0,06	**0,28**	0,08	**-0,27**	-0,21	**-0,30**

VAP	WEST			EAST			NORTH			SOUTH			HIGH LEVEL			LOW LEVEL		
	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR	SUM	WIN	YEAR
PP	**0,26**	0,10	**0,34**	0,00	**-0,28**	-0,04	0,12	0,05	**0,29**	0,20	-0,10	0,22	**0,74**	**0,29**	**0,59**	0,17	-0,07	0,23
TM	**0,77**	**0,91**	**0,81**	**0,54**	**0,86**	**0,65**	**0,72**	**0,92**	**0,77**	**0,57**	**0,73**	**0,59**	**0,83**	**0,72**	**0,77**	**0,74**	**0,91**	**0,79**
DTR	-0,09	-0,15	-0,23	-0,17	-0,14	-0,23	**0,29**	0,01	0,16	-0,03	-0,13	-0,02	0,18	-0,24	0,10	0,06	-0,09	-0,02
PREC	-0,06	**0,26**	-0,05	**0,25**	0,13	0,23	-0,12	**0,27**	0,01	0,04	**0,30**	0,06				-0,05	0,21	-0,02
SUN	**0,25**	0,14	0,20	0,00	-0,05	0,00	**0,31**	-0,01	0,21	0,09	-0,11	0,10	**0,49**	-0,08	**0,40**	**0,26**	-0,01	0,20
CLOUD	-0,05	0,15	0,07	0,13	0,10	0,15	-0,15	0,08	-0,09	0,00	0,19	-0,07	-0,10	0,25	0,09	-0,05	0,09	-0,01
R.HUM	-0,09	**-0,36**	-0,19	0,01	0,07	0,02	**-0,27**	-0,13	**-0,30**	-0,09	0,10	-0,07	0,06	**0,28**	0,08	**-0,27**	-0,21	**-0,30**

PP...mean air pressure, TM...mean temperature, TMMAX...mean daily maximum temp., TMMIN...mean daily minimum temp., DTR...mean diurnal temperature range, PREC...precipitation total, SUN...bright sunshine total, R.HUM...mean relative humidity, VAP...mean vapour pressure
(bold: significant correlation at 99%-level: I r I ≥ 0.25)
bold and shaded: strong correlation: I r I ≥ 0.5

Fig.6.20 summarises the main interesting features of the correlation matrix. It concentrates on the two most probable forcing factors – air pressure and incoming radiation (represented by the antagonistic elements, sunshine and cloudiness).

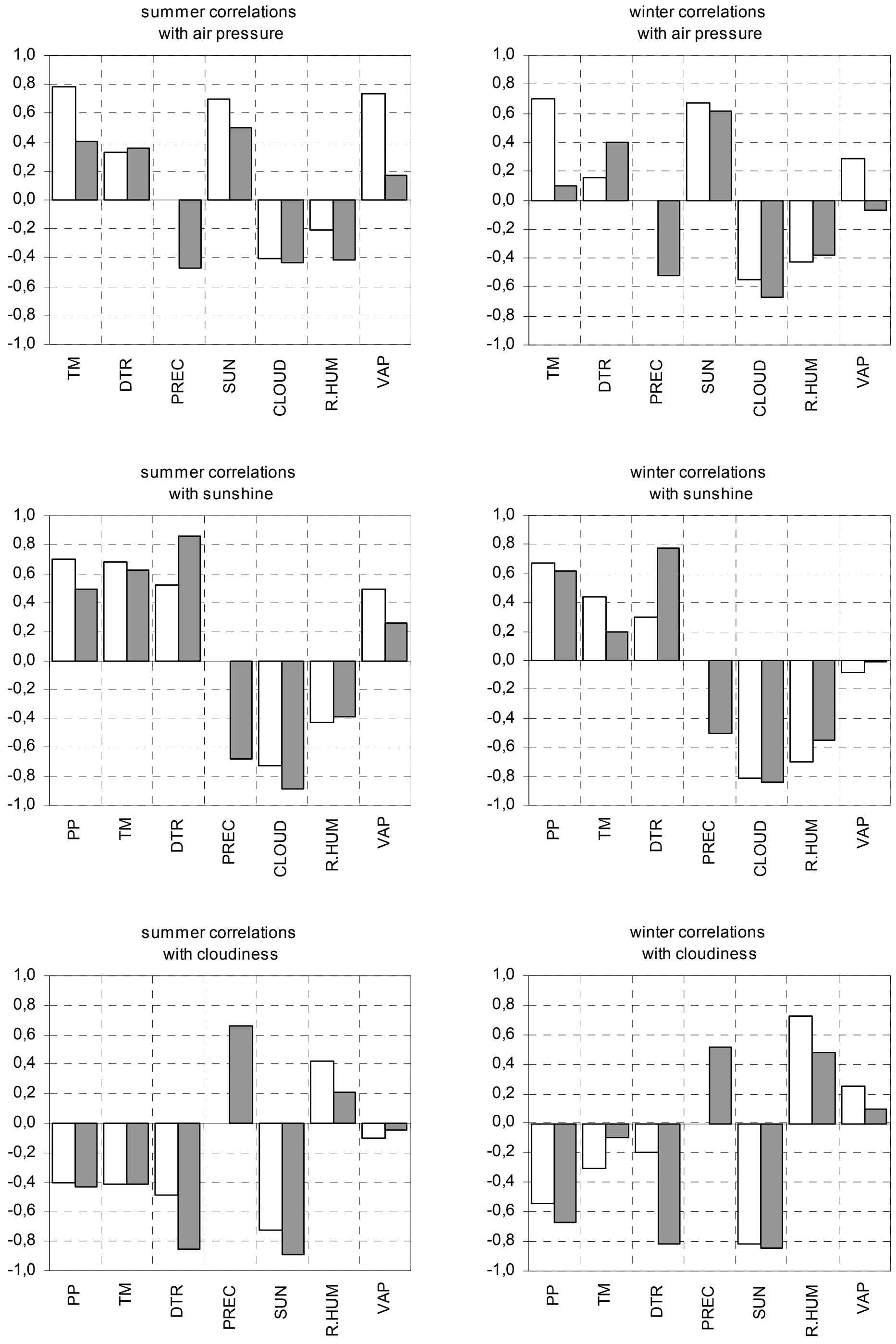


Fig. 6.20. Correlation of air pressure, sunshine and cloudiness with other climate elements.
Summer (months 4 to 9), winter (months 10 to 3), high level (white bars) and low level (grey bars).
Sample: Seasonal and annual means 1886-1999

Air pressure is a good predictor for the hours of bright sunshine in the region, it is similar during summer and winter at high altitudes, and slightly better in low level winters than in low level summers. The two other high positive summer correlations with temperature (summer and winter) and vapour pressure (only summer) at high altitudes do not reflect an air pressure forcing on those elements. It is in fact, the opposite, air pressure and vapour pressure are influenced by the temperature of the air column below the high level sites. The direct positive forcing of air pressure on low level temperature is weaker but also significant and the mean diurnal temperature range is also positively correlated to air pressure. Weaker but also significant negative forcing of air pressure is given for precipitation, cloudiness and relative humidity.

Sunshine correlations are very similar to those of air pressure but in most cases they are stronger – featuring incoming radiation as the factor which is more directly linked to the other climate elements than air pressure. The most prominent increase in correlation is given for low level DTR with approximately 80% correlation with hours of bright sunshine. The strong negative correlation with the antagonistic climate element cloudiness, is not surprising and more a measure of data quality.

Cloudiness correlations are a mirror image to those of sunshine but in each case are slightly weaker. This might be an indication of the slightly lower quality of the cloudiness data (subjectively estimated). However, the differences between the correlation coefficients is not significant and both cloudiness and hours of bright sunshine may be used to represent incoming short wave radiation (for which there are no long-term time series).

An interesting fact is the independence of vapour pressure (a measure for absolute humidity) which is highly independent of the three discussed forcing elements, whereas relative humidity shows significant correlations with sunshine and cloudiness which are stronger in winter than in summer.

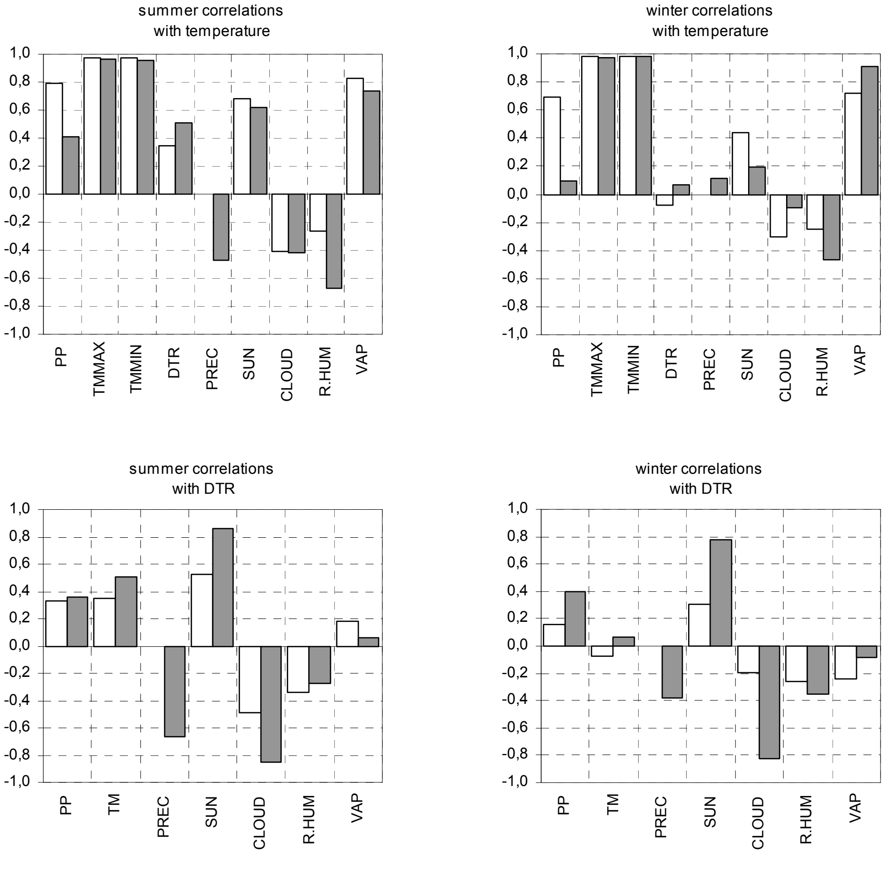


Fig. 6.21. Correlation of mean air temperature and DTR with other climate elements.
Summer (months 4 to 9), winter (months 10 to 3), high level (white bars) and low level (grey bars).
Sample: Seasonal and annual means 1886-1999

Mean temperature and mean diurnal temperature range (DTR), whose correlations are shown in Fig.6.21, are interesting in connection with the question of climate change. It is important to know how other climate elements are connected to changes of mean temperature both as forcing agents or as forced elements. Decreasing DTR is sometimes used as a “signal for climate change”, it is interesting to see how strong and in what way these data are linked to other climate elements. The closest connections exist between mean temperature and the mean daily extreme temperatures. There are high correlations in each sub-region (see also Table 6.3) and it is the case that the correlation of each of the three temperature elements with other climate elements is highly similar and thus, it is sufficient to discuss only one of them. The links between temperature and air pressure and sunshine have already been discussed. A significant positive correlation exists between mean temperature and DTR in summer. In winter DTR is not linked to mean temperature. In summer there is a negative correlation of temperature with three of the four elements of the water-complex (cloudiness, relative humidity and precipitation totals) which is weaker i.e., for cloudiness and relative humidity or non-existent i.e., for precipitation in winter. The correlation of relative humidity with temperature, moreover, is more strongly negative in the low elevation parts of the study region and less negative in the mountains. The fourth element of the water-complex (vapour pressure) on the other hand is closely and positively linked to temperature in each season and each sub-region.

The diurnal temperature range (DTR) shows the highest correlations, $r \geq 0.8$, with sunshine and cloudiness in low elevation regions equally for summer and winter. In the mountains the correlation is weaker, most probably due to the additional forcing of high elevation DTR by convective heat transport from lower altitudes. The strong dependency of DTR on incoming short wave radiation must be kept in mind when DTR is used as a marker for anthropogenic climate change. A careful removal of the short wave radiative forcing is necessary and only the remaining variance may have a certain potential in anthropogenic climate change detection. The absence of a negative correlation with mean temperature in winter, and the positive correlation in summer is remarkable.

6.2.2 The long-term aspect

Global warming from the mid-19th century to the end of the 20th century is often used as an indicator for the onset of warming which climate models forecast for the 21st century. The multiple series of the ALOCLIM series enables the study of the reaction of other climate elements to the increasing temperature or the potential forcing of other elements on temperature. Moreover, the length of some ALOCLIM series provides the opportunity to go further back into the so-called “pre-industrial period”. Fig.6.22 shows the basis of the comparisons – the mean temperature series (single values and smoothed evolution) averaged over all 5 sub-regions (four low elevation and one high elevation sub-region).

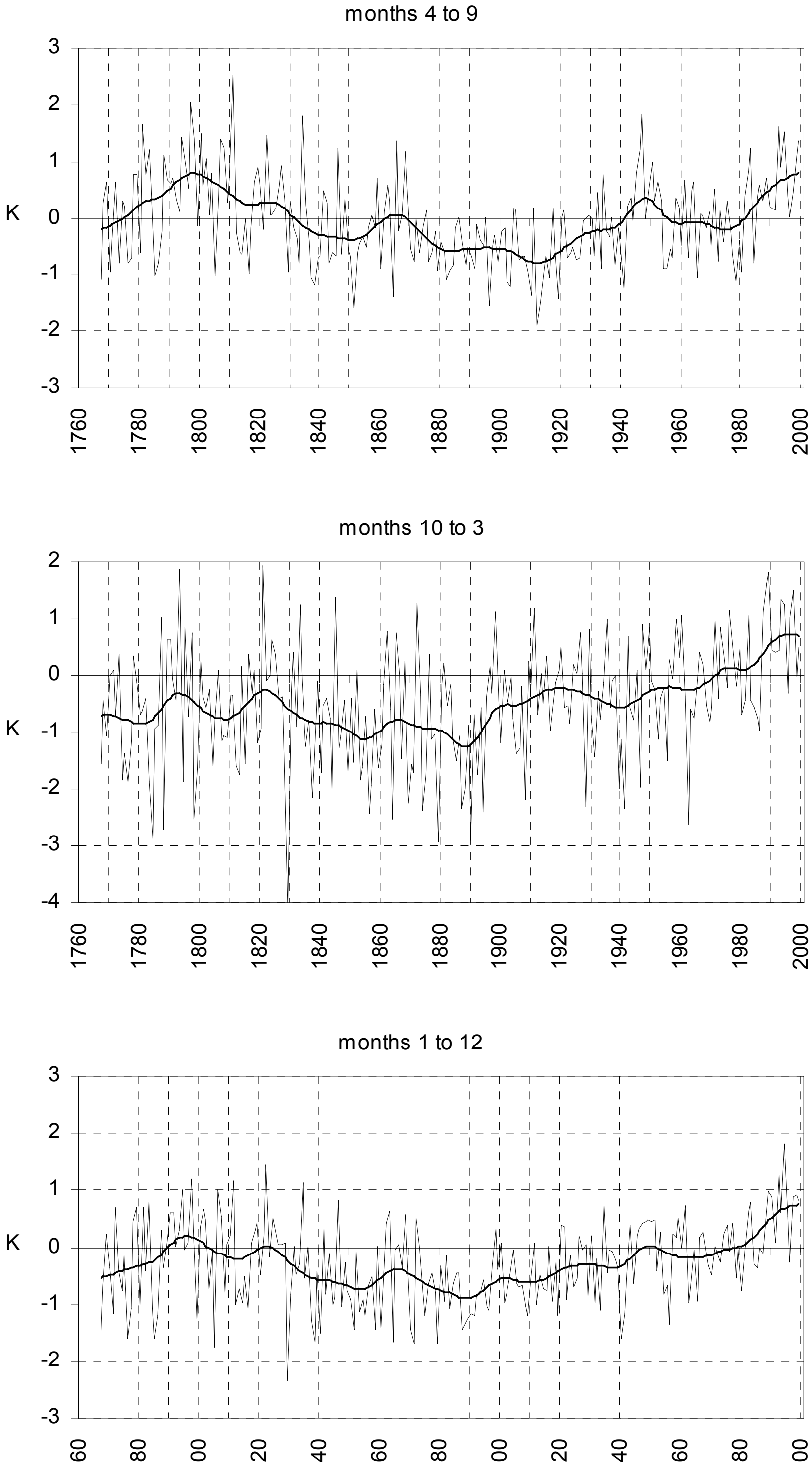


Fig.6.22. Seasonal and annual time series of the spatial temperature mean of the study region relative to the 1961-1990 average.
Same filter technique as in Fig. 6.2 to 6.19

The general features of the long-term temperature evolution of the sub-regions (see Figs. 6.4 and 6.5) are also evident for the average over all sub-regions. An initial short warming phase in the late 18th century culminates in the first main temperature maximum near 1800 which is warmer in summer than in winter. The whole of the 19th century is characterised by cooling with a main summer minimum around 1910 and a respective winter minimum around 1890. From then on, the main characteristic is one of increasing temperature, which culminates in the extraordinary temperature maxima of the 1990s in summer as well as in winter. On shorter time scales there are several secondary extremes like the warm summers of the 1860s (the starting signal for general glacier retreat in the Alps) and of the 1950s, or the cool summers in the 1960s and 1970s. In the cold half of the year, the secondary extremes are less distinct but the segmentation of the recent warming into two distinct steps (the first in the late 1890s, the second in the 1980s) is also clearly visible.

The strong inter-annual variability compared to the long-term evolution of the smoothed curves is typical of climate time series in general. The great variance sometimes causes problems in the application of statistical measures for the significance of long-term trends. Trends that obviously have strong impacts on vegetation, extension of glaciers, forestry, tourism and other environmental and economic parameters often have to be classified in statistical terms as “not significantly different from zero”. For example, neither of the previously mentioned long-term temperature trends in the region - the cooling of the 19th century and the warming of the 20th century – are statistically significant at the 95% level although for example, the warming trend of summer temperatures has reduced the glaciated area in the region by 50%.

The following discussion will pay closer attention to a visual description of the similarities and differences between the long-term evolutions of different climate elements and temperature. This shall serve as a first impression about the behaviour of climate in long periods of general cooling (phase 1) and general warming (phase 2). The full length of phase 1 is completely covered by temperature and air pressure only. For the other climate elements the instrumental period covers only some decades of the cooling phase. For the phase 2 warming, the full range of instrumental series can be used. Figures 6.23 to 6.39 show the smoothed “study area average” temperature curves (from Fig.6.22) in comparison with a selection of different sub-regional or regional single seasonal (annual) and smoothed curves of a number of climate elements.

The significant correlation (Table 6.3, Fig.6.20) between low elevation air pressure and temperature in the region is supplemented by a close similarity of the long-term trends of the two elements especially for the summer half of the year (Fig.6.23). Not only the centennial but also the decadal features of the temperature curve can be found in the air pressure curve. In winter the similarity is weaker. An interesting feature is the recent decoupling of air pressure and temperature in summer whereas during winter, the similarity of the winter curves has become stronger during the recent decades. The similarity between low elevation air pressure and temperature evolution is an expression of the influence of circulation on the climate of the region. The even stronger similarity of the corresponding high elevation curves (Fig.6.24) reflects the greater influence of temperature on the air pressure measured at the high elevation sites (Böhm et al., 1998).

The supposed circulation influence on temperature which is suggested by the air pressure curves might work via two mechanisms, advection and “in situ” effects caused by incoming short wave radiation. The latter could already be seen in the high correlation coefficients between sunshine and temperature (Table 6.3, Fig.6.20) and also the long-term curves of the hours of bright sunshine and of temperature in Figs.

6.25 and 6.26. The undisturbed sunshine curves of the high elevation observatories (Fig. 6.26) are a near perfect copy of the temperature curves – again with the one interesting decoupling in the 1980s and 1990s (which might be a first sign of the anthropogenic signal in the temperature evolution). The low elevation sunshine evolution shows a weaker centennial increase than the high elevation ones. Auer et al. (1998) show that a reasonable explanation of the relative increase of the high level versus the low level hours of bright sunshine is an increase of turbidity of the lower layers of the atmosphere.

At first sight, the cloudiness series could be expected to be the counterpart of sunshine series. On the other hand, there are also some technical differences in their genesis that might alter the expected reciprocal similarity:

- Sunshine totals describe incoming solar radiation as an integral over the seasonally variable length of the day, whereas cloudiness describes the coverage of the total sky at fixed times.
- Sunshine totals are measured, cloudiness is subjectively estimated.

Experience gained by the metadata survey and during the homogenisation work suggests the sunshine series tend to be more reliable than cloudiness series with the consequence that existing inhomogeneities may explain some of the existing dubious points or parts of the curves. However, comparisons of the respective sunshine and cloudiness series shows that the questionable features are rather small. On a decadal scale, there is a good coincidence of respective maxima and minima, only on a centennial scale are there some astonishing effects for example, the weak and statistically insignificant increase of high elevation winter cloudiness parallel to increasing sunshine totals. In general, the cloudiness series are potentially useful in the homogenisation process but should be used carefully and always counterchecked with sunshine series.

Unlike the previously discussed air pressure and sunshine series, which could be expected to be forcing factors on temperature, the following climate elements (starting with precipitation) are interesting in respect to their reactions to temperature variability. This is especially interesting in relation to the oncoming consequences of climate warming in connection with problems of water supply, flooding etc. Therefore, a closer inspection of the reaction of precipitation totals to the centennial warming since the late 19th century in the study region seems worth while.

Concerning high frequent variability, the correlation analysis in section 6.1 has already shown a significant negative correlation between low elevation mean summer precipitation and temperature, and a weak, statistically insignificant, positive correlation of the respective winter values. Nevertheless, the relatively highly variable sub-regional correlation values recommend that, for precipitation, only the sub-regional series be used. The comparative temperature and precipitation series in Figs. 6.29 to 6.32 for the four low elevation sub-regions (homogenised high elevation precipitation series are not available in the region) confirm this. In the more maritime sub-regions, W and N, of the study region winter precipitation has increased parallel to temperature. It is not only the centennial trend, but also the decadal features that are similar. In the more continental sub-regions, E and S, the reaction of precipitation is different for the two distinct “warming steps”. The first strong winter warming from 1890 to 1920 was accompanied by stagnant to slightly increasing precipitation. The second winter temperature increase, which started in the 1940s, shows decreasing winter precipitation in the two continental sub-regions. Summer precipitation clearly shows trends opposite to the summer temperature in sub-region E, only during the recent two decades are rising summer temperatures accompanied by rising precipitation. The same feature exists in sub-region S but with smaller precipitation amplitudes. In the maritime sub-regions W and N there is no centennial precipitation trend during the century of climate warming, only some weak reactions of precipitation on decadal temperature extremes are visible.

In general, it has to be stressed that the most interesting reaction of precipitation to temperature variability is that there is no unique reaction but a variable sub-regional pattern of different reactions both in a spatial and also in a temporal sense. These findings, which are related to such a small region, should be kept in mind when global aspects of precipitation in connection with climate warming are discussed. If there is any global mean precipitation reaction it must be expected to be highly non-representative at a regional or local scale.

Another element of the water cycle is humidity, represented here by time series of vapour pressure (Figs. 6.33 and 6.34) and of relative humidity (Figs. 6.35, 6.36 and 6.37).

Vapour pressure is among those elements with the highest positive correlation with temperature, the comparison of the long-term temperature and vapour pressure series shows a high degree of similarity. The low elevation summer curves of the 20th century and the high elevation summer curves for the whole period of observation are closely linked to the temperature evolution. Only the 19th century parts of the low elevation vapour pressure summer curves show stronger deviations from the temperature series. This could partly be due to lower precipitation amounts in the dry 1860s compared to the wetter 1880s and 1890s. On the other hand, remaining inhomogeneities could also be an explanation – taking into account the very high quality requirements on a climate element with long-term amplitudes of less than 1 hPa compared to the not much lower accuracy of humidity measurement in general. Also, in winter the general long-term features of temperature evolution can be seen in the vapour pressure curves as well – decreasing vapour pressure in the early parts and increasing after the main winter minimum near 1890. Due to the small absolute values of vapour pressure in the cold season, the respective trends are marginal.

In general, the vapour pressure series suggest that atmospheric circulation advects a considerable amount of water from the source regions (the Atlantic mainly) into the study area to increase vapour pressure in a warming atmosphere. Taking into account the lower values of vapour pressure in the colder mountain air, together with the similar vapour pressure increase in absolute figures, the atmospheric water transport from the source regions seems to be more effective at high altitudes. This mechanism is even easier to identify in the time series of the other available humidity measure, the relative humidity series. Figs. 6.35, 6.36 and 6.37 compare the relative humidity series of sub-regions at low elevation (W), with the mean over the other three low level sub-regions (N, E and S), and the high elevation sub-region with the mean temperature series. There is a remarkable difference between the long-term decreasing trend in relative humidity during times of temperature increase in the continental low elevation part of the study region (the S-E-N average in Fig. 6.36) and the stability of relative humidity versus temperature increase at high elevation (Fig. 6.37). The mountains are obviously more closely linked to the Atlantic humidity source regions than the low elevation surroundings (higher wind speed, less stagnating situations). The assumption described is additionally supported by the relative humidity series of sub-region W (Fig. 6.35) which also shows reduced long-term relative humidity decrease compared to the more continental sub-regions.

The difference series of mean daily maximum minus mean daily minimum temperature, the mean diurnal temperature range (DTR), is often used in an ambivalent way in the discussion of climate change. Since attention was called to a global decrease of DTR by the papers of Karl et al., 1993 and of Horton, 1995, their findings have been the subject of a great number of scientific studies and also of many public discussions on the topic of global warming. The mentioned ambivalence is represented by an astonishing gap between the majority of scientific studies, which usually try to find the reasons for the DTR decrease in climatic forcing factors like cloudiness, snow cover, urbanisation, etc., and general statements in the public arena where DTR decrease is considered one of the leading indicators of anthropogenic climate change.

The study region obviously does not belong to those regions with an decrease of DTR. There are rather long DTR series here starting in 1837 for low elevation, and 1886 for high elevation sites. The dominating feature of the DTR series is a very high degree of long-term and also decadal scale stability (Figs. 6.38 and 6.39). Since 1945, there has been a very small (far below any level of significance) DTR decrease of –0.3K at low altitudes and a +0.2K increase at high altitudes. Both these trends reflect, in this period, the respective trends of sunshine series i.e., decreasing at low altitudes and increasing at high altitudes (see Fig.6.13).

It has already been mentioned (see Fig.6.21) that there is a significant positive correlation between DTR and mean temperature in summer, and a zero correlation in winter, both at low and at high altitudes. The very high correlation with sunshine and cloudiness points to the already discussed natural forcing factors for high frequent DTR variability.

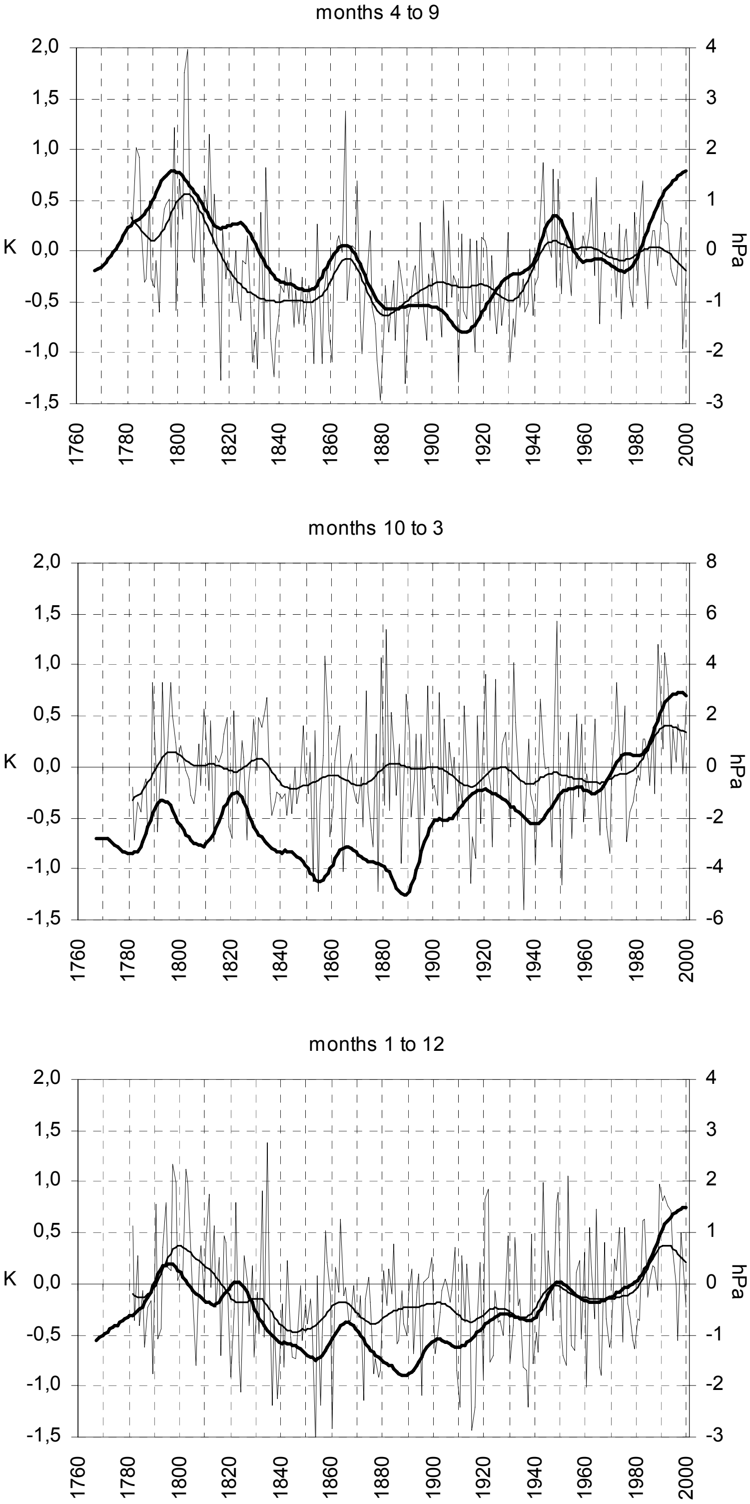


Fig. 6.23. Seasonal and annual variability of mean low elevation air pressure and mean temperature
Bold: 30-years smoothed “study area average” temperature
Medium: 30-years smoothed air pressure
Thin: single years (seasons) air pressure
(all values are deviations from 1961-1990 average, smoothing technique described in Fig.6.2)

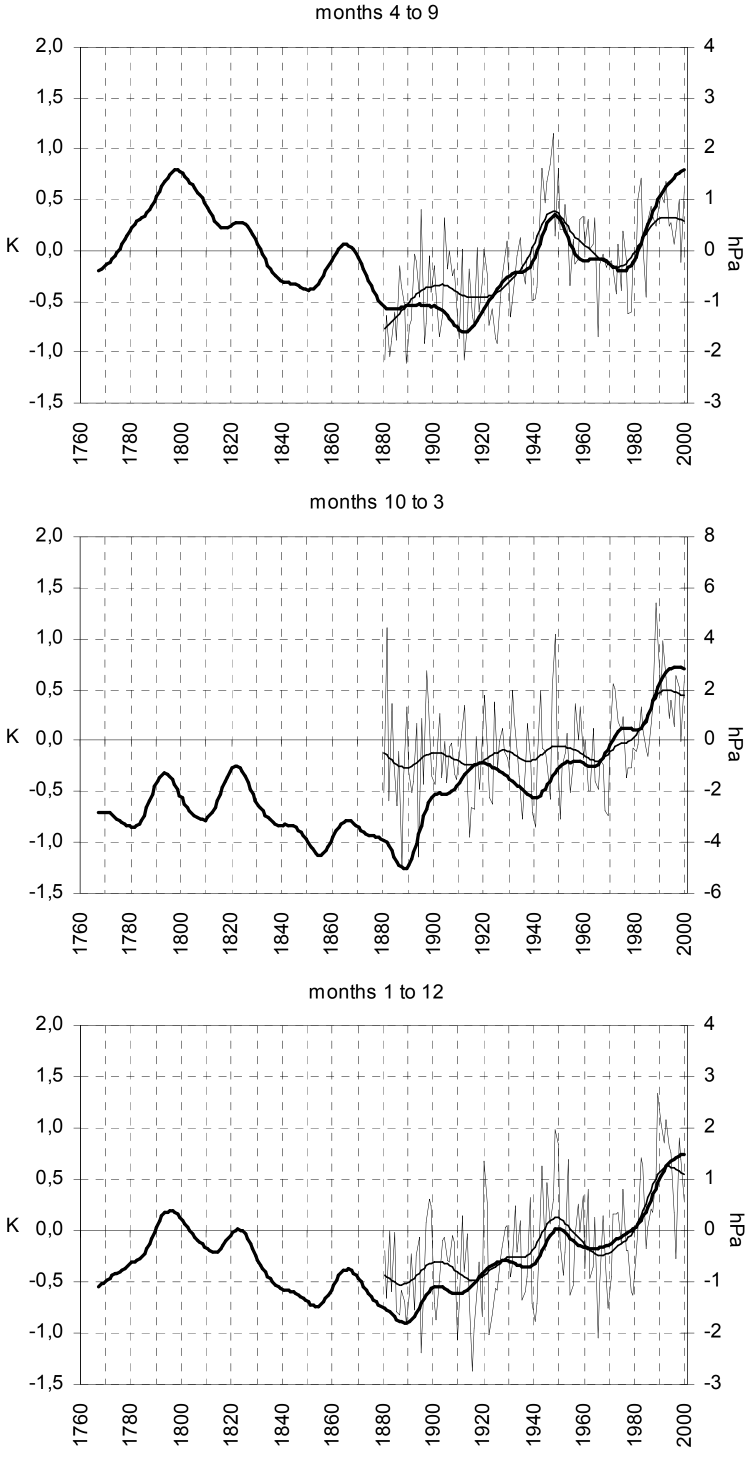
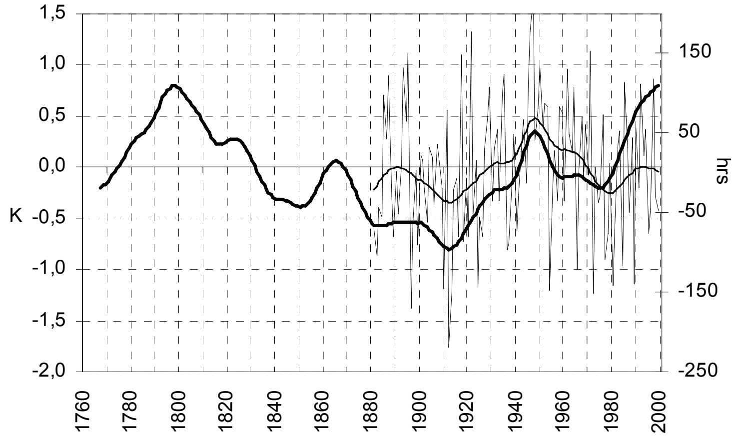
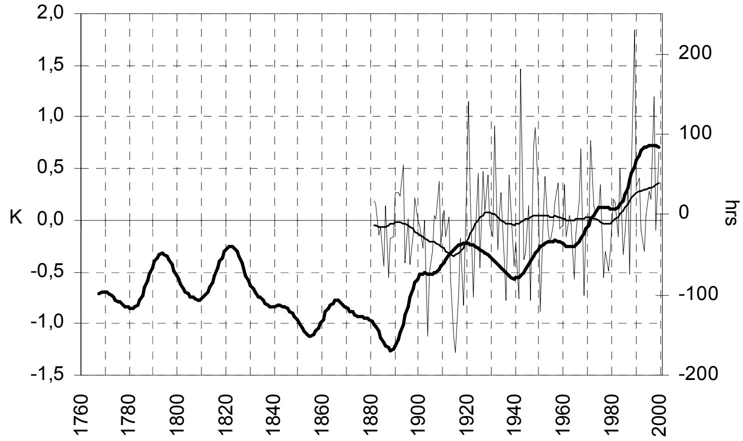


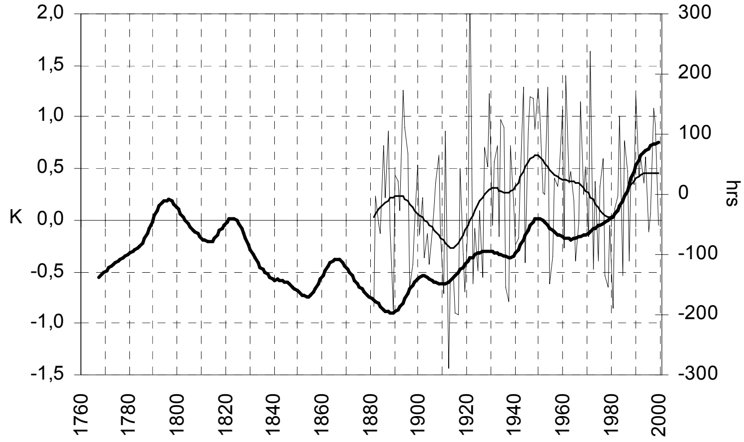
Fig. 6.24. Seasonal and annual variability of mean high elevation air pressure and mean temperature
Same layout as fig.6.22



months 4 to 9



months 10 to 3



months 1 to 12

Fig. 6.25. Seasonal and annual variability of mean low elevation sunshine and mean temperature
Same layout as fig.6.22

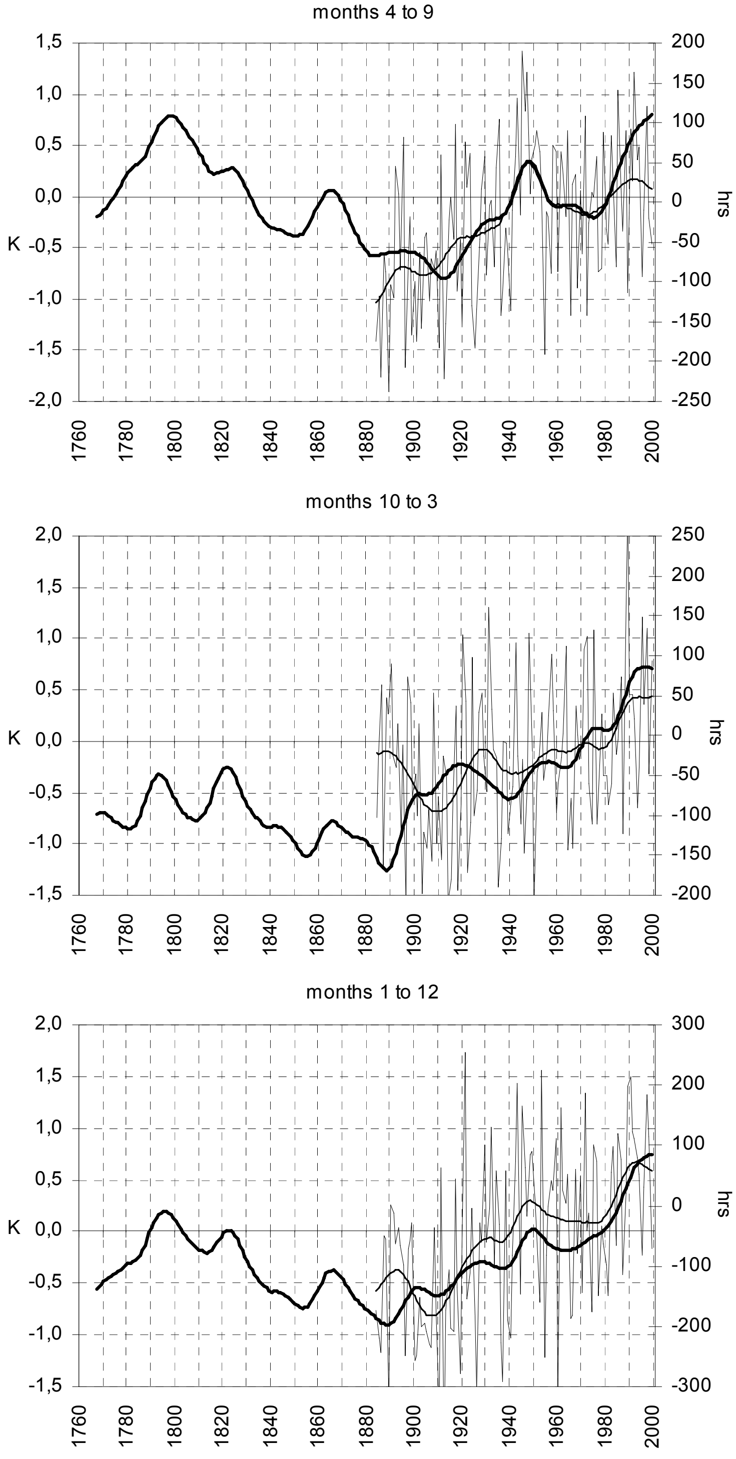


Fig. 6.26. Seasonal and annual variability of mean high elevation sunshine and mean temperature
Same layout as fig.6.22

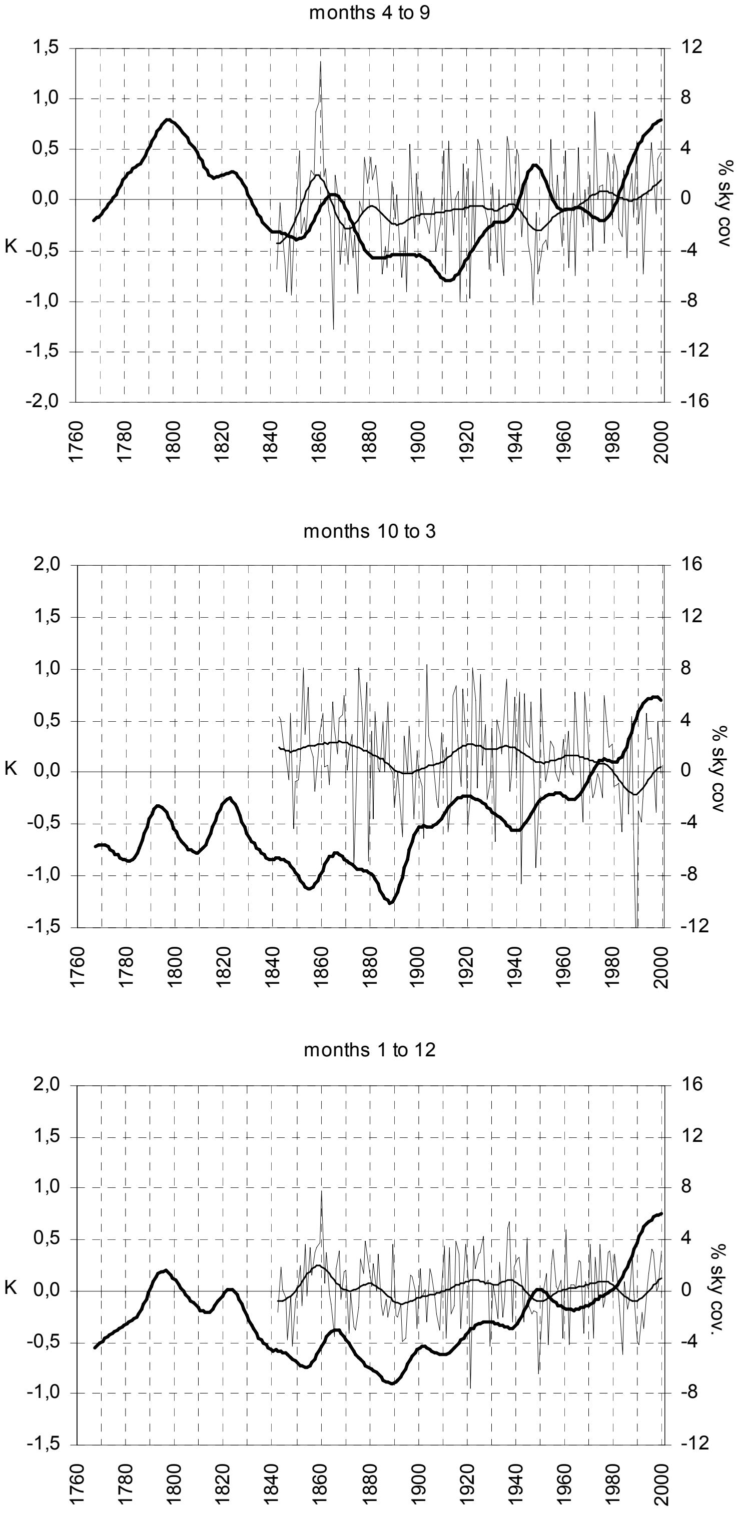


Fig. 6.27. Seasonal and annual variability of mean low elevation cloudiness and mean temperature
Same layout as fig.6.22

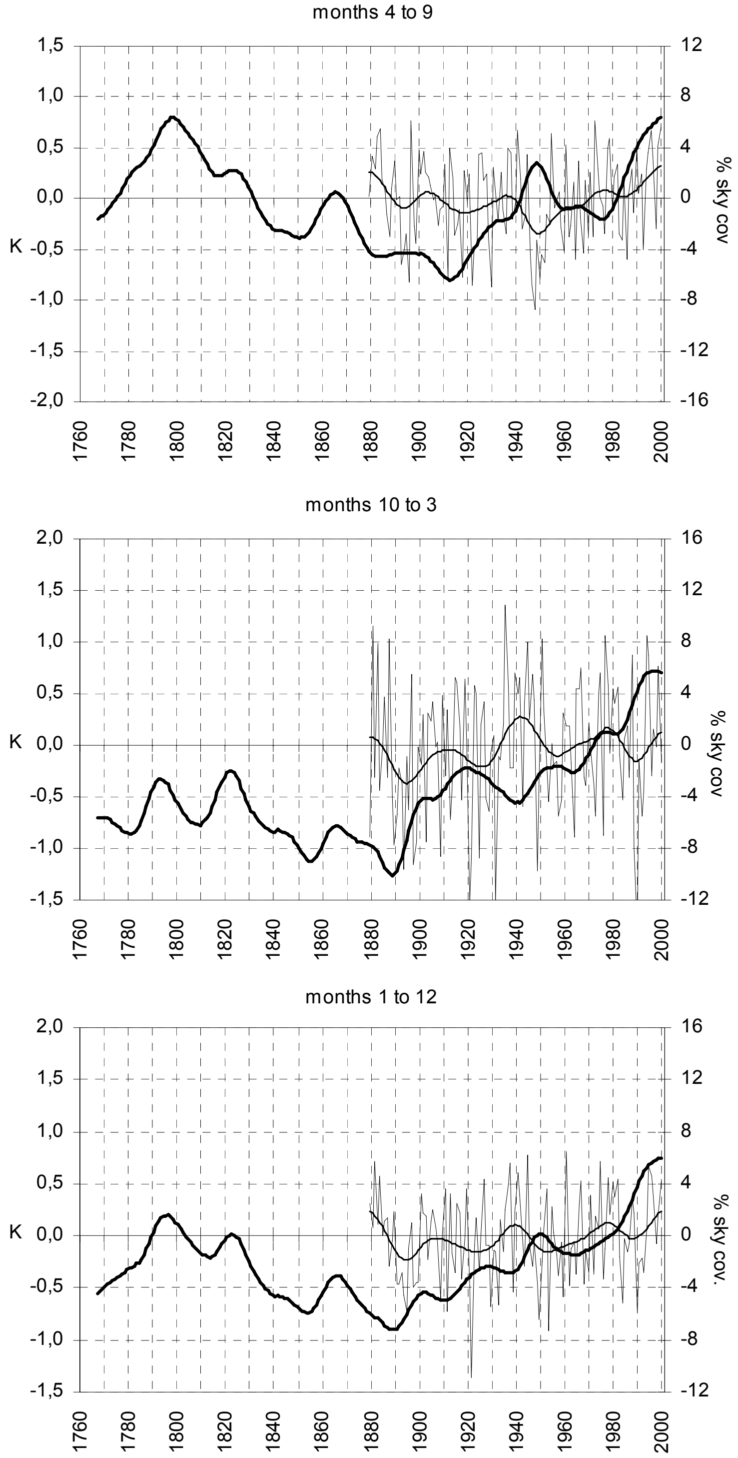
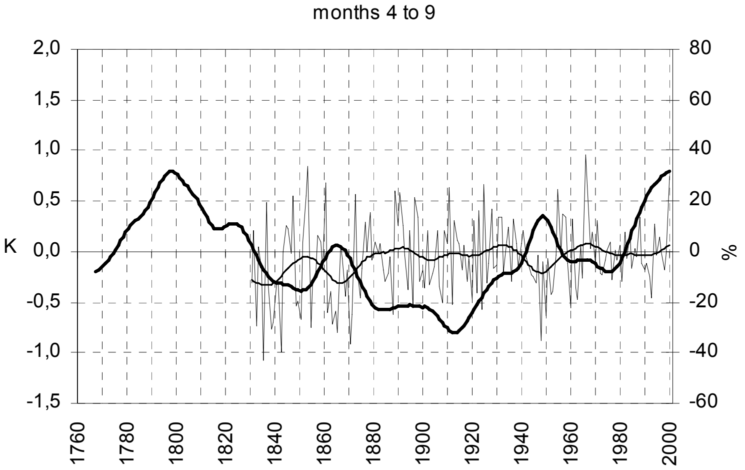
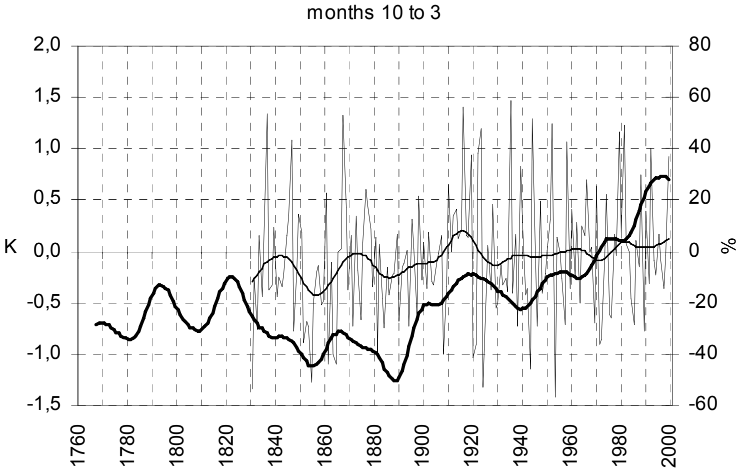


Fig. 6.28. Seasonal and annual variability of mean high elevation cloudiness and mean temperature
Same layout as fig.6.22





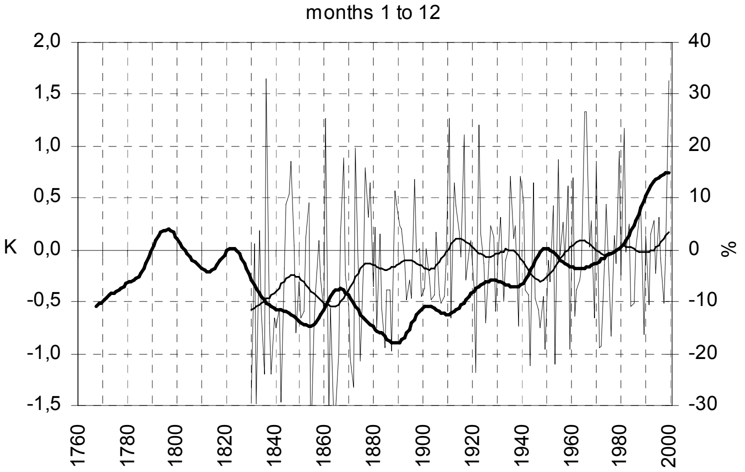


Fig. 6.29. Seasonal and annual variability of precipitation totals in region West and mean temperature
Same layout as fig.6.22

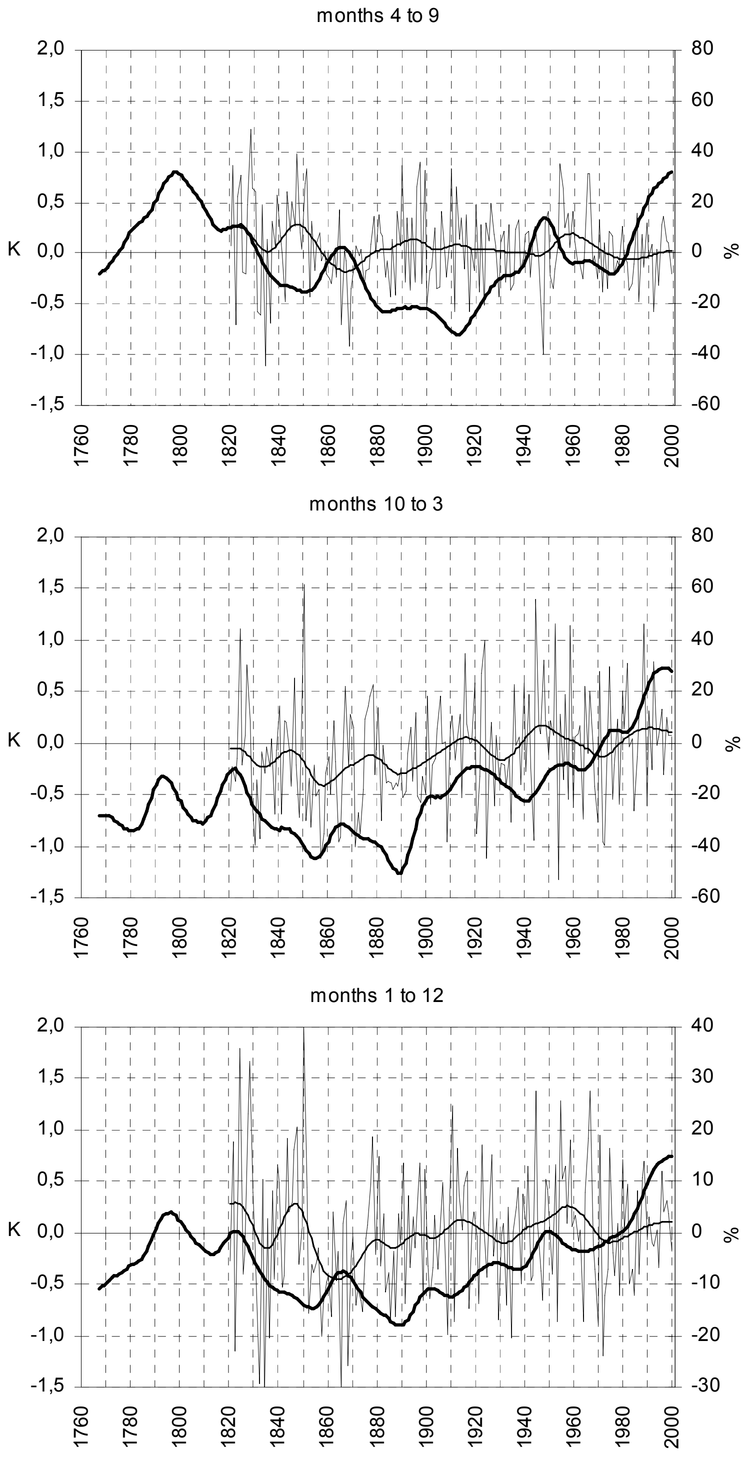


Fig. 6.30. Seasonal and annual variability of precipitation totals in region North and mean temperature
Same layout as fig.6.22

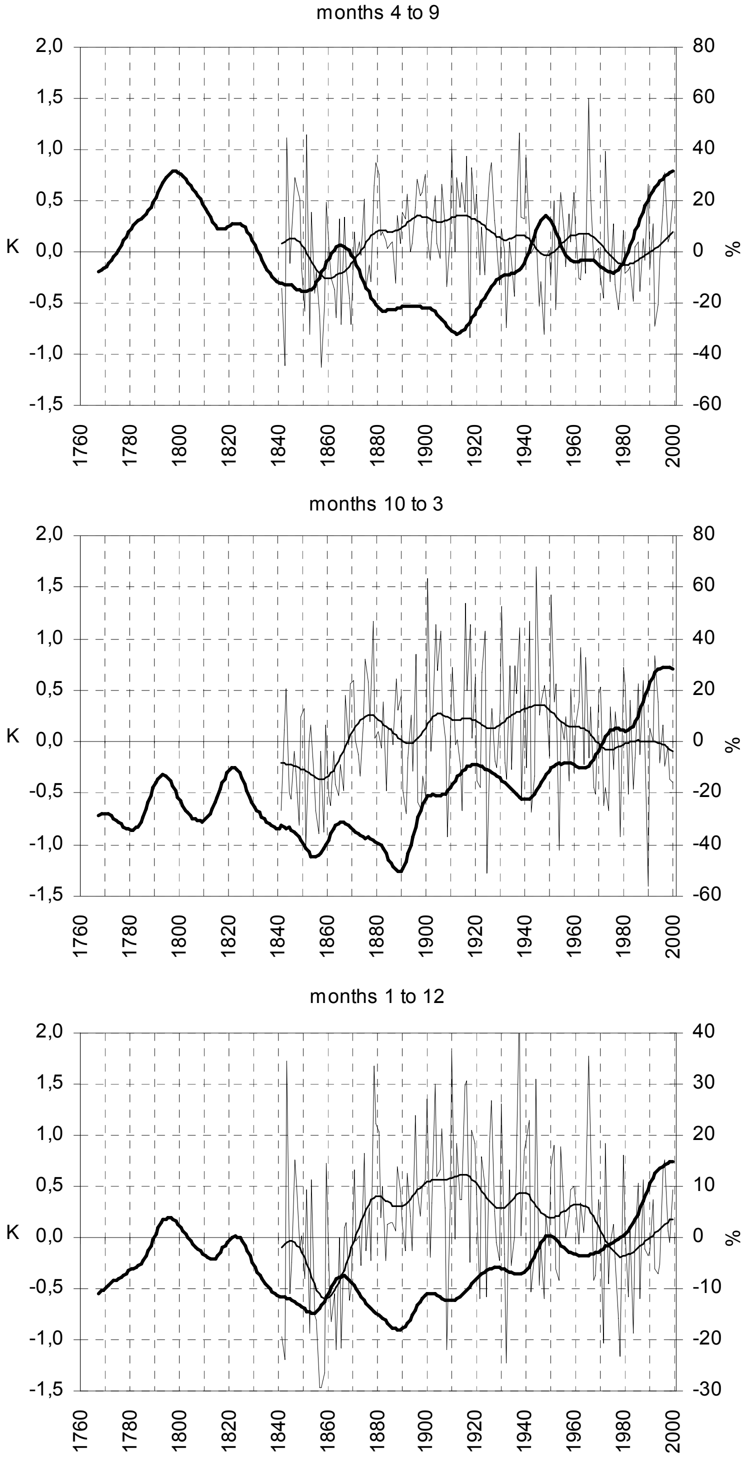
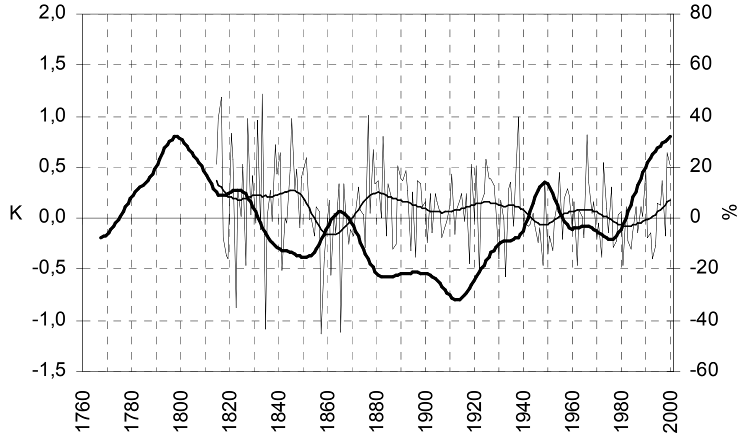
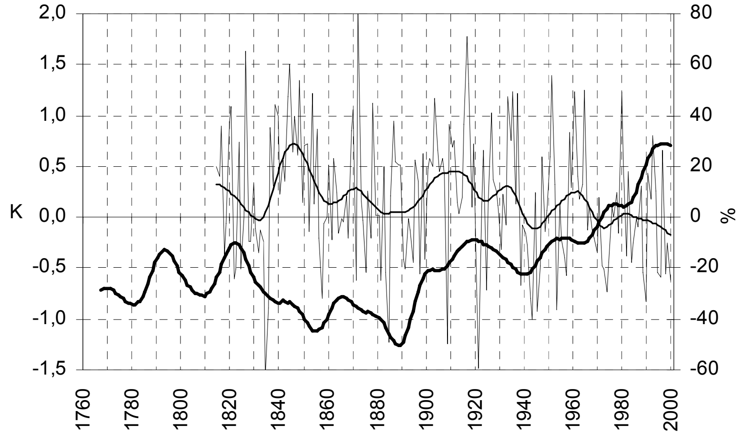


Fig. 6.31. Seasonal and annual variability of precipitation totals in region East and mean temperature
Same layout as fig.6.22

months 4 to 9



months 10 to 3



months 1 to 12

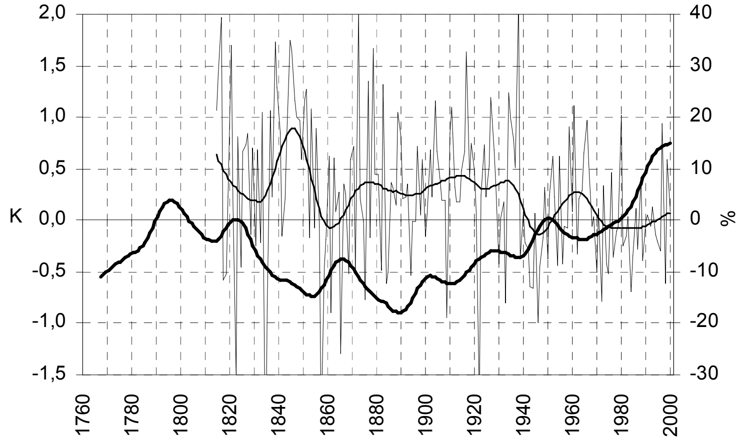
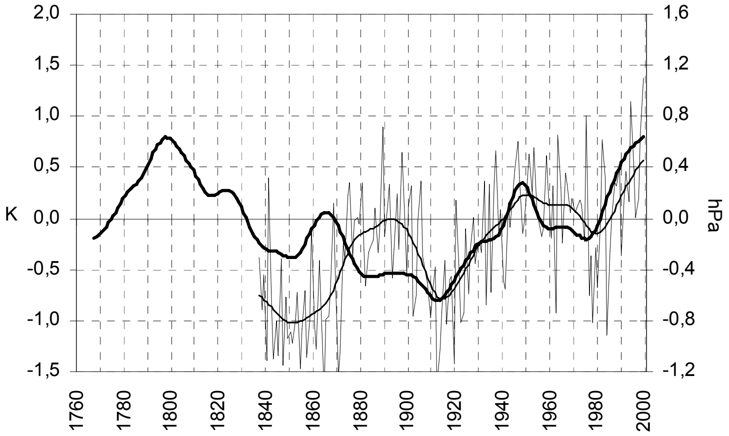
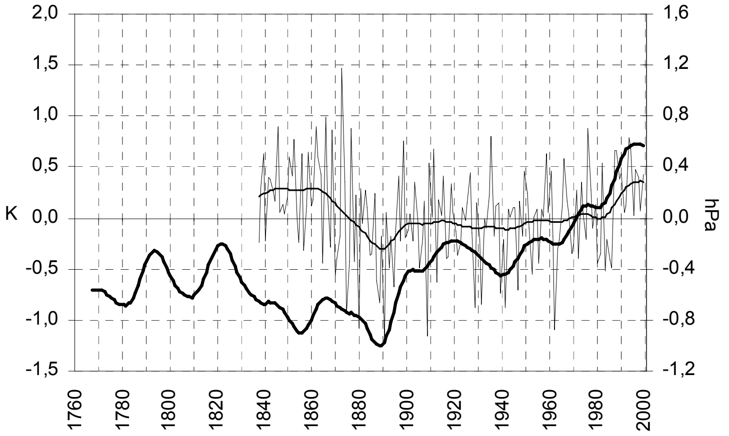


Fig. 6.32. Seasonal and annual variability of precipitation totals in region South and mean temperature
Same layout as fig.6.22

months 4 to 9



months 10 to 3



months 1 to 12

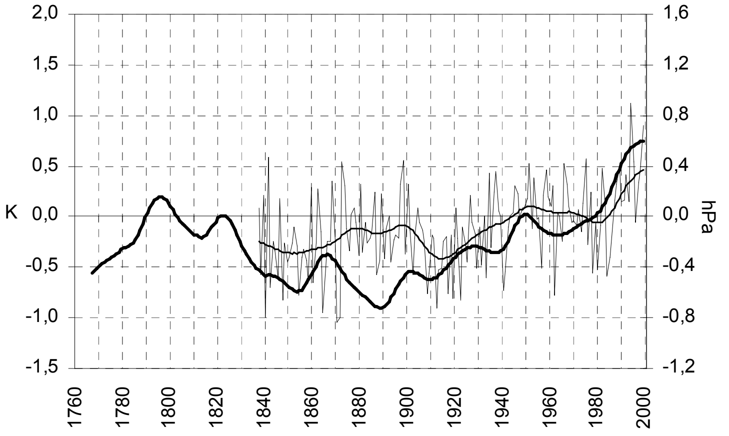
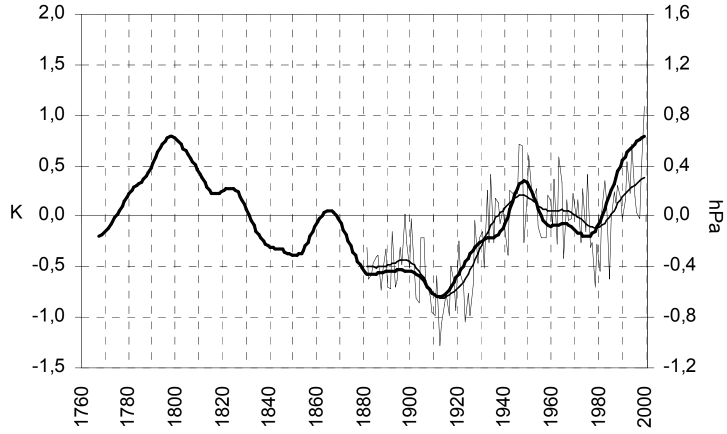
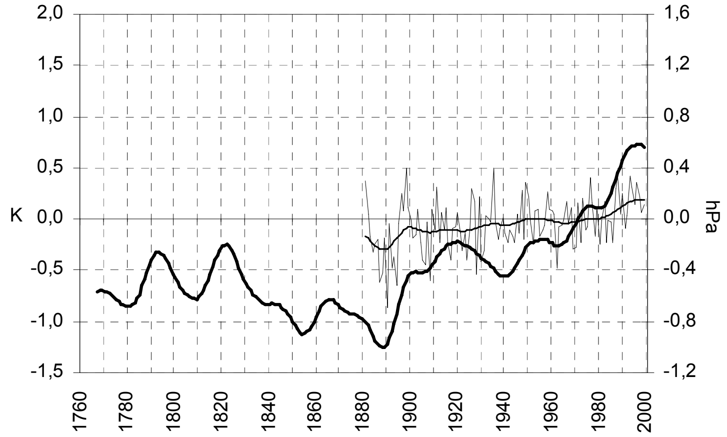


Fig. 6.33. Seasonal and annual variability of low elevation vapour pressure and mean temperature
Same layout as fig.6.22

months 4 to 9



months 10 to 3



months 1 to 12

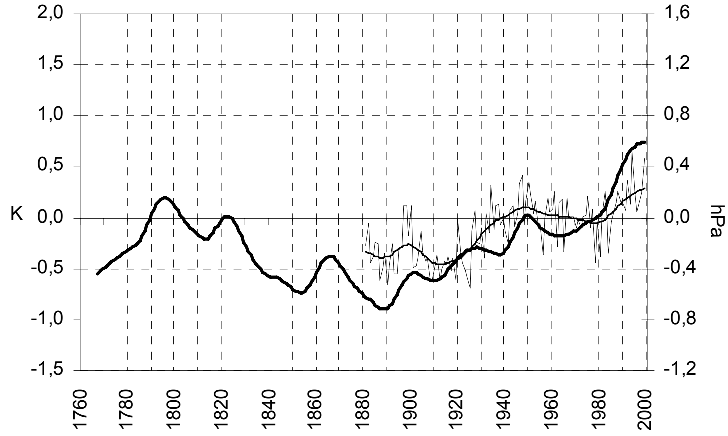
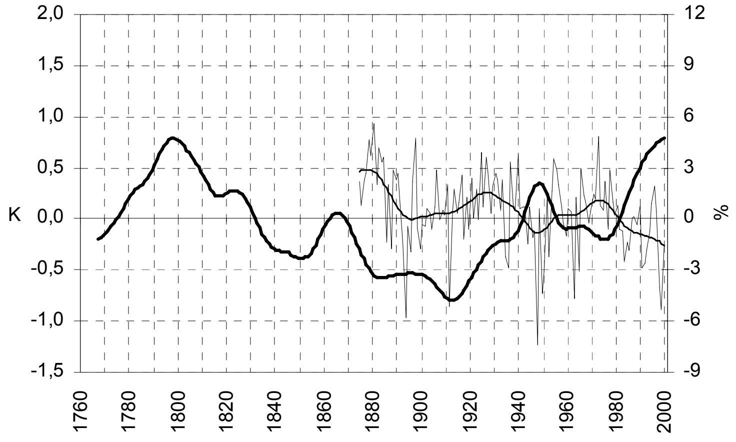
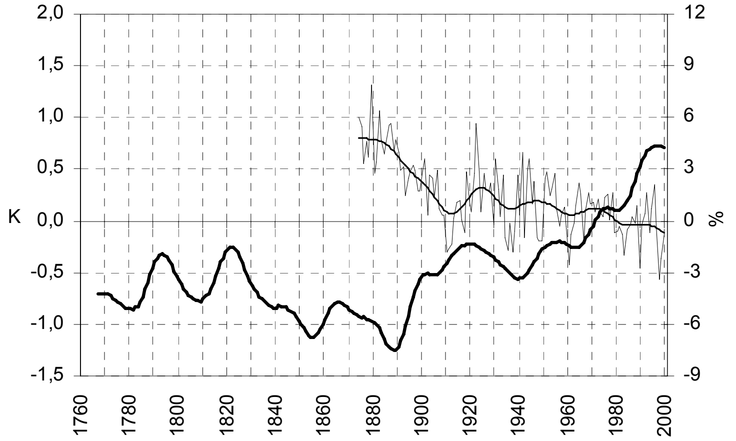


Fig. 6.34. Seasonal and annual variability of high elevation vapour pressure and mean temperature
Same layout as fig.6.22

months 4 to 9



months 10 to 3



months 1 to 12

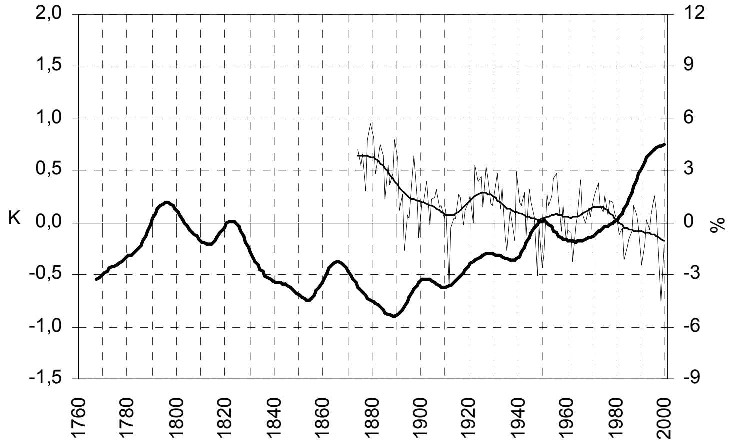


Fig. 6.35. Seasonal and annual variability of low elevation relative humidity in sub-region W and mean temperature
Same layout as fig.6.22

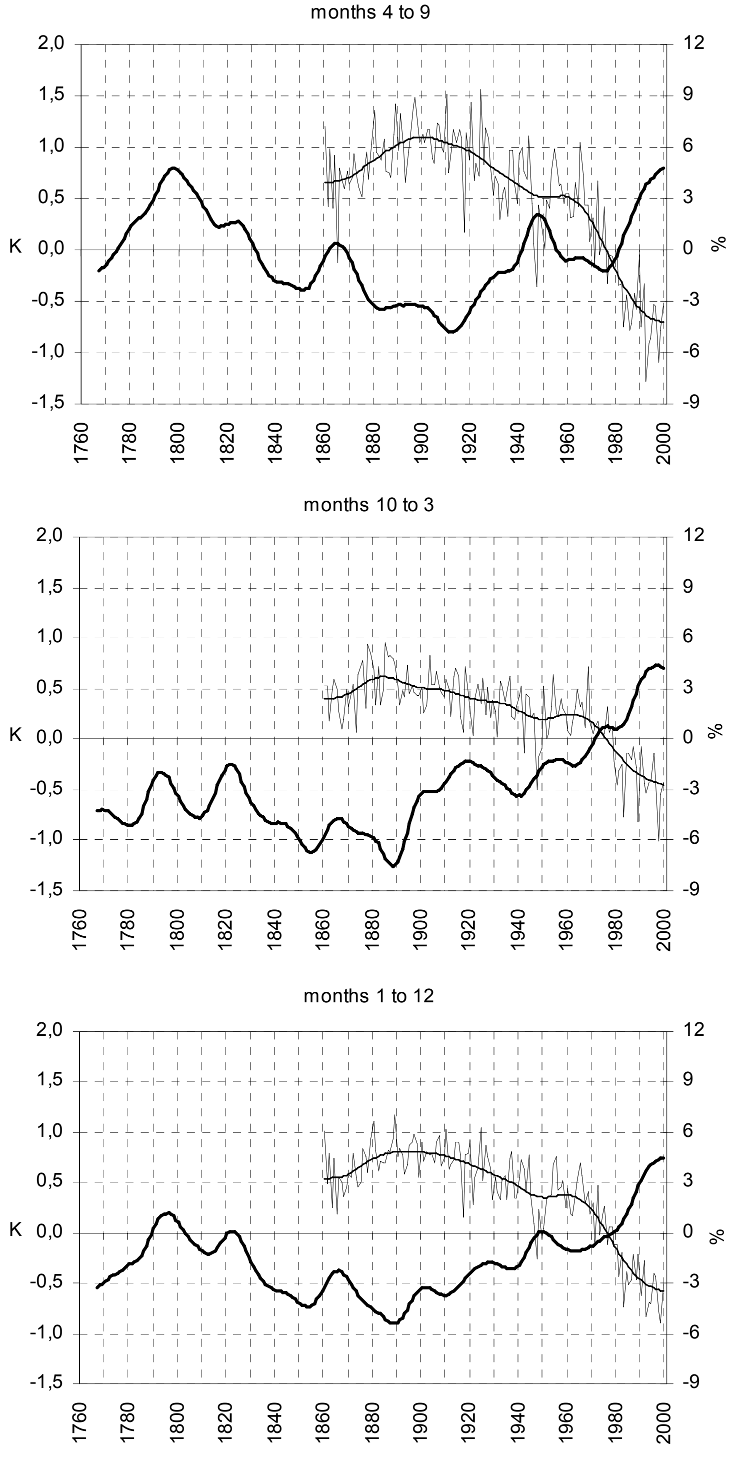


Fig. 6.36. Seasonal and annual variability of low elevation relative humidity in sub-regions S, E and N and mean temperature
Same layout as fig.6.22

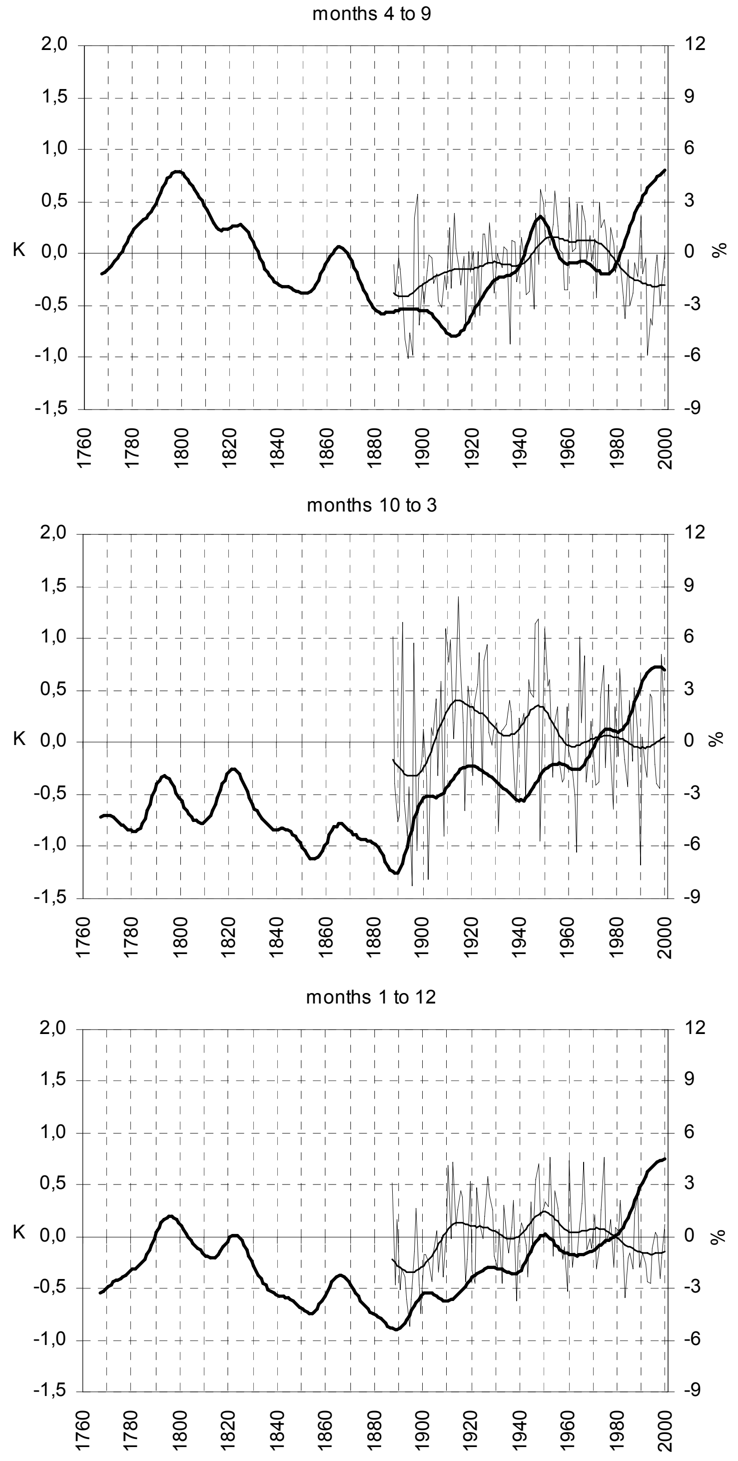
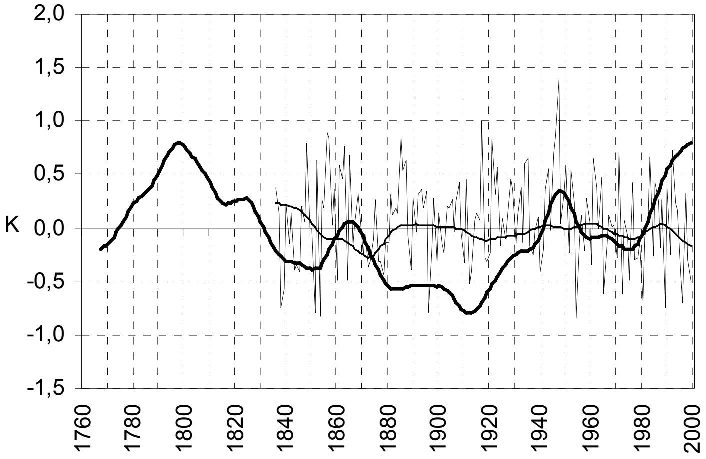
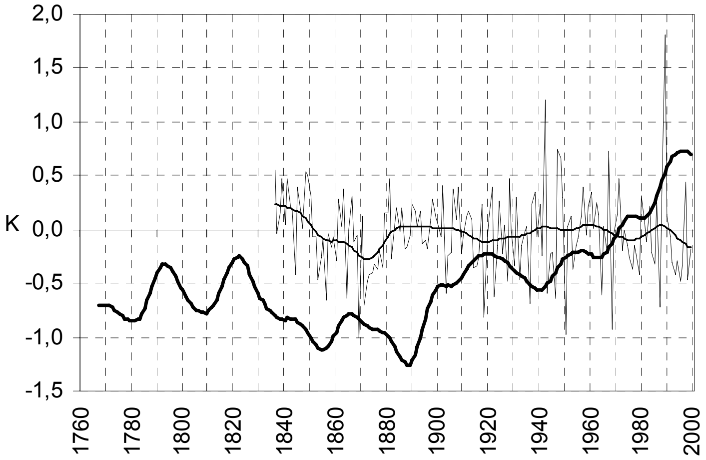


Fig. 6.37. Seasonal and annual variability of high elevation relative humidity and mean temperature
Same layout as fig.6.22

months 4 to 9



months 10 to 3



months 1 to 12

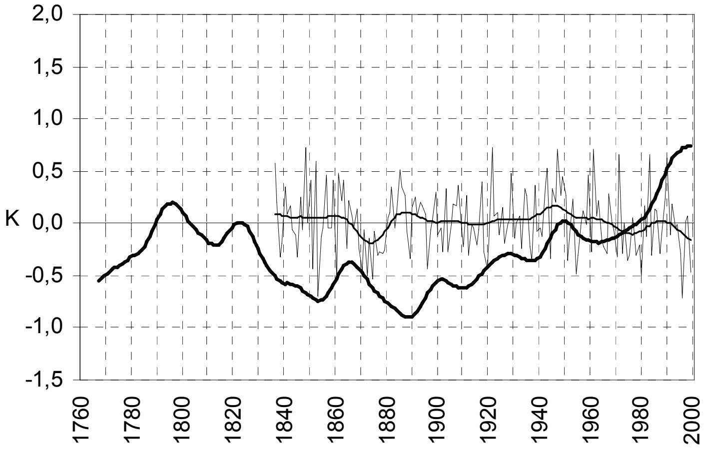


Fig. 6.38. Seasonal and annual variability of low elevation mean diurnal temperature range (DTR) and mean temperature
Same layout as fig.6.22

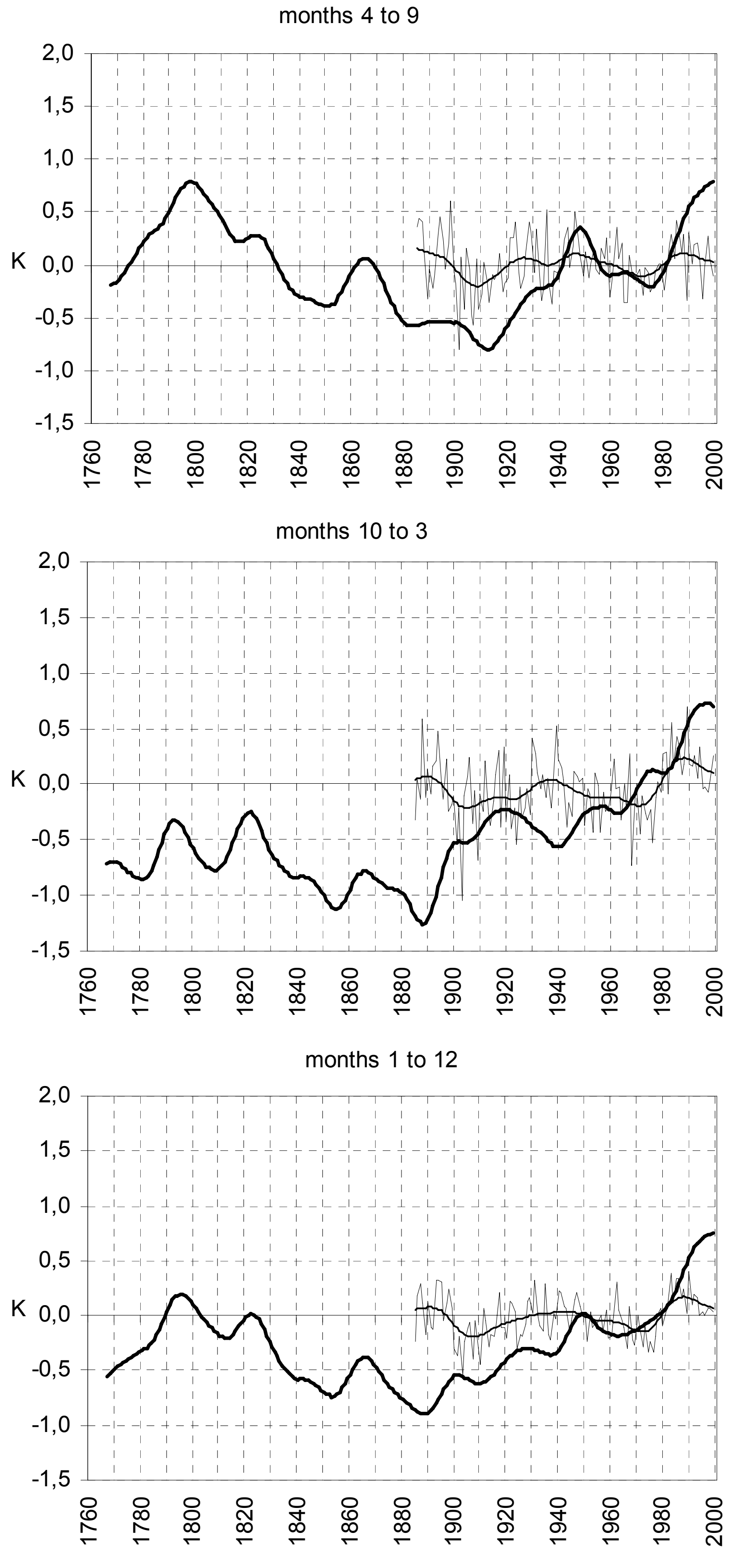


Fig. 6.39. Seasonal and annual variability of high elevation mean diurnal temperature range (DTR) and mean temperature
Same layout as fig.6.22

The last Table, 6.4, serves as a summary of the typical long-term characteristics of multiple climate variability in the instrumental period of the study region. It shows the linear trends of all available climate elements in the two main multi-decadal periods of initial cooling and the following warming. The period lengths are 1800-1910 and 1910-1999 for the summer half of the year, 1790-1890 and 1890-1999 in winter and for the entire year. The first (cooling) period is covered in its entire length by air pressure and mean temperature, the second (warming) period for all climate elements.

In general, and on centennial time scale, the last two centuries in the study region were characterised by:

- A uniform temperature evolution in all sub-regions;
- Decreasing temperature (stronger in summer, weaker in winter) in the 19th century;
- Increasing temperature in the 20th century;
- No asymmetric day-time/night-time temperature trends i.e., stable diurnal temperature range;
- Parallel evolutions to temperature for low elevation air pressure and high elevation sunshine;
- A relative increase of high elevation air pressure and sunshine versus the respective low elevation series;
- Precipitation variability with strong regional differences – no uniform reaction of precipitation to temperature increase;
- Rising winter precipitation parallel to 20th century warming together with stable to slowly decreasing summer trends in the more Atlantic sub-regions W and N;
- 20th century summer and winter drying in the continental parts, but with stronger variability at shorter time scales;
- Very weak long-term trends in cloudiness;
- The close similarity of vapour pressure to the respective temperature series;
- A strong decrease in relative humidity in the warming continental low elevation atmosphere;
- Stable relative humidity at high elevations and in the western (Atlantic) parts of the study region.

Table 6.4. Centennial seasonal and annual linear trends of all climate elements and all sub-regions in the two dominating climate periods in the study region.

	mean air pressure	mean temperature	mean daily max temp.	mean daily min temp.	mean daily temp. range	precipitation totals	totals of bright sunshine	mean cloudiness	mean relative humidity	mean vapour pressure
low elevation	hPa/100y	K/100y	K/100y	K/100y	K/100y	%/100y	hrs/100y	%SC/100y	%/100y	hPa/100y
Summer (4 to 9)										
1800 - 1910	-1.28*	-1.05*								
1910 - 1999	+1.02*	+1.32*	+1.04*	+1.30*	-0.26	-9.1	+19.2	+1.8	-9.8**	+0.91*
Winter (10 to 3)										
1790 - 1890	-0.63	-0.93								
1890 - 2000	+1.14	+1.15*	+1.21*	+1.26*	-0.05	-1.8	+44.5	-0.9	-4.4**	+0.26
Year (1 to 12)										
1795 - 1890	-0.70	-0.97*								
1890 - 1999	+1.14	+1.12*	+1.06*	+1.16*	-0.10	-5.7	+55.4	+0.6	-6.2**	+0.41*
high elevation	hPa/100y	K/100y	K/100y	K/100y	K/100y	%/100y	hrs/100y	%SC/100y	%/100y	hPa/100y
Summer (4 to 9)										
1800 - 1910										
1910 - 1999	+1.62*	+1.37*	+1.24*	+1.17*	+0.07		+84.6	+2.8	-0.7	+0.84**
Winter (10 to 3)										
1790 - 1890										
1890 - 2000	+2.01*	+1.17*	+1.35*	+1.17*	+0.18		+95.7*	+2.4	+0.1	+0.22*
Year (1 to 12)										
1795 - 1890										
1890 - 1999	+1.62*	+1.17*	+1.30*	+1.18*	+0.12		+188.9*	+2.2	+0.7	+0.47**
west	hPa/100y	K/100y	K/100y	K/100y	K/100y	%/100y	hrs/100y	%SC/100y	%/100y	hPa/100y
Summer (4 to 9)										
1800 - 1910	-1.28*	-1.03*								
1910 - 1999	+1.14*	+1.15*	+0.29	+1.41*	-1.11*	-2.7	-25.2	+1.9	-2.0	+0.79*
Winter (10 to 3)										
1790 - 1890	-0.73	-0.87								
1890 - 2000	+1.38	+1.33*	+1.34*	+1.45*	-0.11	+10.5	+69.5*	+2.7	-2.4*	+0.58*
Year (1 to 12)										
1795 - 1890	-1.43*	-0.96*								
1890 - 1999	+1.03*	+1.15*	+0.87*	+1.33**	-0.46*	+1.7	+59.3	+3.1*	-1.7*	+0.56*

Table 6.4. – continued

	mean air pressure	mean temperature	mean daily max temp.	mean daily min temp.	mean daily temp. range	precipitation totals	totals of bright sunshine	mean cloudiness	mean relative humidity	mean vapour pressure
east	hPa/100y	K/100y	K/100y	K/100y	K/100y	%/100y	hrs/100y	%SC/100y	%/100y	hPa/100y
Summer (4 to 9)										
1800 - 1910	-1.05	-1.08*								
1910 - 1999	+0.90	+1.44*	+1.49*	+1.50*	-0.02	-19.0	+45.0	+1.3	-10.5**	+0.72*
Winter (10 to 3)										
1790 - 1890	-0.47	-0.78								
1890 - 2000	+0.90	+1.08*	+1.15*	+1.33*	-0.18	-10.3	+59.3	-3.5	-4.8**	+0.09
Year (1 to 12)										
1795 - 1890	-1.33	-0.90*								
1890 - 1999	+0.79	+1.13*	+1.24*	+1.24*	0.00	-13.3*	+85.3	-1.1	-7.1**	+0.24
north	hPa/100y	K/100y	K/100y	K/100y	K/100y	%/100y	hrs/100y	%SC/100y	%/100y	hPa/100y
Summer (4 to 9)										
1800 - 1910		-1.08*								
1910 - 1999	+1.03*	+1.37*	+1.43*	+1.12*	+0.31	-8.4	+56.0	+0.1	-14.7**	+0.84*
Winter (10 to 3)										
1790 - 1890		-1.17*								
1890 - 2000	+1.23	+1.15*	+1.07*	+1.29*	-0.22	+9.2	+31.6	+0.5	-6.5**	+0.26
Year (1 to 12)										
1795 - 1890		-1.08*								
1890 - 1999	+0.92	+1.13*	+1.08*	+1.12*	-0.04	-1.2	+60.0	+0.3	-9.2**	+0.38*
south	hPa/100y	K/100y	K/100y	K/100y	K/100y	%/100y	hrs/100y	%SC/100y	%/100y	hPa/100y
Summer (4 to 9)										
1800 - 1910										
1910 - 1999	+1.01*	+1.31*	+0.93*	+1.16*	-0.23	-6.2	+1.0	+3.9	-12.0**	+1.29*
Winter (10 to 3)										
1790 - 1890										
1890 - 2000	+1.06	+1.06*	+1.29*	+1.00	+0.30	-16.7	+17.5	-3.5	-4.0*	+0.13
Year (1 to 12)										
1795 - 1890										
1890 - 1999	+0.93	+1.06*	+1.05*	+0.97*	+0.08	-9.8	+22.5	+0.2	-7.0**	+0.44*

***) trend to noise ratio >1   **) trend to noise ratio >2**
%SC...sky coverage in %

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