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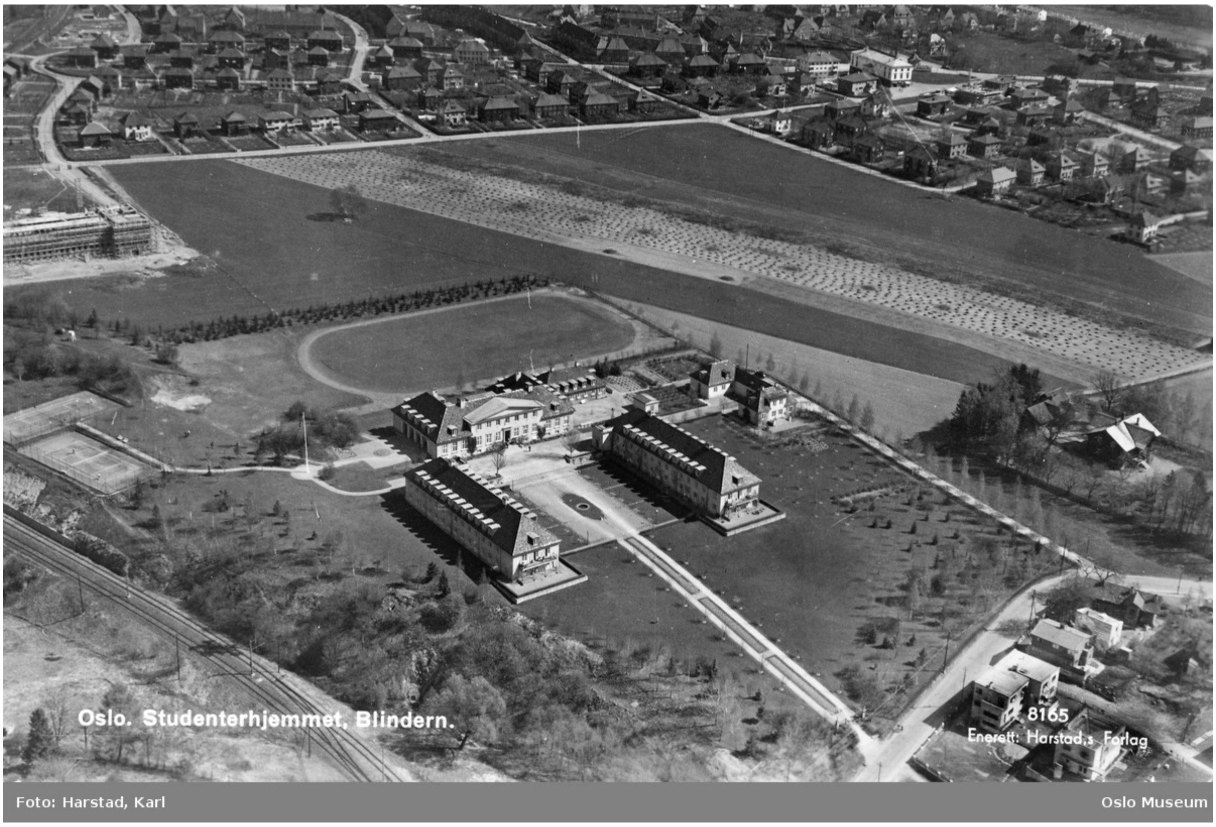

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Homogenization of daily mean temperature in Norway

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Abstract

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Abstract

When assessing trends and variability of climatic time series it is necessary to ensure that these only represent a climate signal, and that the series not are influenced by external factors such as station relocations, instrumentation changes and changes in the surroundings. To check this, the series should undergo a homogenization analysis, where such inhomogeneities are identified and adjusted. This report presents such an analysis for five Norwegian temperature series applying the homogenization software developed in COST action HOME; HOMER and SPLIDHOM. HOMER is applied to detect homogeneity breaks in monthly series, while SPLIDHOM is applied to adjust these breaks in daily time series.

Five temperature series representing different energy consumption regions in Norway are successfully homogenized; Oslo, Kjevik (Kristiansand), Bergen, Værnes (Trondheim) and Tromsø. The study show that HOMER and SPLIDHOM are strong tools and well suited for such analyses.

Keywords

Climate, Daily Homogenization, Splidhom, Homer, Homogeneity

Disiplinary signature

Responsible signature

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1 - Introduction

When analysing trends and variability of climatic time series will the accuracy and consistency of the underlying observations be of extreme importance. A homogenous representation of climate only exists when variations in the time series are only results of variations in weather and climate (Easterling et al, 1996). Changes in the technical and/or environmental conditions such as relocations, change in instruments and sensors, change of observers, change of observing practices, new buildings etc. at observation stations might seriously affect the measurements in such a way that sudden shifts (homogeneity breaks) in the time series will be introduced. Other conditions such as land use changes, urban development and changes in vegetation introduce trends in the time series that might deviate from the regional climate characteristics. Analysing and correcting for such external influences to achieve homogeneous climatic time series is therefore necessary before making an assessment of climatic change.

The homogeneity if climatological time series have traditionally been analysed on annual, seasonal and occasionally on monthly data. Such analyses have been a focus by climatologists in particularly the last two-three decades (Peterson et al, 1998, Venema 2012).
The analyses usually take a *relative homogenization approach* assuming that neighbouring stations are exposed to the same climate signal and thus differences between such stations can be used to detect inhomogeneities, e.g. by using the well-known double-mass principle plotting the cumulative sum of the candidate series with one or more accumulated neighbouring series (Buishand, 1982).

In the recent decades statistical methods for detecting inhomogeneities, such as the SNHT method (Alexandersson, 1986) based on a likelihood ratio test and linear regression models (Easterling and Peterson 1995, Vincent, 1998). More recently developments for identification and adjusting multiple breaks-points and applying inhomogeneous references (Szentimrey, 1999, Mestre, 1999, Caussinus and Mestre, 2004, Menne and Williams, 2009) have been achieved. Peterson et al (1998), Aguilar et al 2003 and Venema et al., 2012 provides good overviews of existing methods for homogenization of monthly data. Homogeneity assessment and adjustment can be quite complex (Aguilar et al. 2003; Vincent et al. 2002) and it often requires close neighbor stations, detailed station history (metadata), and a great amount of time.

The use of climate extreme indices based on high-temporal data is becoming frequently applied in order to assess and understand its impact in natural processes and on society in a changing climate. To study this phenomenon, reliable daily series are required, for instance to compute daily-based indices: high-order quantiles, annual extremes, and so on. Because observed series are likely to be affected by changes in the measurement conditions, adapted homogenization procedures for such high-resolution data are required (Mestre et al, 2011). This is much more complicated than on monthly, seasonal or annual scales. While the change points in a low resolution time series can be detected and removed by using linear techniques, depends daily and sub-daily data strongly of the actual weather situation. Brandsma et al (2002) and Brandsma (2004) demonstrated that a multiple regression model applying wind speed and direction, sunshine duration and parallel measurements as predictors for adjusting temperatures at the De Bilt observatory in the Netherlands was a good approach. Access to such data is however rare, so more simplistic methods need to be applied to adjust the gross of the climate series.

One quite simple way to do it is to apply identified monthly adjustments on the daily or sub-daily values. This method is often called the Vincent method after Vincent et al. (2002) who performed an interpolation of monthly adjustment factors in order to achieve daily adjustments for Canadian temperature series. This approach was also applied by Moberg et al. (2002) for homogenization of the long Stockholm series of temperature and air pressure. This method is however still linear over the entire probability density function, and does not adjust changes in the higher statistical moments. In order to assess such changes, a different approach is needed. Methods assessing the entire distribution functions have recently been taken into use by Trewin (2001), the HOM-method (Della-Marta and Wanner, 2006) and SPLIDHOM (Mestre et al., 2011).

Homogenisation of temperature in the Nordic countries: In Scandinavia large achievements was done in terms of homogenizing Nordic climate series in the 1990'ies, much inspired by the development of the SNHT method (Alexandersson, 1986) at SMHI. The Nordic activities were to a large degree coordinated by the NACD project developing a unique high quality monthly climate dataset covering the North Atlantic region (Frich et al, 1996). In Norway the first results concerning long-term Norwegian temperature series were the analysis of the Dombås series (Nordli, 1995), a spatio-temporal analysis of the NACD temperature series (Hanssen-Bauer et al. 1996) and Arctic series (Nordli et al. 1996). A thorough homogeneity analysis of Norwegian temperature series were presented by Nordli (1996, 1997). All these analyses were at monthly and seasonal resolution, using the SNHT methods and Mann-Kendall trend tests.
Nordli (1997) identified inhomogeneities in 13 of 22 long-term series. The most likely reasons for inhomogeneities were associated with relocations (37%) and sunshine on the wall thermometer screen (24%). More recently, as a part of the European COST HOME initiative (Mestre et al, 2011), an homogeneity analysis of monthly Norwegian temperature series has been carried out (Andresen, 2010, 2011). Homogeneity testing has also recently been performed on a time series from the Norwegian University of Life Sciences (NMBU) at Ås, 30 km in south-east direction from Oslo, where five inhomogeneities were detected (Gjelten et al., 2014). Also these analyses was carried out applying the SNHT method, a method that has proved to be a powerful tool for detecting the inhomogeneities in both monthly temperature and precipitation series (Alexandersson, 1984).

International coordination: Recently the World Meteorological Organization (WMO) set up a task team on homogenization (TT-HOM) in order to (a)Explore ways, building on the existing work, to identify the best performing, skilled and efficient homogenization methods and quality control procedures for the different climate essential variables and time scales (from monthly to sub-daily); (b) Identify and evaluate currently available procedures and software for climate time-series quality control (e.g., identifying non-systematic biases in climatic records); (c) Identify and assess skills and efficiencies of modern and innovative homogenization methods, to identify more robust and efficient methods including the associated software; and (d) Provide guidance to Members on methodologies, standards and software required for quality control of climate time-series, with a special focus on temperature and precipitation variables at the daily scale, but also explore existing quality controls for other variables and time-scales.

As a part of the international effort to provide homogenous climate data series will the Norwegian Meteorological institute continue to test and adapt tools for homogeneity analysis of climate time series on different time resolutions.

This report presents the results for homogeneity analyses of daily mean temperature series representative for five large cities in Norway as a part of the MIST-2 project, which is collaboration between Statkraft SF and MET. Statkraft utilizes temperature as a proxy variable for the modelling of general electricity consumption in price and production forecasting. Consistent and homogenous historical data will thus provide a better background for energy management and production optimization.

This report gives an overview of the methods, and the results of applying recommended method at the locations of interest for Statkraft. The report present a complete homogenization procedure for daily temperature series based on the break detection method SPLIDHOM for temperature (Mestre et al., 2011). SPLIDHOM is the chosen method to homogenize temperature series at a daily time scale in Norway. This method relies on an indirect nonlinear regression method. Estimation of the regression functions is performed by cubic smoothing splines. This method is able to adjust the mean of the series as well as high-order quantiles and moments of the series (Mestre et al., 2011).

The results of these analyses are five homogenized temperature time series during the period 1930 until 2014 at five locations in Norway. These time series are accessible through the eKlima portal (http://eklima.met.no).

2 - Background

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

The main challenge of the homogenisation of daily temperatures compared to monthly data is that the magnitude of inhomogeneities may differ with varying weather situations. The most promising methods are based on the estimation of changes in the overall distribution of an element (Trewin and Trevitt, 1996; Della-Marta and Wanner, 2006; Mestre et al., 2010). Even though these methods do not account for different meteorological parameters that characterize special weather situations (as described by Brandsma et al., 2002; Brandsma, 2004), they do examine the distribution of the element itself and apply variable adjustments depending on the percentiles.

In this study 3 homogenization methods have been considered:

(i) MASH, (Version MASHv3.03), initially developed in the Hungarian Meteorological Service by *Szentimrey* (1994, 1999, 2013); and,

(ii) RHtestV4, developed by Wang & Feng from the Climate Research Division, Atmospheric Science and Technology Directorate, Toronto, Ontario, Canada (published online 2009).

(iii) SPLIDHOM and HOMER developed in the framework of COST Action ES0601 (*HOME*, 2011).

Currently a very few statistical methods for homogenization of daily climate data for temperature and precipitation are available. Homogenization methods on a daily basis are scarce and often disregard uncertainties accompanying the break adjustment. In this study we have tested three different methods SPLIDHOM (Mestre, 2011), MASH (Szentimrey, 1999) and RHTEST (Wang et al., 2010). They are tested for all daily mean temperature (TAM), max (TAX) and min temperature (TAN).

3 - Methods and approach

During the last few decades a number of algorithms for testing homogeneity of climate data series have been developed and applied. This chapter gives a detailed descriptions of the methods applied in this study.

The methods that have been applied, based on recommendations of the COST HOME action are HOMER and SPLIDHOM. In the period 2007-2011 the COST Action ES0601 HOME (www.homogenisation.org) was devoted to evaluate the performance of homogenization methods used in climatology and produce software that would be a synthesis of the best aspects of some of the most efficient methods. HOMER (HOMogenizaton softwarE in R) is software for homogenizing essential climate variables at monthly and annual time scales. **HOMER** has been constructed exploiting the best characteristics of some other state-of-the-art homogenization methods, i.e., PRODIGE, ACMANT, CLIMATOL, and the recently developed joint-segmentation method (*cghseg*). HOMER is based on the methodology of optimal segmentation with dynamic programming, the application of a network-wide two-factor model both for detection and correction, and some new techniques in the coordination of detection processes from multi-annual to monthly scales. HOMER also includes a tool to assess trend biases in urban temperature series (UBRIS). HOMER's approach to the final homogenization results is iterative. It is an interactive method that takes advantage of metadata.

For daily data the method which we have chosen for the homogenization is referred to as spline daily homogenization (SPLIDHOM). This method has proven to handle inhomogenities in higher moments. It is one of the very few methods which can be applied for daily data. SPLIDHOM relies on an indirect non-linear regression method, estimation being ensured by cubic smoothing splines. This method is able to correct the mean of the series as well as high order quantiles and moments of the series. When using well-correlated series, SPLIDHOM improves the results of two widely used methods, as a result of an optimal selection of the smoothing parameter (Mestre et al, 2011).

Homogenization procedures

A combined application of the method HOMER (Mestre et al, 2013) for the detection of an unknown number of breakpoints and the method SPLIDHOM (Mestre *et al.*, 2011) for the calculation of adjustments and the correction of time series was selected for the daily homogenization of temperature time series in Norway.

First step of the homogenization: Choice of reference station

However, before any detection of breakpoints, the first step of the homogenization procedure is the optimal choice of reference stations. Reference stations are chosen according to their horizontal and vertical distance from the target station and most importantly a high correlation coefficient ($\rho > 0.8$) of the daily temperature series. While the correlation criterion was chosen according to Della-Marta (2007), the distance criterion is selected in a way to make sure that the climate is similar at the candidate and the reference stations. E.g. network III: Bergen belongs to a coastal climate and therefore other coastal stations should be included in the network, for example Utsira fyr.

Break detection

Since the break detection algorithm is not suitable for daily data, due to their high variability, the procedure is applied to time series of monthly mean values.

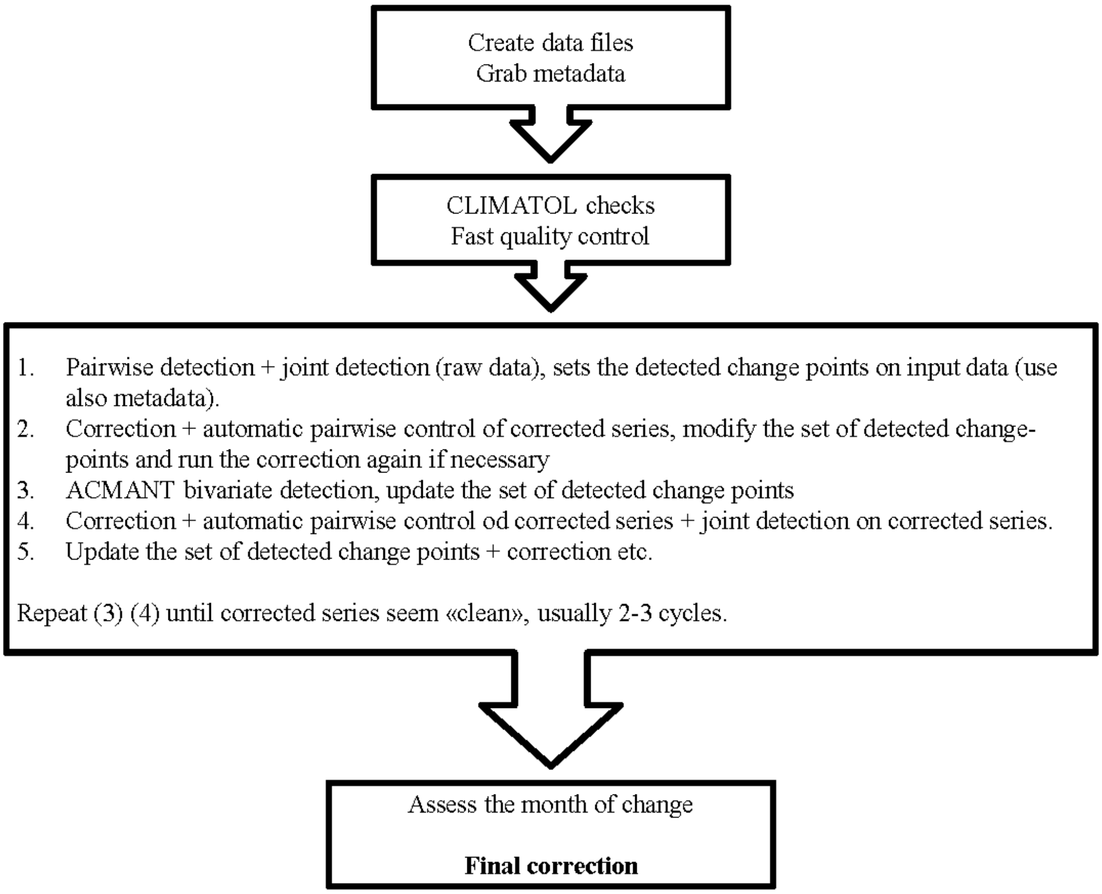


Figure 1: Tasks flow chart of Homer (Mestre et al, 2013). Appendix A contains the main procedure for HOMER.

Homogenization – break adjustment

After break detection by HOMER, SPLIDHOM (Mestre *et al*., 2011) is applied for correcting breaks on daily scale. Homogenization methods on a daily basis are scarce and often disregard uncertainties accompanying the break adjustment. We present a complete homogenization procedure for daily temperature series based on the break detection method SPLIDHOM for break correction. Both parts of the homogenization (HOMER and SPLIDHOM) rely on the existence of highly correlated reference stations. After the statistical comparison with neighbouring stations, detected breaks are verified and further localized by metadata.

An unsatisfying homogenization is primarily defined by a remaining break signal or subjectively strong uncertainties given by bootstrapping. SPLIDHOM is a method for sequential adjustment of breaks in a time series, starting with the most recent break, provided that homogeneous sub periods (period between two break points, the start or end of the series) before and after each break have a minimum length of 2 years.

The adjustments are based on a nonlinear regression function between the candidate and reference stations temperature measurements before and after the break point, making an adjustment of the mean as well as of the higher order moments of the daily temperature series possible. Further, the estimation is being smoothed by a cubic spline. The resulting regression function can be seriously affected by outliers, especially at the margins of the temperature frequency distribution. Therefore, and as enhancement to Mestre *et al.* (2011), the regression is re-estimated by means of a standard bootstrapping technique. Appendix A contains the main procedure for HOMER.

4 - Locations and network

The procedure for homogeneity testing followed the relative principle of comparing a candidate series (the series to be tested) against reference series. Traditionally the reference might be series from one or more neighbouring stations. This chapter will describe the data; metadata and the locations. Subsequent paragraphs will describe more about the candidate stations (chapter 4; I-V) and here it will also describe the reference stations. The main homogenization procedure is to find the breaks in the time series. This is in the chapter 5: Results.

One station from each region is used as candidate stations in the analysis. Temperature is an important indicator for energy consumption, and consequently for the energy production and prize setting in the energy market. Therefore is five areas with a large population chosen for the daily homogenization of temperature; Oslo, Bergen, Kristiansand, Trondheim and Tromsø. The candidate stations are listed in table 1 and their locations are shown as red squares in figure 2.

As HOMER and SPLIDHOM depends on a network of highly correlated neighbor time series representing the same climatological features reference networks for each candidate station are established. The networks are indicated with rectangles in figure 2, and the location of the reference stations are shown as orange squares.

Table 1: List of regions and the meteorological stations targeted in the homogenization of temperature.

Region	Stnr	Station Name	Time period	Relocations	Masl	Municipality
Eastern Norway	18700	OSLO-BLINDERN	1925-2014	1	94	Oslo
Southern Norway	39040	KJEVIK	1939-2014	0	12	Kristiansand
Western Norway	50540	BERGEN-FLORIDA	1903-2014	2	12	Bergen
Central Norway	69100	VÆRNES	1940-2014	3	12	Trondheim
Northern Norway	90450	TROMSØ	1895-2014	3	100	Tromsø

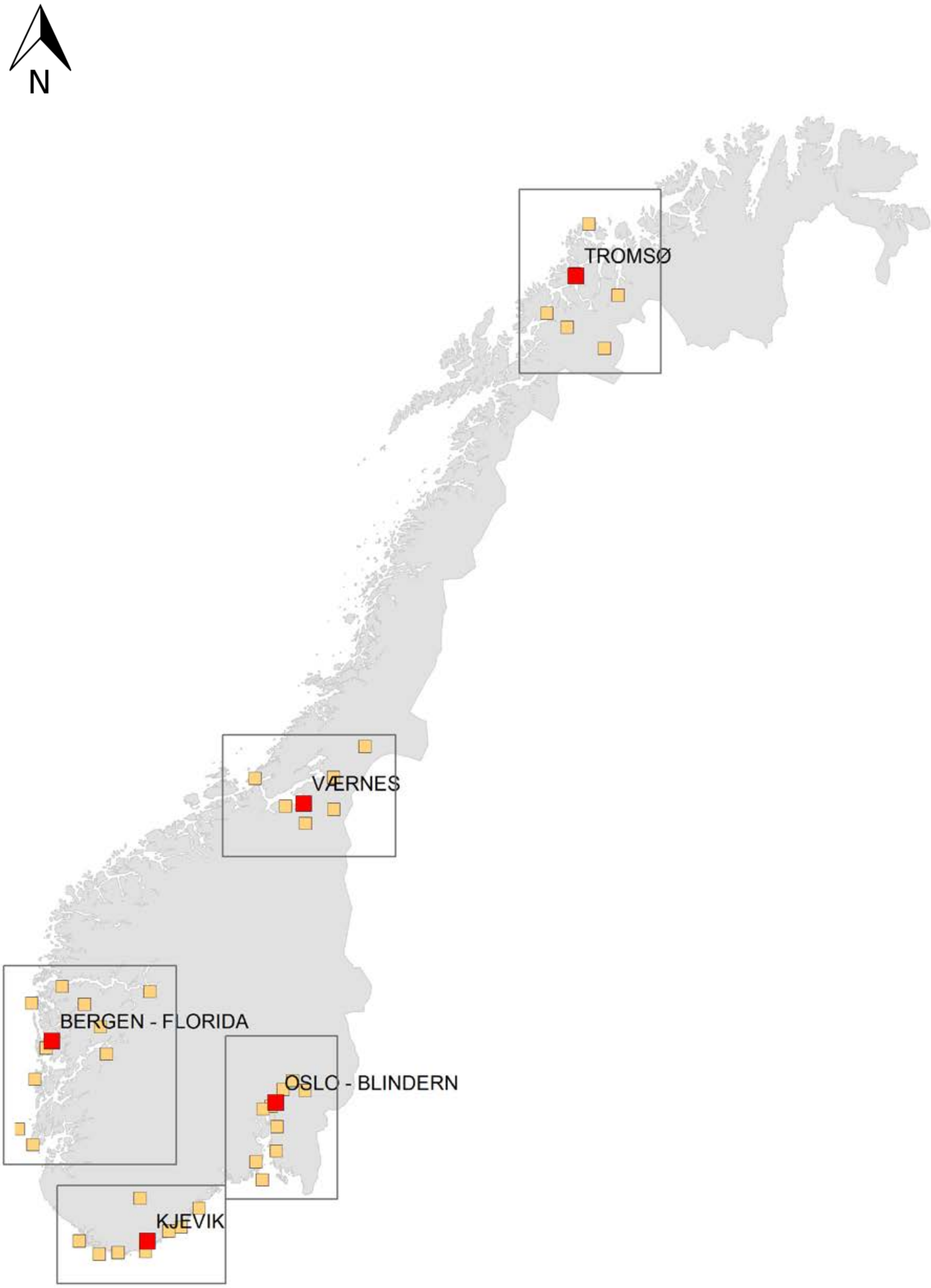


Figure 2: Map of the locations used in this analysis.

I. Oslo

Figure 3: Picture of 18700 Oslo-Blindern met station. The temperature screen is marked red.

18700 Oslo-Blindern

The candidate station in Oslo is 18700 Oslo-Blindern (fig. 3), located at Blindern, near the University of Oslo. Campus Blindern is in the suburban West End of Oslo. The meteorological station was moved to Blindern 1. February 1937. The station was moved 3.5 km from down town (see figure 4, aerial photo).

Figure 4: Aerial photo from Oslo for today shows 3.5 km between the stations Oslo I and Blindern.

The ”new” Meteorological Institute's building was completed in 1939. The building is situated 60 m north of the met-station. Blindern students’ home (1920s) is near the station (100 m south) (figure 5).

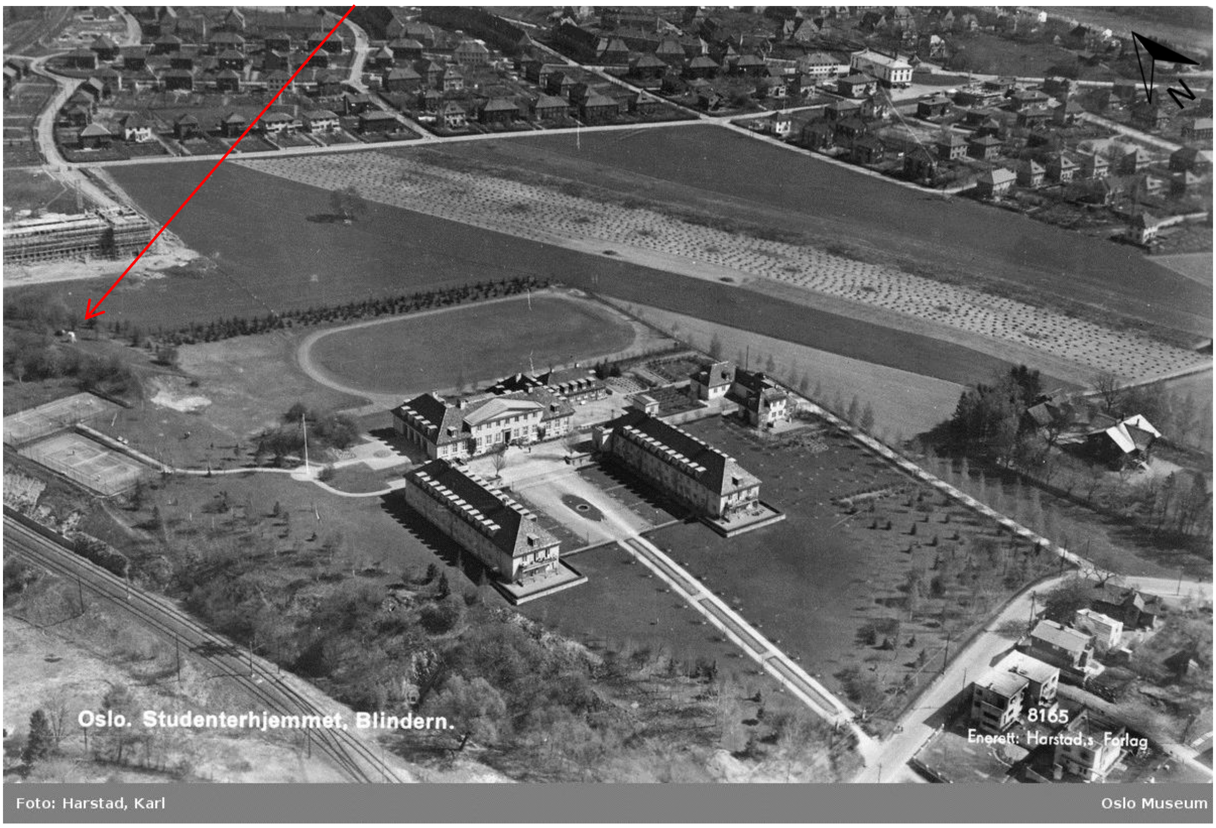


Figure 5: Picture of the “rural” Blindern area from 1939. The Met-Building to the left and the temperature screen (18700 Oslo-Blindern) is marked red arrow.

Before 1st February 1937, the meteorological observations was made down town (Skillebekk) on the so-called Observatory, formally name the Astronomical observatory. In Oslo is located at Solli Plass with address Observatoriegata 1 (22 m a.s.l.). The met-station was named *18650 Oslo I* (Nordli et. al, 2014). The time series in this study starts in 1925 (1930). So this is the two series used in this study. The city of Oslo has been under strong urbanization after the WW2. Now also the area around Blindern has been heavily urbanized. It was small settlement in the area before WW2. All housing in the area in north and east is part of the housing cooperative Ullevål Hageby (build in the 1920s), which is a residential area and garden city. The area borders to the Ullevål University Hospital in the west and the University of Oslo in south and east. The University of Oslo at Blindern was built mostly in the 1960s, but also in the 1990s. Later after the year 2000, the whole Forskningsparken was built in the west. As regards to vegetation, there has been a tree growth (birch, ca 10 m high) in an alley between the station and students home (see fig. 6).

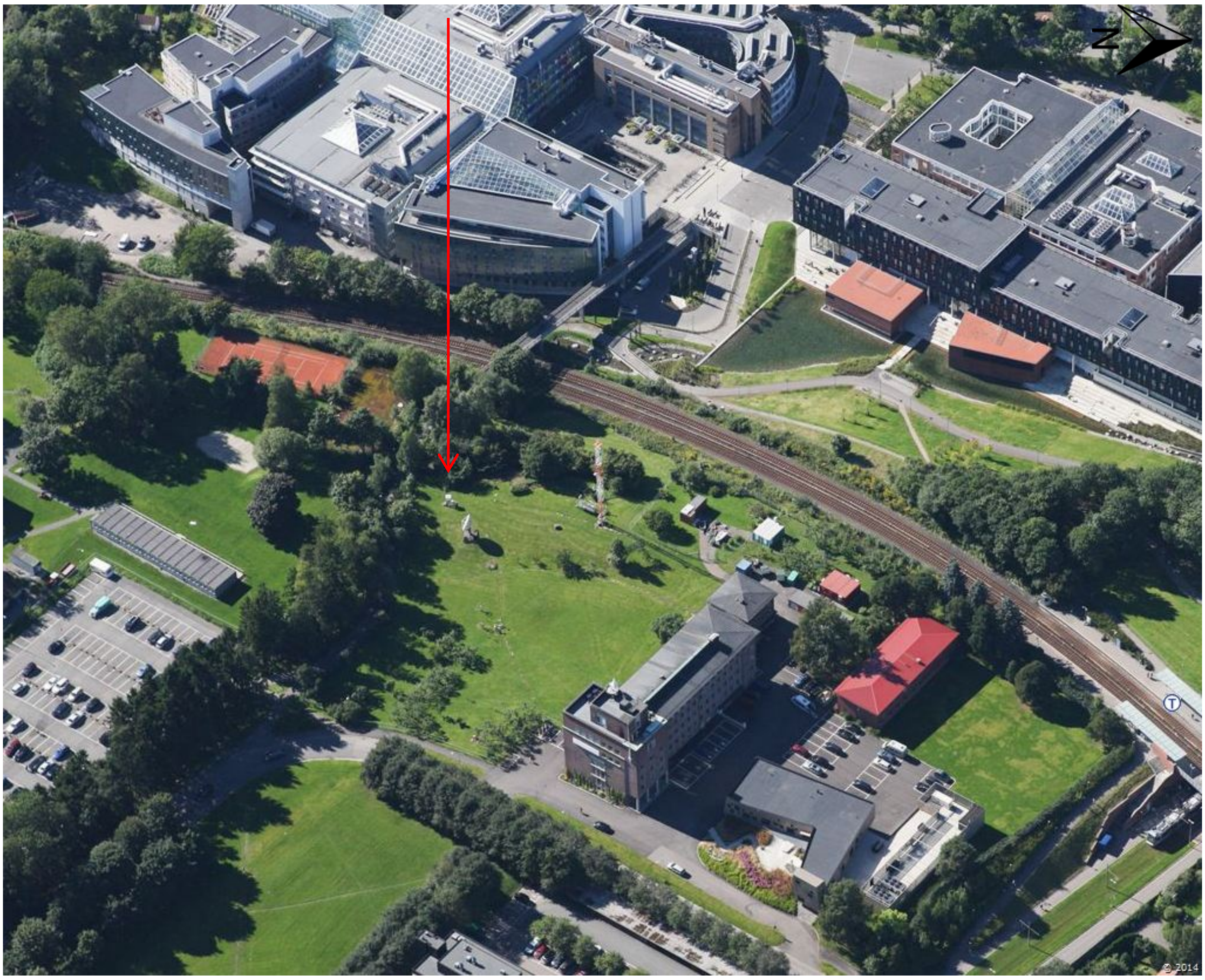


Figure 6: Aerial photo from Blindern today.

Oslo network

The Oslo network consists of 10 series including the candidate series at Oslo-Blindern. The locations of the series are shown in figure 7. The stations are mostly located near the Oslo Fjord (7 series), while three series are located in a more continental climate north of Oslo.

Figure 8 shows the time periods covered by the series in the network. Table 2 shows the series in the network, including the original series from which they are merged. Table 3 shows the correlation matrix between the series in the network. All stations are highly correlated, fulfilling the criterion in HOMER of ρ>0.8. All correlations are higher than 0.95 on an annual basis. The series showing the lowest correlation is 27599 Færder Fyr which is located on a small island and strongly influenced by sea. On the seasonal basis it is different. Table 4 shows the monthly correlations between Oslo-Blindern and the other series in the network.

Table 2: Series in the Oslo network.

Analysed series	Name	Period	Nr of original series	Breaks	Original series	Time coverage original series
18700	Oslo	1925-2014	**2**	**3**	18650 Oslo 1	1877-1937 (30.4)
					18700 Oslo-Blindern	1.2.1937-2014
04440	Hakadal	1982-2014	**2**	**1**	04440 Hakdadal-Bliksrudhagan	1.12.1982-31.12.2009
					04460 Hakadal jernbanestasjon	1.1.2007-2014
04780	Gardermoen	1957-2014	**1**	**4**	04780 Gardermoen	1.1.1959-2014
04930	Hvam	1954-2003	**2**	**2**	04930 Hvam	1.1.1954-31.7.1983
					04940 Hvam-Tolvhus	1.8.1983-30.4.2003
17150	Rygge	1955-2014	**1**	**2**	17150 Rygge	1.3.1955-2014
17850	Ås	1925-2014	**1**	**2**	17850 Ås	1874-2014
						1.5.1988-2014
19400	Fornebu	1954-1998	**1**	**2**	19400 Fornebu	1.1.1954-7.10.1998
19710	Asker	1957-2014	**1**	**0**	19710 Asker	1.1.1957-2014
27450	Melsom	1959-2014	**1**	**1**	27450 Melsom	1.4.1959-2014
27500	Færder Fyr	1925-2014	**1**	**1**	27500 Færder fyr	21.10.1885-2014

Table 3: Correlation matrix of the Oslo network. Number in italics in the columns indicates the highest pairwise correlation (column→row).

Stnr	4440	4780	4930	17150	17850	18700	19400	19710	27450	27500
4440		0.994	0.991	0.981	0.989	0.991	0.991	0.986	0.983	0.954
4780	*0.994*		*0.993*	0.984	0.991	0.993	0.991	0.989	0.985	0.960
4930	0.991	*0.993*		0.986	0.991	0.987	0.986	0.980	0.984	0.954
17150	0.981	0.984	0.986		*0.995*	0.988	0.986	0.983	*0.994*	*0.977*
17850	0.989	0.991	0.991	*0.995*		0.994	0.992	0.988	0.993	0.972
18700	0.991	0.993	0.987	0.988	0.994		*0.996*	*0.994*	0.988	0.971
19400	0.991	0.991	0.986	0.986	0.992	*0.996*		0.991	0.986	0.967
19710	0.986	0.989	0.980	0.983	0.988	0.994	0.991		0.986	0.973
27450	0.983	0.985	0.984	0.994	0.993	0.988	0.986	0.986		0.976
27500	0.954	0.960	0.954	0.977	0.972	0.971	0.967	0.973	0.976	

Table 4: Monthly correlations between 18700 Oslo-Blindern and the reference station network.

Mnd	4440	4780	4930	17150	17850	19400	19710	27450	27500
Jan	0.973	0.972	0.959	0.958	0.976	0.981	0.969	0.958	0.913
Feb	0.976	0.975	0.963	0.964	0.977	0.980	0.976	0.964	0.936
Mar	0.966	0.971	0.961	0.962	0.970	0.973	0.980	0.961	0.925
Apr	0.967	0.973	0.968	0.961	0.974	0.979	0.980	0.955	0.914
May	0.977	0.977	0.976	0.969	0.983	0.990	0.982	0.966	0.924
Jun	0.974	0.974	0.970	0.958	0.979	0.990	0.981	0.954	0.915
Jul	0.961	0.966	0.957	0.948	0.969	0.985	0.973	0.939	0.904
Aug	0.960	0.973	0.944	0.951	0.968	0.985	0.974	0.944	0.922
Sep	0.958	0.968	0.957	0.944	0.968	0.981	0.974	0.947	0.931
Oct	0.976	0.973	0.973	0.958	0.977	0.983	0.976	0.959	0.929
Nov	0.970	0.974	0.960	0.956	0.976	0.983	0.971	0.957	0.898
Dec	0.973	0.972	0.961	0.958	0.971	0.982	0.967	0.957	0.904

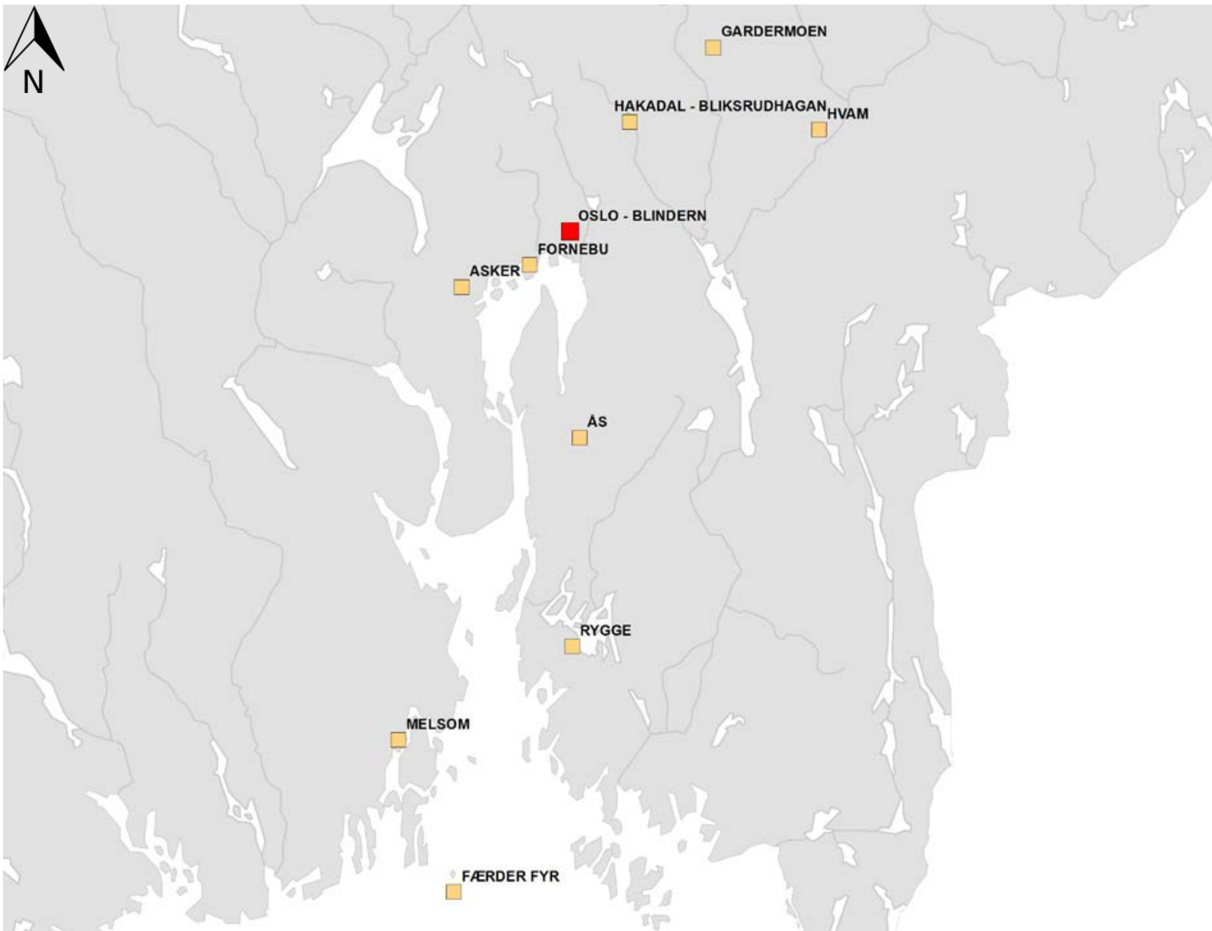


Figure 7: Location of the stations in the Oslo network.

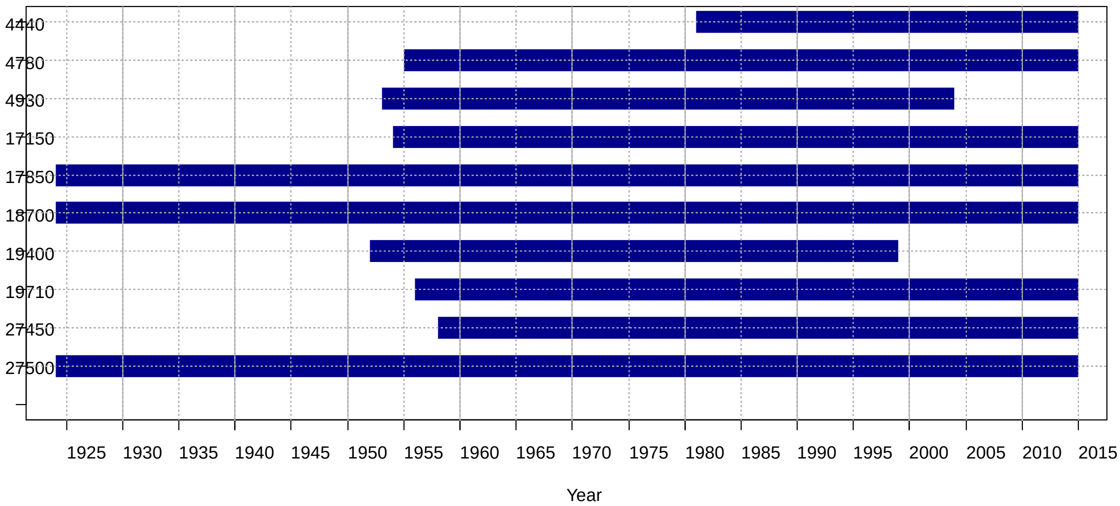


Figure 8: Periods covered by the series in the Oslo network.

II. Kristiansand

Figure 9: Picture of 39040 Kjevik meteorological station. The location of the temperature screen is marked with a yellow circle.

39040 Kjevik

The meteorological station 39040 Kjevik is located at Kristiansand Airport, Kjevik (fig. 7) Kjevik is situated on the grounds of the farm Kjevik at Tveit in Kristiansand, Norway. It is 16 kilometers by road and 8 kilometers by air from the city centre. Due to its long continuous series *39040 Kjevik* is selected to be the candidate station for Kristiansand area.

During the Second World War it the airport was occupied and expanded by the German Luftwaffe. Otherwise instruments have been moved once the runway 100 m towards the SW in 1947. The airport was expanded in 1977 and 2012.The asphalt runway physically measures 2,035 by 45 meters and the landing distances available are 1,920. Kjevik is a large flat area, about 10-15 m a.s.l. ranging from Tovdalselvens outlet into the sea and 2-3 km upriver (see figure 9 & 10). The area is about 1 km wide and goes in the direction SW-NE. It is surrounded by up to 100 m high mountain hills, except on south westerly direction where Topdalsfjorden connects to the sea. The measurements are made in the SW part of the runway / surface area (see figure 9 and 10).

Figure 10: Aerial photo of 39040 Kjevik meteorological station. The location of the temperature screen is marked with a red arrow.

Kristiansand network

The network used to assess homogeneity for Kritiansand (Kjevik) consists of 9 stations. All of them are located along the southern coast of Norway, except 39750 Byglandsfjord that is located inland (figure 11 – map of the area). This station represents a more continental type of climate than most of the other stations in the network that are located in a maritime environment. Five of them are lighthouse stations. 39040 Kjevik is despite its relative close vicinity to the sea a protected location, in the transition between continental and maritime climate.

39040 Kjevik correlates best with 38140 Landvik. This however is a relative short series and therefore not well suited for a homogeneity analysis. The high correlation confirms that the Kjevik series is representative for the city of Kristiansand. The other stations having the highest correlations with Kjevik are generally located in the eastern part of the network, such as Landvik, Torungen Fyr and Lyngør Fyr. Also the inland station Byglandsfjord correlates well with Kjevik. The western part of the network show somewhat lower correlations, confirming that there is a change in the climate characteristics west of Kristiansand into a more westerly, coastal influenced climate. The monthly correlation coefficients confirm this. It also worth to notice, the poor correlations between lighthouse stations and Kjevik (and also the other “off-coast” stations) in the summer months.

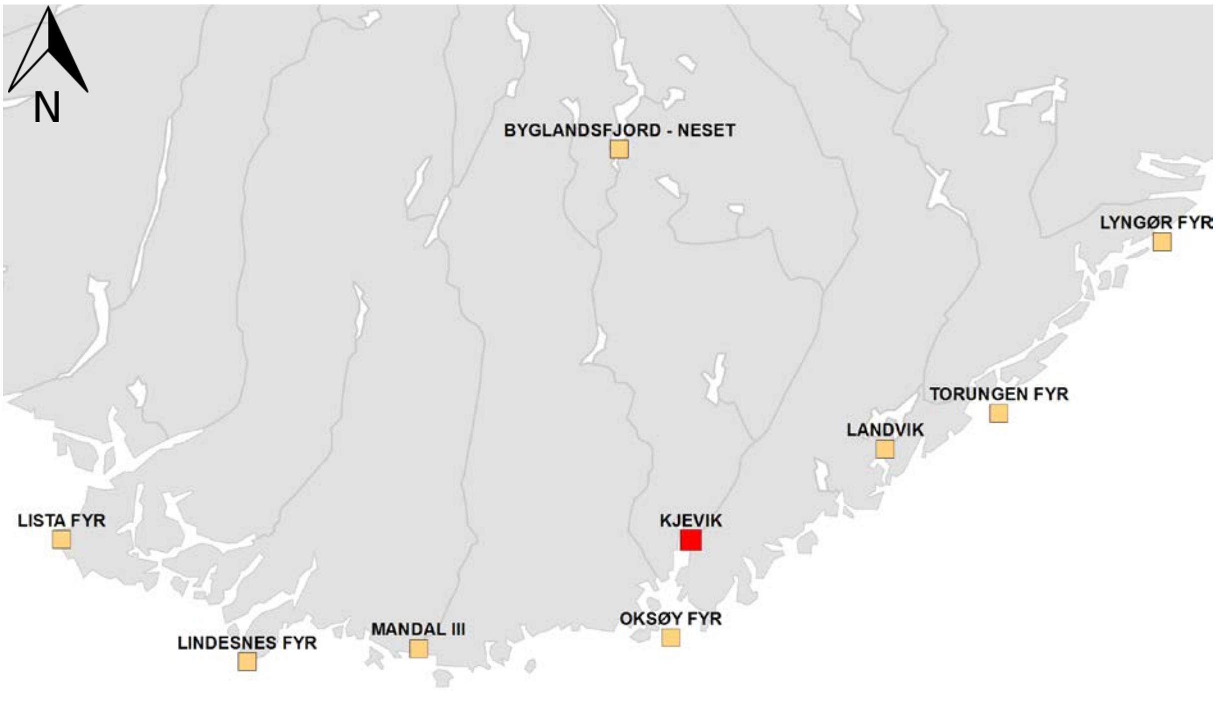


Figure 11: Locations of the series in the Kristiansand network.

Figure 12 shows the time periods covered by the series in the network. Table 5 shows the series in the network, including the original series from which they are merged. Table 6 shows the correlation matrix between the series in the network. All stations are highly correlated, fulfilling the criterion in HOMER of ρ>0.8. All correlations are higher than 0.95 on an annual basis. The series showing the lowest correlation is 42160 Lista which is located south west in the network. This station is strongly influenced by westerly winds (like the Western Norway). On the seasonal basis it is different. Table 7 shows the monthly correlations between Kjevik and the other series in the network.

Table 5: Kristiansand network.

Analysed series	Name	Period	Nr of original series	Breaks	Original series	Time coverage original series
35860	LYNGØR	1956-2014	2	0	35850 Lyngør	1.9.1919-1946
					35860 Lyngør fyr	1947-2014
36200	TORUNGEN FYR	1937-2014	1	1	36200 Torungen fyr	1937-2014
38140	LANDVIK	1957-2014	1	1	38140 Landvik	1.1.1957-2014
39040	KJEVIK	1946-2014	1	2	39040 Kjevik	1.1.1946-2014
39100	OKSØY	1876-2014	1	2	39100 Oksøy	1876-2014
39750	BYGLANDSFJORD	1919-2014	4	3	39700 Byglandsfjord	1.7.1919-31.10.1950
					39710 Byglandsfjord 2	1.11.1950-6.2.2011
					39690 Byglandsfjord - Solbakken	1.12.1969-30.9.2011
					39750 Byglandsfjord-Neset	13.6.2011-2014
41090	MANDAL	1931-2014	3	5	41100 Mandal	1861-31.5.1949
					41110 Mandal 2	1.6.1949-21.12.2007
					41090 Mandal 3	26.8.2009-2014
41770	LINDESNES	1954-2014	2	2	41760 Lindesnes fyr	1.1.1954-31.3.1969
					41770 Lindesnes fyr	1.4.1969-2014
42160	LISTA	1954-2014	1	2	42160 Lista fyr	1.1.1954-2014

Table 6 Correlation matrix, Kristiansand network.

Stnr	35860	36200	38140	39040	39100	39750	41090	41770	42160
35860		0.996	0.986	0.982	0.989	0.976	0.979	0.973	0.963
36200	0.996		0.983	0.982	0.994	0.972	0.979	0.978	0.968
38140	0.986	0.983		0.993	0.979	0.983	0.974	0.956	0.951
39040	0.982	0.982	0.993		0.981	0.982	0.974	0.958	0.956
39100	0.989	0.994	0.979	0.981		0.969	0.984	0.987	0.977
39750	0.976	0.972	0.983	0.982	0.969		0.973	0.952	0.948
41090	0.979	0.979	0.974	0.974	0.984	0.973		0.979	0.97
41770	0.973	0.978	0.956	0.958	0.987	0.952	0.979		0.989
42160	0.963	0.968	0.951	0.956	0.977	0.948	0.97	0.989	

Table 7: Monthly correlations between 39040 Kjevik and the reference stations.

Mnd	35860	36200	38140	39100	39750	41090	41770	42160
Jan	0.924	0.941	0.980	0.951	0.941	0.894	0.891	0.853
Feb	0.947	0.953	0.984	0.962	0.951	0.914	0.913	0.918
Mar	0.954	0.959	0.980	0.966	0.943	0.931	0.929	0.909
Apr	0.939	0.941	0.970	0.957	0.911	0.918	0.912	0.869
May	0.946	0.938	0.970	0.949	0.922	0.932	0.879	0.836
Jun	0.918	0.908	0.963	0.898	0.907	0.909	0.752	0.714
Jul	0.907	0.906	0.954	0.889	0.888	0.889	0.740	0.713
Aug	0.929	0.936	0.951	0.929	0.901	0.884	0.813	0.803
Sep	0.933	0.950	0.964	0.947	0.910	0.891	0.874	0.882
Oct	0.941	0.955	0.975	0.957	0.936	0.921	0.911	0.912
Nov	0.935	0.952	0.976	0.956	0.946	0.916	0.907	0.912
Dec	0.933	0.950	0.979	0.954	0.945	0.901	0.889	0.900

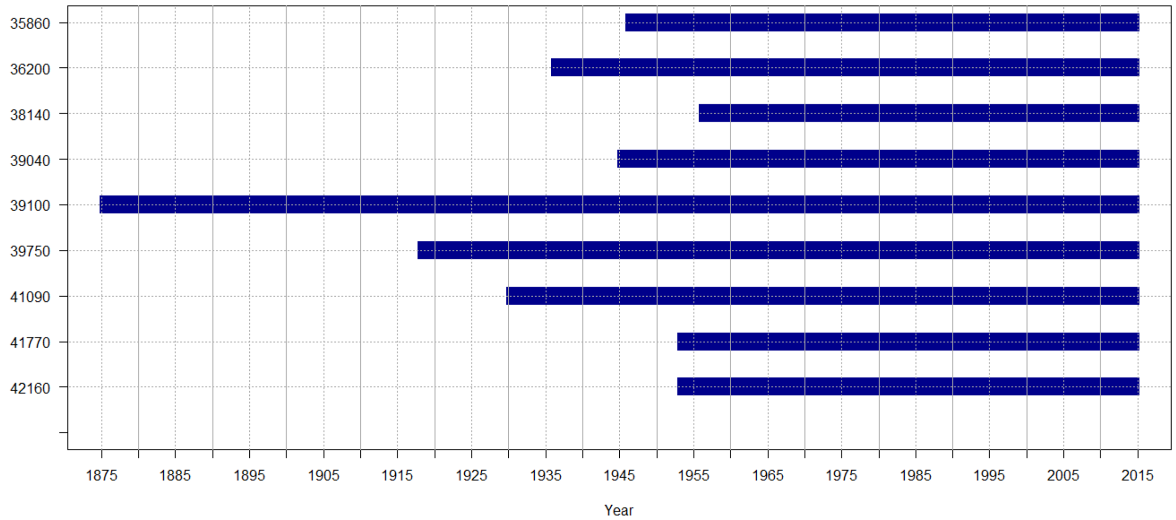


Figure 12: Kristiansand network station data coverage.

III. Bergen

Figure 13: 50540 Bergen-Florida meteorological station. The temperature is in the middle (arrow).

50540 Bergen-Florida

Bergen occupies most of the peninsula of Bergenshalvøyen. Most of the urban area is located on or close to a fjord, although there are several (seven) mountains surrounding the central parts of the city (fig. 14). The meteorological observations at 50540 Bergen-Florida (fig. 13) is located at the Meteorological Institute Forecast Centre for Western Norway. The meteorological observation station in Bergen was formerly at Nordnes (from 1903) at the Norwegian Fortress Frederiksberg (Stnr=50560) (marked blue in in fig. 14). During the war, the observations were moved to Pleiestiftelsen downtown for five years (marked yellow in fig. 14). Since 1928 the Geophysical Institute and the Norwegian meteorological Institute was housed at Florida in Bergen. The meteorological station was established here 1st January 1949 (marked red in in fig. 14). The station is located on the SE part of Nygårdshøyden in a green area between county road 256 and Geophysical Institute. There is a larger sea area to NNE / SSE direction, Store Lungegårdsvann and Puddefjorden in SW-W direction contained 2-300 meters from the station. Against W and NW there is a larger park area with large trees (fig. 13). Towards NNW constitute the U-shaped building complex Geophysical Institute a barrier against the Nygårdshøyden and all the buildings there. The meteorological measurement sites are marked with red arrows.

50540 Bergen-Florida PS 50560 Bergen-Fredriksberg

Figure 14: Bergen panorama.

The station was moved from one side of the town centre (north) to another side (south); 2 km from Nordnes (50560 Bergen-Fredriksberg) to Florida (50540 Bergen-Florida) (see figure 15, aerial photo).

Figure 15: Aerial photo from Bergen today.

Bergen network

Western Norway (Vestlandet) is the region along the Atlantic coast of southern Norway. Bergen is the candidate station in this network. Bergen is the largest city in the region (280 000 pop). The Greater Bergen Region population is 414 900.

Bergen-area features a temperate oceanic climate (Köppen: Cfb). Areas of the municipality at some higher altitude (above ca 200 m a.s.l.) are largely oceanic sub-polar (Cfc), with cool winters and mild summers. Bergen's weather is warmer than the city's latitude (60.4° N). The Gulf Stream provides the city with the warmest winters of all cities in the Nordic countries. Bergen experiences plentiful rainfall in all seasons, with annual precipitation measuring

2250 mm on average. This is because the city is surrounded by mountains that cause moist North Atlantic air to undergo orographic lift, yielding abundant rainfall.

The Bergen network consists of 11 stations and series representing different characteristics of the western Norway climate. Three of the series are extreme coastal stations – old lighthouse stations (Utsira Fyr, Slåtterøy Fyr and Fedje), while Takle, Modalen, Vossevangen, Ullensvang and Lærdal have off-coast characteristics. Bergen and Flesland (Bergen Airport) are in a transition between the maritime and an inland influenced climate. Figure 16 shows the map of the area.

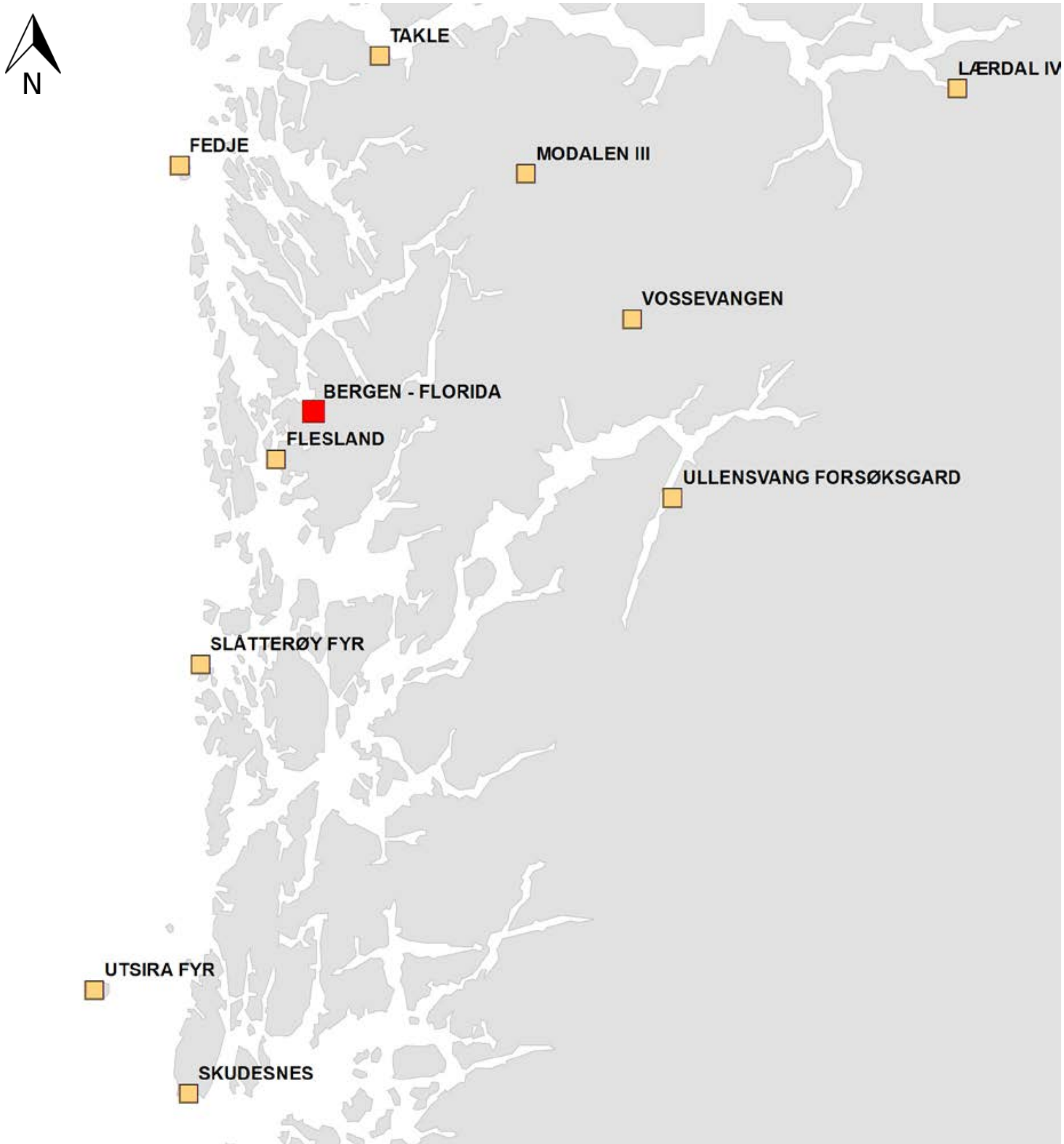


Figure 16: Location of the stations in the Bergen network.

Figure 17 shows the time periods covered by the series in the network. Table 8 shows the series in the network, including the original series from which they are merged. Table 9 shows the correlation matrix between the series in the network. All stations are highly correlated, fulfilling the criterion in HOMER of ρ>0.8. On an annual basis 50540 Bergen-Florida correlates well with all series in the network, and in particular the coastal series. Lowest correlations are found with the three easternmost stations Ullensvang, Vossevangen and Lærdal. The monthly correlations follow the same pattern. Highest correlations are found with the nearest station 50500 Flesland, lowest with 54110 Lærdal. On the seasonal basis it is different. Table 10 shows the monthly correlations between Bergen and the other series in the network.

Table 8: Bergen network

Stnr	Name	Period	Number of stations	Breaks	Original series	Period
47200	Skudenes	1954-2014	4	3	47200 Skudenes	1861-1938
					47200 Skudenes II	1938-1980
					47210 Skudenes III	1981-1992
					47200 Skudenes II	1992-nov.2005
					47260 Haugesund LH	2005-2014
47300	Utsira Fyr	1867-2014	1	2	47290 Utsira I	1867-1925
					47300 Utsira fyr	1926-2014
48330	Slåtterøy Fyr	1954-2014	1	3	48330 Slåtterøy fyr	1923-2014
49490	Ullensvang	1962-2014	6	2	49500 Ullensvang	1865-1926
					49520 Ullensvang II	1932-1947
					49510 Ullensvang-Helleland	1955-1962
					49490 Ullensvang forsøksgård	1962-1977
					49580 Eidfjord-Bu	1978-aug.2005
					49800 Fet i Eidfjord	2005-2008
					49490 Ullensvang forsøksgård	1.1.2009-2014
50500	Flesland	1955-2014	1	1	50500 Flesland	Oct.1955-2014
50540	Florida	1904-2014	2	2	50560 B-Fredriksberg	1904-31.12.1985
					50540 B-Florida	1.1.1949-2014
51530	Vossevangen	1938-2014	6	4	51550 Voss I	1885-1919
					51560 Voss II	1935-1961
					51570 Voss-Tvildemoen	1961-1962
					51580 Voss Tvilde	1962-1967
					51590 Voss-Bø	1967-2003
					51530 Vossevangen	2004-2014
52310	Modalen 3	1956-2014	3	2	52300 Modalen	1945-1980
					52290 Modalen II	1980-Sep.2008
					52310 Modalen III	Oct.2008-2014
52535	Fedje	1951-2014	2	1	52530 Hellisøy fyr	1867-26.8.2004
					52535 Fedje	27.8.2004-2014
52860	Takle	1956-2014	1	1	52860 Takle	1950-2014
54110	Lærdal	1954-2014	4	1	54100 Lærdal	1869-1947
					51130 Lærdal-Tønjum	1948-1996
					54120 Lærdal-Moldo	May 1996-Sep.2008
					54110 Lærdal IV	Sep.2008-2014

Table 9: Correlation matrix for the Bergen network.

Stnr	47200	47300	48330	49490	50500	50540	51530	52310	52535	52860	54110
47200		0.985	0.982	0.926	0.978	0.973	0.933	0.951	0.975	0.965	0.918
47300	0.985		0.989	0.905	0.966	0.960	0.906	0.928	0.983	0.954	0.892
48330	0.982	0.989		0.913	0.975	0.968	0.915	0.938	0.985	0.962	0.904
49490	0.926	0.905	0.913		0.941	0.945	0.950	0.957	0.910	0.947	0.951
50500	0.978	0.966	0.975	0.941		0.994	0.950	0.967	0.976	0.984	0.933
50540	0.973	0.960	0.968	0.945	0.994		0.949	0.970	0.970	0.984	0.935
51530	0.933	0.906	0.915	0.950	0.950	0.949		0.981	0.913	0.955	0.976
52310	0.951	0.928	0.938	0.957	0.967	0.970	0.981		0.939	0.974	0.965
52535	0.975	0.983	0.985	0.910	0.976	0.970	0.913	0.939		0.969	0.901
52860	0.965	0.954	0.962	0.947	0.984	0.984	0.955	0.974	0.969		0.945
54110	0.918	0.892	0.904	0.951	0.933	0.935	0.976	0.965	0.901	0.945	

Table 10: Monthly correlations between 50540 Bergen-Florida and the reference stations.

Mnd	47200	47300	48330	49490	50500	51530	52310	52535	52860	54110
Jan	0.926	0.914	0.934	0.843	0.984	0.887	0.910	0.945	0.954	0.850
Feb	0.925	0.913	0.949	0.816	0.986	0.876	0.889	0.951	0.952	0.848
Mar	0.894	0.886	0.944	0.789	0.981	0.848	0.881	0.938	0.931	0.804
Apr	0.920	0.893	0.937	0.818	0.984	0.881	0.901	0.924	0.927	0.830
May	0.921	0.904	0.919	0.830	0.985	0.898	0.920	0.926	0.955	0.833
Jun	0.895	0.873	0.878	0.817	0.977	0.886	0.914	0.897	0.959	0.809
Jul	0.900	0.858	0.877	0.812	0.977	0.880	0.906	0.875	0.960	0.810
Aug	0.934	0.910	0.922	0.824	0.980	0.890	0.927	0.905	0.952	0.806
Sep	0.933	0.933	0.952	0.810	0.977	0.867	0.918	0.924	0.931	0.743
Oct	0.935	0.930	0.951	0.791	0.981	0.848	0.902	0.935	0.941	0.748
Nov	0.935	0.926	0.937	0.835	0.982	0.874	0.911	0.947	0.959	0.810
Dec	0.939	0.927	0.943	0.831	0.984	0.885	0.920	0.951	0.959	0.840

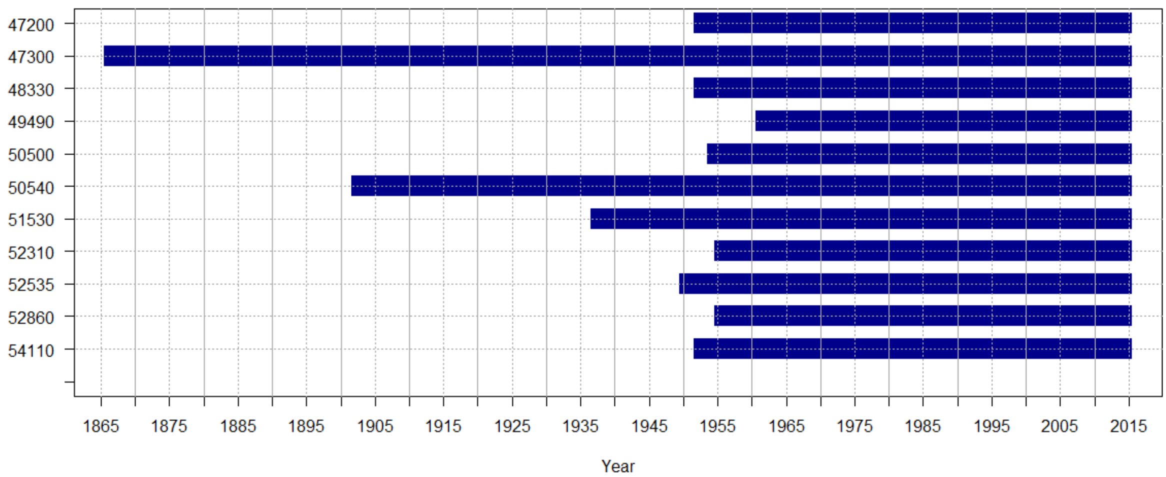


Figure 17: Data coverage in the Bergen network.

IV. Trondheim

Figure 18: Panorama picture of the airport Værnes

69100 Værnes

Værnes is the airport for Trondheim, located in the municipality of Stjørdal in Nord-Trøndelag County. Værnes is 19 km east of Trondheim (fig 18 & 20). Værnes was taken into use by the Royal Norwegian Army in 1887. The first flight was made in 1914.The first main installations, including three concrete runways, were built during World War II by Luftwaffe. The Germans started the meteorological observations 1940. Today it is one main runway in W-E-direction (see fig. 19).

Figure 19: The main runway at Værnes airport (looking from W to E direction).The location of the temperature screen is marked with a red arrow.

The meteorological station is located at the airport and the instruments are 12 m .a.s.l. (see red arrow at the figure 19). The runway has been built up and is higher (10-12 m) than the surrounding area which is at sea level. The valley, Stjørdalen, leading from the Swedish border at Meråker due west and ends out in Stjørdalsfjord. This fjord is a part of the Trondheimsfjord. The valley, Stjørdal, follow the river, Stjørdalselva (70 km). This valley is quite narrow in the upper part but widens at the lower part and the bottom 10 km river flows in meanders over a flat river plain. Værnes Airport is at this river plain, surrounded by mainly crop land. On the northern side is the small town Stjørdal. At 5 km distances the airport is surrounded by hills around 2-500 m a.s.l. (see fig. 18 & 19). Storhei in SW, Strætefjell in SE, Koksås in NE, Bukamoen in N and Vikanfjellan in NW. Tree line is 4-500 meters above sea level in the area.

The observation site (temperature screen) at Værnes has been moved a few times and it has also been used for experiments with new electronics on the instruments. The airport has also been changing, development of new runways and construction and relocation of terminals buildings. This is something we can find in the homogenization results.

Trondheim network

Trøndelag is a geographical region in the central part of Norway, consisting of the two counties Nord-Trøndelag and Sør-Trøndelag. The region is often called Central Norway. The largest city is Trondheim (Sør-Trøndelag).

Trondheim is situated where the river Nidelva meets Trondheimsfjorden. Slightly over 200,000 of the county's population live in Trondheim and its suburbs. The broad and long Trondheimsfjord is at the center of this county, although the coastal areas stretch somewhat further north. The mountain ranges Dovrefjell and Trollheimen are located in the south, while the Fosen peninsula is located north of the fjord. The highest mountain is Storskrymten (1985 m), which is located in the county border between Møre og Romsdal, Oppland and South Trondelag.

Trondheim city has a predominantly Oceanic climate (Koppen: *Cfb*), but closely borders on humid continental, sub-polar oceanic and subarctic climates. The part of the municipality further away from the fjord has colder winters. The part close to the fjord, such as the city center, has milder winters. Trondheim experiences moderate snowfall from November to March, but mixed with mild weather and rainfall. Based on the 1961–90 average recorded at the airport, there are 14 days each winter with at least 25 cm of snow cover on the ground and 22 days with a daily minimum temperature of −10°C.

The weather is very much decided by the direction of the wind; southerlies and easterlies bring sunny weather, while westerlies bring precipitation with mild weather in winter and cool rainy weather in summer. Northwesterlies bring the worst weather with snow in winter (often sleet or rain on the coast). Average yearly precipitation varies from 2,000 mm in some areas of Fosen, to 850 mm in Trondheim and only 500 mm in Oppdal. The interior areas at somewhat higher elevations have cold winters with reliable snow cover, while the coastal areas have a maritime climate with mild and windier winters. The Trøndelag area is known for rapid changes in weather and steep climate gradients because its impact of western, northern and continental climate.

There are no continuous long-term meteorological observations series from the city of Trondheim. The weather station at Voll (127 m a.s.l.) in Trondheim started operating in 1923, but was discontinued in 1967 and did not start up again until 1997. The best candidate for providing a long consistent time series for temperature in this region is 69100 Trondheim Airport-Værnes.

The Trondheim network consists of 7 series including the candidate series from Værnes. The locations of the series are shown in figure 20. 3 of the stations are located near the Trondheimsfjord, while 4 series are located in a continental climate. Værnes has mostly coastal climatic input. There are limitations with this network because there are few stations that have operated a long time (>20 years). Figure 21 shows the time coverage of the 7 stations.

Figure 20: Location of the series in the Trondheim network.

The correlations between the annual daily series in the Trøndelag network is presented in table 12. Correlations are high, all above 0.95. Værnes correlates best with 68860 Trondheim-Voll, 68380 Meråker, 68290 Selbu II and 70150 Verdal-Reppe. Correlations with the more remote stations Ørland and Snåsa are lower. The monthly correlations between Værnes and the reference series in table 13 show the same. In the winter season correlations with the off-coast stations Snåsa and Meråker are higher, while the Trondheim-Voll series are higher in summer. The differences are however marginal.

Table 11: Stations in the Trondheim network.

Stnr	**Name**	**Period**	**Number of stations**	**Breaks**	**Original series**	Stations
68290	Selbu	1957-2014	**3**	**0**	68300 Selbu	1920-1935
					68300 Selbu	1935-30.6.1976
					68310 Selbu-Bogstad	1.11.1976-31.5.1979
					68340 Selbu-Stubbe	1.9.1979-16.11.2006
					68290 Selbu II	27.9.2007-2014
68860	Trondheim-Voll	1923-2014	**4**	**1**	68860 Trondheim-Voll	1.1.1923-28.2.1967
					68170 Trondheim-Tyholt	1.3.1967-30.6.1981
					68130 Trondheim-Moholt	1.11.1993-1.7.1994
69100	Værnes	1946-2014	**0**	**3**	69100 Værnes	1.1.1946-2014

69380	Meråker	1957-2014	**5**	**2**	69350 Meråker	1936-1947
					69360 Meråker II	1947-1969
					69340 Meråker-Lillesve	1.11.1969-4.9.1973
					69330 Meråker-Krogstad	1.11.1974-30.11.1993
					69370 Meråker-Utsyn	1.8.1994-8.5.2004
					69380 Meråker-Vardetun	9.5.2004-2014
70150	Verdal	1971-2014	**4**	**2**	70100 Verdalsøra	1.3.1971-1979
					70120 Verdal-Stiklestad	1.12.1984-31.3.1992
					70150 Verdal-Reppe	01.12.1992-2014
70850	Snåsa	1939-2014	**1**	**3**	70850 Kjøbli i Snåsa	1939-2014
71550	Ørland	1954-2014	**3**	**3**	71550 Ørland III	1955-2014
					71540 Ørland II	No data

Table 12: Correlation matrix for the stations included in the Trondheim network.

Stnr	68290	68860	69100	69380	70150	70850	71550
68290		0.989	0.987	0.987	0.980	0.967	0.972
68860	0.989		0.992	0.984	0.986	0.968	0.984
69100	0.987	0.992		0.988	0.986	0.971	0.976
69380	0.987	0.984	0.988		0.984	0.975	0.965
70150	0.980	0.986	0.986	0.984		0.983	0.975
70850	0.967	0.968	0.971	0.975	0.983		0.959
71550	0.972	0.984	0.976	0.965	0.975	0.959	

Table 13: Monthly correlation coefficients between 69100 Trondheim-Værnes and the reference stations.

Mnd	68290	68860	69380	70150	70850	71550
Jan	0.983	0.979	0.986	0.943	0.906	0.935
Feb	0.981	0.982	0.985	0.949	0.922	0.946
Mar	0.978	0.974	0.981	0.963	0.924	0.938
Apr	0.977	0.975	0.967	0.956	0.924	0.953
May	0.985	0.978	0.966	0.970	0.938	0.953
Jun	0.980	0.979	0.950	0.971	0.940	0.945
Jul	0.960	0.976	0.936	0.960	0.925	0.925
Aug	0.962	0.971	0.942	0.959	0.914	0.931
Sep	0.973	0.973	0.958	0.960	0.927	0.935
Oct	0.967	0.977	0.977	0.962	0.921	0.934
Nov	0.979	0.976	0.978	0.957	0.899	0.930
Dec	0.982	0.972	0.985	0.960	0.900	0.929

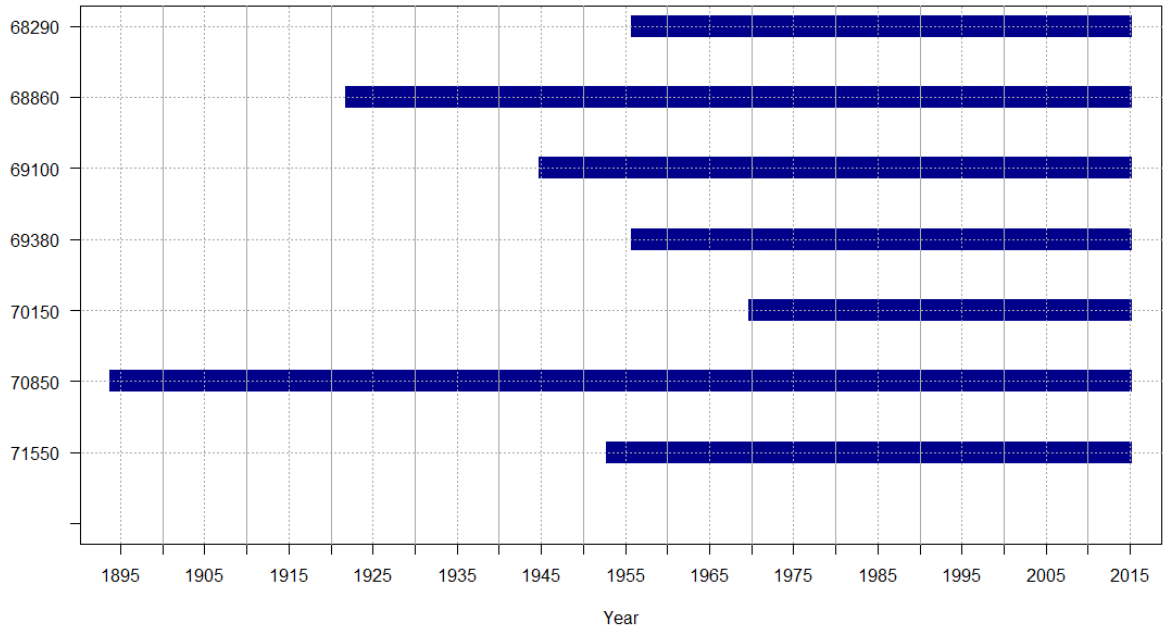


Figure 21: Data coverage in the Trondheim network.

V. Tromsø

90450 Tromsø

Figure 22: Picture of 90450 Tromsø met station. The temperature screen is marked (red arrow).

The first weather observations in Tromsø started in 1867. The observation site has moved three times at the Tromsøya, but two times less than 1 km. The first site *90440 Tromsø I*, was located at Tromsø seminar, about 1 km in NE direction from today's position (marked 1 in the aerial photo, fig. 24). The station was moved in 1902 to Gyllenborg, 800 m south from the first location (marked 2, fig 24). In 1920 the Weather forecast centre for Northern Norway was established at the gepphysical observatory ("Geofysen"), and the weather station was moved there. This location is in the south-middle of the island (marked 3, fig 24). In the start of the 1960'ies the new building of the Forecasting Centre was build 50 m from the existing building (marked 4, fig 24). Since 1961 the meteorological observations are made in the garden, south of the "new" building to the Weather forecast centre for Northern Norway (fig. 22 & 23). The station is an automatic station (from 2001) that reports wind, precipitation, temperature, humidity and radiation. The station is located outside on the lawn - on the south side of the building/office. The station is located on the flat hill that runs along Tromsøya, 100 m a.s.l. in birch forest or park. It is in a residential area that has and there are several roads and some birch trees around the station.

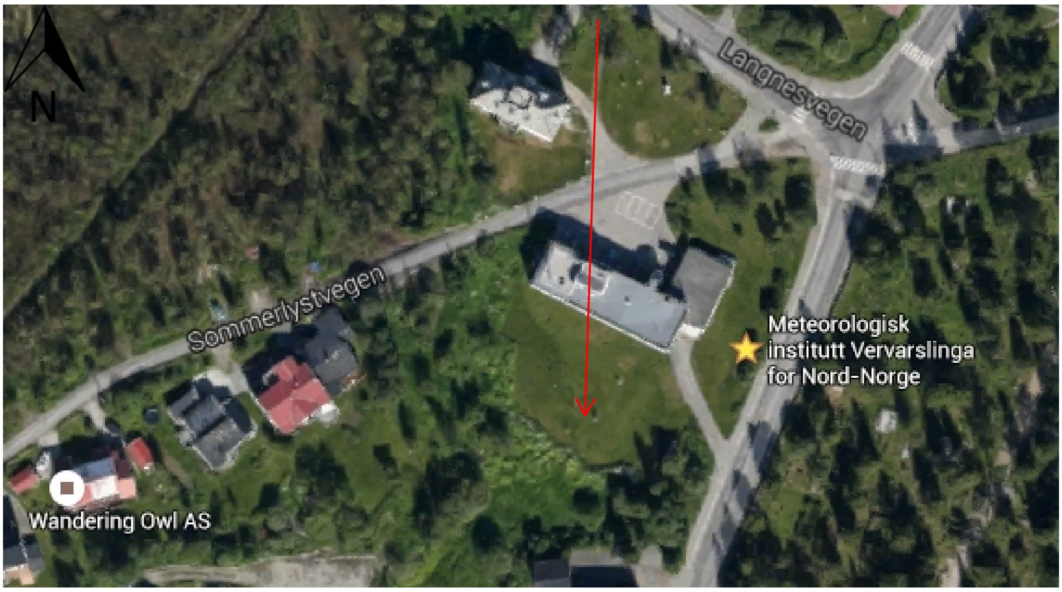


Figure 23: Aerial photo of 90450 Tromsø met station. The temperature screen marked red.

Figure 24: Aerial photo from Tromsø today (4 met stations relocation on Tromsøya.

Tromsø network

Troms is a county in Northern Norway. It borders Finnmark county to the northeast and Nordland County in the southwest. Norrbotten Län in Sweden is located to the south and further southeast is a shorter border with Lapland Province in Finland. To the west is the Norwegian Sea (Atlantic Ocean). Troms has a very rugged and indented coastline facing the Norwegian Sea.

Tromsø is a city and municipality in Troms. The administrative centre of the municipality is the city of Tromsø. Tromsø is considered as the northernmost cities in the world with a population above 50,000.

There are some islands outside of Tromsø, most noteworthy Senja, have a rugged outer coast with steep mountains, and a calmer eastern shore. There are several large fjords that stretch quite far inland.

There are mountains in all parts of Troms; the most alpine and striking are probably the Lyngen Alps (*Lyngsalpene*) east of the city, with several small glaciers and the highest mountain peak in the county, Jiekkevarre with a height of 1,833 m.

Located at a latitude of nearly 70°N, Troms has short, cool summers, but fairly mild winters along the coast due to the temperate sea; Torsvåg Lighthouse in Karlsøy has January 24-hr average of −1 °C. Tromsø averages −4 °C in January with a daily high of −2 °C, while July averages 12 °C with high of 15 °C. Temperatures are typically below freezing for about 5 months (8 months in the mountains), from early November to the beginning of April,. Coastal areas are moderated by the sea: with more than 130 years of official weather recordings, the coldest winter temperature ever recorded in Tromsø is −20.1 °C in February 1985. The all-time high for Troms is 32.7 °C recorded in Skibotn July 10th 2014. Thaws can occur even in mid-winter. Winter temperatures in Målselv and Bardu can get down to −35 °C, while summer days can reach 30 °C in inland valleys and the innermost fjord areas, but 15 to 22 °C is much more common. Along the outer seaboard, a summer day at 15 °C is considered fairly warm.

Figure 25: Locations of the series in the Tromsø network. The candidate series 90450 Tromsø is marked in red.

The Tromsø network consists of 7 series (table 14). The locations of the series are shown in figure 25. The observation periods covered by these series is displayed in figure 26. The distances between the stations in the Tromsø network are large. However, shows the correlations between the series in the Tromsø network (table 15) that the series are well related. Highest correlations with Tromsø are for 99490 Tromsø-Langnes, the airport of Tromsø. Lowest correlations are found for the stations in inner Troms, Bardufoss and Dividalen. The monthly correlations between Tromsø and the reference series in table 16 show the same.

Table 14: Series in the Tromsø network.

Stnr	Name	Period	Number of stations	Breaks	Original series	Periods
88200	Senja	1954-2014	3	4	88900 Gibostad	1.1.1936-1.7.1991
					88920 Senja-Grasmyrskogen	1.10.1992-30.6.1997
					88200 Senja-Laukhella	10.8.1997-2014
89350	Bardufoss	1954-2014	1	4	89350 Bardufoss	1941-2014
89940	Dividalen	1921-2014	3	2	89950 Dividalen	1912-31.5.1977
					89950 Dividalen	1.2.1980-19.8.2009
					89940 Dividalen II	13.10.2009-2014
90450	Tromsø	1920-2014	3	1	90440 Tromsø I	1876-1926
					90450 Tromsø	1.7.1920-2014
90490	Tromsø-Langnes	1964-2014	1	2	90490 Tromsø-Langnes	1.10.1964-2014
90800	Torsvåg	1954-2014	1	0	90800 Torsvåg fyr	1933-2014
91380	Skibotn	1957-2014	4	3	91350 Skibotn	1947-30.4.1972
					91360 Skibotn-Melå	1974-31.8.1984
					91370 Skibotn-Fossbakk	1.9.1984-31.10.2004
					91380 Skibotn II	1.11.2004-2014

Table 15: Correlation matrix of the series in the Tromsø network..

Stnr	88200	89350	89940	90450	90490	90800	91380
88200		0.971	0.958	0.983	0.981	0.946	0.968
89350	0.971		0.971	0.955	0.958	0.897	0.970
89940	0.958	0.971		0.950	0.952	0.908	0.974
90450	0.983	0.955	0.950		0.996	0.975	0.968
90490	0.981	0.958	0.952	0.996		0.968	0.969
90800	0.946	0.897	0.908	0.975	0.968		0.928
91380	0.968	0.970	0.974	0.968	0.969	0.928	

Table 16: Monthly correlation coefficients between 90450 Tromsø and the reference stations.

Mnd	88200	89350	89940	90490	90800	91380
Jan	0.93	0.873	0.855	0.987	0.917	0.907
Feb	0.941	0.89	0.865	0.989	0.932	0.925
Mar	0.95	0.908	0.881	0.988	0.946	0.929
Apr	0.973	0.944	0.889	0.986	0.964	0.928
May	0.976	0.961	0.885	0.988	0.957	0.917
Jun	0.973	0.958	0.892	0.989	0.957	0.924
Jul	0.965	0.947	0.856	0.986	0.94	0.918
Aug	0.965	0.939	0.849	0.985	0.942	0.914
Sep	0.966	0.936	0.882	0.983	0.957	0.904
Oct	0.958	0.909	0.884	0.988	0.955	0.92
Nov	0.926	0.86	0.821	0.984	0.931	0.895
Dec	0.93	0.882	0.853	0.987	0.931	0.915

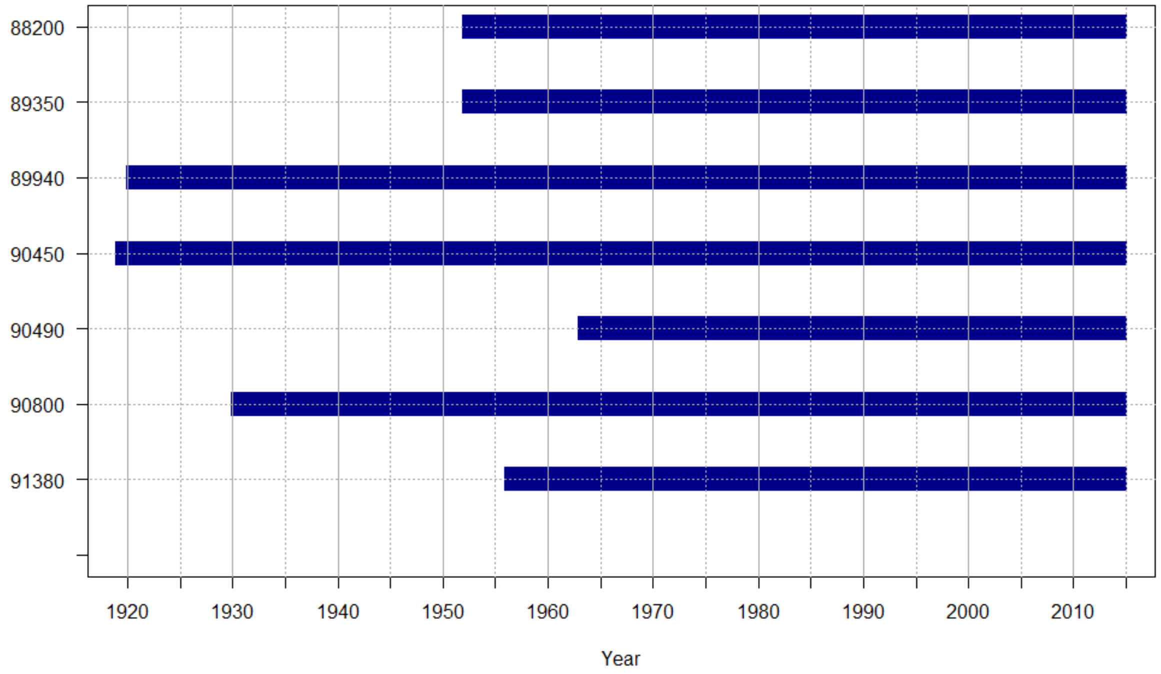


Figure 26: Data coverage in the Tromsø network

5 - Results

Homogenized daily mean temperature series for five major Norwegian cities has been established. The analyses for defining these five series are based on temperature series from 44 locations in five networks (Figure 2), including data from 1876 to present. The homogenized series cover the period from 1930 (or 1946) to present, although with a lower station density in the first half of the 20th century. Most daily temperature time series in Norway are made from 1946.

The 5 networks represent the five major geographical regions in Norway (Fig. 2): Eastern Norway (Oslo), Southern Norway (Kjevik), Western Norway (Bergen), Central Norway (Værnes) and Northern Norway (Tromsø). These data have been comprehensively analyzed for inhomogeneities and data errors ensuring a set of station temperature data which are suitable for the analysis of climate variability and trends.

The methods described in the previous section were applied to assess the homogeneity of the 44 temperature series (Figure 2) on monthly (applying HOMER) and daily (applying SPLIDHOM) scales. For some series homogenization turned out to be impossible due to large uncertainties in the break adjustments or a lack of suitable reference stations. The assessment of uncertainties was done subjectively, by comparing the adjustments proposed by the algorithms relating suggested breaks to station metadata, and by taking the result of the bootstrapping into account.

I. Oslo network

The Oslo temperature series actually starts in 1816 and that was a period when anthropogenic influence on climate was low. The annually mean temperature has increased by 1.5 °C during the almost 200 year’s period of observation for Oslo. The most of the increased temperature is from the last 25 years. The period we study here, 1925-2014 show an increase in annual temperature (fig 27).

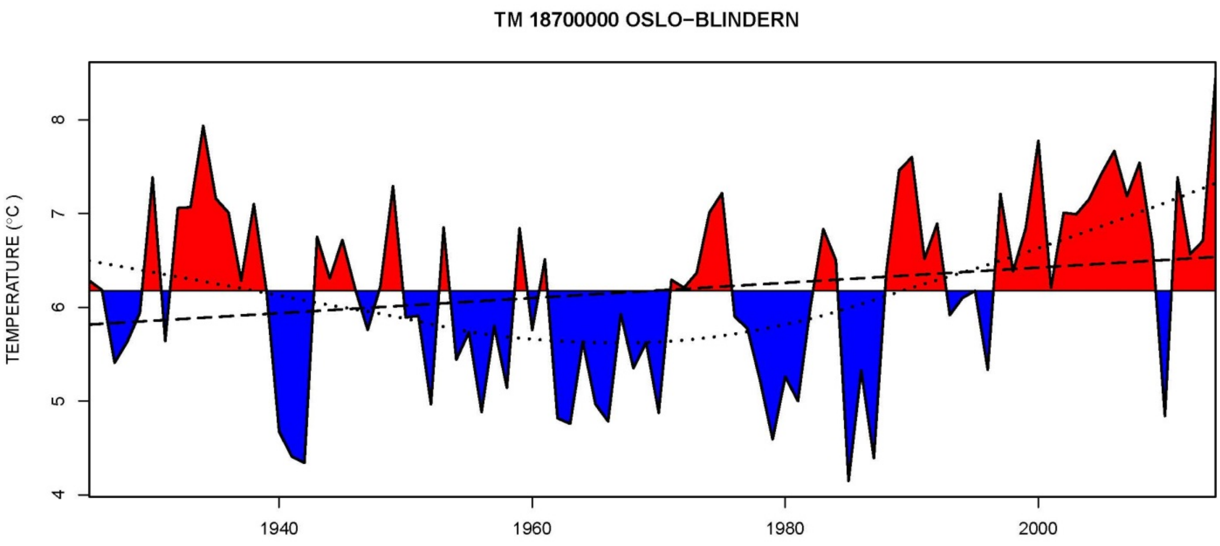


Figure 27: Time series for 18700 Oslo-Blindern (1925-2014) (homogenized).

We can observe a "climate shift" around 1990 (1988) with few cold years (blue) after the "shift". The late 1980'ies and early 1990'es had very warm winter associated with a positive NAO-phase. Regionally averaged temperature series from Akershus show a distinct shift into a warmer phase in the January mean temperatures (figure 30) between 1987 and 1988. This shift is present in all regional temperature series for southern Norway. This shift also caused a reduction and even absence of the snow in several winters in the Oslo area (figure 31. The annual mean temperature is 5.7 °C for Oslo (normal 1960-90) and the highest annual mean temperatures was measured last year 2014 (8.3 °C), and the coldest year are 1942 and 1985 (4.2 °C).

The Oslo-series is the longest running temperature time series in Norway (Figure 8). In this network Oslo (from 1816) and 17850 Ås (from 1874) are both long times series. We have chosen not to analyze the series before 1925 because of the relevance in the project and that there is a lot of gaps in the series for 17850 Ås (<1925). There are three stations in the Oslo-network which has a long time-span (Færder, Oslo, Ås).

Monthly homogeneity analysis

The homogeneity testing detected 3 (or 4) breaks of homogeneity in the Oslo-Blindern temperature series (Table 17). Three of the breaks were supported by the metadata and therefore adjusted, see table 18. These break we will discuss here:

18700 Oslo–Blindern: Oslo meteorological station was relocated 1st of February 1937 from downtown (Skillebekk) to Blindern where the present premises of MET Norway was (under construction.The Blindern station was located on a small hill (Figure 3), about 75m to the southwest of the institute building, on the same spot as the observations are still carried out.

The Blindern area is near downtown Oslo (3 km) within the domain of the Oslo fjord, which creates a local atmospheric circulation cell during winter as most of the fjord has open water. In midwinter during clear skies the temperatures at Blindern are higher than at many potential reference stations inland. Stations in the area of the fjord were thus preferred in the network of series for testing, but also inland stations were alternatively used (Nordli et al, 2014). An additional difficulty, however, was that two of the suitable reference stations near the fjord, Rygge and Fornebu, are airports, where many changes have taken place, so it was not surprisingly that many inhomogeneities were detected by HOMER for those series. The network that was finally used for the correction of Oslo–Blindern is shown in figure 7 and 8, and the corrections themselves are shown in table 3 and 4.

I. The break in 1937 was caused by the station relocation, which is a common reason for the homogeneity break. The correction has yearly break amplitude at -0.55 °C. The relocation in 1937 not only involved a 3.5 km horizontal distance, but also increased the altitude of the measurements from 22 to 94 m a.s.l. As expected, the corrections were negative for all months due to increased altitude, but the values differed in magnitude throughout the year (ref. table 17, column 1). It is "colder" at Blindern than downtown Oslo. This will follow the general adiabatic process and the mathematical / meteorological law with decrease of an atmospheric variable with height.

The composite series of 18650 Oslo I and 18700 Oslo-Blindern was tested by the HOMER software within the time interval 1925-2014, and HOMER creates the break to March 1937 and the relocation really happened the 1st February. The expected inhomogeneity caused by the relocation was detected and corrected for.

Table 17: 3 breaks for 18700 Oslo-Blindern: 12 months & the yearly break amplitude shown in temperature °C from HOMER.

Break	I: 1937 (March)	II:1980 (Dec)	III:1995(Dec)
Month	Break amplitude in °C		
01 :	-0.94	-0.25	-0.06
02 :	-0.85	-0.23	-0.05
03 :	-0.83	-0.22	0
04 :	-0.69	-0.08	0.1
05 :	-0.6	0.04	0.21
06 :	-0.44	0.19	0.28
07 :	-0.3	0.25	0.33
08 :	-0.27	0.18	0.24
09 :	-0.39	0.05	0.12
10 : -	-0.63	-0.07	0.01
11 :	-0.83	-0.14	-0.02
12 :	-0.9	-0.17	-0.03
13 => YEAR	-0.61	-0.06	0.07
BREAK AMPLITUDE[1]:	-0.55	-0.13	0.07

II. A minor break in 1980 was detected and adjusted for -0.13 °C. Here the corrections are positive for the five summer months and negative for the 7 "winter" months (table 17, column 2). An inspection of the station was carried out the 18th April 1979 resulting in and according to the inspection report: Some remarks and instructions were given. The screen was filthy and should eventually be painted.

First note: Washing the screen (summer 1979).

Another note: Painting the screen (summer 1980).

A break caused by painting the screen gives a less heated screen caused by the increased ability to reflect radiation (Mjelstad et al, 2002, s. 39).

III. The last break in the Oslo series is identified in December 1995.

The correction has yearly break amplitude at 0.07 °C. Here the corrections are positive for the spring, summer and autumn and negative for the winter (table 17, column 3). The station had started automation in the autumn 1993 and this process continued some year after (1993-1996) and they changed thermometer 2-3 times. Different types were used e.g. Scanmatic instruments.

1

Amplitude tell how large was the break, but does not give the correction, since data are corrected according to the last homogeneous period (the most recent period), not the preceding one.
Amplitude on annual coefficient, which is difference between two consecutive annual correction coefficients (which are not used by the way: data are corrected monthly).

In the metadata table (table 18) we can see the reason for breaks at every station in the Oslo-network. We see that relocations, new instruments, changing the radiation screens and environmental changes are the main reasons for detected breaks in the time series, except the climate shifts in 1988.

Table 18: Metadata for the homogeneity break in the Oslo network

NR	STATION	YEAR	MONTH	DATE	°C	Reason for break
4440	HAKADAL_BLIKSRUD HAGAN	2000	12	28	-0.17	Shed demolished and tall tree removed from the station area
4780	GARDERMOEN	1945	4		-0.3	Unknown (Documentation lost before 1945)
4780	GARDERMOEN	1967	12	21	-0.33	Relocation of radiation screen (330 m towards SE)
4780	GARDERMOEN	1981	3		0.4	Radiation screen painted & a small relocation of 180 m towards SSW because new buildings
4780	GARDERMOEN	1997	1		0.11	Construction of new main airport & New instruments (Vaisala)
4940	HVAM	1963	12		0.14	Change of observer
4940	HVAM	1984	12		-0.05	Relocation from Hvam (4930) to 4940 Hvam-Tolvhus: 1 km towards NW
17150	RYGGE	1984	11	30	-0.58	New radiation screen: MI-46
17150	RYGGE	1988	10	26	0.57	New radiation screen
17850	ÅS	1969	12		0.14	Radiation screen painted & change of observer (7.11.1967)
17850	ÅS	1987	12	1	-0.33	The station closed down temporarily. Relocation.
18700	OSLO-BLINDERN	1937	3	1	-0.55	Relocation from Skillebekk (18650 Oslo I) to 18700 Oslo-Blindern
18700	OSLO-BLINDERN	1980	12		-0.13	Radiation screen painted
18700	OSLO-BLINDERN	1995	12		0.07	Automation of station-process
19400	FORNEBU	1960	12	21	-0.21	Relocation of NEW radiation screen of 1475 m towards SSE & new instruments
19400	FORNEBU	1987	12	17	0.06	Replacement of thermometer
27450	MELSOM	1994	8	30	-0.22	Replacement of thermometer
27500	FÆRDER_FYR	1995	12	2	-0.26	Automation of station

Daily homogeneity analysis

SPLIDHOM is applied to adjust the daily temperatures. Splidhom applies a spline approach to adjust the temperature distribution, i.e. the adjustment is a function of the temperature itself (a not only a linear shift as for the monthly adjustments). This ensures that the adjustment relates to the actual weather and not only to the longer term climatic conditions.
Figure 28 shows a graphical presentation of the daily adjustments for 18700 Oslo-Blindern. We see at the Splidhom choose 19400 Fornebu as the preferred reference station for the daily homogenization. Ås is the preferred reference station for the first break in 1937. (Fornebu station operates from 1941 and digitized from 1954).

Here are the 3 periods that have been made of the 3 breaks:

I. Estimated adjustment function $\widehat{m}_{YX_{jaft}-YX_{jbef}}\left[\widehat{m}_{XY_{jbef}(Y_t)}\right]$for HSP between 1 Jan 1925 and 31 May 1936, for Oslo daily mean temperature (Y) and spring season (MAM). This function gives the adjustment to be applied to Y as a function of Y itself (°C). Note that this estimation is rounded to a precision of 0.1 °C, which is the precision of the data themselves in the database.

II. 1 Feb 1937 and 29 Feb 1980 from the autumn season (DJF).

III. 1 Dec 1980 and1 Dec 1995 from the autumn season (DJF).

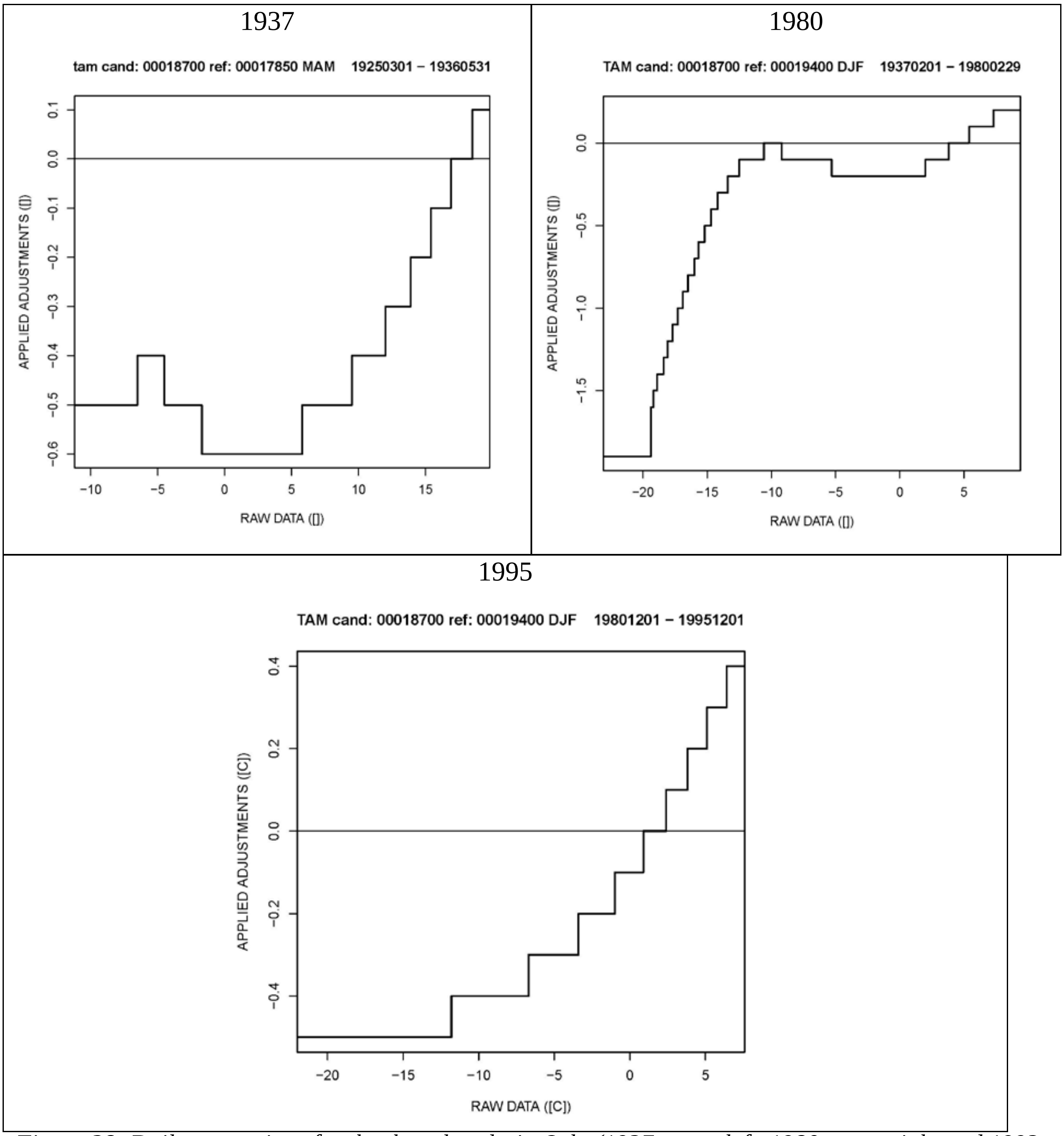


Figure 28: Daily corrections for the three breaks in Oslo (1937 upper left, 1980 upper right and 1993 lower panel).

Figure 29 gives an overview and a plot of the differences in the Oslo-Blindern time series between the original and homogenized values proposed by SLIPDHOM, showing the three breaks (1937, 1980 & 1995).

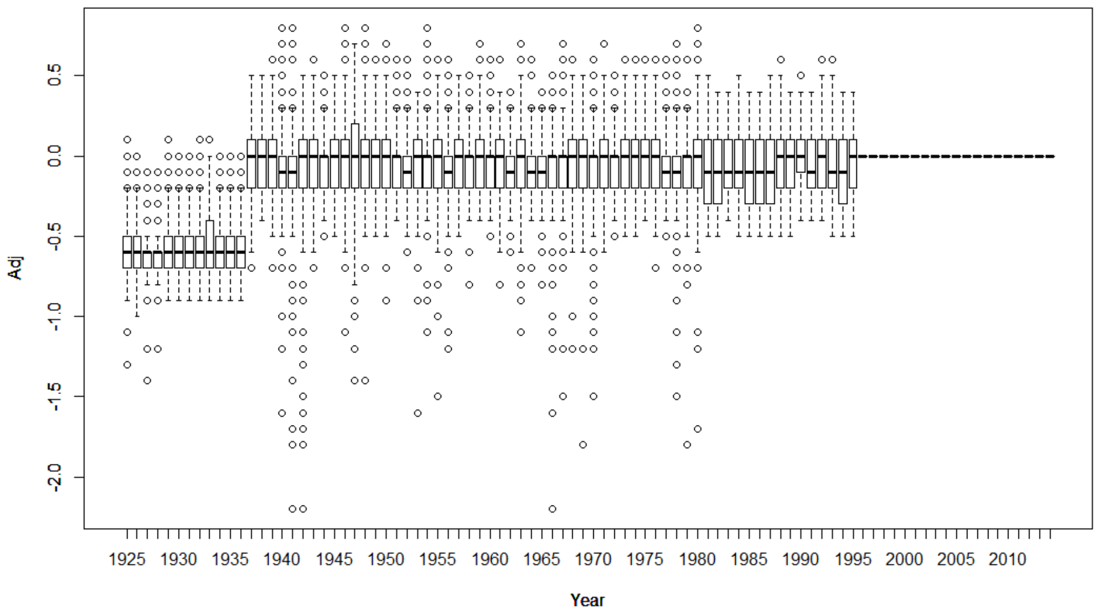


Figure 29: Effect of homogenization, annual distribution of difference between homogenized and original series at 18700 Oslo-Blindern.

The climate shift?

HOMER detected a break in 1987 (Des) in the Oslo-network. HOMER detects breaks at five of the ten series in the in this year. These five stations are located in the Oslo-fjord region and the analysis of the Kristiansand network also shows that most of the stations in that network also get this break. We suspect that the break introduced by HOMER is caused by a climate shift in the winter season. We consider the detected break in 1987-1988-1989 to be a regional climate shift caused by changes in the general large scale atmospheric circulation, and not by non-climatic effects at the stations. The figures 30 & 31 show this climatic change. This break is therefore ignored in most of the stations and in the networks (Oslo and Kristiansand).

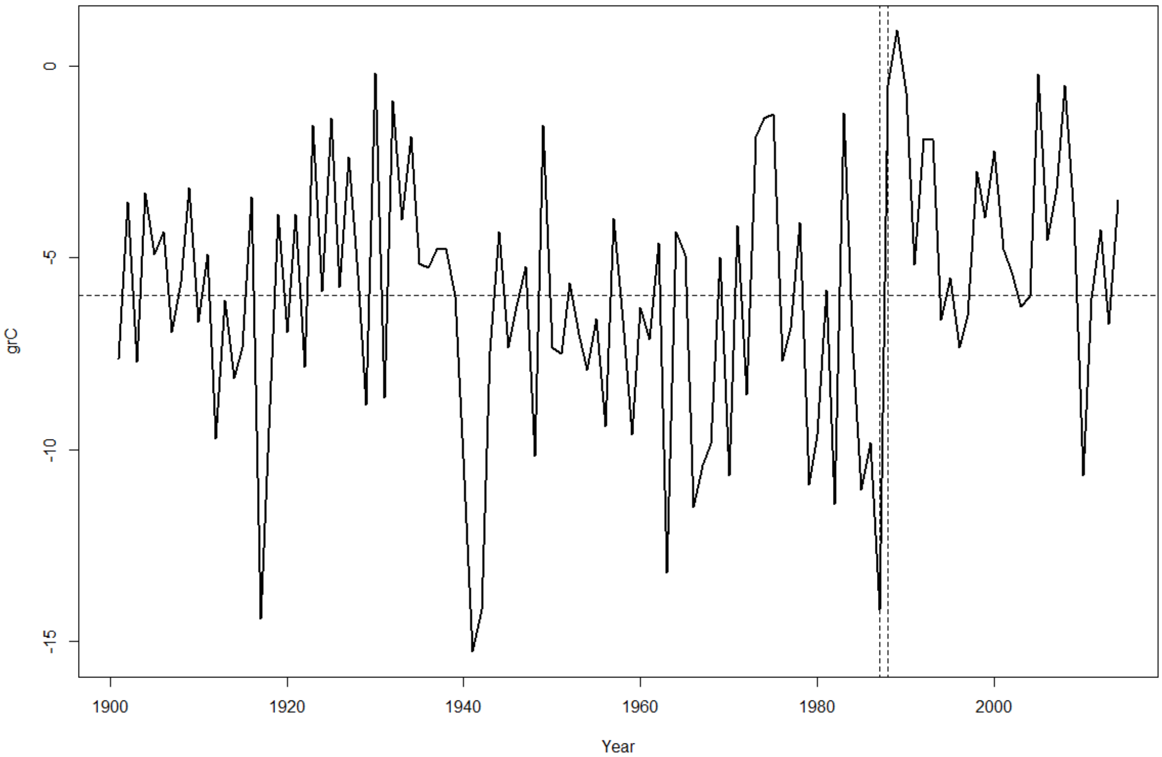


Figure 30: Regionally averaged monthly temperature series for Akershus, January 1901-2014 The horizontal dashed line represents the 1901-2014 average, the vertical lines represent the year 1987 and 1988.

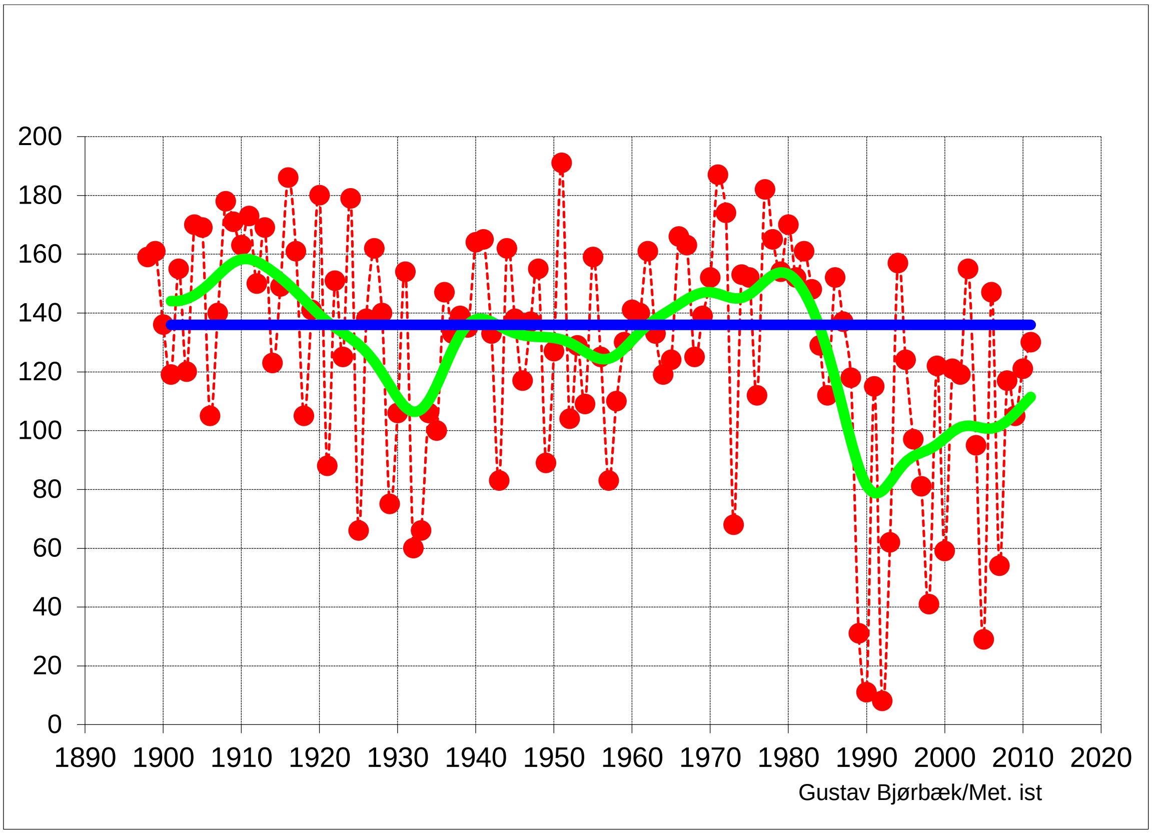


Figure 31: Time series of number of days of skiing conditions in Nordmarka (> 25 cm snow depth at Bjørnholt).

II. Kristiansand network

The Kristiansand or Kjevik temperature series starts in 1939 (1946 for daily data). We observe the same temperature trend at Kjevik (Sørlandet) as in Oslo. The temperature has increased by 1.5 °C (maybe more?) during the 75 year's period of observation for Kjevik. The most of the increased temperature is from the last 25 years. Figure 32 shows us the time series from Kjevik and the increased temperature from 1988.

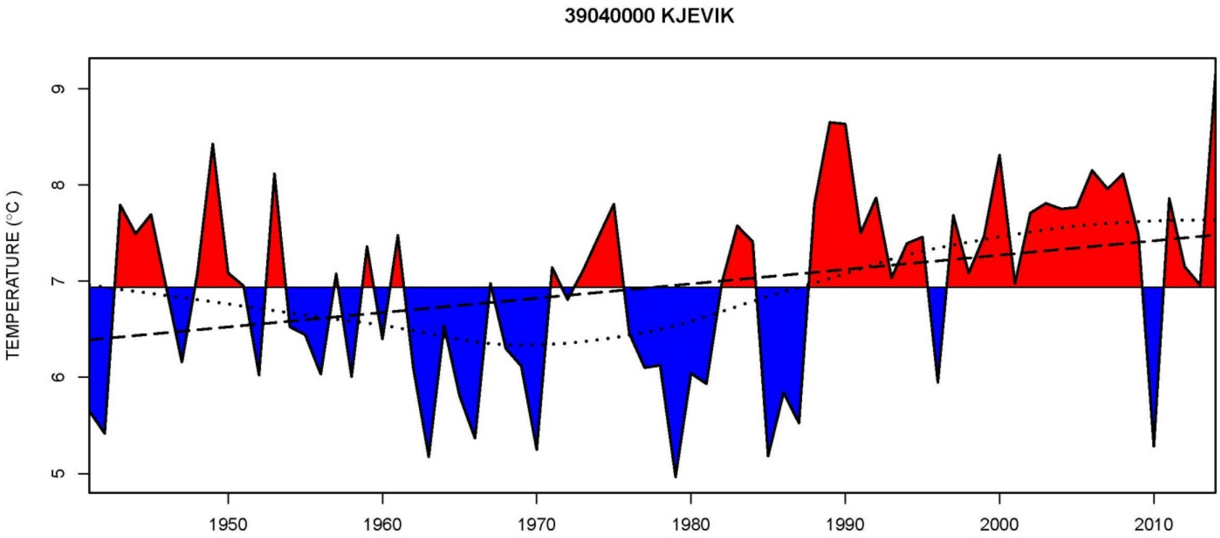


Figure 32: Time series for 39040 (1939-2014) (homogenized).

We can observe the "climate shift" around also here in 1988 with only 2 cold years (1996 & 2010, marked blue) after the so-called "climate shift". The annual mean temperature is 6.6 °C for Kjevik (normal 1960-90) and the highest annual mean temperatures was measured last year 2014 (9.2 °C), and the coldest year were 1970 and 1985 (5.2 °C).

Monthly homogeneity analysis

The homogeneity testing with HOMER discovered 3 breaks of homogeneity in the Kristiansand (39040 Kjevik) temperature series from 1939 to 2014. These 3 breaks were actually supported by metadata (see table 21), but not all were approved. After the analysis we use only 2 breaks from HOMER for homogenizing the daily series applying SPLIDHOM.

I. The break in 1955 was caused by an environment change. It was build a new runway and a parking at the airport. This means that the asphalt zone increase near the measurement site. The break amplitude at -0.24 °C is negative, but we think it is logic that the measurements will be affected (table 19).

As for the Oslo network a break was suspected in the late 80s. At Kjevik, the break is detected in December 1986. The amplitude of the indicated shift is small, at Kjevik in the order of +0.06 °C. Looking at the entire network the analysis indicates homogeneity breaks at all stations except one. At five of the stations (Kjevik, Lyngør, Oksøy, Lindesnes and Mandal) metadata confirms breaks might have occurred due to reasons such as minor relocations, change of radiation screen and painting of the radiations screens. At Byglandsfjord, Lista and Torungen metadata does not confirm homogeneity breaks. The magnitude of the identified breaks indicates strongly that minor changes at the stations can be the reason for the break. As for the Oslo network we assume that the rapid shift in winter climate might be the reason. A complicating factor in this case is that when half of the stations have possibly confirmed breaks in the same year calculation of adjustment factor becomes complicated. The dependences between the series will violate an unbiased assessment of the breaks. In this case it is recommended to extend the analysis by introducing new member in the network, or introduce parallel overlapping networks for an iterative approach to estimate station wise adjustment factors.

In order to check the 1987-88 break the Oslo and Kristiansand network was pooled together, and a pairwise detection of possible breaks applying HOMER was carried out. The pairwise (station by station) comparison is a strong tool in verifying the results of the joint detection. By bringing in the Oslo network stations (that also are strongly correlated with the Kristiansand network) the issue of possible cross-adjustments due to simultaneous changes in the network will be reduced.

The results of the pairwise detection reveal no evidence of breaks in 1986 in the Kjevik series (figure 33). So 1986 break in Kristiansand network is ignored. The break in 1995 (next paragraph) is however clearly identified (figure 33).

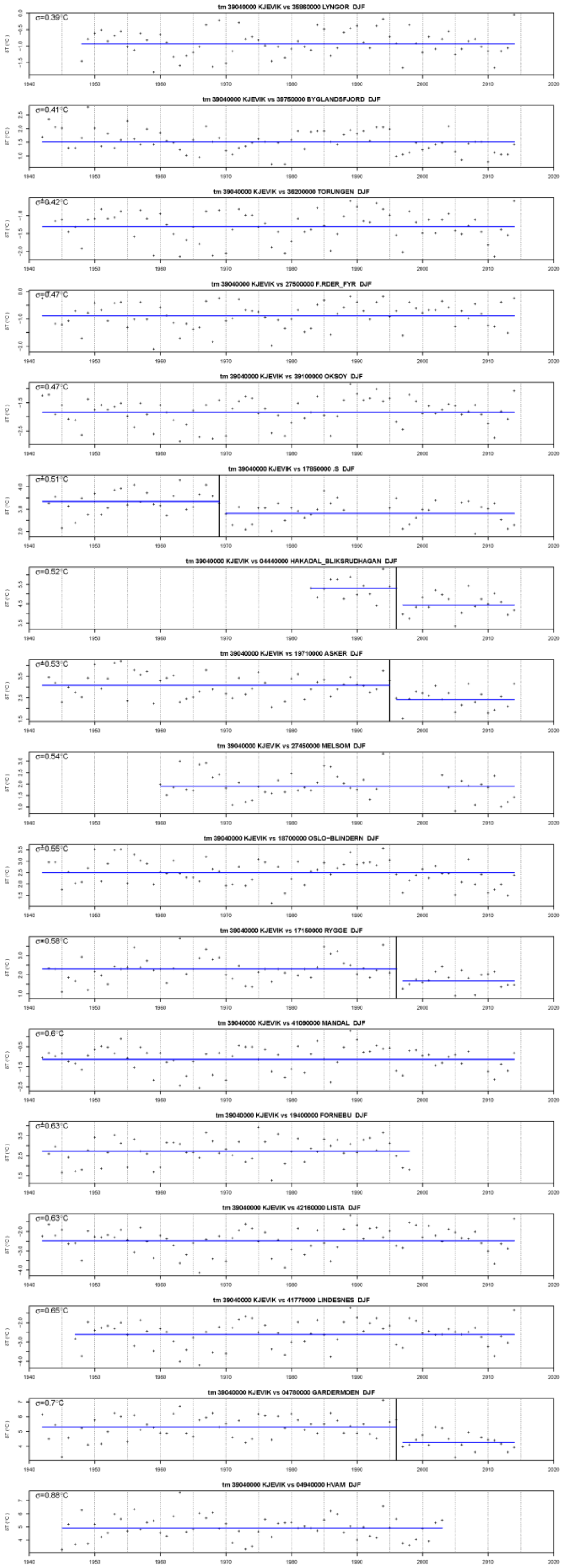


Figure 33: Results of the pairwise detection of the joint Kristiansand and Oslo network.

II. Break in March 1995. The station was automated and equipped with new instruments. Adjustment and break amplitude for this break id -0.21 °C. Automation may seem to be a fairly common cause of breaks of these stations / networks in Norway (ref. Personal note Nordli).

Table 19: 2 breaks at 39040 Kjevik: 12 months break amplitude shown in temperature °C

Break	I: 1955 (March)	IV:1995(March)
Month	Break amplitude in °C	
01 :	0.01	-0.45
02 :	0.06	-0.34
03 :	-0.19	-0.34
04 :	-0.22	-0.12
05 :	-0.22	-0.22
06 :	-0.29	-0.35
07 :	-0.33	-0.48
08 :	-0.31	-0.3
09 :	-0.27	-0.31
10 :	-0.31	-0.35
11 :	-0.38	-0.54
12 :	-0.09	-0.4
13 => YEAR	-0.18	-0.21
BREAK AMPLITUDE:	-0.24	-0.21

In the metadata table (table 20) we can see the reasons for possible breaks at all stations in the Kristiansand-network. We see that relocations, new instruments, changing the radiation screens and environmental changes are the main reasons for breaks in the time series, except the shift in 1987-88.

Table 20: Metadata for the homogeneity break in the Kristiansand network

NR	STATION	YEAR	MONTH	DATE	°C	Reason for break
36200	TORUNGEN	1954	6	30	-0.02	Change of observer and new radiation screen
38140	LANDVIK	1986	11		-0.2	Automation of station (new instruments)
39040	KJEVIK	1955	3	1	-0.24	New runway and parking
39040	KJEVIK	1986	12		0.06	Relocation of radiation screen
39040	KJEVIK	1995	3	1	-0.21	Automation of station (Scanmatic)
39100	OKSOY	1925	3	4	-0.13	Problems with the thermometers
39100	OKSOY	1987	12		0.03	New radiation screen (MI-33)
39750	BYGLANDSFJORD	1924	2		-0.54	Startet with radiation screen
39750	BYGLANDSFJORD	1950	10		0.37	Relocation of station (500 m)
39750	BYGLANDSFJORD	1968	5		0.18	Relocation of station (500 m)
41090	MANDAL	1900	3		-0.34	Unknown (documentation lost before 1918)
41090	MANDAL	1934	12		0.14	New radiation screen (MI-33) & change of observer
41090	MANDAL	1949	7		-0.41	Relocation of station (New station 41110 Mandal)
41090	MANDAL	1970	12		-0.07	A small relocation of 50 m towards NW (less trees)
41090	MANDAL	2007	82		0.42	The station closed down temporarily (New AWS in 2009)

41770	LINDESNES	1921	11		0.51	Inspection
41770	LINDESNES	1969	4		0.01	A small relocation of 90 m towards W
42160	LISTA	1944	12		0.2	Change of instrument height

Homogenization of daily temperature

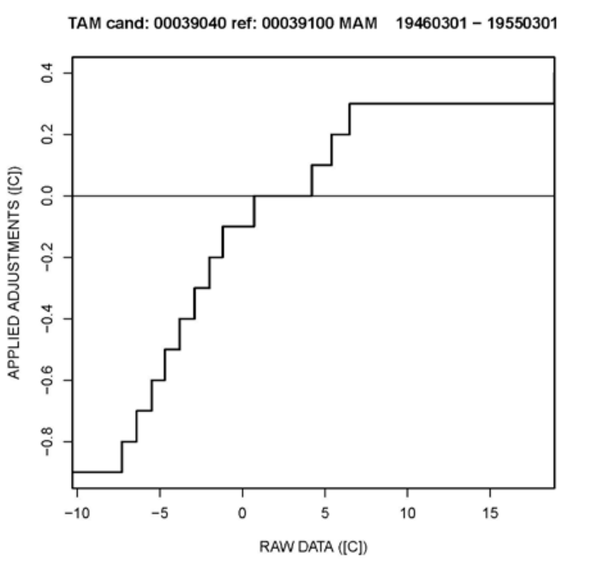
In figure 34 are the adjustment for daily temperatures at 39040 Kjevik presented. We see at the Splidhom results choose 39100 Oksøy as the reference station for the daily homogenization in the first break and 38140 Landvik in the second break. (Landvik station operates from 1957).

Here are the 2 periods that have been made of the 3 breaks:

I. Estimated adjustment function $\widehat{m}_{YX_{jaft}-YX_{jbef}}\left[\widehat{m}_{XY_{jbef}(Y_t)}\right]$ for HSP between 1 Mar 1946 and 1 Mar 1955, for Kjevik daily mean temperature (Y) and spring season (MAM). This function gives the adjustment to be applied to Y as a function of Y itself (°C). Note that this estimation is rounded to a precision of 0.1 °C, which is the precision of the data themselves in the database.

II. 1 Mar 1955 and 1 Mar 1995 from the spring season (MAM).

1955



1995

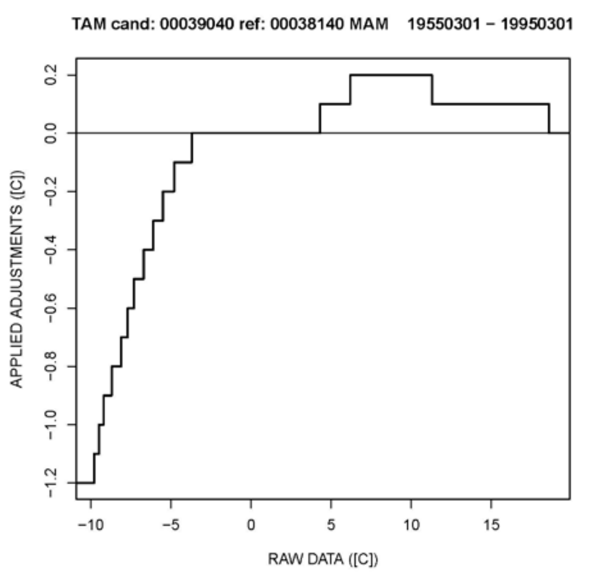


Figure 34: Graphical output of the 2 breaks at Kjevik (I left & II right).

Figure 35 gives an overview and a plot over the Kjevik time series with the two breaks (1955 & 1995). The SPLIDHOM program has produced a new daily mean temperature time series for 39040 Kjevik.

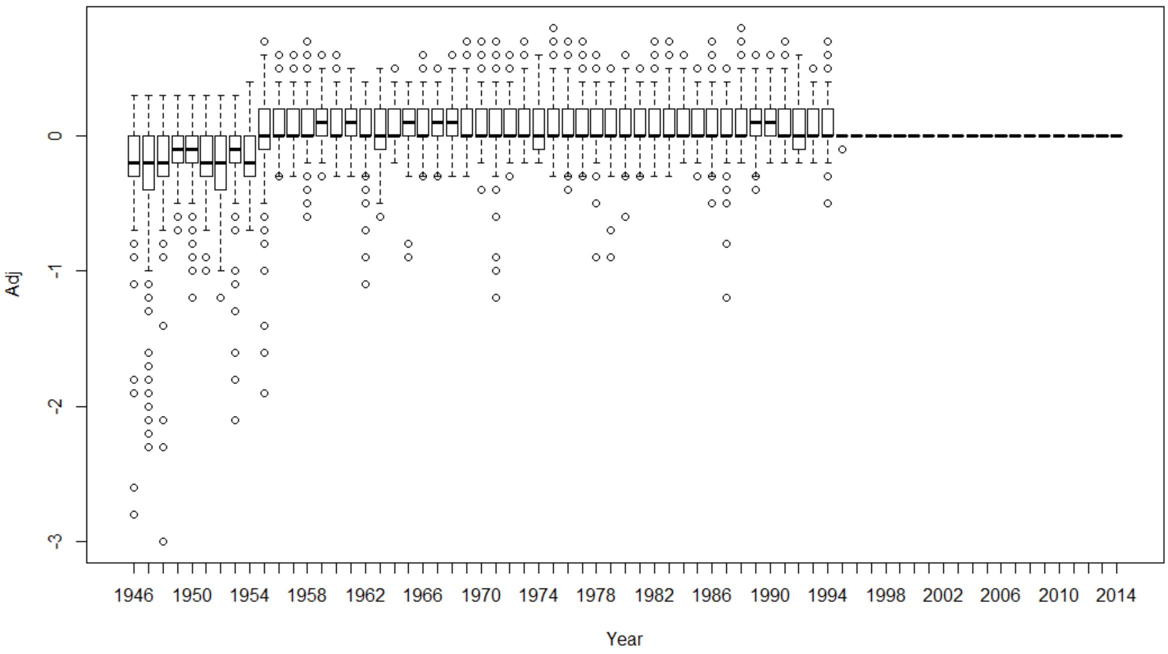


Figure 35: Effect of homogenization, annual distribution of difference between homogenized and original series at 39040 Kjevik.

III. Bergen network

The Bergen temperature series actually starts in 1818 and that was a period when anthropogenic influence on climate was low. The annually mean temperature has increased by 1-1.5 °C during the almost 200 year's period of observation for Bergen. The most of the increased temperature is during the last 20 years. The period we study here, 1904-2014 (fig. 36) shows an increased temperature. We can observe the "climate shift" also in Western Norway. Especially from 1997 with only two "cold" years (2001 & 2010 marked as blue) since 1997. Annual mean temperature is 7.6 °C in Bergen (normal 1960-90) and the highest annual mean temperatures was measured last year 2014 (9.9 °C), and the coldest year in the study period (1930-2014) are 1942 (6.6 °C).

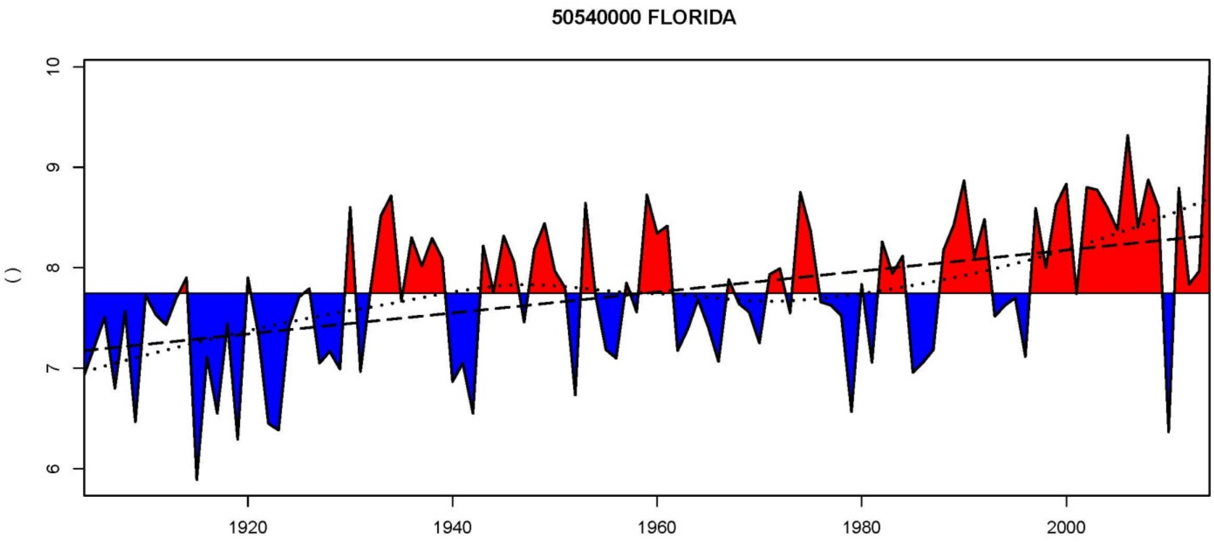


Figure 36: Time series for 50540 Bergen-Florida (1904-2014) (homogenized).

Monthly homogeneity analysis

HOMER identifies 2 breaks in the monthly temperature time series at 50540 Bergen-Florida for during the period 1904 – 2014. Table 21 show the yearly break amplitude and for months in °C.

Table 21: 2 breaks at 50540 12 months break amplitude shown in temperature °C

Break	I: 1927 (Dec)	II:1987 (Dec)
Month	Break amplitude in °C	
01 :	-0.3	-0.53
02 :	-0.2	-0.46
03 :	0.09	-0.17
04 :	0.42	0.08
05 :	0.6	0.25
06 :	0.55	0.24
07 :	0.5	0.25
08 :	0.45	0.17
09 :	0.37	0.05
10 :	0.18	-0.13
11 :	-0.05	-0.29
12 :	-0.21	-0.44
13 => YEAR	0.18	-0.1
BREAK AMPLITUDE:	0.28	-0.1

I. HOMER detects the first break in the Bergen-series in 1927. There is no metadata from this period (documentation lost before 1932). We just accept the break. The break amplitude is positive at 0.28 °C.

II. The break in 1987 was caused by station relocation. Actually, this is the time where the old series from 50560 Bergen-Fredriksberg was merged with the present 50540 Bergen-Florida series. 50560 Bergen- Fredriksberg station closed down the 31. December 1985. We believe that this exchange of stations is the reason for the break in 1987, slightly delayed, which is also common for this kind of breaks. The corrections are positive in the summer half year: April-October and negative in the winter. The correction has yearly break amplitude at -0.1°C. Fredriksberg was closer to the sea, so that can explain the half-year difference and it is more maritime climate at Fredriksberg (Nordnes) and more continental conditions at Florida.

The two stations ran parallel from 1949-1985, but only the composite series covering the entire study period is applied here in order to keep the series in the analysis independent. The composite series was tested by the HOMER software within the time interval 1904-2014, and HOMER detect, as expected, a break in December 1987. We chose to use the data from 50560 Frederiksberg as long as possible (31.12.1985) because it has been a lot of changes with the measurements at Florida. E.g. the instruments and measurements have been done on the roof of buildings at Geofysen (!). Figure 37 shows a picture from the station at Florida after it settled for good in the Geofysen garden in 1986.

Figure 37: Picture (against N) of the "new" main met-station in Bergen: 50540 Bergen-Florida (1986).

In the metadata table (table 22) we can see the different reasons for breaks at every station in the Bergen-network. We see that relocations, new instruments, changing the radiation screens and environmental changes are the main reasons for breaks in the time series.

Table 22: Metadata for the homogeneity break in the Bergen network

NR	STATION	YEAR	MONTH	DATE	°C	Reason for break
47200	SKUDENES_II	1939	1		-0.18	New radiation screen (cage discarded)
47200	SKUDENES_II	1981	12		0.07	Relocation of station: 700 m towards NW (Lahammer)
47200	SKUDENES_II	1992	4		0.03	Relocation of station: 800 m towards W (Hålandsdalen)
47200	SKUDENES_II	2005	11	1	-0.48	47200 Skudenes 2 closed down. New station 47260 Haugesund Lufthamn (Distance: 30km)
47300	UTSIRA_FYR	1927	12		0.02	Radiation screen redecorated and painted
47300	UTSIRA_FYR	1988	12		0.14	Sitka spruce grows up in westerly direction
48330	SLÅTTERØY_FYR	1928	5		0.4	Inspection
48330	SLÅTTERØY_FYR	1976	12	3	-0.05	New radiation screen (MI-46)
48330	SLÅTTERØY_FYR	1988	12		0.23	Inspection with remarks
49490	ULLENSVANG	1877	10		0.37	Unknown
49490	ULLENSVANG	1964	12		0.19	Relocation of station (2 km towards N From Helleland)
49490	ULLENSVANG	1976	11		0.24	49490 Ullensvang closed down. New station in Eidfjord created (Distance: 40km)
50500	FLESLAND	1980	1		-0.23	Instrument failure (damage due to lightning)
50540	FLORIDA	1927	12		0.28	Unknown (Documentation lost before 1932)
50540	FLORIDA	1987	2		-0.1	Relocation of station from 50560 Fredriksberg to 50540 Florida (2 km)
51530	VOSSEVANGEN	1939	11		-0.48	Relocation of station (1.12.1939) Voss sentrum
51530	VOSSEVANGEN	1961	12		-0.53	New station 51570 Voss-Tvilde. Relocation: 1.11.1961
51530	VOSSEVANGEN	1966	2		0.59	New station 51580 Voss-Bø. Relocation.
51530	VOSSEVANGEN	2003	12		0.18	New station 51530 Vossevangen. Relocation: 1.1.2004
52310	MODALEN_III	1987	5		-0.12	Shift of observer & radiation screen painted
52310	MODALEN_III	2008	12		-0.31	New station 52310 Modalen III. Relocation: 2.10.2008
52535	FEDJE	1992	12		0.16	Automation of station Aug 1992
52860	TAKLE	1970	12		-0.18	Garage built up and 2 houses near the screen was demolished
54110	LÆRDAL	2009	12		0.12	New station 54110 Lærdal IV.

Homogenization of daily values

Figure 38 shows the adjustments for daily temperatures for the breaks at 50540 Bergen-Florida. Splidhom results choose 47300 Utsira (1927-break) and 50500 Flesland (1987-break) as the reference stations for the daily homogenization.

Here are the 2 periods that have been made of the 2 breaks:

I. Estimated adjustment function $\widehat{m}_{YX_{jaft}-YX_{jbef}}\left[\widehat{m}_{XY_{jbef}(Y_t)}\right]$ for HSP between 1 Jan 1904 – 1 Dec 1927, for Bergen daily mean temperature (Y) and winter season (DJF). This function gives the adjustment to be applied to Y as a function of Y itself (°C). Note that this estimation is rounded to a precision of 0.1 °C, which is the precision of the data themselves in the database.

II. 1 Dec 1927 – 1 Dec 1977 from the winter season (DJF).

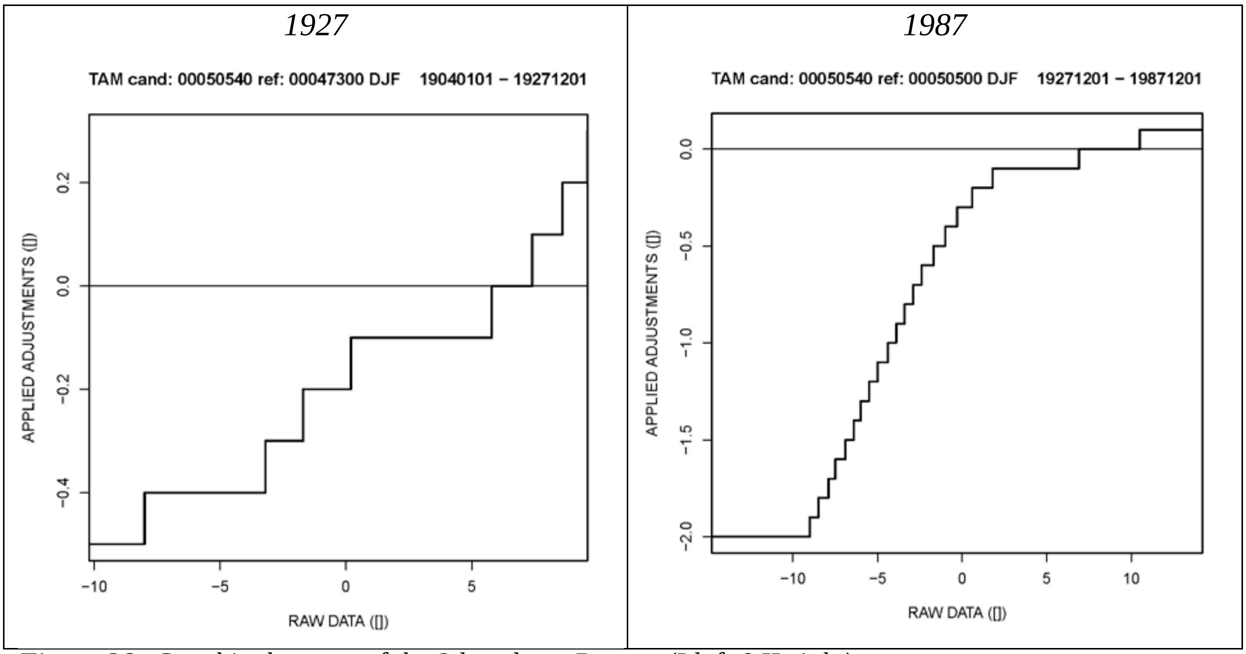


Figure 38: Graphical output of the 2 breaks at Bergen (I left &II right).

Figure 39 gives an overview and a plot over the Bergen time series with the two breaks (1927 & 1987). The SPLIDHOM program has produced a new homogenous daily mean temperature time series for 50540 Bergen Florida.

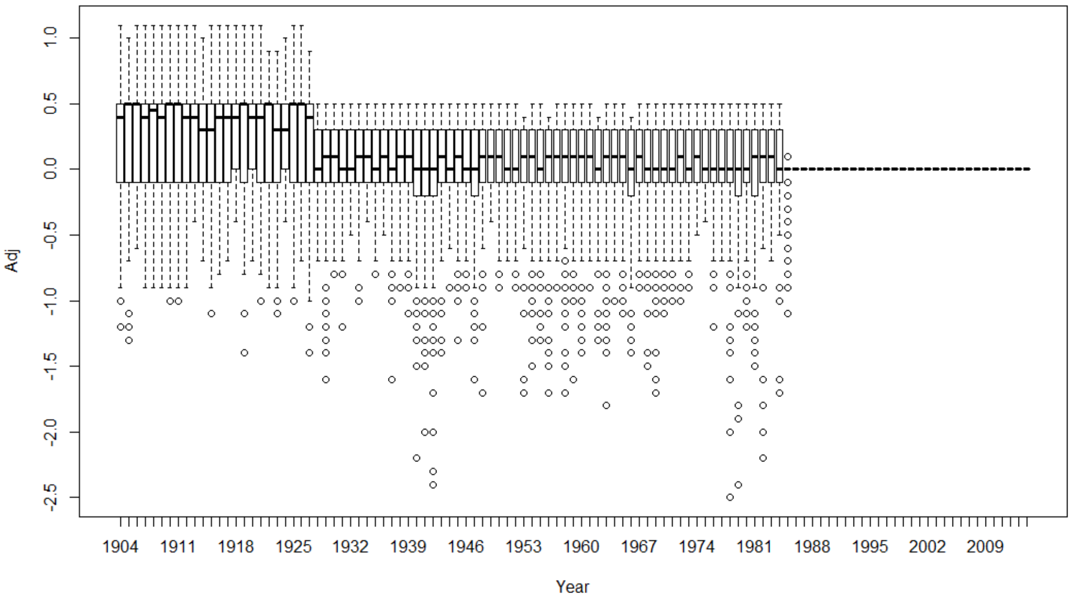


Figure 39: Effect of homogenization, annual distribution of difference between homogenized and original series at 50540 Bergen-Florida.

IV. Trondheim network

The Trondheim temperature series starts in 1946. The annually mean temperature has increased by 1.5 °C during the 70 year observation period at Værnes. The strongest increase is seen in the last 25 years (see figure 40). We can also observe a “climate shift” in Central Norway. Especially from the last 1980s with only a few “cold” years (1996 & 2010 marked as blue) the last 3 decades. Annual mean temperature is 5.0 °C at Værnes (normal 1960-90) and the highest annual mean temperatures was measured last year 2014 (9.9 °C), and the coldest year in the study period (1946-2014) are 1965 (3.7 °C).

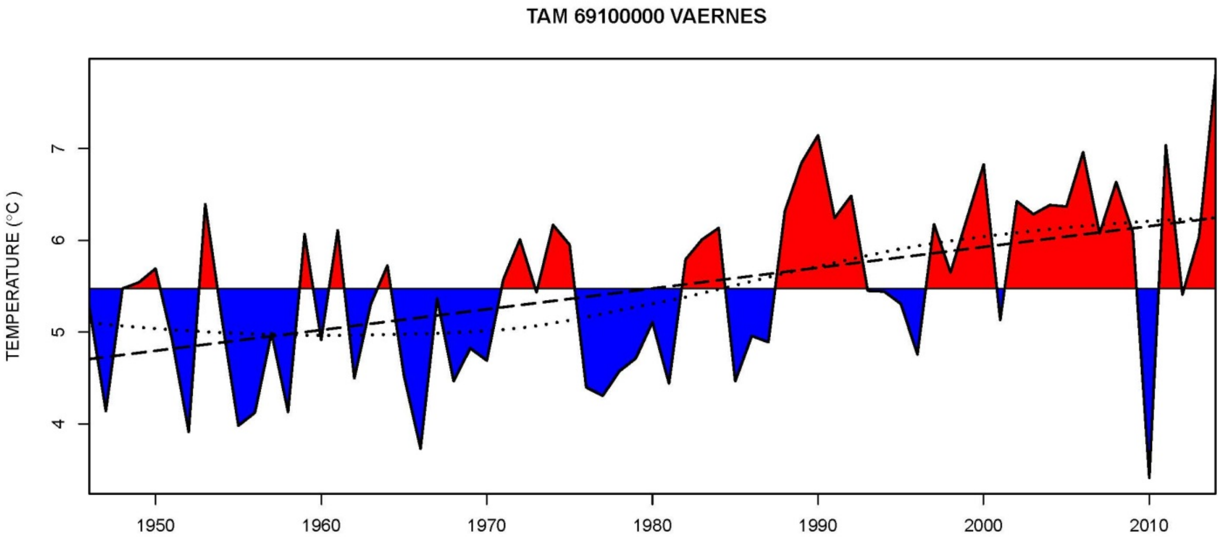


Figure 40: Time series for 69100 Værnes (1946-2014) (homogenized).

Monthly homogeneity analysis

HOMER identifies three breaks in the temperature time series at 69100 Værnes for monthly mean temperatures in the period 1946 – 2014. These breaks are supported by metadata (see table 24).

I. The break in 1949 (Dec). The break amplitude is positive at 0.49 °C (table 23, column 1). The reason for the breaks is the introduction of a new radiation screen (MI-46) (see fig. 41).

II. The break in 1978 (Jan) seem to be caused by a new temperature sensor. The break amplitude is positive at 0.47 °C (table 23, column 2).

III. The break in 1987 (Dec) was caused by an environmental change. A new runway and a parking at the airport was constructed. This caused that the asphalt zone increase near the measurement site. The break amplitude at -0.14 °C is negative (table 23, column 3).

Figure 41: The “new” radiation screen (MI-46) at Værnes from 1949.

Table 23: 3 breaks at 69100 Værnes for 12 months break amplitude shown in temperature °C.

Break	I: 1949 (Dec)	II: 1978 (Jan)	III:1987 (Dec)
Month	Break amplitude in °C		
01 :	0.59	0.26	-0.23
02 :	0.47	0.21	-0.28
03 :	0.69	0.26	-0.25
04 :	0.92	0.33	-0.19
05 :	1.13	0.41	-0.02
06 :	1.01	0.38	0
07 :	0.91	0.35	-0.04
08 :	0.83	0.32	-0.14
09 :	0.92	0.39	-0.18
10 :	0.87	0.39	-0.24
11 :	0.87	0.39	-0.26
12 :	0.68	0.3	-0.27
13 => YEAR	0.82	0.33	-0.14
BREAK AMPLITUDE:	0.49	0.47	-0.14

In the metadata table (table 24) we can see the different reasons for breaks at every station in the Værnes-network. We see that relocations, new instruments, changing the radiation screens and environmental changes are the main reasons for breaks in the time series.

Table 24: Metadata for the homogeneity break in the Trondheim network.

NR	**STATION**	**YEAR**	**MONTH**	**DATE**	°C	**Reason for break**
68860	TRONDHEIM_VOLL	1966	12		0.46	The station closed down temporarily (relocation)
69100	VAERNES	1949	12	21	0.49	New radiation screen (MI-46)
69100	VAERNES	1978	1	29	0.47	New temperature sensor (MITEF)
69100	VAERNES	1987	12		-0.14	Reconstruction of the runway and extension with asphalt
69380	MERAAKER	1970	3		0.17	Relocation of station (8 km)
69380	MERAAKER	2008	2		-0.1	Inspection with remarks and adjustment
70150	VERDAL	1978	12		-2.11	The station closed down temporarily (relocation)
70150	VERDAL	1984	12		1.87	Relocation of station (12 km)

70850	SNAASA	1961	12		-0.14	Radiation screen painted
70850	SNAASA	1988	12		0.3	Radiation screen painted & new min thermometer
71550	ORLAND	1970	12		-0.08	Inspection with remarks and adjustment
71550	ORLAND	1988	11		-0.16	Relocation of station (200 m)
71550	ORLAND	2002	5		0.43	New thermometer

Homogenization of daily temperatures

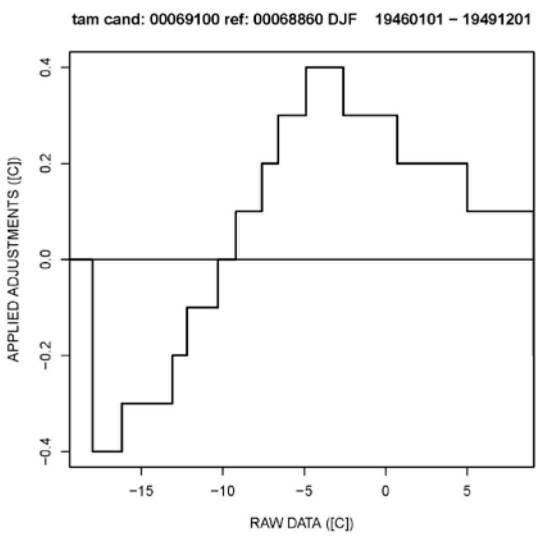
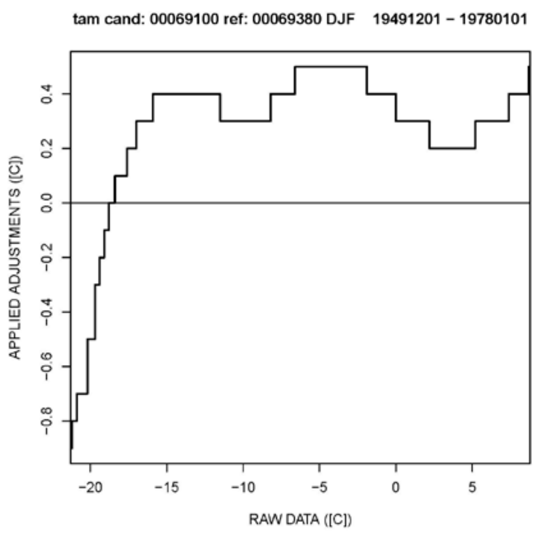
Figure 42 shows the daily adjustments for 69100 Værnes. Splidhom choose 68860 Trondheim (don’t run the hole period) and 69380 Meråker as reference station for the daily homogenization.

Here are the three breaks that are adjusted:

I. Estimated adjustment function $\widehat{m}_{YX_{jaft}-YX_{jbef}}\left[\widehat{m}_{XY_{jbef}(Y_t)}\right]$ for HSP between 1 Jan 1946 and 1 Dec 1949, for Værnes daily mean temperature (Y) and winter season (DJF). This function gives the adjustment to be applied to Y as a function of Y itself (°C). Note that this estimation is rounded to a precision of 0.1 °C, which is the precision of the data themselves in the database.

II. 1 Dec 1949 and 1 Jan 1978 from the winter season (DJF).

III. 1 Jan 1978 – 1 Dec 1987 from the winter season (DJF).

1949	1978
	

1987

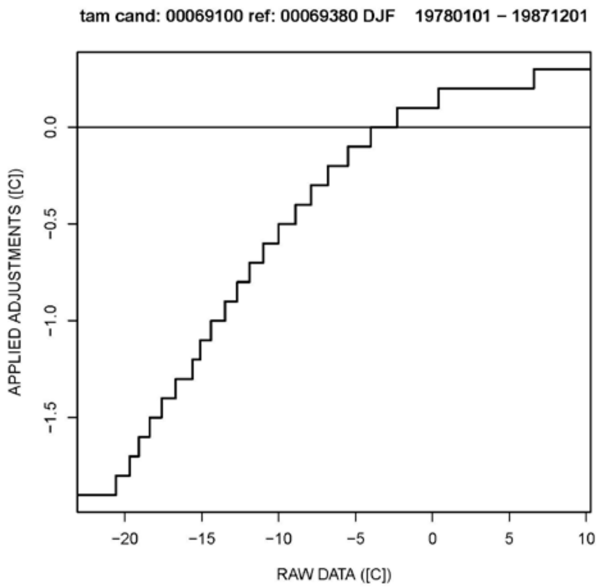


Figure 42: Graphical output of the 3 breaks at Værnes (1949 upper left, 1978 upper right and 1987 lower panel).

Figure 43 gives an overview and a plot over the Værnes time series with the three breaks (1949, 1978 & 1987). The SPLIDHOM program has produced a new homogenous daily mean temperature time series for 69100 Værnes.

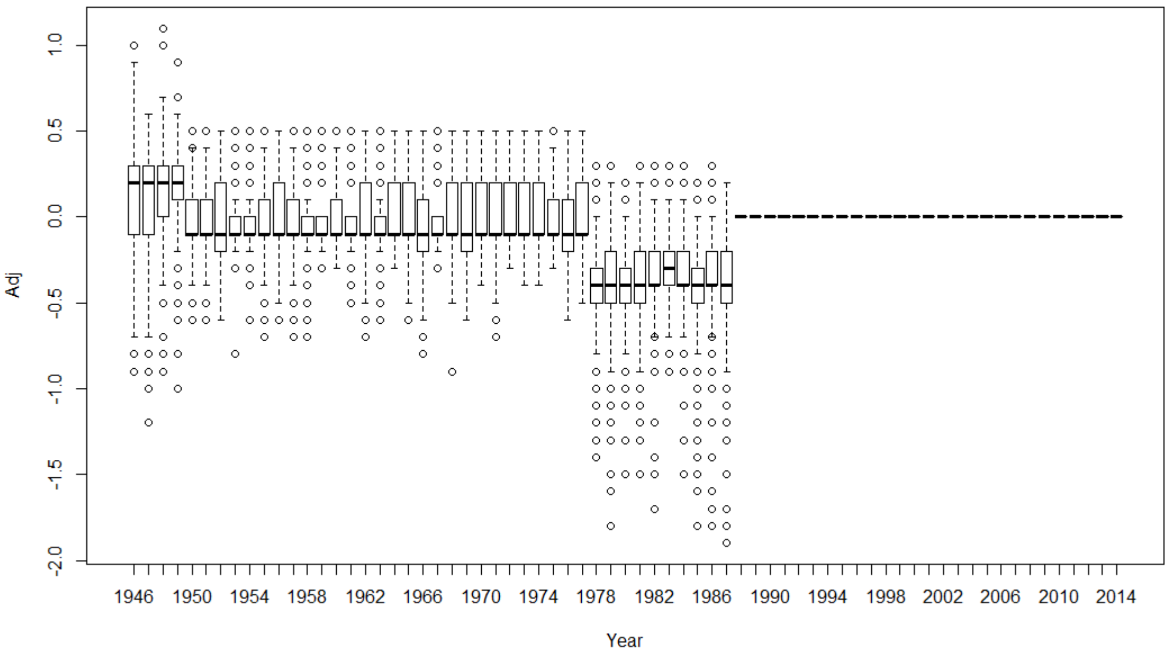


Figure 43: Differences between homogenized and original daily temperature series at 69100 Værnes.

V. Tromsø network

The Tromsø temperature series starts in 1920. The annual mean temperature has increased by 1-1.5 °C during the 95 years of observations. Most of the increase temperature is during the last 15 years (see figure 44). We can also observe a “climate shift” in Northern Norway. Especially from the turn of the century with only a one “cold” year (2010 marked as blue). Annual mean temperature is 2.5 °C in Tromsø (normal 1960-90) and the highest annual mean temperatures was measured in 2011 (4.5 °C), and the coldest year in the study period (1920-2014) are 1955 (1.1 °C).

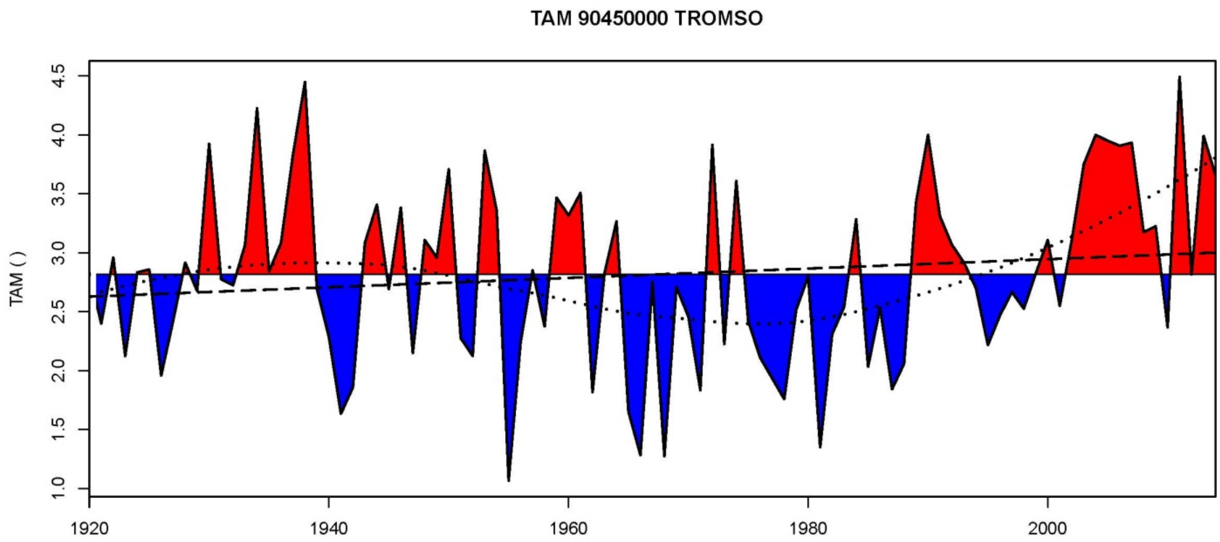


Figure 44: Time series for 90450 Tromsø (1920-2014) (not need to be homogenized).

Monthly homogeneity analysis

HOMER detects one break in the monthly temperature series for 90450 Tromsø 1921 – 2014. The daily homogeneity testing discovered no breaks in homogeneity in Tromsø temperature series.

The only break HOMER found in the Tromsø series is the break in 2001 (December). The correction has yearly break amplitude at 0.15 °C. Here the corrections are positive for all months (table 25). In this year the station was automatized and got new instruments from Scanmatic.

The result of the pairwise detection from the Tromsø-network is shown in figure 43. There is a clear break in 2001 in the Tromsø series (figure 45).

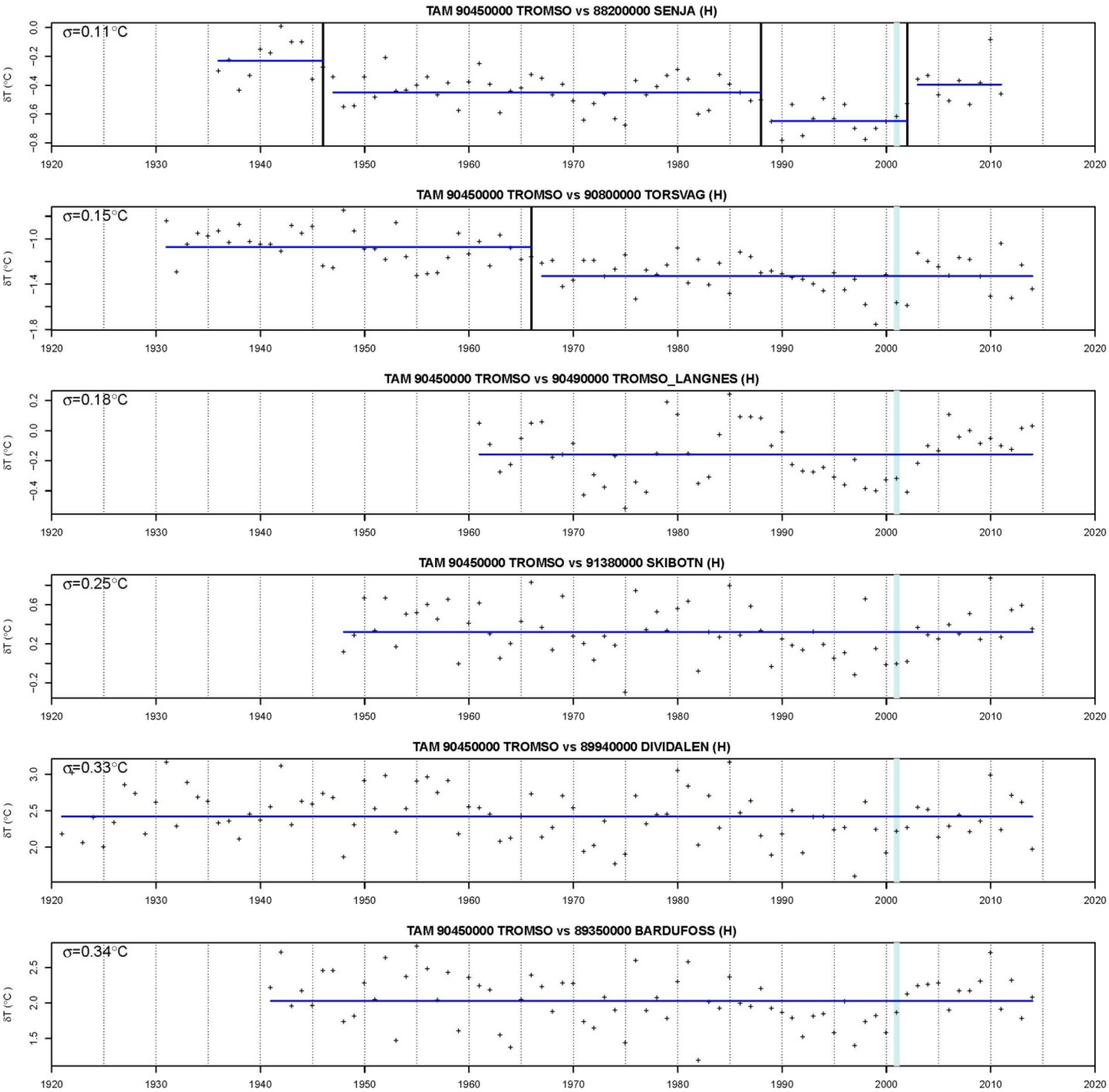


Figure 45: Pairwise detection compares after Homogenization for 90450 Tromsø (1920-2014).

Table 25: 1 break at 90450 12 months break amplitude shown in temperature °C

Break	I: 2001 (Dec)
Month	Break amplitude in °C
01 :	0.2
02 :	0.21
03 :	0.09
04 :	0.23
05 :	0.21
06 :	0.24
07 :	0.1
08 :	0.07
09 :	0.06
10 :	0.14
11 :	0.19

12 :	0.29
13 => YEAR	0.15
BREAK AMPLITUDE:	0.15

In the metadata table (table 26) we can see the different reasons for breaks at every station in the Tromsø-network. We see the same pattern as in the other networks, that relocations, new instruments, changing the radiation screens and environmental changes are the main reasons for breaks in the time series.

Table 26: Metadata for the homogeneity break in the Tromsø network

NR	STATION	YEAR	MONTH	DATE	°C	Reason for break
88200	SENJA	1991	6		-0.98	New station: 88920 Senja-Grasmyrskogen. Relocation: 1. 1991 from 88900 Gibostad (15 km SW)
88200	SENJA	1997	4		0.78	New station 88200 Senja-Laukhella. Relocation: 1.1997 (8 km SE)
89350	BARDUFOSS	1975	12		-0.32	Relocation of radiation screen (150 m S)
89350	BARDUFOSS	1988	9		0.73	Radiation screen redecorated and painted
89350	BARDUFOSS	2011	12		-0.61	New radiation screen (MI-2000)
89940	DIVIDALEN	1929	10		0.87	Relocation of radiation screen (110 m S) and moved slightly higher
89940	DIVIDALEN	2008	12		-0.57	New station 89940. Relocation: 2009 (500 m NW)
90450	TROMSO	2001	12		0.15	Automation of station
90490	TROMSO_LANGNES	1970	12		-0.22	Cluttered observational basis
90490	TROMSO_LANGNES	1990	12		-0.07	New instrument/change instrument (MITEF)
91380	SKIBOTN	1971	12		-0.24	Relocation of station and construction of hydropower plants in the valley
91380	SKIBOTN	1984	1		0.26	Relocation of station (2 km)
91380	SKIBOTN	2000	12		-0.3	Overgrowth of vegetation -felling of trees and bushes

Homogenization of daily temperatures

Running Splidhom on the series adjusted by HOMER it turned out that no further adjustment for daily values were possible to identify. This means that there is no evidence for significant differences in the temperature distribution functions before and after the adjusted break. The pairwise detection results of the homogenized data confirm that the series in this region are well homogenized.

Figure 46 gives an overview and a plot over the Tromsø time series with the break in 2001. The SPLIDHOM program could not produce a new daily mean temperature time series for 90450 Tromsø, because the beak could not be displayed in Splidhom. We accept this and do nothing with the mean daily time series for Tromsø.

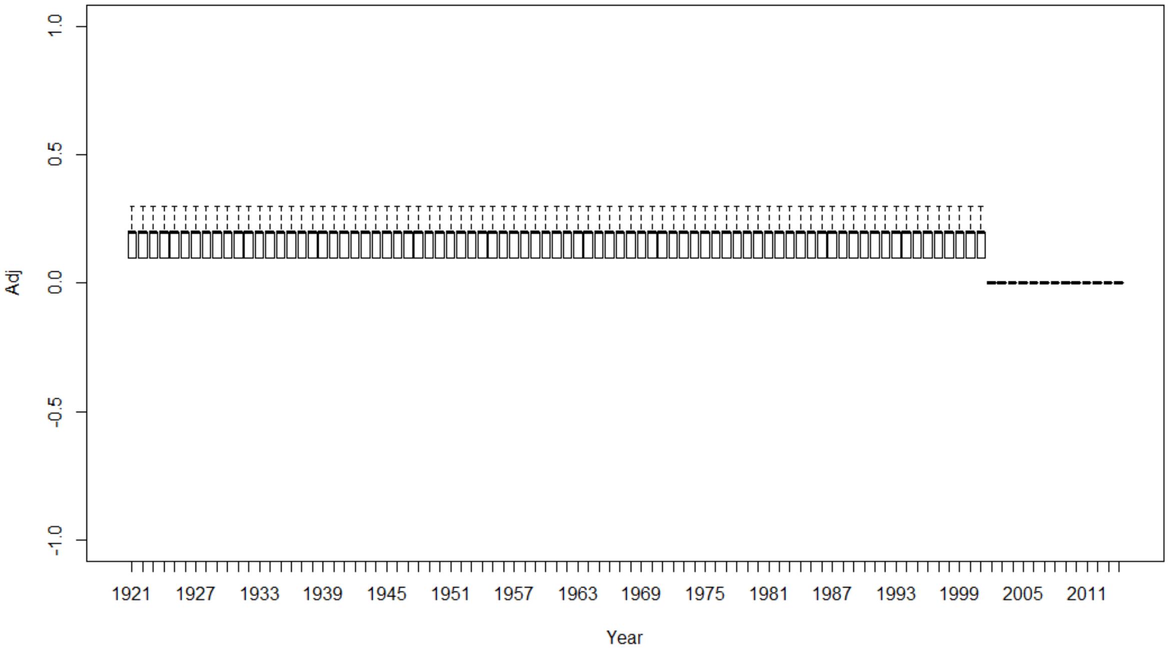


Figure 46: Differences between homogenized and original daily temperature series at 90450 Tromsø.

6 - Conclusions

In this analysis daily mean temperature series for five major cities has been homogenized. The analysis include in total temperature series from 44 locations in five networks (Figure 2). The time period analyzed is 1930 (1946) to present.

The analyses detected in total 85 breaks in the 44 stations and the 5 network. Table 27 shows the 11 detected breaks at the 5 candidate stations in the survey.

Table 27: The time series from the candidate stations and the detected breaks

Station	Time series: Homogenized	Detected Breaks	Years for break
18700 Oslo-Blindern	1925-2014	3	1937,1980 & 1995
39040 Kjevik (Kristiansand)	1946-2014	2	1955 & 1995
50540 Bergen-Florida	1904-2014	2	1927 & 1987
69100 Værnes (Trondheim)	1946-2014	3	1949, 1978 & 1987
90450 Tromsø	1920-2014	1	2001

A homogenized monthly temperature series for Oslo was established by applying the adjustments obtained by HOMER in the period 1925–2014, which gives the opportunity to calculate homogenized daily mean temperatures in SPLIDHOM. The Oslo temperature series was adjusted for three homogeneity breaks (1937, 1980 & 1995). The seasonal adjustments of the breaks lay between –0.55°C and + 0.07°C.?

The two long-term series 18650 Oslo I and 18700 Oslo–Blindern were successfully merged and corrected for (break: 0.55°C) in 1937. In the 18700 Oslo–Blindern series (1937 to present) located at the Meteorological Institute two sets of monthly corrections were needed (1937–1980) and (1981–1995) in order to homogenize the record. An almost 90 years long homogenized record for Oslo of daily mean temperatures was established mainly composed of a neighborhood network of 10 stations in the Oslofjord area + inland stations.

For the whole Oslo series of 90 years the linear temperature increase was estimated to be 1.5°C, with the steepest trend in the latest 15-20 year of the series. The warmest year was 2014 and the coldest one 1942.

A homogenized temperature series for Kristiansand was established by applying the adjustments obtained by HOMER in the period 1946–2014, which gives the opportunity to calculate homogenized daily mean temperatures in SPLIDHOM. The Kristiansand temperature series was adjusted for two homogeneity break (1955 & 1995). The seasonal adjustment of the two break was -0.24 °C & +0.3°C.
An almost 70 years long homogenized record for Kristiansand of daily mean temperatures was established mainly composed of a neighborhood network of 9 stations from the Southern Norway

For the whole Kristiansand series of 70 years the linear temperature increase was estimated to be 1.5°C, with the steepest trend in the latest 25 year of the series. The warmest year was 2014 and the coldest one 1970.

A homogenized temperature series for Bergen was established by applying the adjustments obtained by HOMER in the period 1904–2014, which gives the opportunity to calculate homogenized daily mean temperatures in SPLIDHOM. The two long-term series 50560 Bergen-Fredriksberg and 50540 Bergen-Florida were merged (1987). The Bergen temperature series was adjusted for two homogeneity breaks (1927 & 1987). The seasonal adjustments of the breaks are between –0.10°C and + 0.28°C. An almost 110 years long homogenized record for Bergen of daily mean temperatures was established mainly composed of a neighborhood network of 11 stations in Western Norway.

A homogenized temperature series for Trondheim was established by applying the adjustments obtained by HOMER in the period 1946–2014, which gives the opportunity to calculate homogenized daily mean temperatures in SPLIDHOM. The Trondheim temperature series was adjusted for three homogeneity breaks (1949, 1978 & 1987). The seasonal adjustments of the breaks lay between –0.14°C and + 0.49°C. An almost 70 years long homogenized record for Trondheim of daily mean temperatures was established mainly composed of a neighborhood network of 7 stations from the Central Norway.

A homogenized temperature series for Tromsø was established by applying the adjustments obtained by HOMER in the period 1920–2014, which gives the opportunity to calculate homogenized daily mean temperatures in SPLIDHOM. The Tromsø temperature series was adjusted for one homogeneity break (2001). The seasonal adjustment of the break was 0.15°C.

An almost 95 years long homogenized record for Tromsø of daily mean temperatures was established mainly composed of a neighborhood network of 7 stations from the Northern Norway. In this case the daily homogenization program SPLIDHOM did not identify significant changes in the distribution of daily mean temperatures, so the series is only adjusted on monthly and seasonal level.

The analyses showed that especially the joint detection algorithm in HOMER is sensitive to regional shifts in climate and indicate breaks when the temperature suddenly change from one "mode" to another. This caused several indications of homogeneity issues in the time series in 1987-1989 where there was a sudden regional shift to warmer temperatures, especially in winter. The effect of such sudden climate variability on the homogeneity detection algorithms needs to be further examined,

Although HOMER and SPLIDHOM might have some weaknesses by identifying false breaks, they are powerful tools in identifying homogeneity breaks in monthly and daily temperature series when carefully interpreted and compared with station metadata. The results of this study show that the analyses should be extended to homogenize all relevant Norwegian daily temperature series.

Acknowledgements

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The project HISTKLIM at MET Norway is acknowledged for having performed the digitalization and quality control of the historical observations from the long time series in this study.

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Appendix A - HomeR

Main points – list to follow when using the program:

0. Preparing the data

A. Fast quality control
• Basic checks (CLIMATOL)
• Fast QC
• Outlier file creation
• Removal of outliers

B. Homogenization
• Detection (pairwise, joint detection, ACMANT)
• Correction
=> The homogenization process

C. Effects of the homogenization
• Visualization of the corrected time series

HOMER main procedures

Homogenization is a well-documented topic; however, so far it is a very disparate juxtaposition of various methods.
The problem at hand is tackled in two steps:

- Detection of the inhomogeneities.
- Correction of the series.

The mostly used "relative homogeneity principle" (Conrad and Pollack, 1950) states that the difference between the data at the tested station and reference series, usually assumed to be homogeneous, is fairly constant in time, up to the inhomogeneity to be detected. Usually, it is assumed that the distribution of the difference series is normal, and that most of the shifts (inhomogeneities) are step-like changes, which typically alter the average value only, leaving the higher moments unchanged (Alexandersson, 1986). These steps are then to be detected by means of a statistical procedure. When no homogeneous reference series exist in the same climatic area as the candidate (which is mostly the case when considering long observation series), references are computed, based on averages of surrounding series. The most commonly used methods create references by means of weighted averages of surrounding series (Alexandersson, 1986, Easterling and Peterson, 1993).

The "Home" R contributed package is mostly devoted to the problem of homogenizing climatological series, that is to say, remove the perturbations produced by changes in the conditions of observation or in the nearby environment to allow the series to reflect only (as far as possible) the climatic variations.

0. Preparing the data

Station coordinates and climatological data must be provided in the way explained here in order to be properly read by the homogenization function.

First we need to prepare the input data in two plain text files with adequate formats. The first one is the station file: Here we provide the coordinates and names of the stations, containing a line of the form: `CODE X Y Z NAME` for each station, an identification CODE of the station, where the coordinates X and Y may be in geographical degrees with their fractional part in decimals (not in the degrees, minutes and seconds form). The other parameters are the elevation above sea level Z in meter, and the NAME of the station itself. The second file is the data file. Here is the station-ID (CODE) very import because it is linked to the station file. In the raw data file it is written the year + 12 months (missing flag -999.9).
E.g. `2015 -0.3 0.3 3.5 7.1 9.0 14.2 16.2 16.5 12.5 7.2 3.2 2.1`

A. Fast quality control (Basic checks)

1. CLiMATOL Checks (i)

First, we run an input check. A check consistency between station files and data files. The next step is in HOMER is a basic quality control and network analysis. These figures (1-6) below are dedicated to a description of the input data: Figure 1 shows the overall number of available data.

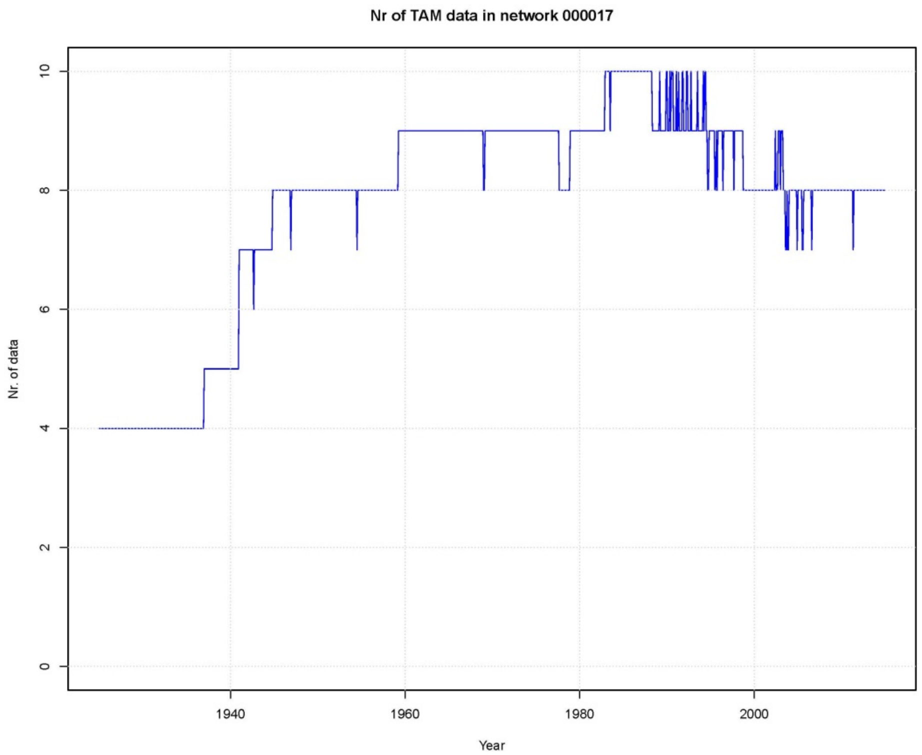

Figure 1: Overall number of available data.

The next one is a box-plots (monthly if applicable, as the January example in figure 2), and a histogram (figure 3). Big outliers or any major problems in the input data revealed by these graphics may suggest a corrective action before repeating the homogenization process. They can also help in selecting stations in and out of the network. Figure 4 is a plot of correlation coefficients versus distance; this plot is useful to assess the smoothness of spatial climate variations.

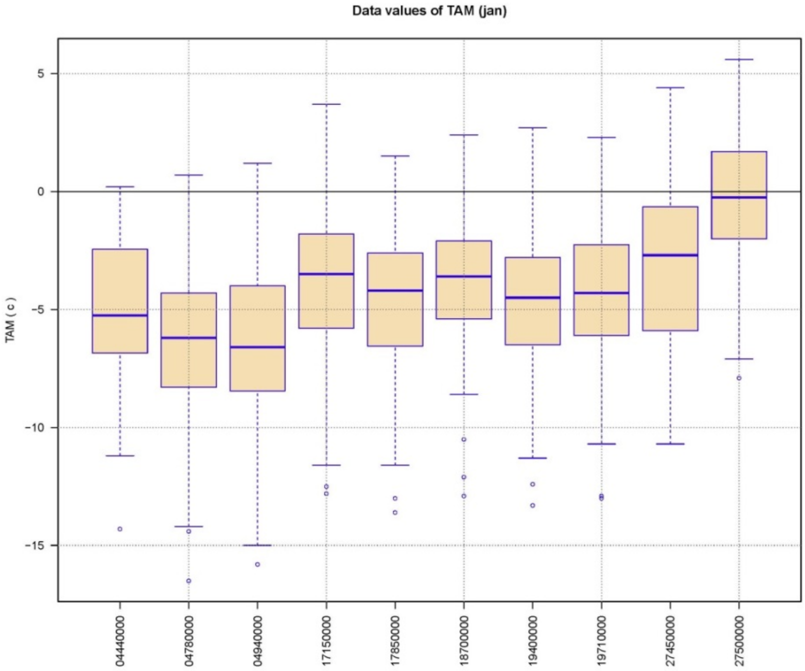

Figure 2: Example of monthly box-plots of the data.

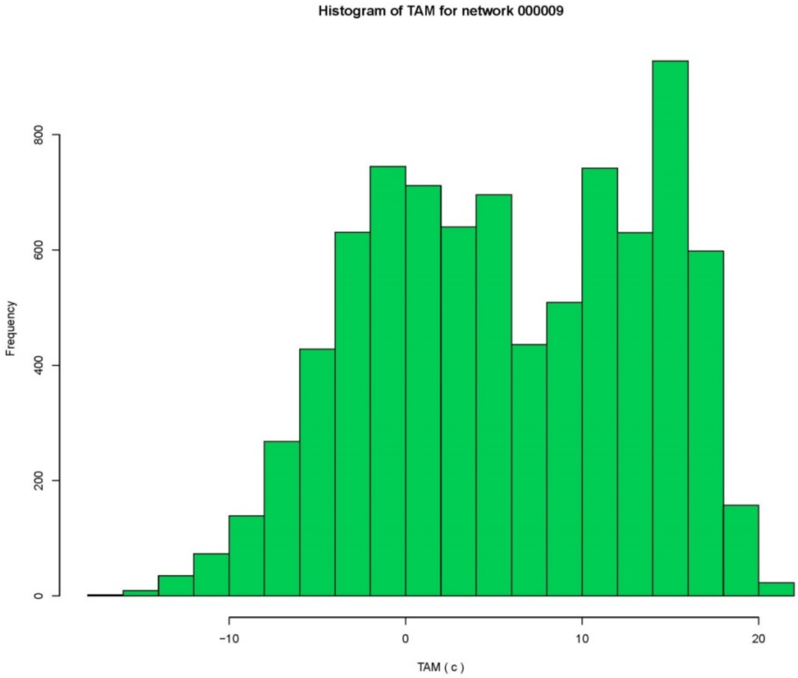

Figure 3: Histogram of all data.

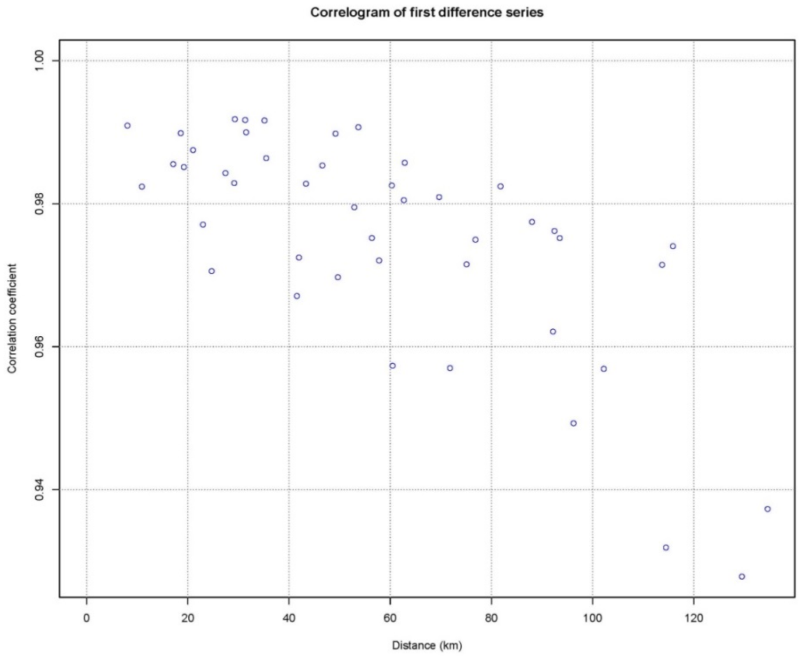

Figure 4: Correlation–distance plot.

A cluster analysis is then performed, based on the correlation matrix, which serves to produce two more figures: A dendrogram, where you can see the stations grouped by similarity of their data regimes, and a map locating the sites of the stations, identified by their ordinal numbers and in different colors according to their clusters. This is intended as a first approximation to a climatic classification of the stations, although the number of clusters, automatically chosen by the dashed red horizontal line in the middle of the dendrogram. If the clusters are very different (are connected by high dissimilarity distances in the dendrogram) and their spatial location depicts clearly delimited areas, the climate of the study area may be subject to strong discontinuities, and hence the investigator should consider doing separate homogenizations for each climatic subarea.

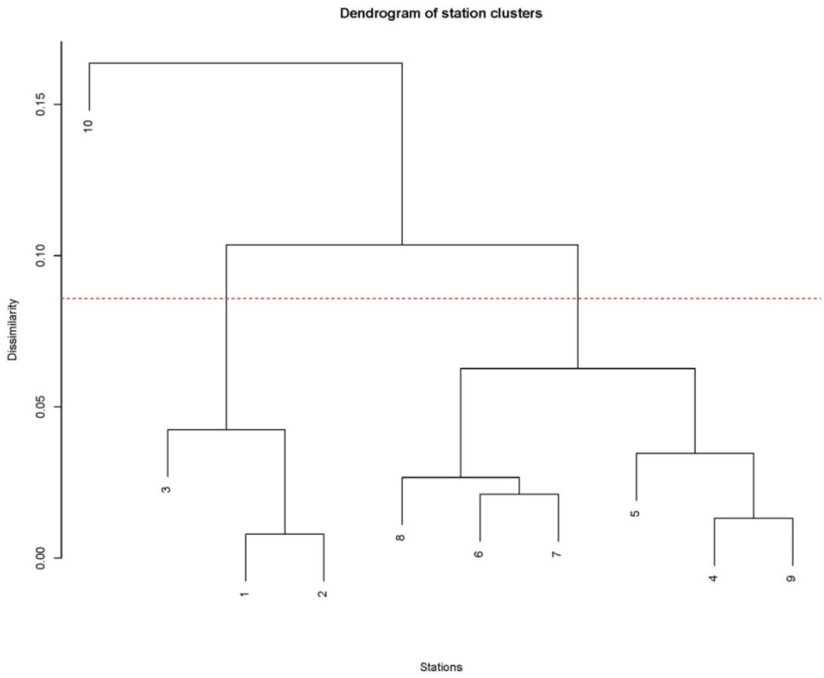

Figure 5: Dendrogram built from the correlation matrix.

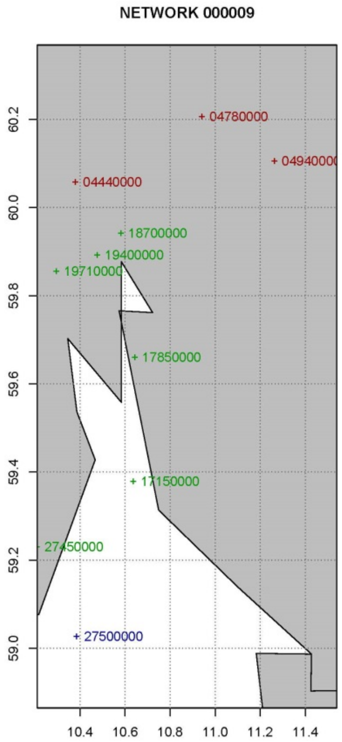

Figure 6: Map of the stations, colored according to their clusters.

2. Fast Quality Control (f)

This part of the program performs QC on input files (or on corrected files). Here is a table of the correlation of the neighborhood.

Table 1. Correlation of the neighborhood of the Oslo network (p. 15).

```
Staion ID |Correlations with neighbour stations |Station name
18700000 OSLO-BLINDERN
=====================================
CORRECTION NEIGHBORHOOD
04440000 0.995 HAKADAL_BLIKSRUDHAGAN
19400000 0.991 FORNEBU
19710000 0.991 ASKER
17850000 0.990 ÅS
04780000 0.985 GARDERMOEN
17150000 0.984 RYGGE
27450000 0.977 MELSOM
04940000 0.973 HVAM
27500000 0.969 FÆRDER_FYR
```

3. Outliers

– **Outlier file creation (o)**

After having estimated all the data, for every original series we can compute a series of anomalies (differences between the normalized original and estimated data), and apply to them tests for the detection of. Figure 7 shows how Homer finds outliers. Table 2 shows how Homer creates and how the removal of outliers takes place.

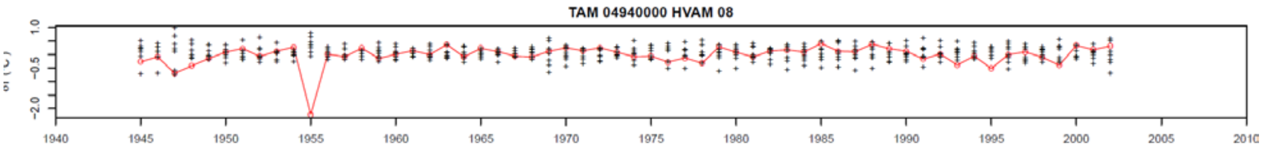

Figure 7: Time series with an outlier.

– **Removal of outliers (r)**

Here is a table of the outlier (s) in the Oslo network. The outlier will be removed in the homogenization process.

Table 2. The outlier file from the Oslo network.

```
Station ID (txt.file)|Year|Month|Station name

ra/ratmm04940000d.txt    1955 8    HVAM
```

B. Homogenization

1. Pairwise detection (d)

The third stage in this homogenization program-process is the detection which is the action or process of identifying the presence of something concealed in the data files. First is the detection of changes in pairwise series. The statistical tools for the pairwise detection are 1) the model, which is based on this formula:

$$\overline{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$$

2) Dynamic programming; when detection is performed for change-points in a normal sample, a DP algorithm can be used.

Pairwise detection uses predefined neighborhood and it looks like this (fig. 7):

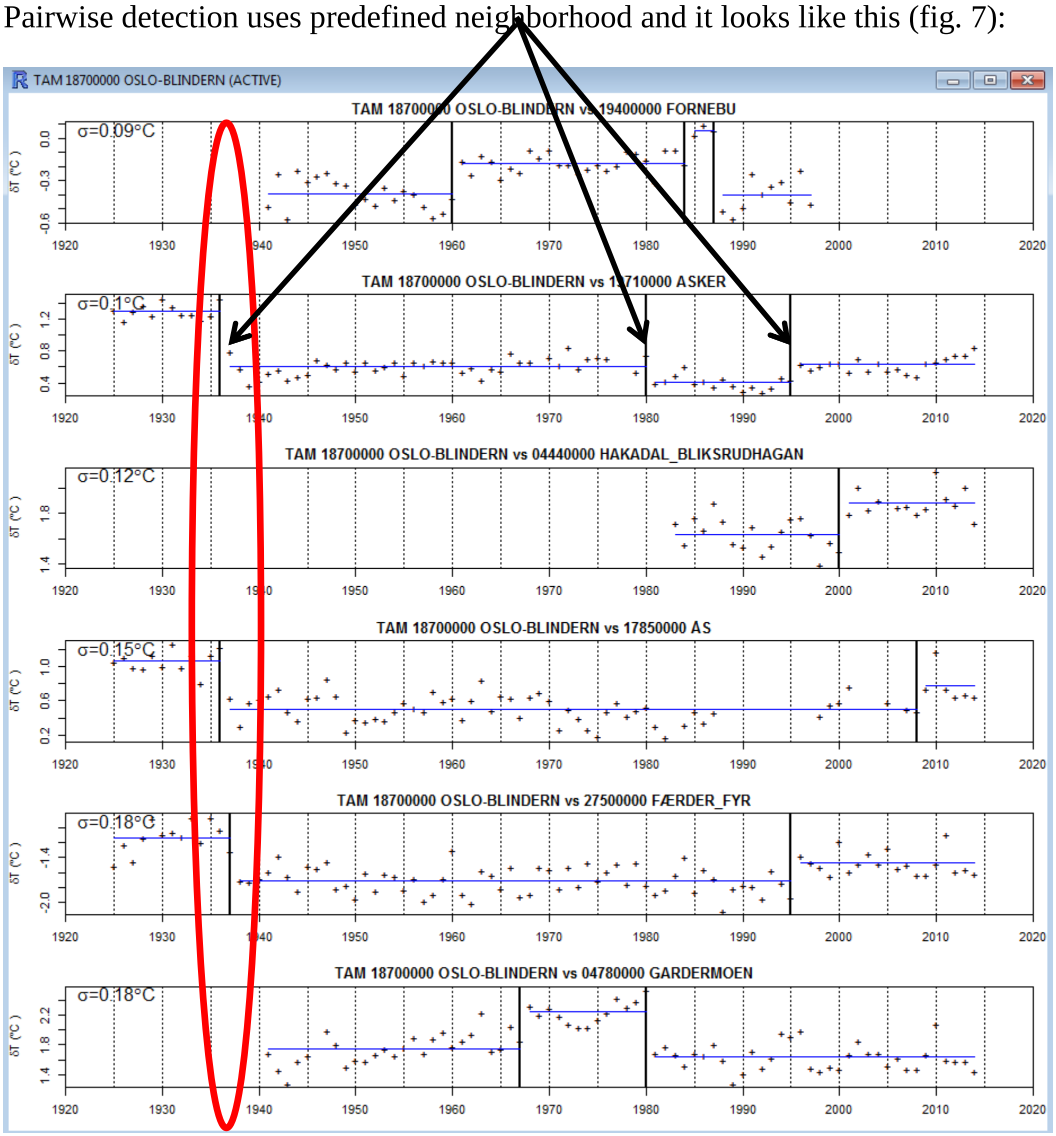

Figure 7: Pairwise detection from the Oslo network.

3) Selecting the number of changes using likelihood ratio tests and standard deviation of the residuals.

2. Joint detection (j)

The next step is joint detection. The classical DP algorithm cannot be applied here (Caussinus and Mestre, 2004). It takes place a segmentation of multiple series, which is a 2-stage DP algorithm. The first stage consists in finding all optimal solutions for each factor separately. The second stage uses outputs from the first stage to optimally allocate the number of each factor. The joint detection creates a "detected" file and it is interactive window for modifications (fig. 8 & 9)

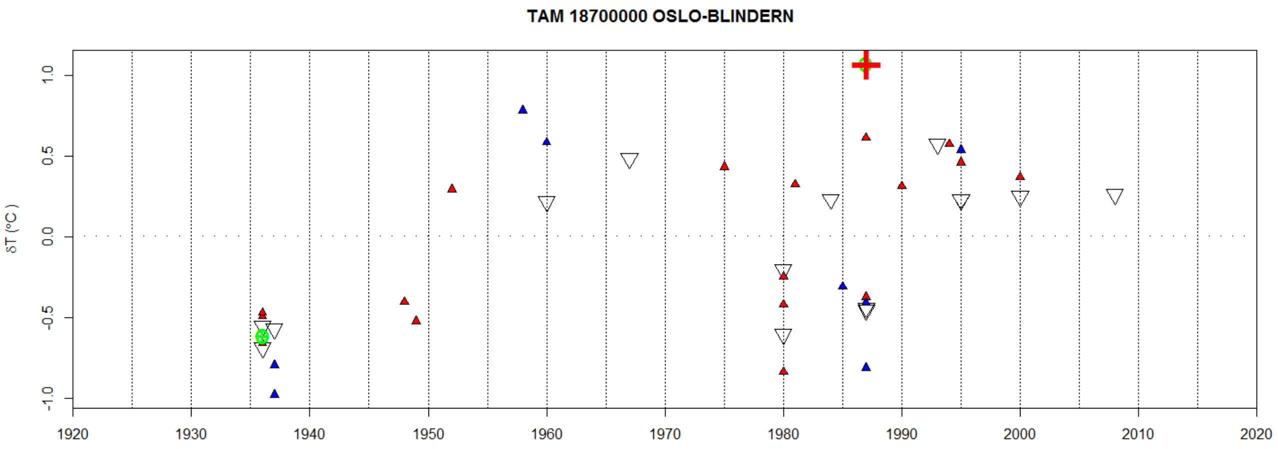

Figure 8: Joint detection from the Oslo network.

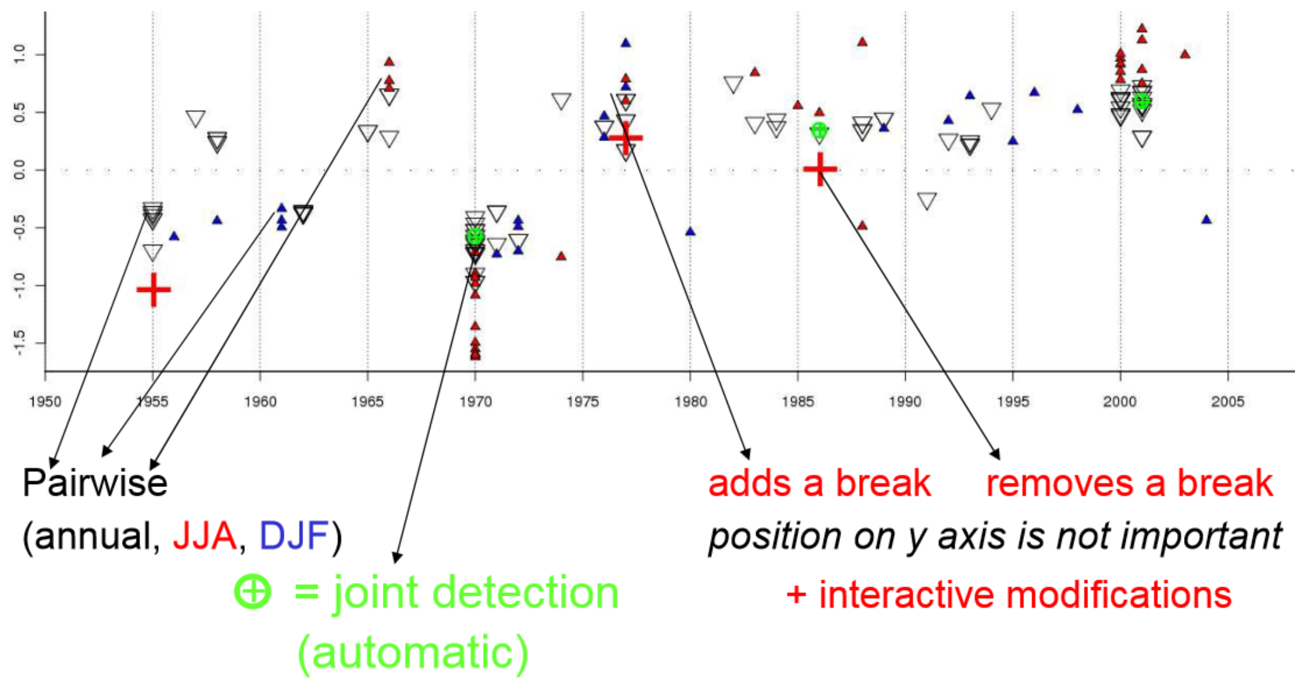

Figure 9: The interactive window in joint detection.

3. ACMANT detection (a)

ACMANT (adapted caussinus mestre algorithm for homogenizing networks of monthly temperature data, Domonkos, 2011) was developed from PRODIGE during the HOME period. ACMANT is fully automatic and it applies reference series built from composites for time series comparisons. The other main novelties of ACMANT are i) it applies pre-homogenization in a way that the double use of the same spatial connection is excluded, ii) it coordinates the operations on different time scales (from multiannual to monthly) in a unique way. Figure 10 and 11 shows how ACMANT look likes as a step in the HOMER program.

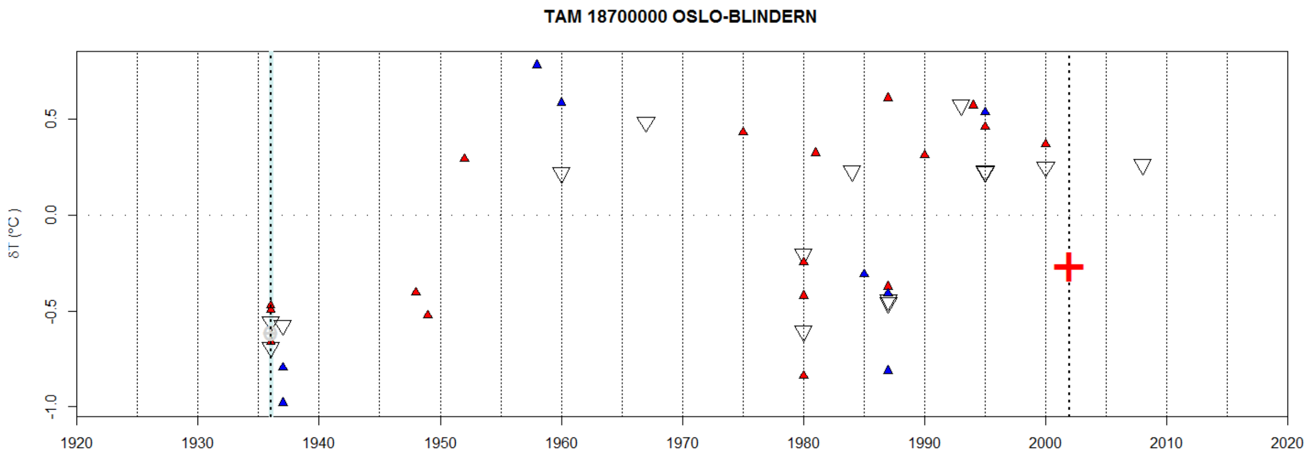

Figure 10: ACMANT from the Oslo network.

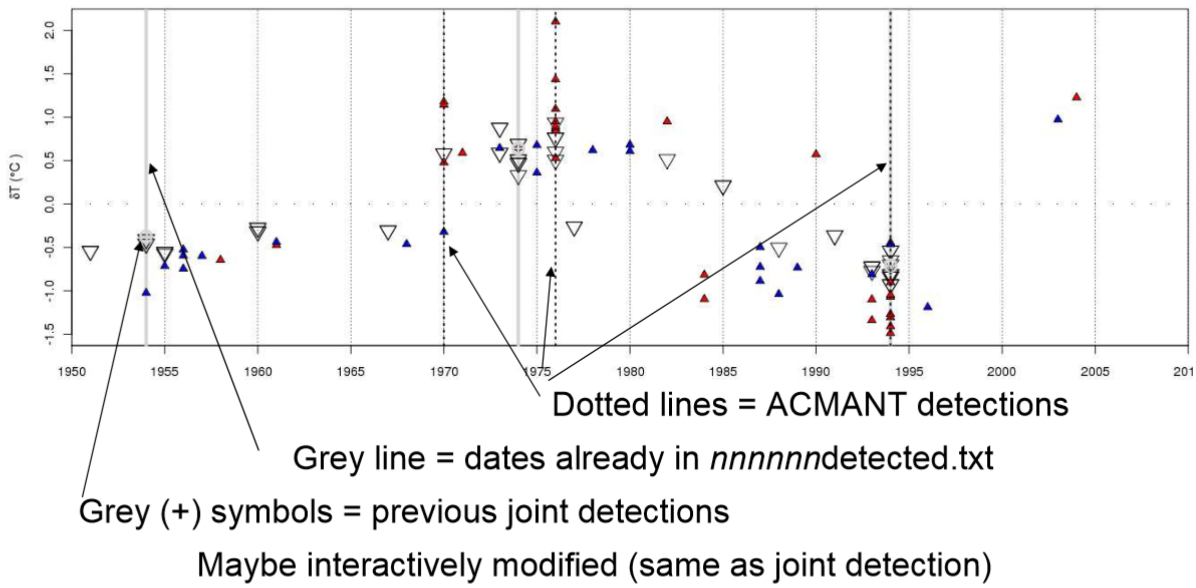

Figure 11: The interactive window in ACMANT.

4. Correction (c)

Let us consider p series belonging to the same climate area in such a way that all the series are affected by the same climatic conditions at the same time. This assumption is realistic when considering monthly or annual observations of the same geographical region. We assume that each series of observations is the sum of a climatic effect, a station effect, and random white noise. This is a simple two-factor analysis of variance model without interaction, and we will denote it by ANOVA in the following.

Table 3. Correction of the neighborhood in the Oslo network

```
Station ID |Correlations with neighbour stations |Station name

Correction of:  18700000 OSLO-BLINDERN
==============================================
04440000 0.995 HAKADAL_BLIKSRUDHAGAN
19400000 0.991 FORNEBU
19710000 0.991 ASKER
17850000 0.990 ÅS
04780000 0.985 GARDERMOEN
17150000 0.984 RYGGE
04940000 0.978 HVAM
27450000 0.977 MELSOM
27500000 0.969 FÆRDER_FYR
```

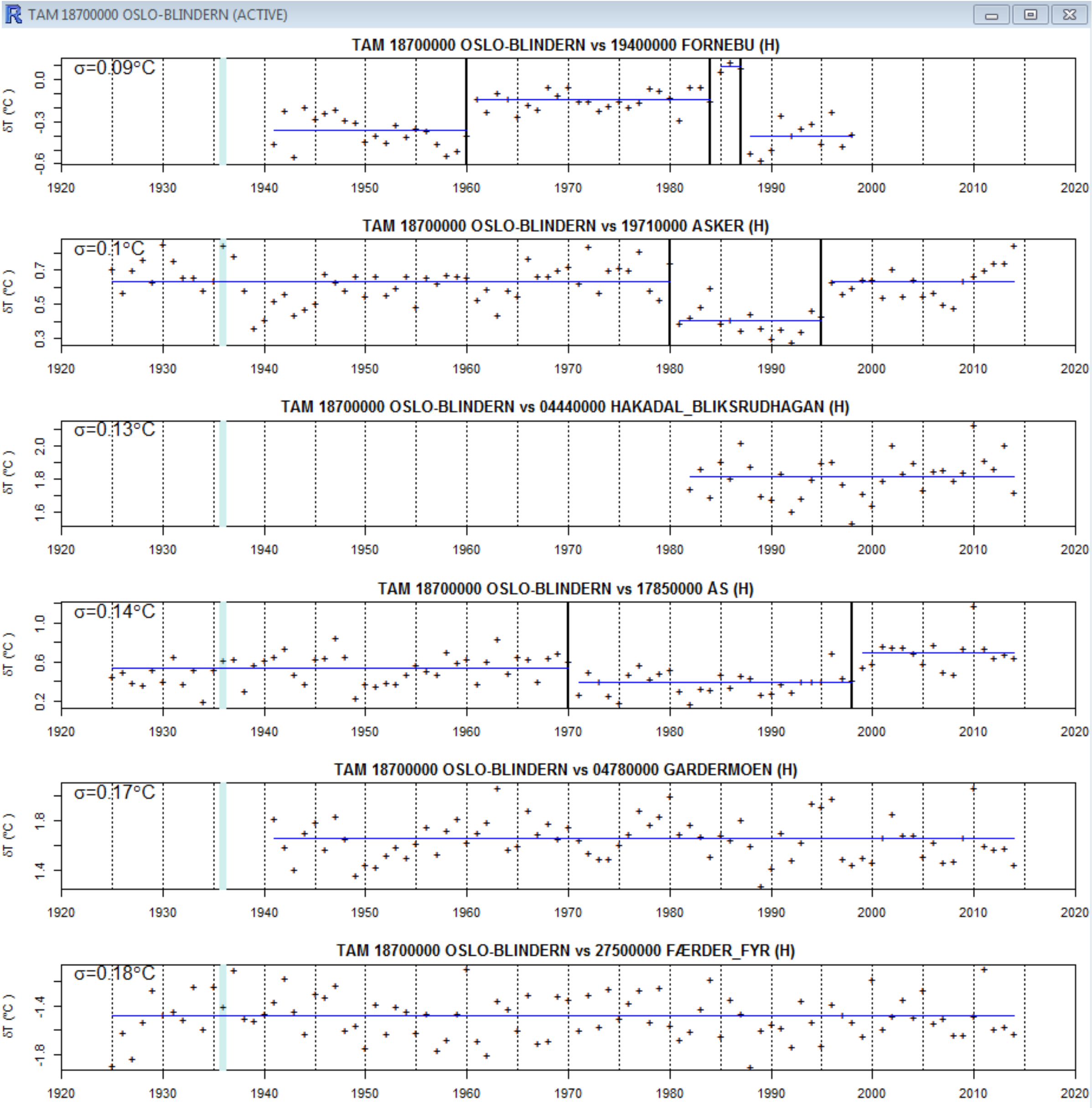

Figure 12: Correction of the Oslo network.

Some further characteristics of the model:

a) Estimation can be performed with missing data with the following conditions: there should be at least one non-missing value per year on the whole network (estimation of the μ's) and one non-missing value between two breaks for each sub period on each series.

b) Climate signal is treated as a fixed parameter so that no assumption is made about the shape of this signal.

c) Conditionally to the climate signal, the disturbances are considered independent.

d) Local variabilities are very similar, which leads to the expression of Var(X).

5. Assess month (m)

Another feature has been included in HOMER is its procedure for finding the most likely month of a change-point. If the precise month of the change is not known, since detection is mainly performed on annual indices, the default is to validate the break at the end of the year. At the end of the homogenization procedure, a more precise detection is made, using the monthly series serially (that is, the sequence of January, February, March, etc, for each year).

C. Effects of the homogenization

6. Visualization (v)

Another example of the effect of correction is shown for Oslo series (*Fig. 13* upper panel for the raw, lower panel for the corrected series).

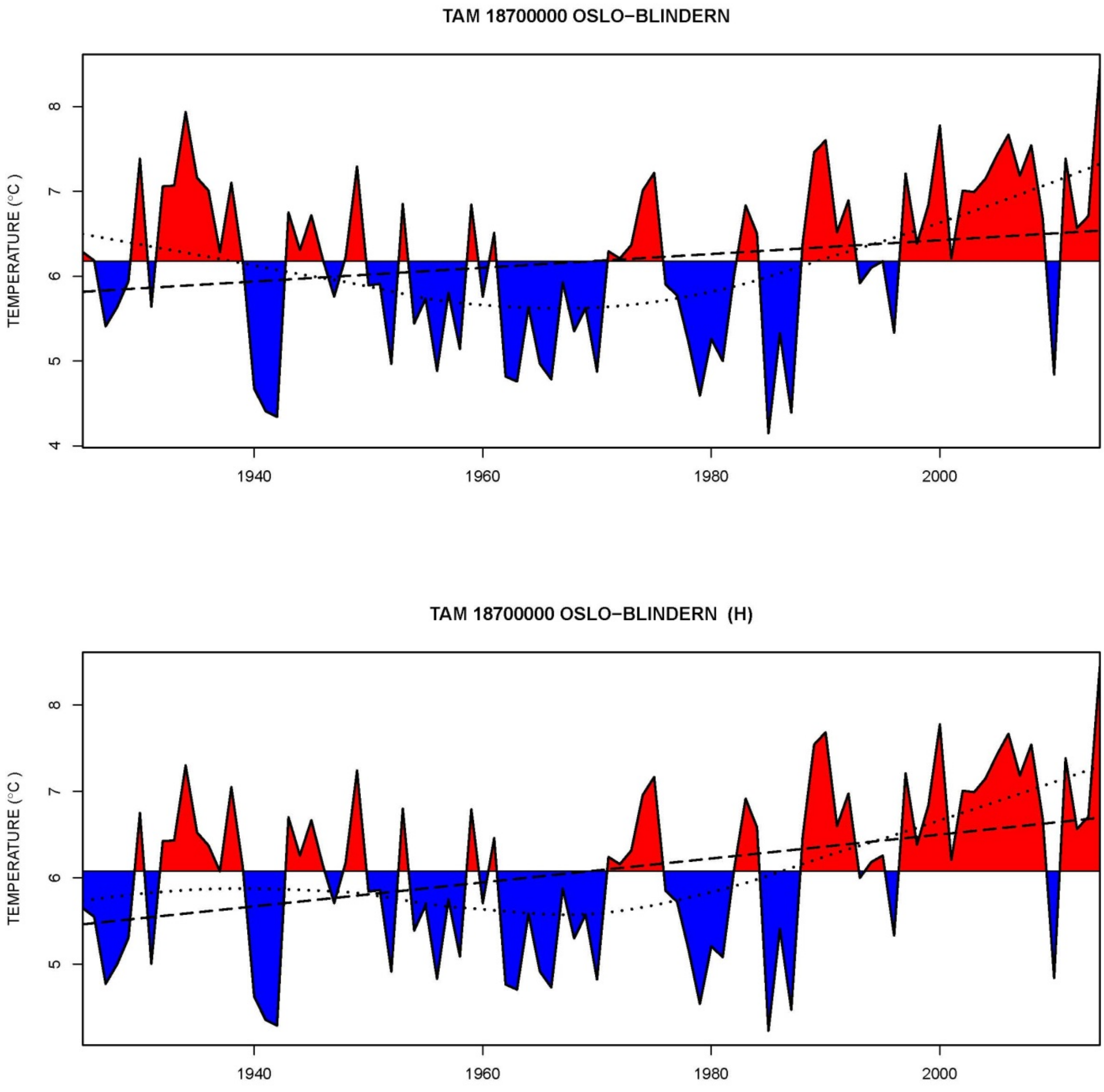

Figure 13. Raw (up) and corrected (down) series of Oslo.