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NORWEGIAN METEOROLOGICAL INSTITUTE
P. O. BOX 43 BLINDERN, N - 0313 OSLO

TELEPHONE (+47) 22 96 30 00

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TITLE

A SERIES OF SPRING AND SUMMER TEMPERATURES (1749 – 2000) OF SOUTH EASTERN NORWAY, BASED ON GRAIN HARVEST DATA AND INSTRUMENTAL OBSERVATIONS

AUTHOR

Per Øyvind Nordli

PROJECT CONTRACTOR
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ABSTRACT
A temperature series of late spring and summer temperatures (April – August) from the climate region Austlandet (South Eastern Norway) was reconstructed back to 1749 by a temperature proxy: the start of the grain harvest. The source was farmers' diaries originating from 10 farms covering the period 1749 – 1918. The period partly overlapped instrumental observations 1871 – 2000. The instrumental and proxy series were nested together to a composite series for the period 1749 – 2000.

Each series of harvest dates was checked for inhomogeneities by comparison with series from neighbouring farms, and linear regression equations were used as transfer functions from harvest dates to temperatures. The method of regression suppresses variability of the reconstructed series, and an inflation technique was used to compensate for the suppression. In the period 1837 – 1870 the reconstruction overlaps the Oslo instrumental series, and the variance of the two series were found to be in good agreement during the period.

In the composite Austlandet series (1749 – 2000) a marked trend was detected, amounting to 1.4 °C. The trend was largely concentrated within the 20th century, where it was estimated to 0.9°C, while in the 19th century the trend was only 0.5 °C. In the last half of the 18th century no significant trend was detected. The coldest decade, 9.9 °C, occurred in 1796 – 1805, while the warmest one, 11.9 °C, occurred in 1988 – 1997.

The series was found to be significantly auto-correlated for all lags tested (1 to 16). The auto-correlations, however, were caused by the long-term trend, and no cyclisity was detected in the series.

SIGNATURES

Per Øyvind Nordli
SENIOR SCIENTIST

Bjørn Aune
HEAD OF THE DIVISION

Så signa då Gud det gode så
til rugjen ein gong er mogen.

So bless God the good seed
until the rye once is ripen.

Elias Blix (1836 – 1902)

A SERIES OF SPRING AND SUMMER TEMPERATURES (1749 – 2000) OF SOUTH EASTERN NORWAY, BASED ON GRAIN HARVEST DATA AND INSTRUMENTAL OBSERVATIONS

1 Introduction

The national network of weather stations can be traced back to the 1860s with the introduction of five observation stations along the Norwegian cost. The stations were run by the telegraph authorities, and situated on telegraph stations. After the foundation of the Norwegian Meteorological institute in 1866, the network grew denser, and what we may call a national weather observation network was well established before the end of the decennium.

Long before the network was established, sporadic temperature measurements were carried out, in Trondheim for instance since 1762. These were performed by private persons and were often subject to frequent relocations (Birkeland 1949), and nesting of these series together resulted in inhomogeneities (Nordli 2001).

In order to have a supplement to the instrumental series, and to extend them further back in time, several temperature proxies have been developed for temperature reconstructions. One method, based on the first date of the grain harvest, has been used in the Møre and Trøndelag regions in Norway (Nordli 2001), and in Estonia and Finland (Tarand and Kuiv 1994; Tarand and Nordli 2001). Similar long-term temperature reconstructions have been performed on the basis of the vintage (Le Roy Ladurie and Baulant 1980).

Southeastern Norway, Austlandet, is one climatic region in which similar temporal patterns for temperature variations are present (Hanssen-Bauer and Nordli 1998). It makes sense therefore to base the reconstruction entirely on diaries within this region and the neighbouring Swedish county Värmland with similar climatic conditions. Diaries from the other side of the central south Norwegian mountain ridge are omitted, for instance those from the Trøndelag and Vestlandet regions.

2 Data

The farms used for the reconstruction are situated in South Eastern Norway and from the Swedish county Värmland. All farms are shown on the map, figure 2.1. In table 2.1 a list of the farms is presented, sorted by the starting year of the first harvest data. In figure 3.2 the data coverage is shown graphically, and in the following text further characteristics of the farms are given.

Table 2.1 Cereals and farms used for temperature reconstruction.

Farm	Municipality	Data period	No. of years	Main cereal
1) Åker	Vang	1749 - 1835	66	Rye
2) Skavhaugen	Elverum	1774 - 1787	13	Barley
3) Sørum	Stange	1780 - 1820	29	Rye
4) Rakkestad	Rakkestad	1784 - 1831	40	Rye
5) Stenhammar	Elverum	1788 - 1830	41	Barley
6) Rød	Råde	1802 - 1872	62	Oats
7) Berg	Kristinehamn	1809 - 1833	19	Rye
8) Flåvik	Säffle	1825 - 1862	38	Rye
9) Grøtvedt	Rakkestad	1845 - 1879	24	Rye
10) Hverven	Stange	1853 - 1918	59	Rye

1) Åker 1749 - 1835

The farm is situated near an inlet of lake Mjøsa called Åkersvika that is named after the farm. The site is very near the town Hamar, figure 2.1. The diaries are stored in the State Archives at Hamar. They cover the years 1749 – 1835, but are not complete. Out of the 81 harvests in the period, the exact starting date is known in 66 of them, i.e. 15 harvests are missing. These are 1764,1783, and the period 1789 – 1801 except the year 1798. The large gap is caused by a lack of diaries. It is proved that they have existed, but may now be lost. The State Archive has not so far been able to locate them, but is still searching.

The date for 1812 barley harvest turned out to be an outlier. Usually the rye was harvested before the barley, but in this occasion it was different, following the diary the barley harvest started 36 days before that of rye. Also if the harvest date is compared to that of Stenhammar (see farm No. 5), it turns out to be an outlier, and the reason may be a writing error of the month. The barley harvest date from 1812 was removed from the data.

The harvest at Åker is for most of the years specified for up to four different cereals, rye, barley, winter wheat and summer wheat. In the first part of the diary (1749 – 1788) only rye and barley are noted, and sometimes only the start of harvest is noted without any specification of cereal. In this period both rye and barley are specified only three times.

In the last part (1803 – 1835) the harvesting at Åker is given in details. For each cereal the exact dates of harvesting are specified, not only the start and end, but also if there has been any intermediate stop. It is also specified when harvesting is resumed. From these data it is clear that the start of the rye harvest may affects the start of the barley harvest and vice versa. Therefore only the first harvesting day is compiled for climate reconstruction purposes, but in most cases the starting date concerns rye.

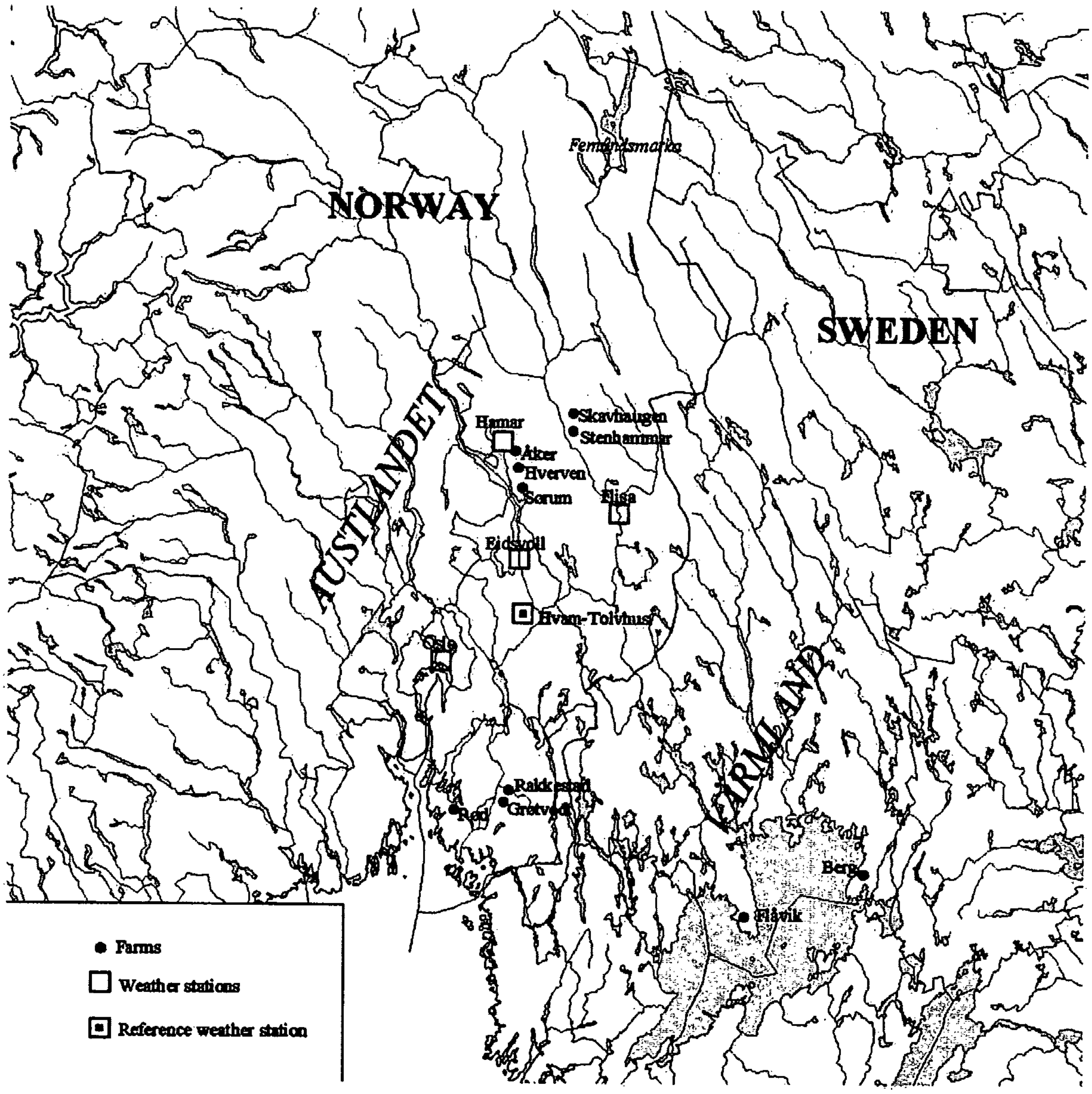


Figure 2.1 Map of Austlandet (South eastern Norway) and Värmland in Sweden with the meteorological stations for instrumental observations (squares), and farms with available diaries for reconstructions.

2) Skavhaugen, 1774 - 1787

This small farm is situated in a forest district to the north of Elverum town. Though the diary is complete, the date of harvest of 1784 is still missing because the grain was struck by heavy frost this year, and there was no harvest of ripen grain.

The farm was visited in the autumn of 1999 by the historian Kari Lintoft, see details in Ch. 3.2

3) Sørum, 1780 - 1820

The farm is of middle size situated to the south of Hamar. Without knowing the exact grain field used at the time of the diary, the farmland seemed to be fairly flat. The diary from Sørum covers the years 1780 – 1820, but from 1807 to 1820 most data are missing. Only the years 1810, 1811 and 1820 are present. Of the 41 harvests in the period, the exact starting date is known in 23 and 25 cases for rye and barley respectively. For 19 harvests the starting dates are known for both cereals. The median of the differences is 5 days that was used for interpolation purposes.

4) Rakkestad, 1784 - 1831

The farm is the old vicarage of the Rakkestad parish. The diary gives detailed information concerning the sowing, and thereby the cereals cultivated on the farm are known. On the other hand each cereal is not separated in the harvesting, and only one starting date is known each year. This was interpreted as the start of the harvest without regard to cereal. Because rye is the earliest of the cereals, it is assumed that the dates mainly concern that cereal. The details of the sowing assure that rye was cultivated on the farm every year. In the 48-year time span of the diary the harvest date is missing in 8 of them, mainly in the last years.

5) Stenhammar, 1788 - 1830

Like Skavhaugen Stenhammar is another small farm to the north of Elverum. The diary-writer at Skavhaugen settled down at Stenhammar and continued his habit of diary writing. Except from the years 1826 and 1827 the harvest data are complete. In 1999 the farm was visited by the historian Kari Lintoft, see Ch. 3.2.

6) Rød, 1802 - 1872

This is a farm of medium size near the lake Vannsjø. The farm is situated on flat terrain near the church of Råde. From the diary it is clear that oats is by far the most important cereal of the farm, but rye and barley are also cultivated through the entire period, and from 1823 also winter and summer wheat.

For most of the years the start of harvest is not specified concerning cereal. The diary-writers let us only know when the grain harvest starts. Some years, however, it is noted the start of the rye cutting and the start of the harvest. It seems like the rye harvest was not counted among the real harvests. So when the harvest is mentioned, it is anticipated that this means oats, the most important cereal on the farm.

The first part of the diary is almost complete, only 1811 is missing. In the last part the years 1863 – 1870 are missing. The diary is only available in original version on the farm Arneberg in Råde municipality.

7) Berg, 1809 - 1833

The farm is situated in Värmland in Sweden, the bordering county to middle and southern parts of Austlandet. The farm Berg lies on a headland in the eastern part of lake Vänern in the Visnums-Kil parish. The cereals on the farm were at that time rye and oats, but for climate reconstruction purposes, only rye was used. The harvest dates are missing for 6 of the 25 years. The diary is published by Lövgren (1970).

8) Flåvik, 1825 - 1862

The farm is situated on Värmlandsnes in Eskilsäter parish on the western side of lake Vänern opposite to Visnums-Kil, see No. 7. The last part of the original diary is at Värmland Museum, Karlstad, but there exists also transcripts.

In most cases only the finish of the rye harvest is known, not the start. However, in twelve years both the start and the finish are known. The length of the harvest in these years varies between 1 and 21 days, but the median value is rather small, between 3 and 4, and the second longest harvest lasts for 7 days. Johansson (2000) has interviewed old people about old working methods and tried to reconstruct the starting day taking into account the manpower available on the farm. He has also been aware of the calendar and adjusted for Sundays. His results are adopted in the reconstruction.

The diary is almost complete in the period; only the harvest of 1827 is missing.

9) Grøtvedt, 1845 - 1879

A second diary exists from Rakkestad municipality, cf. diary No. 4. This one is from the farm Grøtvedt. The diary-writing starts in 1830 with information about the starting date of the spring work, but we have to wait until 1845 before the first harvest date is seen. And that means the start of the rye harvest. The diary is stored at the Rakkestad municipality archive, and is easily available by a transcript. There is a few missing data, 11 out of 35 potential years.

10) Hverven, 1853 - 1918

The farm Hverven is of considerable size and is situated in between the farms Sørum (No. 3) and Åker (No. 1). In the period for the diary both rye and barley was cultivated on the farm, and for 20 harvests the starting dates are known for both cereals. A scatter plot of these 20 cases is shown in figure 2.2. The correlation between the harvests is 0.91.

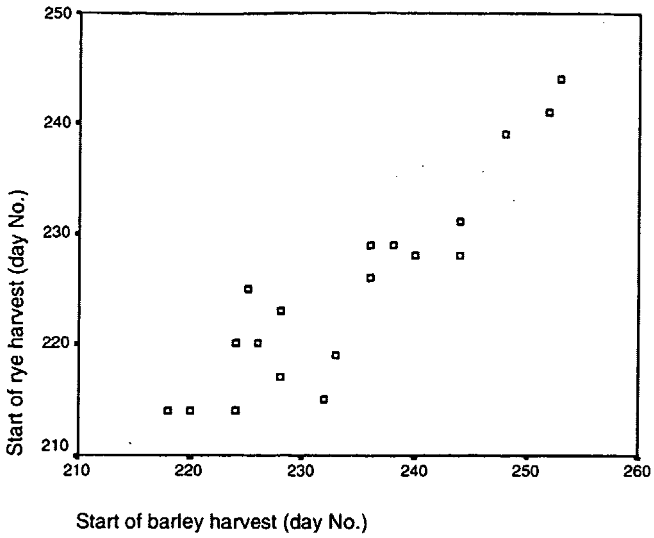


Figure 2.2 Scatter plot of the starting dates of barley and rye harvests on the farm Hverven in Stange.

The Hverven diary is far from complete. Out of its potential of 66 harvests exact starting dates are known in 25 and 50 cases for rye and barley respectively.

3 Instrumental and proxy series, testing of homogeneity

Unfortunately a homogenous, long-term instrumental series from rural South Eastern Norway does not exist. The Norwegian capital Oslo is situated in the region, but the old Oslo series is not thoroughly tested, neither for inhomogeneities nor for urban heat island effects. However, the series is not thought to contain major inhomogeneities and will be used as a control for the temperature reconstruction.

3.1 Instrumental series

The instrumental series used as control for the proxy data contain series nested together mostly from rural stations, all situated in between Oslo and Hamar. The resulting long-term series may be called the Austlandet instrumental series (Austlandet = south eastern Norway) and the shorter series incorporated are mentioned in the following text by their station numbers, names and the period adopted in the long-term series. For testing of homogeneity the SNHT was used, i.e. the standard normal homogeneity test (Alexandersson 1997).

04940 Hvam – Tolvhus, 1983.08 – present. For the most recent data in the Austlandet series, the currently run station Hvam – Tolvhus was chosen. Its temperature series was tested against reference stations and found to be homogenous. Also the other shorter series incorporated in the long-term series was tested by the same method.

04930 Hvam, 1944.11 – 1983. 07. Previous to Hvam – Tolvhus the station 04930 Hvam was operated in the district, and testing showed that 04930 Hvam could be added to the long-term series without adjustments. The most important reference series in this test and also in some of the other homogeneity tests was 06040 Flisa that was run in the period (1919 – 1999).

0604 Flisa, 1934.05 – 1944.10. This long, homogenous series was not brought into the Austlandet series by its whole length because of its easterly position, somewhat off the central area for the long-term series. It was adjusted to be valid for Hvam by the 56 overlapping years with the Hvam stations; the adjustment terms are shown in table 3.1.

Table 3.1 Adjustment terms to be added to the original series to make them valid for the long-term Austlandet series

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11090 Eidsvoll, 1870.08 – 1882.12											
-1,3	-1,2	-0,5	0,1	0,0	0,4	0,6	0,4	-0,1	-0,2	-0,7	-1,5
12300 Hamar, 1883.01 – 1934.04											
1,3	1,0	0,8	0,1	0,3	-0,2	-0,3	-0,2	0,2	0,4	0,4	0,8
0604 Flisa, 1934.05 – 1944.10											
1,8	1,2	0,7	0,4	0,4	0,2	0,1	0,4	0,7	0,9	1,1	1,8
04930 Hvam, 1944.11 – 1983.07											
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
04940 Hvam – Tolvhus, 1983.08 - present											
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

12300 Hamar, 1883.01 – 1934.04. This is the only urban series used in the Austlandet series. Hamar is a small town at the eastern shore of lake Mjøsa. The series overlaps the Flisa series by about 15 years, and the adjustment terms are mainly based on this period, see table 3.1.

Some data are missing in the 1880s and around 1920, and these were interpolated by the stations Eidsvoll, Lillehammer and Flisa.

11090 Eidsvoll, 1870.08 – 1915.12. The Eidsvoll station was the first station in the district. The series overlaps the Hamar series with 43 years. It had to be adjusted to be valid for Hvam, see table 3.1.

3.2 Testing the homogeneity of the grain harvest data

The grain harvest data were tested for inhomogeneity by the following procedure: For series having at least 10 years overlapping, the differences of the starting dates between two and two series were calculated, and a series of differences was established. If we assume that the series of differences is not auto correlated, the significance of possible trends can be tested by the non-parametric Mann-Kendall's trend test, see for example Sneyers (1990). It is a rank test, and as such robust for outliers in the series. The overlapping of the series is shown in Fig. 3.2.

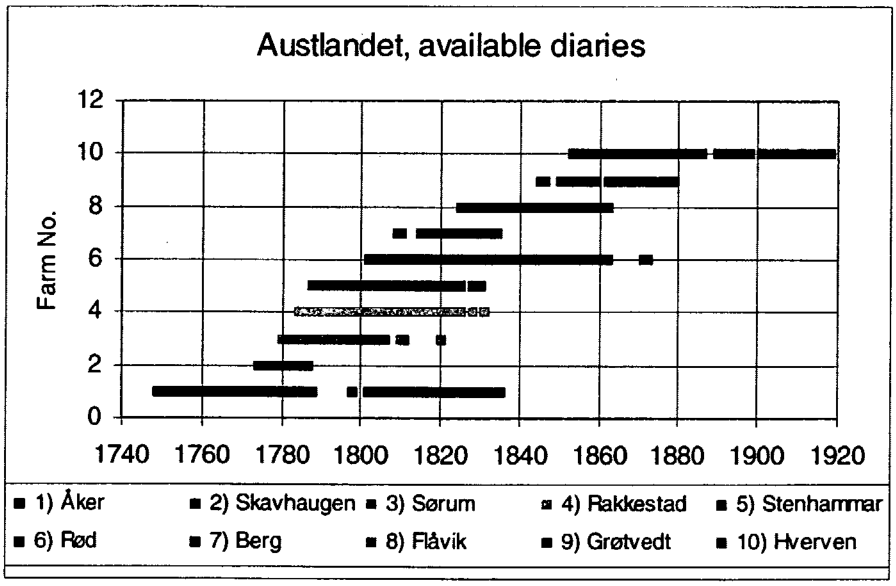


Figure 3.2 Available diaries in Austlandet (South-eastern Norway) where the start of the grain harvest is noted down.

The differences were tested systematically starting with the most recent series, Hverven and Grøtvedt, and proceeding stepwise to the oldest ones. The results are shown in figure 3.3

As all of the farms are situated in the same climate region, possible trends in the differences are not likely to be caused by spatial variations. Detected trends are therefore thought to be caused by inhomogeneities in the series of differences. The level of significance used in the tests was 0.05.

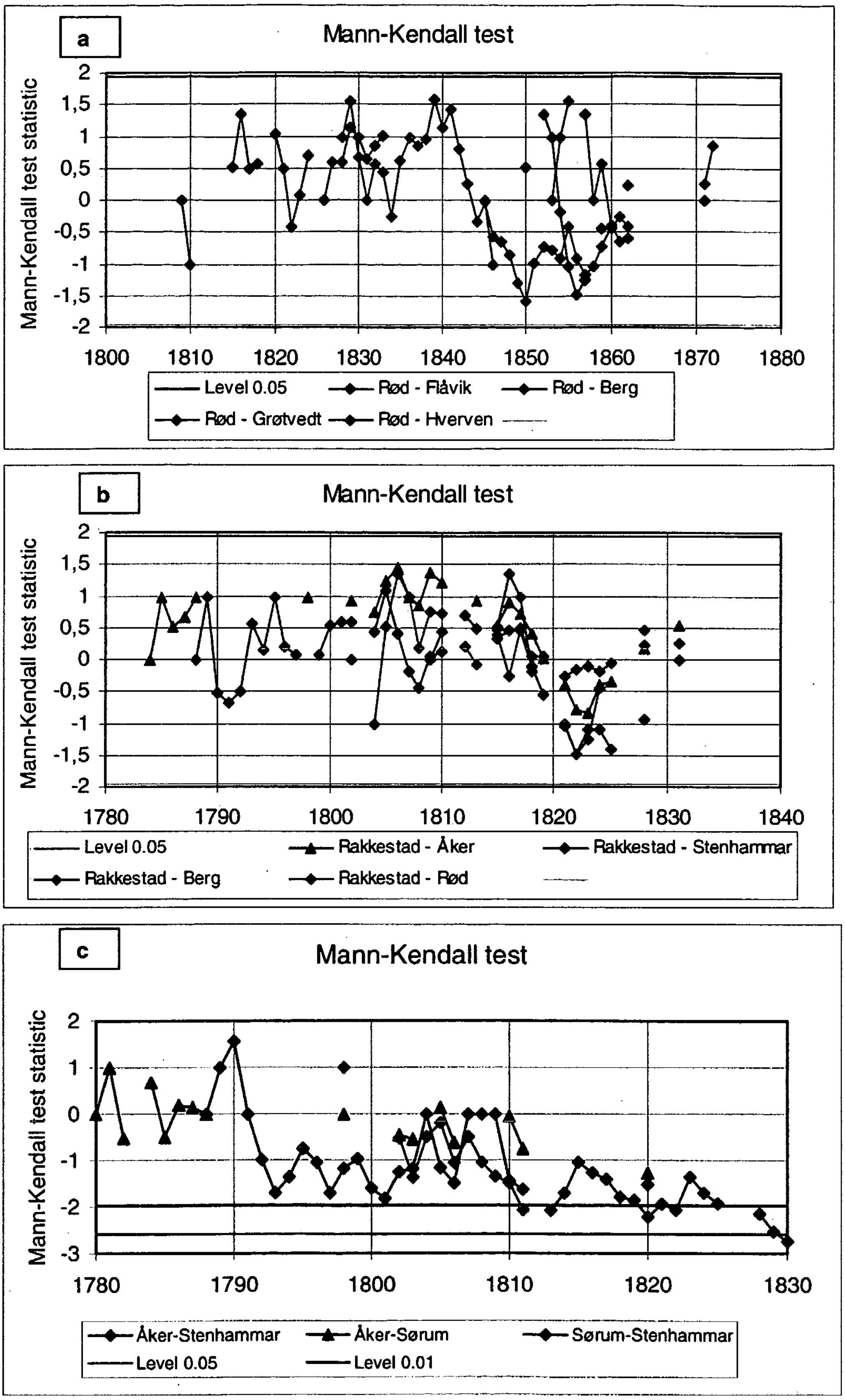


Figure 3.3. The time evolution of the Mann-Kendall test statistics for the series of differences. The testing is performed by adding one by one year of data to the series and applying the test for each year added.

In figure 3.3a tests are shown where the Rød series of harvest dates is tested successively against the farms Flåvik, Berg, Grøtvedt, and Hverven. No inhomogeneity was detected in those tests. Tests where Rakkestad is included are shown in figure 3.3b, where the farms Åker, Stenhammar, Berg, and Rød act successively as references. The ensemble of lines is sloping downwards from 1915 to 1925, thus indicating that the Rakkestad series has a somewhat different trend than the reference series. However, the trend in the differences is not significant even at the 0.05 level.

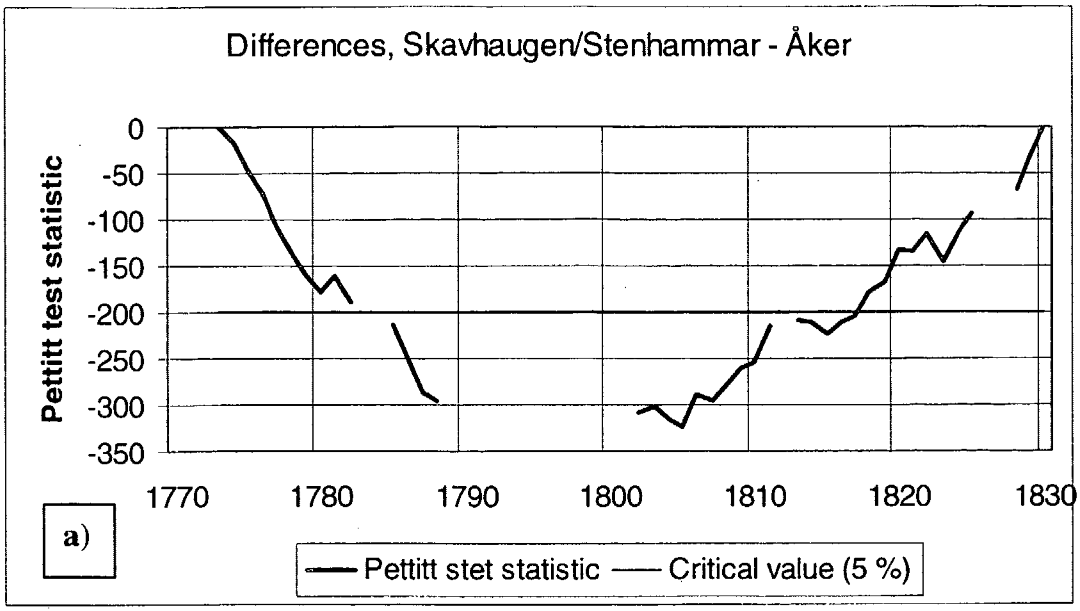
In Fig. 3.3c the series from Åker and Stenhammar are further tested against each other and also against Sørum. An inhomogeneity occurs in the differences between Åker and Stenhammar. Tested against other farms both Stenhammar and Åker seem to be homogenous. Thus, no clear conclusion can be drawn concerning the homogeneity of Åker and Stenhammar, but for the rest of the farms no inhomogeneities of the grain harvest series were detected.

After having furnished us with a complete register of harvest dates of Skavhaugen, 1774 – 1787, the diary-writing farmer moved to the near by farm Stenhammar and continued his habit, which lasted for the period 1788 – 1830. The question is whether the whole series 1774 – 1830 is homogenous or not. To come closer to this question a competent farmer in the 1960s looked at the grain ripening conditions on the two farms and judged them to be equally favourable, (Høgåsen 1999).

In 1999 the farms Skavhaugen and Stenhammar were visited by the historian K. Lintoft and climatologist P.Ø. Nordli. At Skavhaugen they found a field sloping about 20 % to the south, which Lintoft thought could be the oldest field for grain production. The field was now used as pasture land, and most probably, this was also the case in the 1960s. At Stenhammar there was also a south-facing field, but less steep, 12 %. If the hills were used for grain production in the 18th century, the grain could be expected to gain a larger amount of solar radiation at Skavhaugen than at Stenhammar and therefore ripen earlier.

The series of Skavhaugen and Stenhammar were combined and tested for abrupt changes by the non-parametric Pettitt test (Sneyers 1990). Also this test is a rank test, and thus robust for outliers. The reference stations were Åker and Sørum, see figure 3.4.

Both tests show that the series of differences are inhomogenous, but the most likely year for the break differs somewhat from the year 1787 when the farmer moved. Using Åker and Sørum as references, the predicted year of break occurs 6 and 3 years too late respectively, corrected for missing data at Åker. An inhomogeneity in the Skavhaugen/Stenhammar series can explain the inhomogeneity detected in both series of differences. But given that the Skavhaugen/Stenhammar series is homogenous, means that both Åker and Sørum are inhomogenous. Though some discrepancies in the predicted year for the break, it seems reasonable that the inhomogeneity is in the Skavhaugen/Stenhammar series and is caused by the relocation of the grain field.



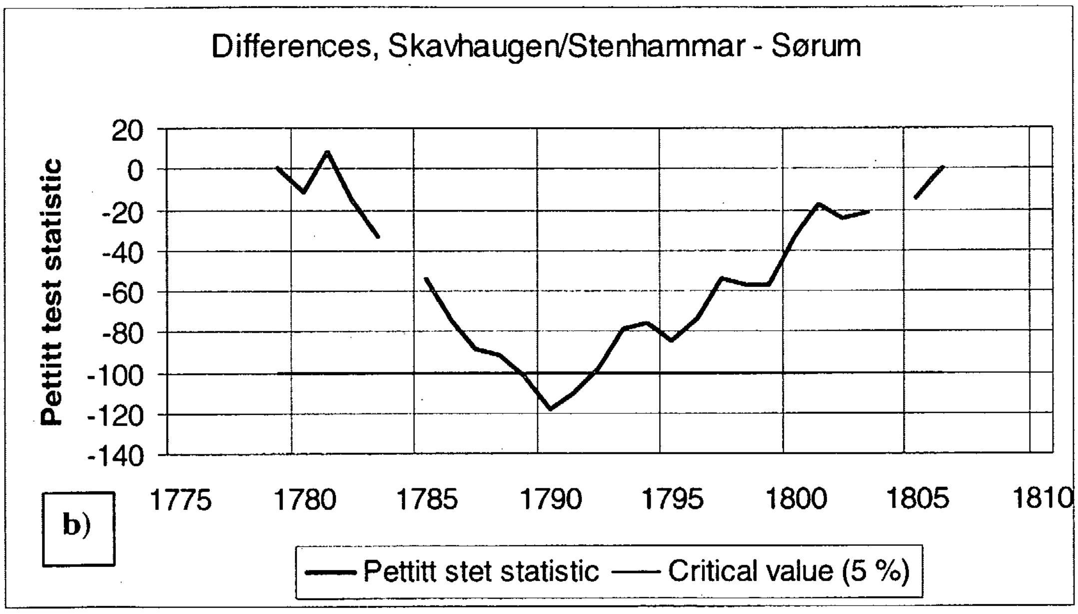


Fig. 3.4. Pettitt test statistic used on the series of differences:
a) Skavhaugen/Stenhammar minus Åker and **b)** Skavhaugen/Stenhammar minus Sørum.

4 Method for climate reconstructions

Summer temperature has been reconstructed back to the early 19th century in the districts of Møre and Trøndelag and in the central south-Norwegian mountain district (Nordli 2001) by the use of linear regression analysis. As dependant variable in the regressions was used mean summer temperature (May – August) taken from modern instrumental series, and as free variable was used the start of the grain harvest taken from farmers' diaries. A common cereal in those districts was barley, but also oats were cultivated to a certain extend, especially in the Møre district.

Moving to southeastern Norway (Austlandet) rye was widely grown in addition to barley and oats. In cases when the first harvesting date was given without further specification, the grain type in question was often winter rye, as this cereal was first to become ripen.

The only proxy series that overlaps the instrumental series over an appreciable long period is the Hverven series. The overlapping period is 1871 – 1918, although not quite complete, see Ch. 2. Regression analysis was performed as already outlined with instrumental data from Austlandet as dependant variable and the start of the grain harvest as independent variable. At Hverven starting dates for both rye and barley are available. Both summer mean temperature April – August and May – August was used in the regression in order to test which parameter was most predictable from the harvest data. For rye the correlation coefficient was 0.82 for April – August and 0.79 for May – August temperature. For barley the figures were 0.71 and 0.68. The period April – August was adopted because it was the one that obtained the highest score.

The mean difference of the starting dates of rye and barley was 9.1 ± 4.2 days, while the median value was 9 days (start of barley harvest minus that of rye). This difference was used to interpolate missing data, either rye or barley. The missing barley harvests for the five years in question were thus interpolated from the rye harvest data by adding 9 days, and the missing rye harvest was interpolated by subtracting 9 days. With mean temperature April – August as dependent variable, regression analysis were performed also with the interpolated values in the rye and barley series as independent variables. The results of the regressions are listed in table 4.1. It is shown, however, that the interpolated series correlate poorer with temperature than the series without interpolations. The interpolations are therefore not adapted for further work. The regressions without the interpolations are plotted in figure 4.1.

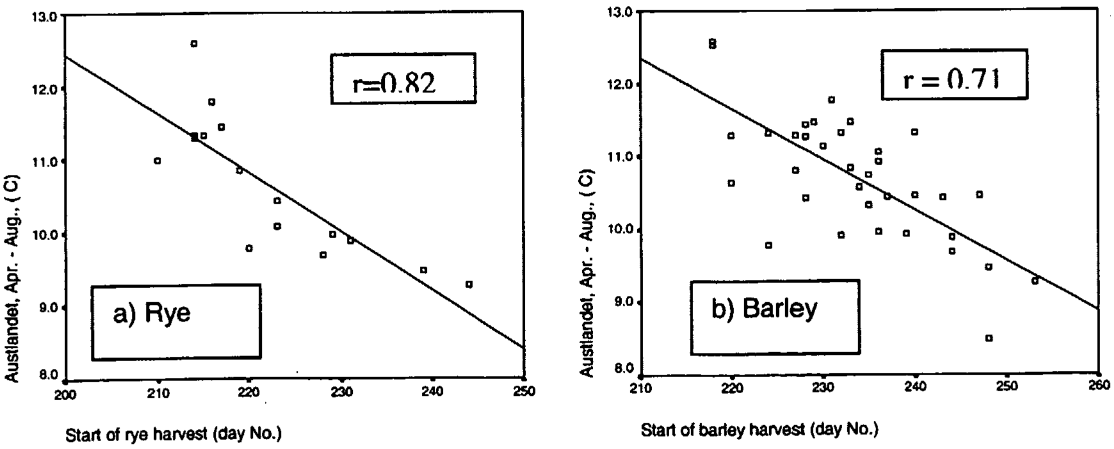


Figure 4.1 Spread diagrams for spring/summer temperature (April – August) for the Austlandet long-term series and the first harvest day at the farm Hverven for a) rye and b) barley.

Table 4.1 Regression analysis with mean spring/summer temperature (April – August) for the Austlandet series as dependant variable and the starting date of the grain harvest at the farm Hverven. Also series that contain interpolated (int.) values were tested

Cereal and season A – A: April – Aug., M – A: May – Aug.	Rye A - A	Rye int. A - A	Barley A - A	Barley int. A - A	Rye M – A
Regression coefficient	0.82	0.71	0.71	0.70	0.79
Slope coefficient, a	-0.0808	-0.0693	-0.0718	-0.0669	-0.0883
Std. error for a	0.015	0.012	0.012	0.011	0.019
Constant term, b	28.6	26.9	26.8	26.3	32.2
Std. error for b	3.3	2.8	2.7	2.7	4.1
Cross-validated std. of the residuals	0.62 °C		0.65°C		0.77 °C

The cross-validated standard deviation of the residuals for rye and barley were 0.62 °C and 0.65 °C respectively. This means that for individual years the proxy method is less accurate than the 19th century thermometers. However, under the assumption of randomness, the standard error of the mean value of a decade reduces by a factor $1/10^{1/2}$, i.e. about 0.2 °C, which might easily occur also in instrumental observations if they are not well calibrated for zero point displacement (Middleton 1966).

The Hverven series starts in 1853, and going further back in time it is necessary to use data from other farms. At most farms the harvest starts with the winter rye, but on some farms the first harvest noted concerns barley or oats. From table 4.1 is seen that the slope coefficient (response function) for rye and barley differ by only 0.0090 deg/day. Even for extreme late or early harvests the difference of the response functions only leads to moderate differences in the reconstructed temperatures. For example if the harvest starts 33 days later than the mean value, the difference in the reconstructed temperature amounts to only 0.3 °C. Experiences by use of data from the farm Frøystad at the Møre district support this finding (Nordli 1997). The difference of the response functions for barley and oats was at Frøystad only 0.0056 deg/day.

This indicates that the response function established for one cereal might be used for another one without risking unreliable reconstructions. It is however necessary to adjust for different ripening times for the cereals. This can be done by adjusting the constant term in the equation. In the case of Hverven, the mean difference between barley and rye is 9 days:

$$(3.1)\quad \check{T} = -0.0808x_{rye} + 28.6 \approx -0.0808(x_{barley} - 9) + 28.6 = -0.0808x_{barley} + 19.6$$

where $\check{T}$ is the reconstructed temperature and x_{rye} and x_{barley} is the first harvest day for rye and barley respectively.

In order to establish long-term series of spring/summer temperature, it is necessary to combine some of the shorter series. To avoid major inhomogeneities in the long-term series, the shorter series usually have to be adjusted. Applying the method used for the instrumental data, the adjustment terms were derived from overlapping years of the shorter series. However, rather than applying the mean differences of the overlapping periods as adjustment terms, the median values were applied. This was done to reduce or eliminate the influence of possible outliers. The series used in the reconstruction were all adjusted to be valid for the farm Hverven. That means that the whole series was reconstructed by the use of the regression equation for rye developed on the basis of the Hverven data.

5 Reconstruction of temperature series (1749 – 2000)

For all reconstructions, regression analysis is used with the start of rye harvest as predictor and mean spring/summer temperature as predictand, see Ch. 4. At Austlandet mean temperature in the season April – August correlates slightly better with the harvest data than the season May – August. In the Møre, Trøndelag and Dovre districts, the best correlations were obtained with the May – August season (Nordli 2001).

For most of the period of reconstruction data from more than one farm are available. This means that it is possible to make slightly different reconstructions by applying different combinations of farms. This will also give some ideas of how accurate the reconstructions are. In the following various reconstructions will be shown, and for each reconstruction the data used are denoted by the names of the farms, e.g. Rød. If a farm is used only for interpolation purposes, the name of the farm is set in parentheses, e.g. (Grøtvedt). Some characteristic parameters for the overlapping time interval are given in table 5.1.

Table 5.1 Characteristics for the overlapping time interval for various combinations of grain harvest data. The columns in the table are: Farm 1; Name of the series that is subject for interpolations. Farm 2; name of the series used for the interpolation. After the name of the farm the cereal is denoted by capital letters, R = rye, B = barley, O = oats. To describe the difference between the dates of harvest the median, mean, standard deviation (Std.), maximum (Max) and minimum (Min) are used. In the last column is given the number of years of the overlapping period.

No.	Farm 1	Farm 2	Dates of harvest, difference farm I – farm II					Years of
			Median	Mean	Std.	Max	Min	overlap
1	Hverven R	Hverven B	-9	-9.1	4.2	0	-17	20
2	Rød O	Grøtvedt R	2	3.3	5.5	-3	14	12
3	Rød O	Rakkestad R	-3	-3.0	5.0	7	-12	22
4	Åker R	Sørum R	-2	-2.1	4.2	5	-10	16
5	Hverven[1] R	Rød[1] O	-9	8.3	6.8	2	-23	21
6	Rød[1] O	Åker[1] R	2	2.0	8.0	17	-13	49
7	Hverven R	Grøtvedt R	-7	-5.9	6.0	4	-18	17
8	Stenhammar[2]	Åker[3] R	5	4.9	4.5	14	-3	19
9	Composite 1	Rød O	-8	-8,3	6,3	0	-22	16
10	Composite 2	Flåvik R	2	2.2	6.5	16	-9	36
11	Composite 3	Åker R	-5	-5.5	6.7	9	-19	32
12	Composite 4	Rakkestad R	-8	-9.1	6.3	5	-22	22
13	Composite 5	Stenhammar B	-17	-16.3	5.7	-4	-29	41
14	Composite 6	Sørum R	-8	-7.3	4.8	2	15	28
15	Composite 7	Skavhaugen B	-6	-7.6	4.3	-1	-20	13
16	Composite 7	Berg R	3	3.8	4.5	11	-3	19

[1] With interpolated values, [2] Skavhaugen/Stenhammar without adjustment for inhomogeneity, [3)] Åker 1749 – 1805.

5.1 Reconstruction of April – August temperatures by Åker, (Sørum), (Rakkestad), Rød, (Grøtvedt), and Hverven.

The Hverven series of rye harvest is far from complete, and missing data might be interpolated. However, since 1871 instrumental data are available in the Austlandet series and there are no need for interpolations. Before 1871 nine years are missing: 1853 – 1856, 1858, 1859, 1865 – 1867. These were interpolated by adding an adjustment term of –9 days to the starting date of the barley harvest, see table 5.1 line 1.

Missing values in the late part of the Rød series were interpolated by the near by farm Grøtvedt. These are: 1863, 1865 – 1868, 1870. In order to obtain a longer overlapping period with the Hverven series also some years after the stop of the Rød series in 1872 were interpolated by use of Grøtvedt data. These are: 1873 – 1877 and 1879. Altogether 12 years in the Rød series were interpolated by adding an adjustment term of 2 days to the Grøtvedt series, see table 5.1 line 2.

The Rød series were extrapolated further back in time by using the overlapping with the farm Rakkestad in the period 1784 – 1797 and 1799 – 1801. The adjustment term was –3 days, see table 5.1 line 3.

The missing values of the Åker series were interpolated by the farm Sørum by adding an adjustment term of –2 to the Sørum data. The interpolated years were: 1783, 1789 – 1797, 1799 – 1801, altogether 13 years.

With these interpolations and extrapolations included, three long series of harvest data are established with considerable long overlapping periods: The Åker series 1749 – 1835, the Rød series 1784 – 1889 and the Hverven series 1853 – 1918. The Hverven series 1853 – 1918 and the instrumental observations 1871 – 2000 are connected through the regression equation. In the final reconstruction of a composite series the first priority is given to the instrumental observations, and the second priority is given to the proxy data from the district around Hamar. The farm Rød does not belong to the district and the farm's contribution to the series is reduced as much as possible. The data from Rød, however, are important in the sense that they combine the early data represented by Åker with the later data represented by Hverven. For trend studies this is essential.

In nesting the shorter series together in order to established one long-term series, it is of crucial importance to adjust the shorter series in order to make the final the long-term series homogenous. Again constant adjustment terms based on overlapping periods were used. The adjustment terms for Rød to be valid for Hverven, $\Delta D_{HvRø}$, and for Åker to be valid for Rød, $\Delta D_{RøÅk}$, are:

$$(5.1) \quad \Delta D_{HvRø} = D_{Hverven} - D_{Rød} \quad \text{and} \quad \Delta D_{RøÅk} = D_{Rød} - D_{Åker}$$

where $D_{\text{name of the farm}}$ denotes the start of grain harvest on the farm in question.

By combining the equations (5.1) the start of the grain harvests of Åker may be adjusted to be valid for Hverven.

$$(5.2) \quad D_{Hverven} = D_{Rød} + \Delta D_{HvRø} = D_{Åker} + \Delta D_{RøÅk} + \Delta D_{HvRø}$$

The adjustments terms $\Delta D_{HvRø}$ and $\Delta D_{RøÅk}$ are –9 days and 2 days respectively, see table 5.1 lines 5 and 6. Inserting these values in equation (5.2) yields an adjustment by –7 days of the Åker series to make it valid for Hverven.

Even after interpolation by Sørum, the Åker series contains two missing years, 1764 and 1812. These were interpolated by data from the farm Klyve (western Norway) and Stenhammar respectively. The resulting April – August reconstruction is shown in figure 5.1.

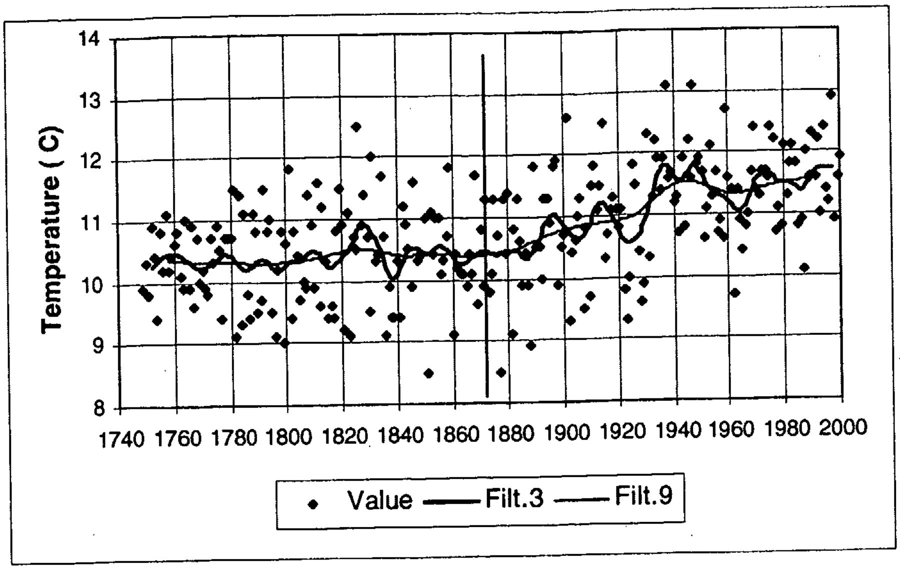


Figure 5.1 Reconstruction of mean spring/summer temperatures (April – August) 1749 – 1870 for Austlandet (South-Eastern Norway) by proxy data mainly from the farms Åker, Rød and Hverven, and since 1871 by instrumental observations. No inflation technique was used. Individual years are represented as dots (Value) in the diagram. The values are filtered by a Gaussian low pass filter with standard deviations of 3 (Filt.3) and 9 (Filt.9) years in its distribution.

The use of linear regression equations for reconstruction leads to a an underestimation of the variability of the reconstructed series. To compensate for this, the values in the series can be inflated. The procedure is started by detrending and normalising the series to zero mean. As is readily seen from figure 5.1 the increasing trend is far from linear, and instead of a linear trend line, a Gaussian low pass filter was used for detrending. The filter had a standard deviation of 30 years in its distribution, corresponding to a time scale of about one hundred years. The inflation method used is given by the equation (5.1) (von Storch 1999).

$$(5.1)\quad \tilde{y} = \beta\hat{y} = \sqrt{\frac{\mathrm{var}(y)}{\mathrm{var}(\hat{y})}}\cdot\hat{y}$$

where $\hat{y}$ is the detrended, normalised temperature, $\tilde{y}$ is the inflated, detrended, normalised temperature, while var(y) and var($\hat{y}$) are variances of temperature; of the instrumental series and the reconstructed series respectively in the overlapping interval of diaries and instrumental observations. The quantity β was calculated to 1.22, and the inflated temperature T is given by:

$$(5.2)\quad T = \beta\hat{y} + T_G$$

where T_G is the smoothed temperature by the Gaussian filter. The reconstruction is not shown.

5.2 Reconstruction of May – August temperatures by Åker, (Sørum), (Rakkestad), Rød, (Grøtvedt), and Hverven

This reconstruction is parallel to the one in Ch. 5.1. Rather than the April – August temperature the May – August temperature is used in the regression as predictor variable. The harvest data are exactly the same and the diagram, figure 5.2, reveals the same pattern as figure 5.1. The only difference being that the temperature is somewhat higher, and the vertical temperature scale is slightly amplified reflecting a higher temperature and larger variability of the May – August mean temperature compared with that of April – August. A delay of the harvest of 12.3 days represents a decrease of the April – August temperature by 1 °C, while 11.3 days represent 1 °C in the May – August temperature.

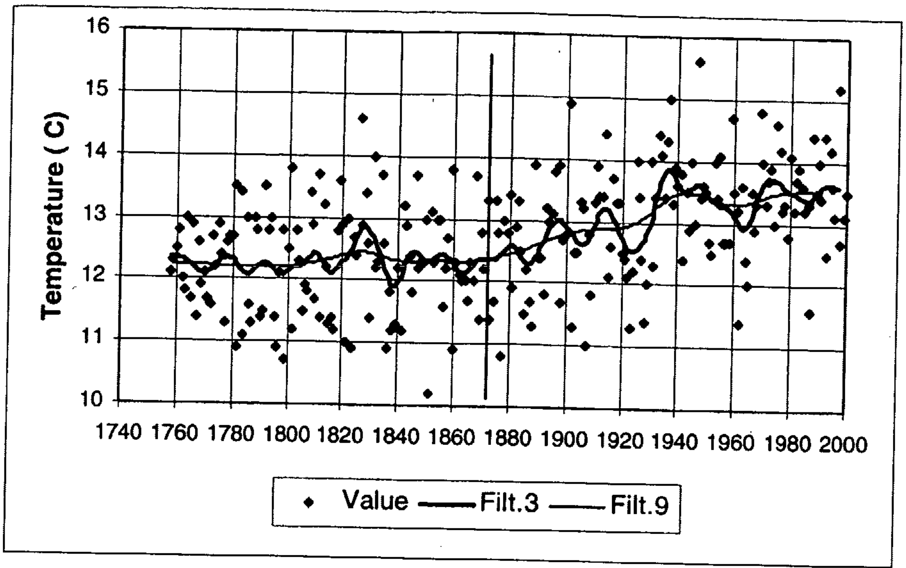


Figure 5.2 Reconstruction of mean summer temperatures (May – August) 1749 – 1870 for Austlandet (South-Eastern Norway) by proxy data mainly from the farms Åker, Rød and Hverven, and since 1871 by instrumental observations. No inflation technique was used. For the filtering technique, see figure caption 5.1.

5.3 Reconstruction April – August temperatures by Åker, Stenhammar, (Rakkestad), Rød, (Grøtvedt), and Hverven

As shown in Ch. 3.2 at least one of the series Skavhaugen/Stenhammar, Åker and Sørum is inhomogenous. It was concluded that the inhomogeneity most probably was located in the Skavhaugen/Stenhammar series in connection with a change from one grain field to another one. The reconstructions of Ch. 5.1, 5.2 and 5.4 are based upon this assumption. If we make the alternative assumption, i.e. Skavhaugen/Stenhammar is homogenous, it means that both Åker and Sørum must be inhomogenous. For simplicity we denote the Skavhaugen/Stenhammar series as the Stenhammar series.

In this reconstruction the Stenhammar series is given the priority, but in the years 1749 – 1773 Åker is used as the only farm available at Austlandet. The Åker series is adjusted by use of 19 overlapping years with Stenhammar in the period 1774 – 1805. In this period the Åker and Stenhammar series may be considered homogenous (not shown). See lines 7 and 8 in table 5.1.

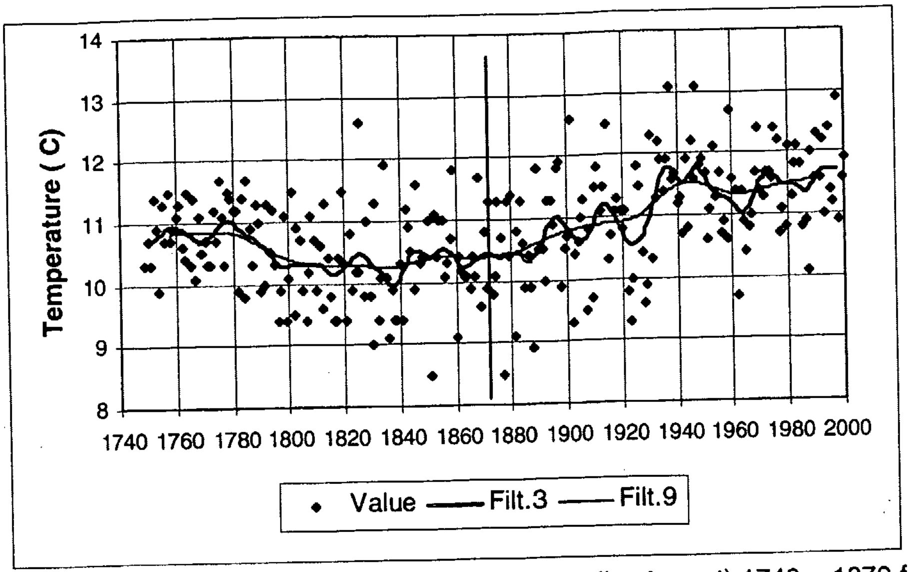


Figure 5.3 Reconstruction of mean summer temperatures (April – August) 1749 – 1870 for Austlandet (South-Eastern Norway) by proxy data mainly from the farms Åker, Skavhaugen/Stenhammar, Rød and Hverven, and since 1871 by instrumental observations. In this approach the Skavhaugen/Stenhammar series is considered to be homogenous. No inflation technique was used. For the filtering technique, see figure caption 5.1.

5.4 Reconstruction of April – August temperatures by Åker, Skavhaugen, Sørum, Rakkestad, Stenhammar, Rød, Berg, Flåvik, Grøtvedt and Hverven

In this approach data from all available farms in the Austlandet and Värmland regions were used. One by one the individual series were adjusted to be valid for Hverven, and added to a composite series. The procedure started with the series that overlaps Hverven with the maximum number of years, i.e. Grøtvedt, and a composite series of Hverven and Grøtvedt was established. As the Rød series had the longest overlap with the composite series the procedure was continued with Rød, followed by Flåvik, Åker, Rakkestad, Stenhammar, Sørum, Skavhaugen and Berg. The characteristic values of the differences between the series are shown in table 5.1, line 7, and lines 9 - 16. Hereafter the temperature reconstruction obtained by using data from more than one farm in the same time interval will be mentioned as the *multi farm series*, while those reconstructions based on data from only one farm will be mentioned as the *one farm series.*

By use of an ensemble of data series for each year in the composite series, and taking the mean value of them, the variability is expected to be smaller than if only data from one farm is used. The more data series in the ensemble, the smaller variability is expected, and a larger inflation factor should be used to maintain a realistic variability. The idea for the following approach is to amplify the variability of the multi farm series to make it equal the one farm series. That means that the corresponding inflation factor has to be calculated.

The work was done stepwise: The series was normalised to zero mean by subtracting the filter values of a centennial scaled Gaussian filter (standard deviation of 30 years in its distribution). This led to a series of anomalies without a long-term trend. The individual years in the series were grouped by the number of farms involved in the seasonal average as shown in figure 5.4, and the standard deviation within each group was calculated, given in table 5.2. The largest number of farms used was six, but this group comprised only 2 elements, and these were included in the group of five farms. The remaining 5 groups contained after this from 18 to 31 elements.

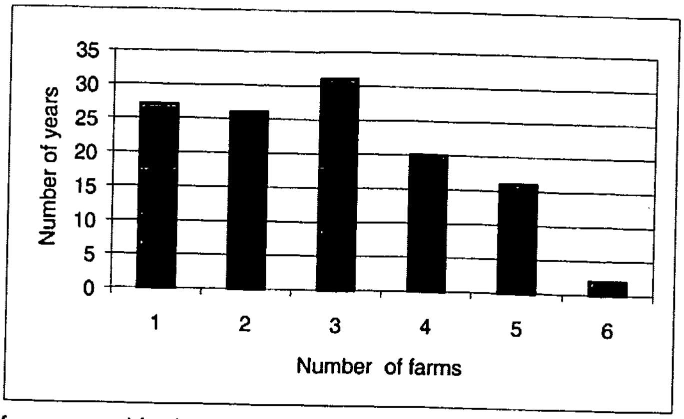


Figure 5.4. Number of farms used in the reconstruction of summer temperature at Austlandet.

Table 5.2 The grouping of the observations for inflation purposes. The β value is the factor by which the observations may be inflated.

Number of farms	Number of years	Multi series approach Std. (°C)	One series approach Std. (°C)	β
1	27	0.48	0.60	1.25
2	26	0.56	0.91	1.62
3	31	0.75	1.05	1.40
4	20	0.68	0.89	1.32
5	18	0.67	1.05	1.58
2-5	95	0.70	1.00	1.43

The variance within each group was calculated both for the one farm series (Ch. 5.1) and the multi farm series. The ratio of the standard deviations (one farm series / multi farm series), β, is shown in table 5.2. From the table is seen that the ratio varies much from one group to another, and does not increase from the group of 2 farms to the group of 5 farms as might be expected. The ratio, β, seems to be too noisy to be a reasonable inflation factor in equation (5.2). In order to reduce the noise, the groups 2 – 5 were joined into one group. The joint group now contained 95 years, and the inflation factor for the group was calculated to 1.43. This was the inflation factor used in the multi farm series for all years that consisted of mean values of more than one series. In years where only one farm was involved, the inflation factor used was 1.25. The result is shown in figure 6.1.

5.5 Comparisons of different approaches of temperature reconstruction

In order to illustrate the effect of inflation, the inflated and not inflated series (those presented in chapter 5.4) are shown in the same diagram, figure 5.5. In the coldest and warmest summers the effect of the inflation amounts to about 1 °C, for instance in 1812 and in 1826. The effect on the filtered curves, however, is not larger than 0.1 – 0.2 °C at the local maxima and minima, and hardly recognisable at other points of the curves, see figure 5.6. It is also seen that the inflation does not affect the long-term trend. This was avoided by the detrending procedure that was performed before the inflation.

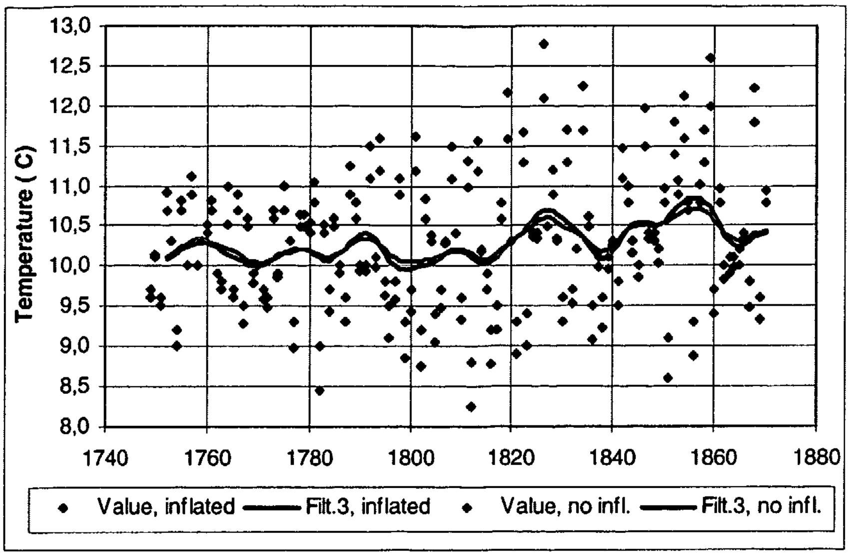


Figure 5.5 The reconstructed series of mean summer temperatures (April – August) 1749 – 1870 for Austlandet. Inflated series is shown in blue colour and the corresponding non-inflated series in red. For the filtering technique, see figure caption 5.1.

Different approaches were used in the reconstruction processes, see chapters 5.2, 5.3 and 5.4, and somewhat different curves are presented, for comparison see figure 5.6 The question whether or not the Skavhaugen/Stenhammar series is homogenous, give rise to the largest differences between the curves, see the red curve in figure 5.6. If Skavhaugen/Stenhammar is considered homogenous, it follows by homogeneity tests that the series from Åker and Sørum both are inhomogenous.

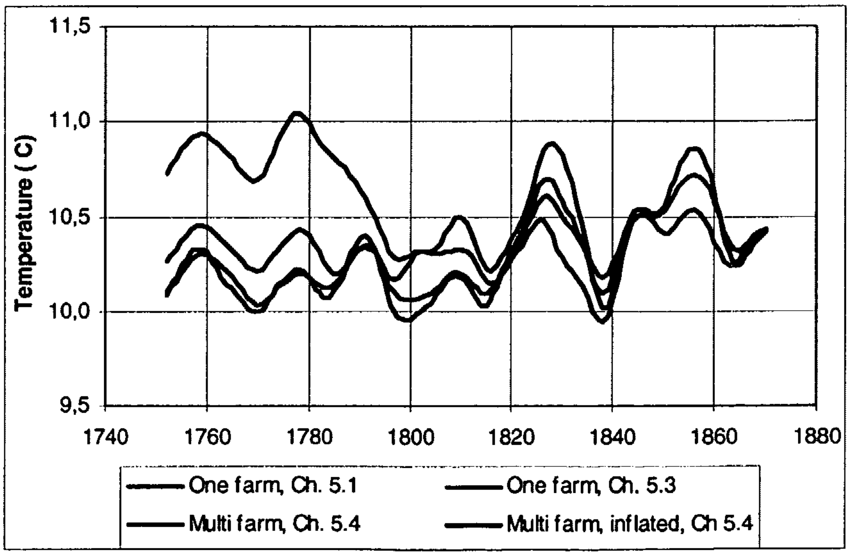


Figure 5.6 Comparison of the reconstructions of mean summer temperatures (April – August) 1749 – 1870 for Austlandet (South-Eastern Norway) shown by Filt.3, see figure caption 5.1 for explanation.
Dark blue curve: Skavhaugen/Stenhammar inhomogenous, inflated, multi farm series (Ch. 5.4).
Pale blue curve: Skavhaugen/Stenhammar inhomogenous, non-inflated, multi farm series (Ch. 5.4).
Green curve:, Skavhaugen/Stenhammar inhomogenous, non-inflated, one farm series (Ch. 5.1).
Red curve: Skavhaugen/Stenhammar homogenous, non-inflated, one farm series (Ch. 5.3).

In 1837 professor Hansteen started his series of instrumental observations at the new Astronomical Observatory in Oslo (Birkeland 1923). There has also been earlier observations in Oslo, but those series are rather short or inhomogenous and not easy to homogenise. The

Oslo series has a major relocation in the 1930s, when the station's altitude increased. By rural reference stations adjustment terms are calculated and applied to the series in order to overcome the inhomogeneity of the relocation. This might have reduced a possible urban heating effect on the series.

In figure 5.7 a comparison between the composite series of harvest data and instrumental observations of Austlandet (inflated, multi farm series) and the Oslo instrumental series is shown. The series are normalised to zero mean to easy the comparison. It is readily seen that during the reconstructed part of the series, 1837 – 1870, the trend is somewhat larger for the instrumental series than for the reconstructed one. However, none of the trends turned out to be significant (not shown). In the reconstructed part of the series the correlation with the Oslo series was 0.88 while in the instrumental part (1871 – 2000) the correlation amounts to 0.94, i.e. the correlation with the Oslo series is not much better in the instrumental period than in the reconstructed part of the series.

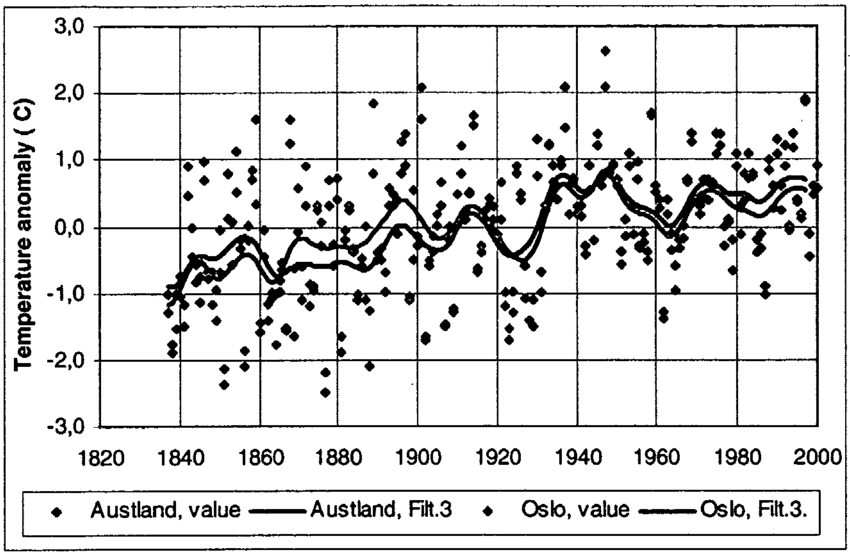


Figure 5.7 The composite series originating from harvest data (inflated, multi farm series) and instrumental observations, April – August, 1837 – 2000, for Austlandet (South-Eastern Norway), shown together with the Oslo instrumental series, April - August. For the filtering technique, see figure caption 5.1.

One of the most difficult quantities to assess correctly is the standard deviation of the series. To what extent this has been a success, can be tested by comparison to the Oslo series, 1837 – 1870. During this period the standard deviation of the reconstructed Austlandet series (inflated, multi farm series) is 1.0 °C, while the same quantity of the instrumental series was 0.9 °C. In the period 1871 – 2000, the standard deviation amounted to 0.9 °C both for the instrumental Austlandet series and the Oslo series.

Based on tree rings from the Femunden area Kalela-Brundin (1999) has reconstructed July/August temperature back to AD 1500. The area is situated near the Norwegian/Swedish border, and the analysed timber was taken from places near the tree line. Her reconstruction since 1749 is shown in figure 5.8 together with the reconstruction based on harvest data. The two methods show approximately the same long-term trend from the early 19th century to present, but the reconstructions differ in the middle and late 18th century by more than 1 °C, the tree ring curve being the warmest one.

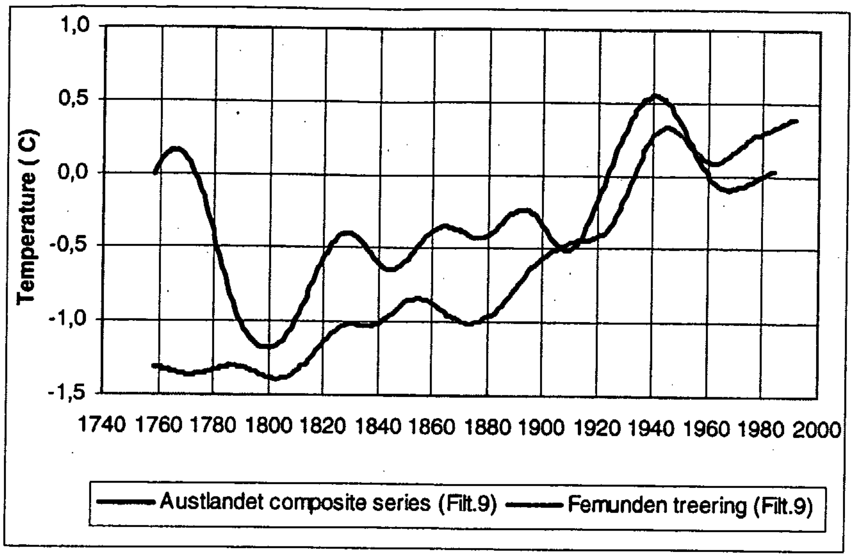


Figure 5.8 Reconstructed mean temperatures April – August from Austlandet and July – August from the Femunden area (Kalela-Brundin 1999). The Femunden series is based on tree rings.

One possible reason for the discrepancy is obvious, i.e. at least one of the reconstructions is inhomogenous, and has thereby an inaccurate long-term trend. In the 1750s and 1760s for instance, the Austlandet series can not be homogenised by comparison to neighbouring harvest data because there is not any. However, there is nothing in the written diary that indicates any inhomogeneity. Another possible reason for the discrepancy is an overweight of cold springs and warm summers in the late 18th century. This would alter the differences between the curves, as the tree rings respond to temperature in high summer only, while the harvest dates also respond to spring and early summer temperatures.

The Austlandet series reveals also low temperatures in the late 18th century compared to known instrumental series in northern Europe. In the early and mid 19th century, however, there are large differences between the instrumental series. The Uppsala and Stockholm series show higher temperatures than the St. Petersburg and Oslo (from 1837) series. The St. Petersburg and Oslo series have positive trends of about the same magnitude as the Austlandet reconstruction, while the two Swedish series have slightly negative trends through the century. In central Europe negative trends through the 19th century are also seen in the Vienna and Hohenpeissenberg (in Germany) series, while the western series (Central England and De Bilt) are without any pronounce trend.

6 Analysis of the Austlandet composite series

For further analysis of the climate of Austlandet (South Eastern Norway), the inflated multi farm series described in Ch. 5.4 is adopted, see figure 6.1. It is a homogenised, composite series of proxy and instrumental observations made valid for the currently run meteorological station *04940 Hvam – Tolvhus* (see figure 2.1) situated about 40 km north east of Oslo. The series shows mean temperatures, April – August, for the period 1749 – 2000. For convenience we call them summer temperatures even though a part of the spring also is represented in the mean values. From the diagram is seen that the warmest summers occur mainly later than 1930 and the coldest ones before 1880. The summers of 1937 and 1947 are the warmest ones, both 13.1 °C, but also 1826 was a very warm summer, 12.8 °C, if it is reconstructed correctly. Of especially cold summers is 1877 in the instrumental period, and the famous frost year 1812 in the reconstructed part, see figure 6.1.

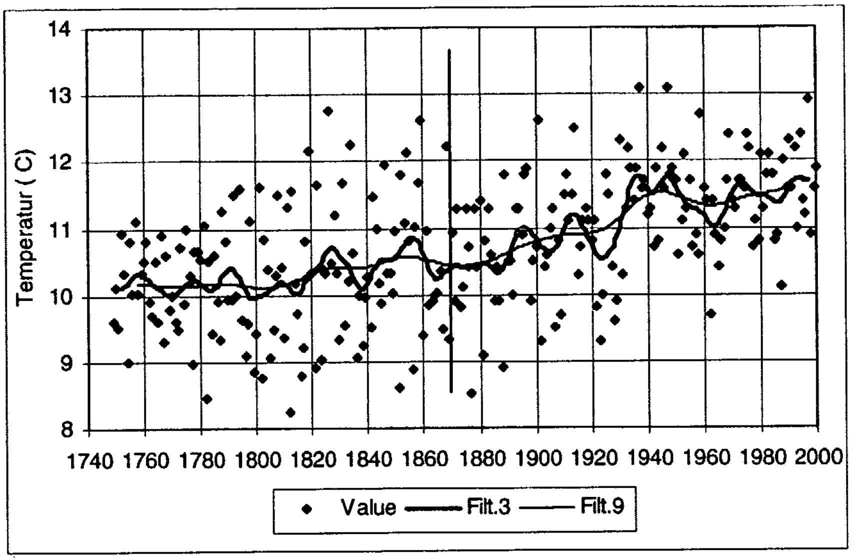


Figure 6.1 Reconstruction of mean summer temperatures (April – August) 1749 – 1870 for Austlandet (South-Eastern Norway) by proxy data from the farms Åker, Skavhaugen, Sørum, Rakkestad, Stenhammar, Rød, Berg, Flåvik, Grøtvedt and Hverven, and since 1871 by instrumental observations. The data are inflated. The series is made valid for the currently run station *04940 Hvam – Tolvhus*. For a description of the filtering technique, see figure caption 5.1.

To analyse the variations on certain time scales, Gaussian low pass filters are used with standard deviations in the distributions of 3, 9 and 30 years, corresponding to time scales of about 10, 30 and 100 years respectively. The main feature of the curves is an increasing summer temperature during the 252 years represented in the diagram. The increase seems often to have occurred in abrupt shifts like the one in the 1920s. During the two following decades the temperature remained high, but decreased in the 1950s, and did not reach the level of the 1930s and 1940s before the early 1990s. Analysed on a decadal scale these local maxima are the highest ones in the series.

Also in the early and middle 19th century the temperature has undergone large variations with warm summers in the 1850s, also called the golden years, in between cold summers in the late 1830s and the 1860s. In the 1860s the summer of 1867 is of special interest. The spring was exceptionally cold and this led to crop failure in the mountain villages in Norway, and in Finland the rye did not ripen (Jantunen and Ruosteenoja 2000) with a famine as a consequence. On this background it is of special interest what the farmer at Hverven writes in his diary in 1867 "Avlingen maae Henregnes til et stort Aar" (the grain harvest must be estimated to a great year). An above normal August had ripened the grain in the lowland districts around Hamar.

Amplitudes generated by different filters as well as trends for the whole series and for specific centuries are shown in table 6.1. The difference between the warmest and coldest summer amounts to almost 5 °C. For the centennial filter (Filt.30 in figure 6.2) the maximum and minimum values are located at the ends of the series, so that the amplitude may also be interpreted as a measure for the long-term trend that amounts to 1.4 °C. The linear trend is considerably higher. The reason is that a trend line does not fit the data well, as the long-term trend is absent in the start and end of the series, see the black line in figure 6.2. A trend line is in this case a bad approximation for a changing mean value, and estimating the trend from the line leads to an exaggeration of the trend in the series. The amplitude of the centennial filter, 1.4 °C, seems to be a more reasonable estimation of the long-term trend. The same result is also obtained if the trend is defined as the difference between the last (1971 – 2000) and first (1749 – 1778) thirty year periods of the series.

Table 6.1. The Austlandet series, amplitudes (°C) and trends (°C).

	Amplitudes (°C)				Linear trends (°C)			
	Individual year	Filter 3 years	Filter 9 years	Filter 30 years	Whole series	18th century	19th century	20th century
Min. year	1812	1799	1803	1749	1749	1749	1801	1901
Max. year	1947	1937	2000	2000	2000	1800	1900	2000
Value	4,8	3,1	1,5	1,4	1,7	-0,1	0,5	0,9

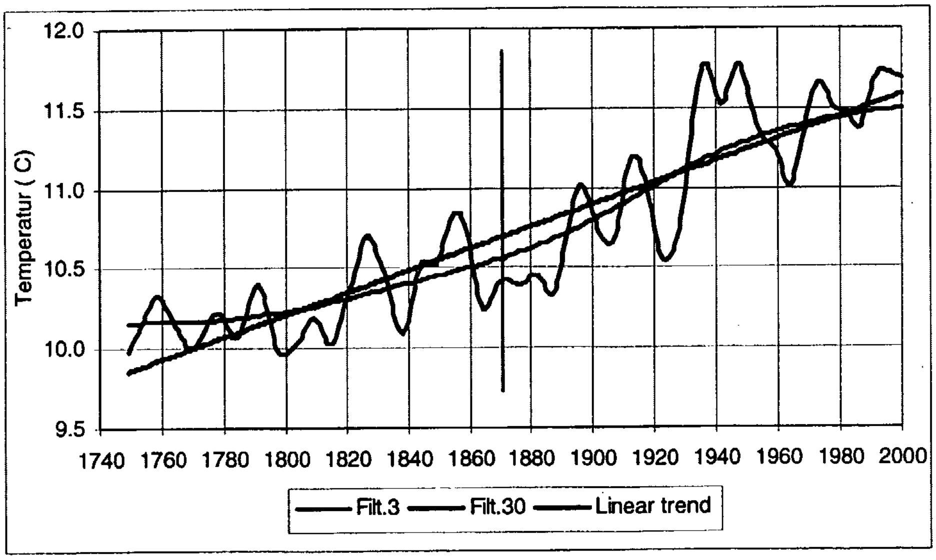
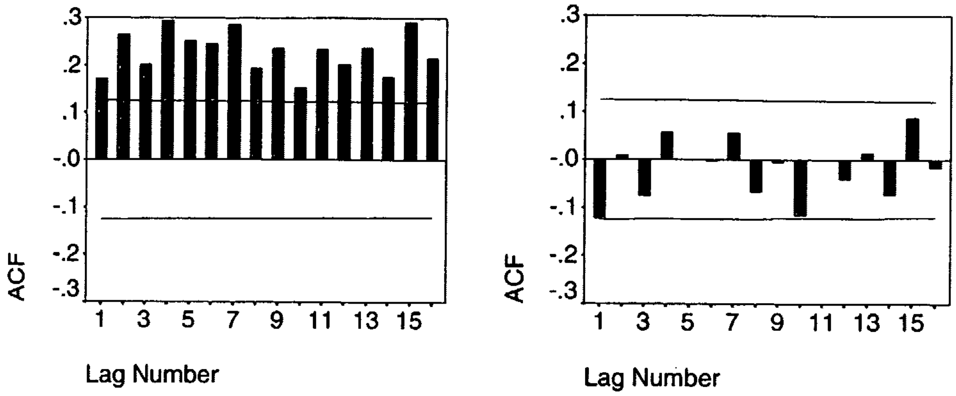


Figure 6.2 A comparison of different filters and a linear trend line applied on the Austlandet series.

The significance of the trends in the series was also studied by the non-parametric Mann-Kendall test. The testing was done stepwise by adding one by one year from the start of the series. The trend was not significant on level 0.05 before the year 1896 was added, and not on level 0.01 before 1911. The trend of the whole series was significant on the 0.01 level.

The series was tested for auto-correlation with lags from 1 up to 16 years, and found to be significantly auto-correlated at all of the 16 lags, see figure 6.3a. In order to test the influence of the long-term trend on the auto-correlation of the series, the series was detrended and the testing was undertaken once more. This gave a much different results, see figure 6.3b. No significant auto-correlation was detected at any of the 16 lags. Thus, the Austlandet series is auto-correlated only because of its long-term trend.



a) b)

Figure 6.3 Autocorrelation (ACF) for the Austlandet series for lags from 1 to 16 without a) and with b) detrending. The detrending was done by applying a Gaussian filter (Filt.30). The confidence intervals are marked with lines in the figures.

The structure of the series was also examined by Fourier analysis, and the power density for the different frequencies is shown in figure 6.4. The whole series consists of 252 years so that a frequency of for example 0,1 corresponds to a wavelength of about 25 years. Again we see that it is only the low frequency, i.e. the longest wavelength that is significant. The long-term trend must be represented by the longest wavelength (the first harmonic). Thus, the results from the spectral analysis are consistent with the auto-correlation analysis.

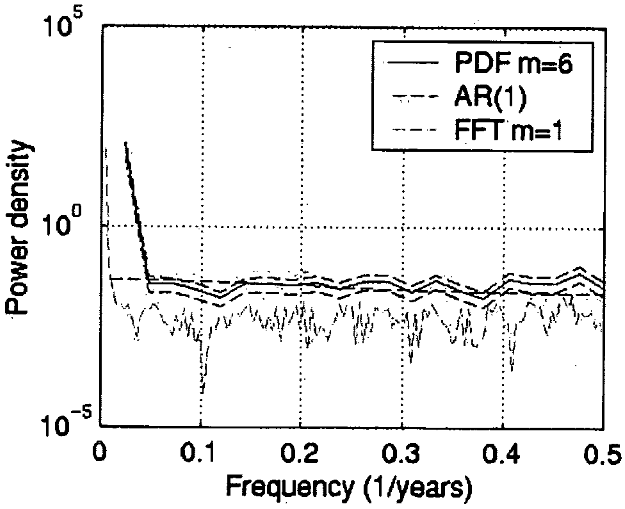


Figure 6.4 Power spectrum for the Austlandet series shown in pale blue (FFT m=1) compared to an autoregressive model, red colour (AR(1)). The power density of the 6 neighbouring frequencies is also shown, dark blue (PDF m=6).

In table 6.2 the warmest and coldest periods in the Austlandet series are given. The result reflects the fact that there is a long-term trend within the series, so that the warmest periods are located in the latest years, while the coldest ones are located in the beginning of the series. The 20th century is 0.9 °C warmer then the 19th century, and the absolute coldest 100 years are located in the very beginning of the series, while the 100 warmest years are located at the very end. However, the former normal period, 1931 – 1960, is still the warmest normal period, but the thirty-year period 1968 – 1997 is as warm as the former normal period.

Table 6.2. Warmest and coldest periods of the Austlandet series. The start of the non-overlapping thirty-year periods is chosen so as to co-inside with the three official normal periods

Not overlapping periods	Decades	Thirty year periods	Half a century	Century
Warmest	1991 – 2000 11.7	1931 – 1960 11.6	1951 – 2000 11.4	1901 – 2000 11.3
Coldest	1791 – 1800 10.1	1781 – 1810 10.1	1751 – 1800 10.2	1801 – 1900 10.4
Floating periods				
Warmest	1988 – 1997 11.9	1968 – 1997 11.6	1936 – 1984 11.5	1901 – 2000 11.3
Coldest	1796 – 1805 9.9	1795 – 1824 10.1	1768 – 1817 10.1	1749 – 1848 10.2

7 Summary and conclusions

The Austlandet series of late spring and summer temperatures (April – August) was reconstructed back to 1749 by the use of a temperature proxy; the start of the grain harvest. The source was farmers' diaries originating from 10 farms covering the period 1749 – 1918. The period partly overlapped instrumental observations 1871 – 2000. Both proxy and instrumental series were made valid for the currently run station *04940 Hvam – Tolvhus.*

In the period 1749 – 1773 harvest data from only one farm were available, in the rest of the period homogeneity testing of the harvest dates were performed by comparison with other series. All series but one was found homogenous, and the reason for the only break was considered to be caused by the fact that the farmer had moved from one farm to another, and thus shifted to another grain field. The inhomogenous series was split into two non-overlapping series in the year of the shift.

The series of harvest dates were nested together by overlapping periods and adjusted in order to obtain one homogenous series. The adjustment terms were calculated by use of the differences of the median values within the overlapping periods. The median values were chosen as a more robust expression for the difference of harvest starting dates than the arithmetic means, which may be more affected by outliers.

The harvest dates were correlated with mean temperature taken over different periods, and the period April – August was found to give the best correlations, slightly better than May – August. The data fitted nicely into a linear regression model, and regression equations were therefore used as transfer functions from harvest dates to temperature. The regression coefficient was 0.82.

Most of the harvest dates used in this reconstruction refer to rye harvests, but for some farms only barley and oat harvest dates were available. At the farm Hverven both barley and rye were available, and the Hverven series also overlaps with instrumental observations. The median difference between rye and barley harvest dates was -9 days, and using the method of constant adjustments terms, the dates for one cereal could be adjusted to be valid for the other one. The regression equations for rye and barley had slightly different regression coefficients, so that the harvest dates of barley cannot be transformed to rye by the method of a constant adjustment term without introducing an error. The error, however, seems to be acceptable as 70 % of the differences is found in the interval –0.2 to +0.2 °C.

For the temperature reconstruction two different approaches were used called the one farm approach and the multi farm approach. By the one farm approach harvest dates from only one farm were selected for each year, and the farms around Hamar were given priority to other farms. In the multi farm approach the arithmetic mean for each year of all adjusted harvest dates was used, i.e. farms from all over Austlandet and also Värmland in Sweden. The two approaches did not result in any large difference in the reconstructed temperatures. For further analysis the multi farm approach was chosen.

The method of regression suppresses variability of the reconstructed series, and an inflation technique was used to compensate for it. This was done after the series were detrended, and for the one farm approach the inflation factor was constant throughout the reconstructed part of the series. For the multi farm approach the series required larger inflation factors than the series of the one farm approach, because of further suppression of the series' variability by taking the mean values of the harvest dates.

The inflated series (multi farm series) was compared to the Oslo instrumental series, which from 1837 originates from the Astronomical Observatory. In the period 1837 – 1870 the variance of the reconstructed series could be compared to the instrumental series. In this period of comparison the variances of the two series were in good agreement with each other.

The Oslo instrumental series is adjusted for one major relocation in 1936, from down-town Oslo to the new DNMI building at Blindern, i.e. higher up in town near the Oslo university campus. The relocation is adjusted for by use of rural neighbouring stations. The long-term trend of the composite series from Austlandet was in good agreement with that of the Oslo instrumental series.

The Austlandet series was found to be auto-correlated on all investigated lags from 1 to 16, but after detrending the significant auto-correlation disappeared. Power spectrum analysis was also performed and the result supported those from the auto-correlation analysis. Only the first harmonic that represents the trend in the series is significant. This means that there is no significant high frequent cyclisity within the series, and from a statistical point of view, the decadal variations in the series could have been established by poor chance.

The difference between the warmest and coldest summer in the Austlandet series amounted to about 5 °C, the difference between the warmest and coldest decades was 2.0 °C, and that of the thirty-year periods, 1.5 °C. The linear trend of the whole series was calculated to 1.9 °C, but the trend did not fit well into a linear model, and the calculated linear trend seemed exaggerated. The data were also fitted by a low pass filter with 30 years standard deviation in its distribution. The highest and lowest filtered values were the last and first years of the series respectively. Therefore, this difference can be interpreted as the long-term trend of the series. With this fitting the long-term trend was 1.4 °C, and this also figured out as the temperature difference between the means of the last and first thirty years of the series.

The mean summer temperature of 20th century was found to be 0.9 °C warmer then the 19th century. The former normal period, 1931 – 1960, is still the warmest normal period, 0.2 °C warmer than the currently used normal, 1961 – 1990. Some meteorological institutions change normal period every tenth year, so that the currently used normal comprises the years 1971 – 2000. The mean temperature of these years equals that of the former 1931 – 1960 normal.

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References

Alexandersson, H. 1997: Homogenization of Swedish temperature data. Part I: Homogeneity test for linear trends. *International Journal of climatology*, **17**, 25-34.

Birkeland, B.J. 1923. Ältere Meteorologische Beobachtungen in Oslo (Kristiania). Luftdruck und Temperatur seit 100 Jahren. Geofysiske Publikasjoner. **III**, pp 1-56.

Birkeland, B.J. 1949. Old meteorological observations at Trondheim. Atmospheric Pressure and Temperature. *Geofysiske Publikasjoner* **XV**, 1-38.

Brundin, M. 1999: Climate information from tree-rings of Pinus sylvestris L. and a reconstruction of summer temperatures back to AD 1500 in Femundsmarka, eastern Norway, using partial least squares regression (PLS) analysis. *Holocene*, **9,** No. 1, 59 - 77.

Hanssen-Bauer, I, P.Ø. Nordli. 1998: Annual and seasonal temperature variations in Norway 1876 – 1997. *DNMI-klima*, Report 25/98, 29 pp.

Høgåsen, S. 1999: Personal communications.

Jantunen, J. and Ruosteenoja, K. 2000: Weather Conditions in Northern Europe in the Exceptionally Cold Spring Season of the Famine Year 1867. *Geophysica*, **36**, (1-2), 69 – 84.

Johansson, S. 2000: *Bondedagbok, 1825 – 1862, skriven av Anders Andersson i Flåvik, Eskildsäter (in Swidish). A farmer's diary, 1825 – 1862, written by Anders Andersson i Flåvik, Eskildsäter.* Unpublished.

Le Roy Ladurie, E and M. Baulant, 1980: Grape Harvests from the Fifteenth trough the Nineteenth Centuries. *Journal of Interdisciplinary History*, **10**, 839 - 849.

Lövgren, O. 1970: *En bondes dagbok 1809 – 1833 (in Swedish). "A farmer's diary 1809 – 1833".* Värmland Museum, Karlstad. 118 pp.

Middleton, W.E.K. 1966: *A history of the thermometer and its use in meteorology*. The John Hopkin Press, Baltimore, Maryland. 249 pp.

Nordli, P.Ø. 1997: The Herøy series. A composite series of summer temperatures (1843-1903). *DNMI-report*, No. 26/97Klima, 8 pp.

Nordli, P.Ø. 2001: Reconstruction of Nineteenth Century summer temperatures in Norway by proxy data from farmers' diaries. *Climatic Change*, **48**, 201 – 218.

Sneyers, R. 1990: On statistical analysis of series of observation. *WMO. Technical note* No. 143, WMO No. 415, Geneva, Switzerland, 192 pp.

Tarand A., Kuiv P. 1994: The beginning of the rye harvest - a proxy indicator of summer climate in the Baltic Area. *Paleoclimatic Research.* **13** (Special issue ESF project «European Palaeoclimate and man» 8 1994.), 61-72.

Tarand A., Nordli P.Ø. 2001: The Tallinn temperature series reconstructed back half a millennium by use of proxy data. *Climatic Change*, **48**, 189 – 199.

von Storch, H. 1999: On the use of "inflation" in Statistical Downscaling. *Journal of climate*, **12**, 3505 – 3506.