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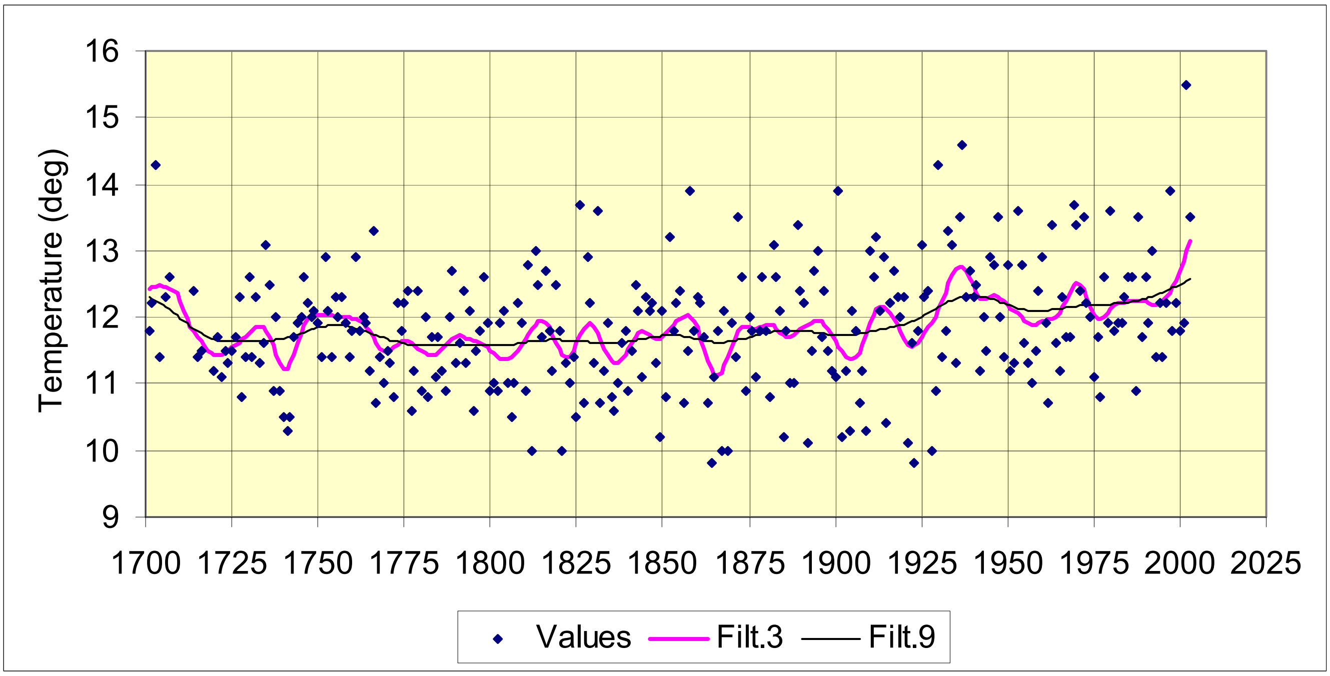
Climate

Spring and summer temperatures in Trøndelag 1701 - 2003

P.Ø. Nordli



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Abstract

The time evolution of spring-summer temperature for the Trøndelag region was reconstructed by use of one particular proxy source: the first day of grain harvest taken from farmers' diaries. As the growing conditions are different in the region, the shorter series had to be adjusted before they were nested together to form a composite series for Trøndelag, 1701 – 2003. The adjustments were based on overlapping periods. Generally the series overlap well, but a crucial point in the reconstruction, is the overlapping between the 19th and 18th centuries where the overlapping consists of only six years.

A significant, linear trend for the whole series of +0.6 °C (+0.2 °C per century) was detected. The trends within individual centuries differ much from each others. During the 18th century the trend is negative (-0.4 °C), whereas the trends are positive during the 19th and 20th centuries, +0.3 °C and +0.5 °C respectively.

By using a Gausian, decadal, low pass filter the Trøndelag series and an earlier derived western Norwegian series were compared. The maxima and minima of the two series were located in the same decades. Historically severe climatic decades described in narrative sources like the early 1740s, the first decade of the 19th century, the late 1830s, and the 1860s, also show low summer temperatures in the reconstructed series. The 1860s seem to have been much more severe in Trøndelag than in western Norway whereas the late 1830s seem to have been less severe.

The study show that the summer AD 2002 in the Trøndelag region is the warmest ever since the beginning of the series 300 yeasrs ago.

Keywords

temperature; farmers' diaries; grain harvest; Little Ice Age; Trøndelag; Trondheim; regression analysis

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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 coast, Sandøysund, Kristiansand, Mandal, Skudeneshavn and Ålesund, and one station inland, Dombås. 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, for instance in Trondheim since 1762; the oldest observations in Norway. These were performed by private persons and were subject to frequent relocations (Birkeland 1949). Thus, both the quality of the observations and homogeneity through the relocations should be questioned.

However, a supplement to the instrumental series exists. In historical documents temperature proxies have been detected that can be used for temperature reconstructions. Examples are the vintage in southern and central Europe (Le Roy Ladurie and Baulant 1980) and the rye harvest in Estonia and Finland (Tarand and Kuiv 1994; Tarand and Nordli 2001). In Norway the first day of barley harvest at the farm Kjellen has been used for quality control of the Trondheim series. In spite of an attempt of homogenisation by (Birkeland 1949) many large inhomogeneities remain in the Trondheim series (Nordli 2001a).

In the Dovre mountain area the Kjøremsgrende series was extended back to 1813 (Nordli 1997a, 2001a) by use of barley harvest at the Synstbø farm, the Ålesund series in Møre was reconstructed back to 1843 (1997b, 2001a) by the Frøystad farm, the Hvam series in Austlandet, back to 1853 (Nordli 2001b) by the Hverven farm. Harvest data from several farms located within the same temperature region have also been used for reconstruction of regional series, like the Austlandet series back to 1749 (Nordli 2001b) and the Vestlandet series back to 1734 (Nordli et al. 2003).

Trøndelag, Central Norway, is an area in which the same pattern of temporal temperature variations is seen. The area is therefore defined as one climate region (Hanssen-Bauer and Nordli 1998). Thus, it makes sense to base the reconstruction entirely on diaries within this region. There exists, however, harvest data from the neighbouring Swedish county Jämtland back to 1701, starting more than 30 years earlier than the first Trøndelag data. For this reason also the Jämtland data are incorporating in the Trøndelag temperature reconstruction.

2 Data series and data homogeneity

The farms used for the reconstruction are situated in the district of Trøndelag in southern Norway and from the Swedish county Jämtland at the border to Trøndelag. The farms are shown on the map (figure 2.1) and the data coverage is illustrated in figure 2.2. Some further information is also given in the following text, where the farms are sorted by starting year of the harvest data series. The harvest information from Jämtland is not connected to any specific farm, but to several farms of three vicarages near Storsjön in the municipality of Östersund. In the headings below the data series are named by municipality and the farm's name (except the farms in Östersund where the farms' names are unknown).

2.1 Description of the farms

1) Östersund – Storsjön, 1701 - 1766
Lake Storsjön is situated in Jämtland in Sweden within the municipality of Östersund, the largest town in the area. The town lies some 200 km to the east of Trondheim at about the same latitude. The dates of harvest are taken from a table listing of von Stockenström (1767), who presents harvest dates from the area near Storsjön. More precisely he states that the data comprise flat fields at the vicarages of Sunne, Brunflo and Rödön. He is aware of different ripeness of the cereals, and tells that his table comprises the "korn" harvest. The Scandinavian word korn (cf. English corn) is in Swedish often used as a name for barley, and in Stockenström's text it is obviously so. He tells that in Jämtland the rye reaches ripeness somewhat later than barley, while at more southern areas of Sweden the situation is opposite; the rye (probably autumn rye) ripens before barley.

One of von Stockenström's informants was Mr. Eric Tryggdahl, an "Auditeure" at the Regiment of Jämtland, who provided the observations from the period 1701 – 1753. They contain not only harvest dates but also ice break-up dates of Storsjön, starting dates of spring work and crop yields, all sent to the Royal Swedish Academy. The earliest observations were carried out by Erik Tryggdahl's father, while the later observations were either made by Tryggdahl himself or had been collected by him using other sources. During the last 13 years of the period, 1754 –1766, the harvest dates were observed by Olof Granbom, who also made meteorological observations at Brunflo (cf. also Moberg 1996).

2) Rissa - Groven, 1733 – 1817
The farm lies about 7 km in north-easterly direction from the municipality centre of Rissa and about 9 km from the outer Trondheim fjord shore. Trondheim lies about 26 km in south-easterly direction on the other side of the fjord. Groven was a small farm that is now abandoned. There have been two diary writers at the farm, Jon Steffensen Øverland and Anders Groven. Certainly the last period of the diary (1804 – 1812) is written by Anders Groven. In the period 1770 – 1803 the information from the diary is very sparse. The strength of the series is, however, the long period of information from the same farm.

A detailed map of the area in the scale 1:2500 is provided by Rissa municipality. From the map it is seen that the farm is situated on the top of a small hill with the fields sloping about 10 % in south-westerly direction. This is favourable conditions for cultivation in this area, where summer heat often is a minimum factor; while precipitation most often is affluent. It is thus very probable that the farmers have used this favourable position of the grain field through the whole history of the farm. The altitude of the farm houses is about 150 m a.s.l.

The harvested cereals at the farm are unspecified in the diary. It can be expected that the harvest starts with barley (se remarks from Jämtland).

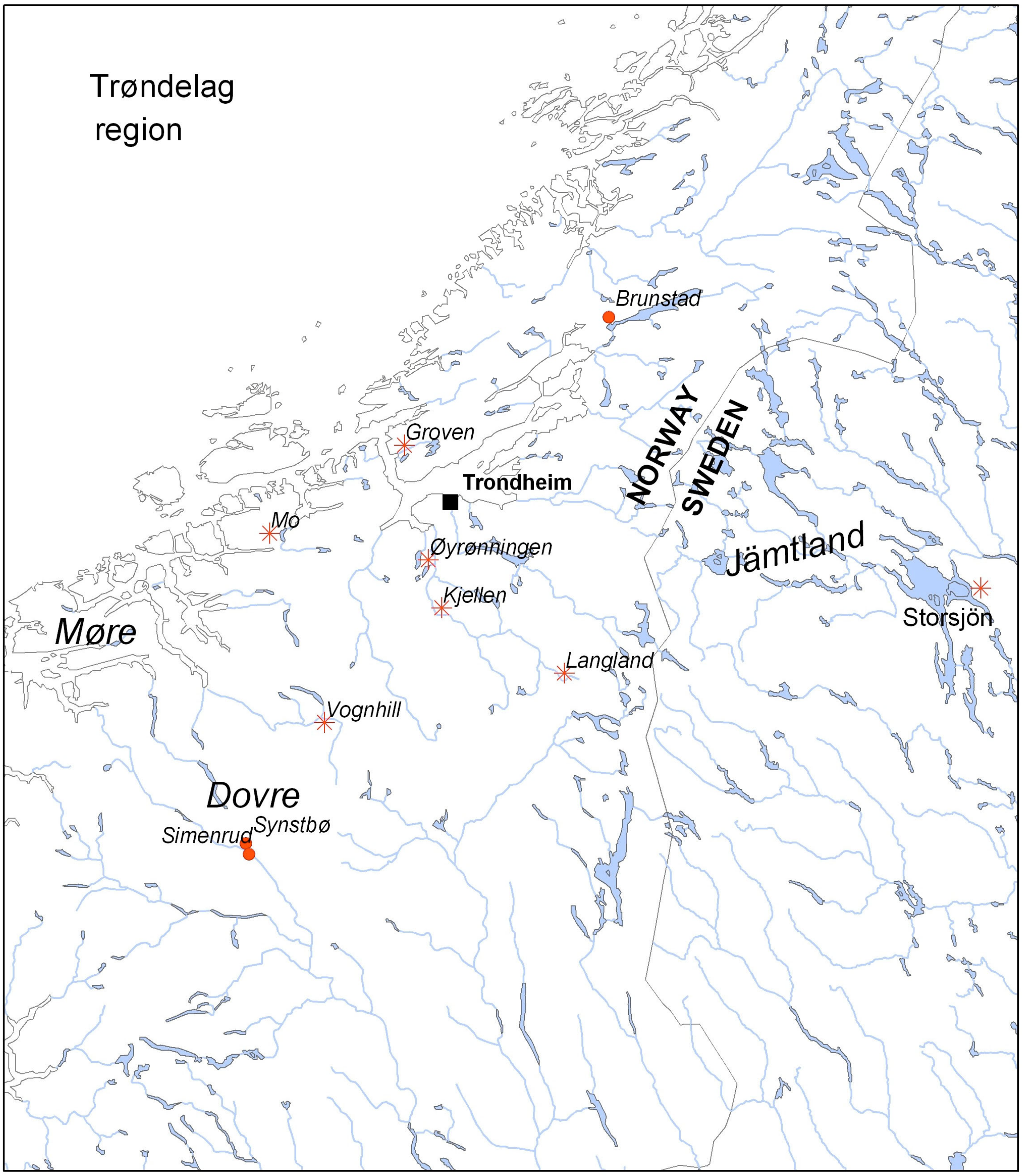

Figure 2.1 Map of the Trøndelag and Jämtland regions. The farmers' diaries are marked with red colour on the map, those used in the reconstruction with sand-flowers, the others with red dots.

2) Holtålen - Langland, 1762 – 1804

The farm is situated in Gauldalen Valley on the south-western bank of River Gaula, 75 km in south-eastern direction from Trondheim (figure 2.1). The historical grain fields of Langland are almost flat, situated between 380 and 385 m a.s.l. The valley has a continental climate, which does not allow other cereals than barley to be cultivated on the farm. The diary is written by only one person, Bør Langland (1732 – 1821).

The farm is split up into many farms, but this was done later than 1804, when this diary stops. Today the site of the main farm is called Western Langland, farm No. 92/1.

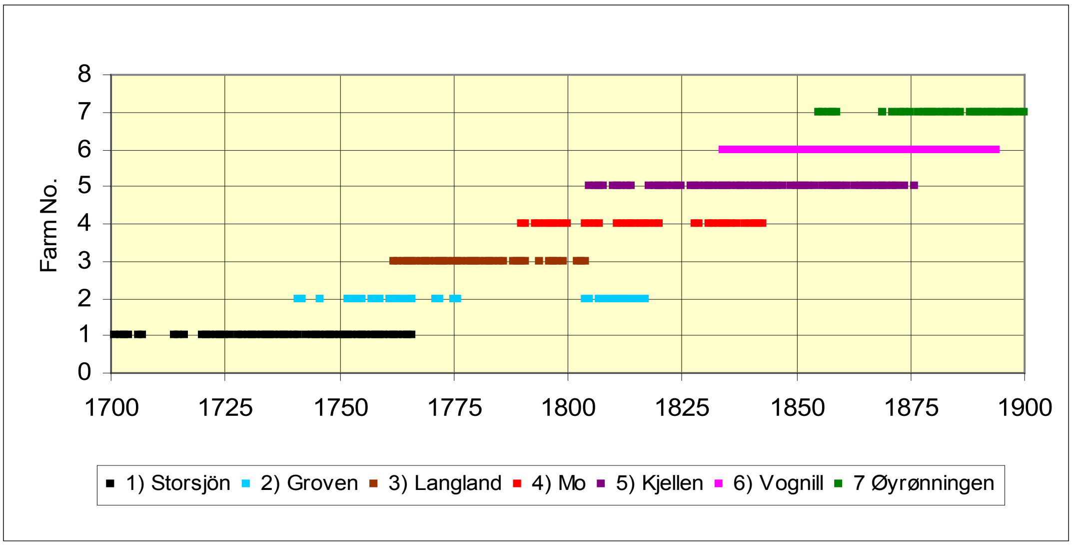

Figure 2.2 Available diaries in which the starting date of harvest is recorded. The figure comprises diaries in the districts of Trøndelag and Jämtland.

4) Hemne - Mo, 1790 - 1843
The farm (No. 107/1) is situated at the western shore of Lake Rovatnet in Hemne municipality in south-western Trøndelag (figure 2.1). The distance from the local centre Kyrksæterøra is about 5 km in south-easterly direction, while Trondheim lies about 72 km to the east. The grain field is sloping in westerly direction towards the lake. The altitude of the field near the farmhouses is about 100 m a.s.l.

The harvested cereals at the farm are mostly unspecified in the diary but in one case, it is clearly stated that it was barley. Barley is in Trøndelag probably the cereal that ripens earliest (see remarks from Jämtland) and all harvest dates much probably refer to barley. However, in 1794 it is documented that rye was cultivated at the farm together with barley and oats, and even potatoes. The possibility that the start of harvesting in some years refer to rye can not be excluded.

5) Gauldal - Kjellen, 1805 - 1876
The farm is situated at the flat banks of the river Gaula 115 m a.s.l. about 50 km to the south of Trondheim. The harvested cereals at the farm are unspecified in the diary but in one case; then it is said to be barley.

6) Oppdal - Vognill, 1834 - 1894
The farm (No. 234/1 Uppigard Vognill) is situated at the mountain village near Vognillan 6 km in west-north-westerly direction from the Oppdal railway station in the municipality centre of the same name. Today the field of the farm is divided by the neighbouring farms and only the old farmhouse is preserved. The grain field slopes very gently to the south (inclination less than 1 %).

The grain harvest is unspecified in the diary, but at Vognill, situated 605 m a.s.l., barley is the only cereal that can be cultivated.

7) Melhus - Øyrønningen, 1855 – 1918
The farm is situated at Melhus, a neighbouring municipality to Trondheim to the south of the city. It is clearly stated in the diary that the harvesting is started in the field of barley.

2.2 Testing of homogeneity

The series of starting dates of the grain harvest were tested for inhomogeneities by the following procedure: For two series having at least 10 years overlapping, a series of differences was established. It is assumed that the series of differences is not auto correlated, and 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. The testing was performed stepwise by adding one by one year to the series of differences and calculating the Mann-Kendall test statistics for each step, like in figure 2.3.

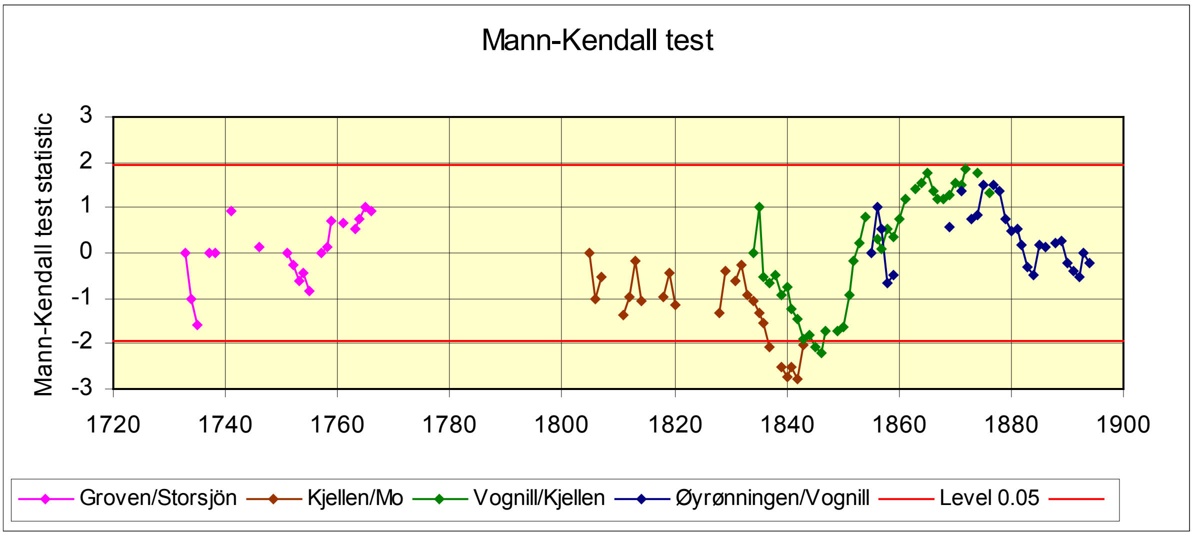

Figure 2.3 The time evolution of the Mann-Kendall test statistics for the series of differences. The testing is performed by adding one by one year of data to the series and applying the test for each year added. The level of significance of 0.05 is marked by the brown straight line.

Storsjön - Groven. There exist 19 overlapping years for Storsjön and Groven and no significant trend in the series of differences is detected.

Kjellen – Mo. There exist 24 overlapping years for Kjellen and Mo. The series of differences shows a significant decrease at the 0.05 level. This means that the latest harvests at Kjellen occur earlier compared to Mo. A tendency towards earlier harvests at Kjellen, however, during the period 1834 – 1844 is not confirmed when Kjellen is compared with Vognill, see figure 2.3 for Kjellen – Mo and Vognill – Kjellen. Therefore the inhomogeneity is most likely present in the series of Mo.

The series of differences was further examined by the Pettitt test (not shown) that pointed out the year 1815 as the most likely year for the inhomogeneity. The Mo series was treated as being two series, hereafter named Mo 1 (1816 – 1843) and Mo 2 (1790 – 1815). There are missing years in the series so that Mo 1 consists of 17 years and Mo 2 of only 7 years.

Vognill – Kjellen. There exist 38 overlapping observations for Vognill and Kjellen. From the start of the series and to the last years of the 1840s there are some significant values indicating a decrease in the differences (i.e. a tendency towards earlier harvests at Vognill compared with Kjellen), but this tendency is not confirmed when values for the following years are added to the series.

Øyrønningen – Vognill. There exist 27 overlapping observations for Øyrønningen and Kjellen, and no significant trend in the differences is detected.

The Groven series is the only link between the 18th century and 19th century. The trend of the reconstruction between those centuries has to be based on this data series. It is therefore of crucial importance for the reconstruction that the Groven series is homogenous. Without overlapping with other series, it is not possible to have the homogeneity tested during this period. The Groven farm was in the 18th century run by another person than in the 19th century. The agricultural methods did not change much in this period, and most probably the harvest dates of the early user of the farm are directly comparable to those of the later user, so that the series is homogenous.

2.3 The instrumental series

Unfortunately a homogenous, long-term instrumental series from Trøndelag does not exist. The regional capital Trondheim has long traditions for meteorological observations, but the classical Trondheim series (Birkeland 1949) is nested together from many different series brought forward of private persons. However, in 1870 met.no also started meteorological observations in the inner town. Nowadays no observations are made in the centre of Trondheim.

The classical Trondheim series has been adjusted to be valid for the Trondheim Airport Værnes, 26 km to the east of Trondheim, where observations continue. Although valid for Værnes, the series will in this paper for simplicity also be called the Trondheim (Værnes) series. The series has been homogenised by Nordli (1997c) starting the homogenisation with met.no's observations from 1870.

The Trondheim series starts in 1762, but there is a gap from 1803 - 1817 that was interpolated by Birkeland (1949), using the series from Stockholm and Edinburgh. Since 1818 the series is based on measurements from several places in the inner town. The observers of the principal series were: Vibe (1818-34, before 1828 only one observation a day), Møllerup (1835-51), Balsløw (1852-54), Rosenvinge (1855[1]-69). According to Birkeland (1949) Rosenvinge's observations "convey a very reliable impression" and the Rosenvinge/DNMI series (1858[1]-1875) has been used for the establishing of a regression with the Kjellen proxy series (Nordli 2001a). In the next chapter the possibility of using the Rosenvinge's observation for regression analysis will be discussed.

[1] There has been some doubt about what Birkeland used as the principal series in 1855-57. Therefore these years were omitted as a basis for the regression.

3 Method for climate reconstructions

It has been shown that there is a good correlation between spring-summer temperature and the first day of grain harvest at sites near to the instrumental series. If there exist an overlapping period between the two data types, linear regression analysis may be used to derive spring-summer temperature by the harvest data (Nordli 2001a). Furthermore, if the harvest data starts earlier than the modern instrumental series, the harvest data might be used to reconstruct the series beyond the modern instrumental period. In Norway the modern instrumental period starts in the 1860s so diaries from earlier decades might be used for temperature reconstruction, see the introduction.

As dependant variable in the regressions the mean spring-summer temperature for the period that gave the best correlation was used. In the Trøndelag, Møre and Dovre mountain areas, this was the period May – August, whereas in Austlandet and Vestlandet the period was April – August. The most common cereals were barley and oats, but at Austlandet rye was also cultivated. In the Dovre mountain area only barley was cultivated because of too short growing seasons for the other cereals.

As an example of regression analysis is shown (figure 3.1) of the Trondheim (Værnes) instrumental series (predictand) and the Kjellen farm (predictor). This regression analysis was used for the control of the old Trondheim (Værnes) series, quoted from Nordli (2001a). The correlation coefficient is -0.87 between the variables.

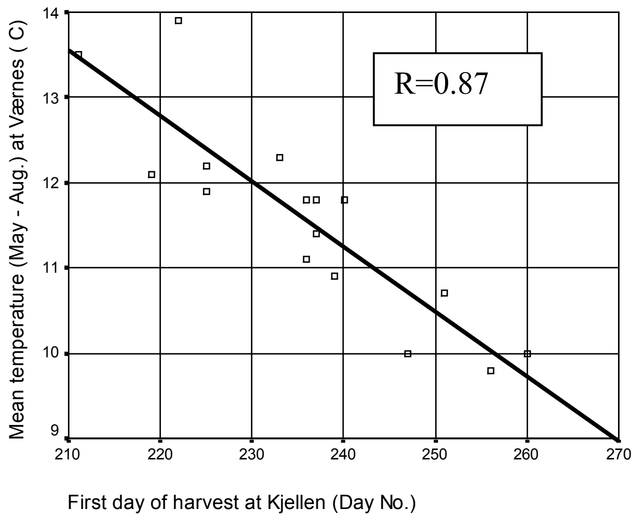

Figure 3.1 A spread diagram for spring/summer temperature (May – August) for the Trondheim (Værnes) series and the first day of harvest at the farm Kjellen during the period 1858 - 1876. R is the regression correlation.

Generally the regression equations take the form

$$\check{T} = \alpha D + \Delta T \qquad (3.1)$$

where $\check{T}$ is the predicted temperature, D is the first day of grain harvest (day No.) and α and ΔT are constants. The regression coefficient, α, will hereafter be called the *temperature response factor* and ΔT the *temperature level*. The response factor for harvest data series in Trøndelag and neighbouring districts is shown in table 3.1.

Table 3.1 Results of simple linear regression analysis with the first date of harvest as predictor and mean temperature in May – August as predictand in Trøndelag and neighbouring districts. The response factor, α, is the regression coefficient and R is the regression correlation. N is the number of cases.

Municipality - Farm	District	Cereal	Response factor (α)	R	N
Oppdal – Vognill	Sør-Trøndelag	Barley	-0.0700	0.75	36
Gauldal – Kjellen	Sør-Trøndelag	Barley	-0.0760	0.87	17
Melhus - Øyrønningen	Sør-Trøndelag	Barley	-0.0696	0.88	49
Steinkjer – Brunstad	Nord-Trøndelag	Barley	-0.0713	0.98	12
Steinkjer – Brunstad	Nord-Trøndelag	Oats	-0.0660	0.91	8
Lesja – Synstbø	Dovre area	Barley	-0.1208	0.97	10
Lesja - Simenrud	Dovre area	Barley	-0.0721	0.78	39
Herøy – Frøystad	Sunnmøre	Barley	-0.0760	0.86	12
Herøy - Frøystad	Sunnmøre	Oats	-0.0745	0.78	13

The response factor for barley varies between -0.0696 and -0.0760 if the value for Synstbø is considered as an outlier. The response factor for Synstbø is not confirmed by the neighbouring farm Simenrud that overlaps the same instrumental observations for 39 years compared with only 10 years for Synstbø. Omitting the outlier, the temperature response factor seems not to vary much from farm to farm and can be assessed to about -0.07 °C/Day.

To avoid major inhomogeneities in the reconstructed long-term series, the shorter, individual series usually have to be adjusted for different temperature levels (ΔT in equation 3.1). These differences are due to different growing conditions at the farms like altitude of the field, height above the valley floor, distance to the sea, conditions of the soil on which the grain grows, and the orientation and slope of the field. Early and late varieties of the cereals may also be used resulting in different times needed for ripening (Nordli 2003). The temperature level can be derived by comparison of mean values for overlapping periods of harvest dates from different farms, after having performed a homogeneity test, see Ch. 2.2.

4 Reconstruction of temperature series (1701 – 2003)

The diaries from Trøndelag describe the starting harvest for fields at various altitudes, aspects and distances from the sea. As the temperature level varies (cf. equation 3.1) each series needs to be adjusted if the shorter series shall be nested together into one series. This is performed by simply applying constant adjustments terms. These are derived by overlapping periods between certain principal series, using the mean values of the differences. Four principal series are chosen according to their overlapping. These are Vognill, which overlaps well with modern instrumental observations, Kjellen, Groven and Storsjön.

Step 1: There are 38 overlapping years between the series Vognill and Kjellen (it was detected that AD 1862 was an outlier in the Kjellen data, and was removed from the series). The adjustment term for Kjellen that should be used to make the series valid for Vognill is denoted by ΔD_{VoKj}:

$$\Delta D_{VoKj} = D_{Vognill} - D_{Kjellen}\,, \quad D_{Vognill} = D_{Kjellen} + \Delta D_{VoKj} \qquad (4.1)$$

where $D_{Vognill}$ and $D_{Kjellen}$ are the mean start of the grain harvest during their common overlapping period. The adjustment turns out to be -5.4 days (table 4.1) and a homogenous series can be established back to AD 1805, the starting year of the Kjellen series.

Step 2: The Kjellen series has 6 overlapping years with the Groven series and 7 years with the Mo2 series, similarly as equation (4.1) the adjustment terms can be written:

$$\Delta D_{KjMo2} = D_{Kjellen} - D_{Mo2} \qquad D_{Kjellen} = D_{Mo2} + \Delta D_{KjMo2} \qquad (4.2a)$$

$$\Delta D_{KjGr} = D_{Kjellen} - D_{Groven} \qquad D_{Kjellen} = D_{Groven} + \Delta D_{KjGr} \qquad (4.2b)$$

By inserting (4.2a) and (4.2b) in (4.1) also the series from Groven and Mo2 can be adjusted to be valid for Vognill:

$$D_{Vognill} = D_{Mo2} + \Delta D_{KjMo2} + \Delta D_{VoKj} \qquad (4.3a)$$

$$D_{Vognill} = D_{Groven} + \Delta D_{KjGr} + \Delta D_{VoKj} \qquad (4.3b)$$

The adjustment terms are given in table 4.1. By using (4.3b) the series of harvest dates can be reconstructed back to 1733, whereas many gaps in the Groven series are filled by data from Mo using (4.3a) during the period 1790 to 1800. Only in AD 1804 both Mo and Groven had data.

Step 3: Data from Groven overlaps the Storsjön series from Jämtland by 19 years.

$$\Delta D_{GrSt} = D_{Groven} - D_{Storsjøen} \qquad D_{Groven} = D_{Storsjøen} + \Delta D_{GrSt} \qquad (4.4)$$

By inserting (4.4) in (4.3b) the data for Storsjön are adjusted to be valid for Vognill:

$$D_{Vognill} = D_{Storsjön} + \Delta D_{GrSt} + \Delta D_{KjGr} + \Delta D_{VoKj} \qquad (4.5)$$

The harvest dates for Storsjön have to be adjusted by -1.6 day to be valid for Groven (Table 4.1), and the total adjustment for Storsjön to be valid for Vognill is -8.8 days.

Table 4.1 Adjustment terms for farm a to be valid for farm b based on common overlapping periods. The standard deviations of the adjustment terms (s) as well as the number of overlapping years (N) are also shown.

Farm a adjusted	Valid for farm b	Terminology used in the equations	Adjustment terms, ΔD_{XxYy} (Days)	Standard deviation of the difference, s. (Days)	Overlapping years, N
Kjellen	Vognill	ΔD_{VoKj}	-5.4	6.6	38
Mo 1	Kjellen	ΔD_{KjMo1}	-9.1	9.0	17
Mo 2	Kjellen	ΔD_{KjMo2}	-6.7	4.8	7
Groven	Kjellen	ΔD_{KjGr}	-1.8	4.9	6
Langland	Groven	ΔD_{GrLa}	1.1	8.0	9
Storsjön	Groven	ΔD_{GrSt}	-1.6	9.5	19
Øyrønningen	Vognill	$\Delta D_{VoØy}$	-11.6	7.4	27

Step 4:
During the years 1816 – 1817 and the years 1767 – 1770 none of the principle series have data, but these gaps may be interpolated by the series Mo1 and Langland respectively by the equations (4.7) and (4.9).

$$\Delta D_{KjMo1} = D_{Kjellen} - D_{Mi1} \qquad D_{Kjellen} = D_{Mo1} + \Delta D_{KjMo1} \tag{4.6}$$

$$D_{Vognill} = D_{Mo1} + \Delta D_{KjMo1} + \Delta D_{VoKj} \tag{4.7}$$

$$\Delta D_{GrLa} = D_{Groven} - D_{Langeland} \qquad D_{Groven} = D_{Langeland} + \Delta D_{GrLa} \tag{4.8}$$

$$D_{Vognill} = D_{Langeland} + \Delta D_{GrLa} + \Delta D_{KjGr} + \Delta D_{VoKj} \tag{4.9}$$

The adjustments for the series from Mo1 and Langland to make them valid for Groven and Kjellen are -9.1 days and +1.1 days respectively (table 4.1). To be valid for Vognill the Mo1 series has to be adjusted -14.5 days (equation 4.7), and Langland has to be adjusted -6.1 days (equation 4.9).

By using the adjustment terms above a composite series of homogenised first day of harvest dates is established back to 1701 with only a few missing years. When there are more than one data source for the same year, the priority among the farms are: 1) Vognill 2) Kjellen 3) Groven 4) Mo1 5) Storsjön 6) Mo2 7) Langeland. The farm Øyrønningen was not used.

The farm Vognill has 24 overlapping years with modern instrumental observations in Trondheim in the period 1870 – 1894. However, Rosenvinge's observations starting in 1858 have shown to be much reliable and have been used also in earlier works (Nordli 2001a). By adding them to observations carried out by the Meteorological Institute, the overlapping between instrumental and proxy data consists of 36 years in the period 1858 – 1894. The spread diagram and regression line is shown in figure 5.1. The regression correlation was 0.75 and the RMSE was 0.71 °C derived by "leaving one out" cross-validation. The temperature response factor was -0.070 ±0.011.

Alternatively there is also a possibility to use all available data for the reconstruction. After having adjusted all series to be valid for Vognill, the mean value of all adjusted harvest dates is used to establish a series of homogenised harvest dates. In this case also Øyrønningen is used and the overlapping with the Trondheim (Værnes) series comprises 42 years during the period 1858 – 1900. The harvest dates used in the regression originate from the farms Kjellen, Vognill and Øyrønningen (figure 5.2). At about AD 1900 research on the cereals was started that might have changed the times of ripening of the cereals in use (Nordli 2003). Later harvest dates than AD 1900 are therefore omitted from the regression analysis.

By using all harvest dates the regression correlation increased from 0.75 when Vognill was used as the only farm, to 0.86 when all available data were used. The main reason is not different overlapping intervals (not shown), but the fact that Kjellen and Øyrønningen correlate better with Trondheim than Vognill. This should also be expected according to the distance to the city, and also according to the topographical position of Vognill. Vognill lies in the Oppdal mountain valley, while Kjellen and Øyrønningen are both situated at lower altitudes than Vognill. The RMSE of the residuals was 0.52 °C derived by leaving one out cross-validation, which is appreciably less than when only Vognill was used. The temperature response factor was -0.074 ±0.007 ($p = 0.05$).

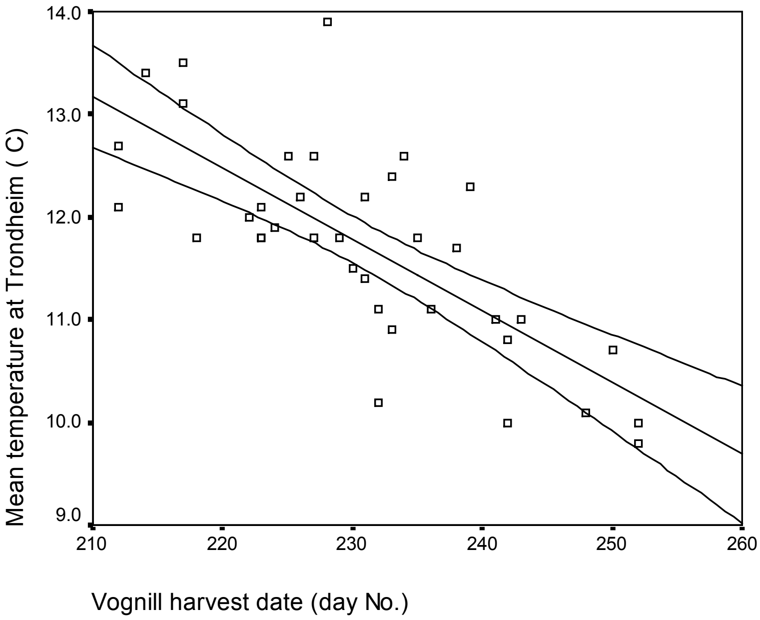

Figure 5.1 Spread diagram for spring/summer temperature (May – August) for the Trondheim (Værnes) series and the first day of harvest at the farm Vognill during the period 1858 - 1894. In the diagram also the regression line is shown, and the 95 % confidence level for this line.

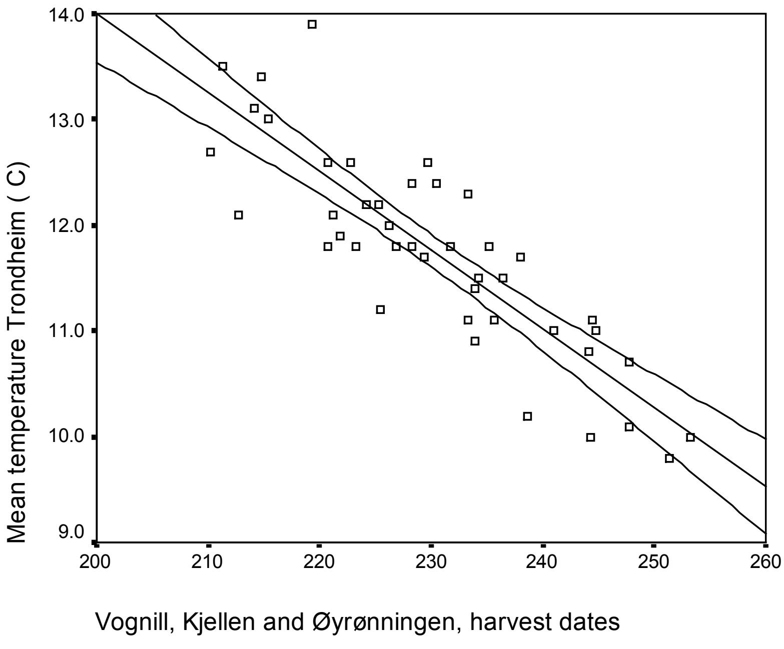

Figure 5.2 Spread diagram for spring/summer temperature (May – August) for the Trondheim (Værnes) series and a homogenised series of the first harvest days at the farms Kjellen, Vognill and Øyrønningen during the period 1858 - 1900. In the diagram also the regression line is shown, and the 95 % confidence level for this line.

The two reconstructions differ a lot in some years as shown in figure 5.3, and for the common period of reconstruction, 1701 – 1894, the mean difference is 0.26. The reconstruction using all diaries is the warmest one. For further work, the reconstruction based on all diaries is chosen because of its smaller RMSE.

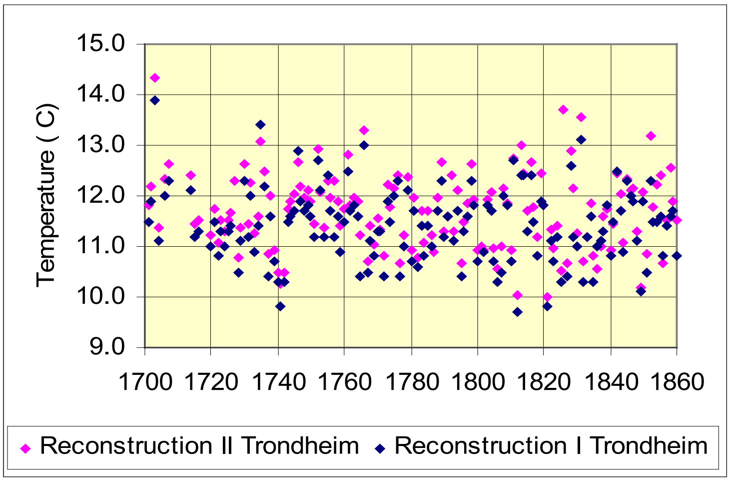

Figure 5.3 Reconstruction of Trondheim temperature series. Reconstruction II: Based on all available grain harvest data each year. Reconstruction I: based on one series each year, see text.

After having used all available diaries, there are still some missing years:
1705, 1708 – 1713, 1717 – 1719. Before 1722 neither instrumental observations nor additional farmers' diaries exist in Scandinavia, and these 10 missing years are not interpolated. The other missing years are interpolated by instrumental data, using only a limited number of years on each side of the missing value, not letting the interpolated values influence the long-term trends of the proxy series.

1727: Interpolation by Uppsala, 1722 – 1737
1761: Interpolation by Uppsala, 1751 - 1771
1787, 1792, and 1801: Interpolations by Fester's series at Trondheim, 1780 - 1802
1826: Interpolations by Vibe's first series at Trondheim, 1818 - 1827

By inserting the six interpolated values, the series is complete since AD 1720. In the period 1701 – 1719 half of the values are missing. The reconstruction indicates high temperatures for this period, but the lacking years should be kept in mind. If the lacking years are colder than those present the series is biased too warm. According to the reconstruction the warmest summer has occurred very recently, AD 2002. This summer can now be seen in the context of the 293 previous summers. It is remarkably warm, being 0.9 °C warmer than the second warmest (1937). The next ones on the list of warm summers are those in 1703 and 1930. The first one is based on proxy data and its estimate is less reliable than those based on instrumental observations.

The coldest summers seem to be those in 1864 and 1923, but some reconstructed summer temperatures are very near to be as cold as the two mentioned, and taking the errors of the reconstruction into account, they might in reality be colder.

Looking at decadal variations (red curve in figure 5.4), warm spells occur in the end of the series and in the 1930s, and maybe also at the beginning of the series. Cold spells are present particularly in the early 1740s and in the 1860s. These periods are well known to historians also as years of famine (Pontoppidan 1752; Jantunen and Rostenoja 2000). During the early years of the Dalton solar spots minimum (1795 – 1830) the Trøndelag temperatures were very low, but within this period there was also a local maximum, around 1815. The eight years from the late Maunder minimum period (1675 – 1715) represented in the reconstruction was also warm.

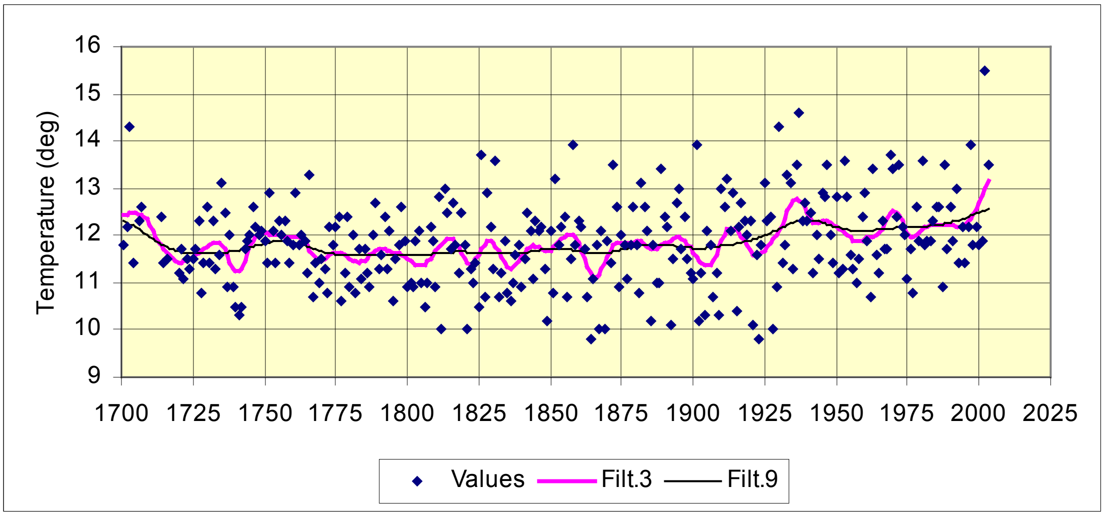

Figure 5.4 Mean spring/summer temperatures (May – August) for Trøndelag. In the period 1701 – 1857 the series is reconstructed by proxy data, since 1858 the series consists of instrumental observations. The whole series is made valid for the currently run station *69100 Værnes*. Individual years are represented by dots (Values) 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 filters suppress variations on time scales shorter than approximately 10 and 30 years.

Significant linear trend for the whole period is +0.6 °C or 0.2 °C per century. For the 18th century the trend is negative (-0.4 °C), whereas the trends during the 19th and 20th centuries are positive, 0.3 °C and 0.5 °C respectively. The accuracy of the derived trend during the 18th century may be poorer than during the other centuries due to the missing 10 summers at the start of the series.

6 The errors of the applied method

When the shorter series stepwise was nested together in order to establish one long-term series, it is a challenge to keep the series homogeneous through each step of nesting. Equation (4.1) used for reconstruction of temperature during the period 1805 – 1857 contains only one adjustment term, whereas equation (4.5) used for reconstruction during the period 1701 – 1766 contains three adjustment terms. The reconstruction of temperature at the early period has therefore larger errors than the reconstruction at the later period.

If the differences between the harvest days for two farms are assumed not to be serial correlated, the standard deviation of the mean differences, $s_{D,\ mean}$, can be calculated by the formula:

$$s_{D,mean} = \frac{s_D}{\sqrt{N}} \qquad (6.1)$$

where s_D is the standard deviation of the difference and N is the number of cases (summers). The parameters s_D and N listed in table 4.1 can be inserted in equation (6.1). The results of the calculation (table 6.1) show that $s_{D,mean}$ varies from about 1 day to almost 3 days.

Table 6.1 Standard deviations, S_{Dmean}, of the adjustment terms for the series of harvest dates. The symbols are explained in the beginning of Ch. 4. The standard deviation of the adjustment terms are also transformed to temperature by a response factor of -0.07 °C/day (S_{Tmean}).

N	ΔD_{VoKj}	ΔD_{KjMo1}	ΔD_{KjMo2}	ΔD_{KjGr}	ΔD_{GrLa}	ΔD_{GrSt}
$S_{D\ mean}$ (Days)	1.07	2.18	1.81	2.00	2.67	2.18
$s_{T\ mean}$ (°C)	0.07	0.15	0.13	0.14	0.19	0.15

Generally the standard deviation of a sum is given by equation (6.2) under the assumption that the adjustment terms are not correlated. The formula can be used for calculating the standard deviation of the sum of adjustment terms in formulas 4.1 to 4.9.

$$s_{sum} = \sqrt{\sum_{k=1}^{n} s_k^2} \qquad (6.2)$$

S_k is the standard deviation of the k^{th} adjustment term, while n is the number of terms. For example the standard deviation of the sum of adjustments for the Storsjön series to be valid for Vognill, three adjustment terms are needed: ΔD_{GrSt}, ΔD_{KjGr}, and ΔD_{VoKj}. By using the values from table 6.1 in equation (6.2), S_{sum} = 0.24 °C. Under the assumption that the sum is normally distributed, the p = 0.05 confidence interval is 0.9 °C. For the later part of the reconstruction the standard deviations are less (table 6.2).

Table 6.2 The standard deviation of the sum of adjustment terms used for the reconstruction of the Trøndelag series. The corresponding confidence interval of the sum is also given.

Reconstruction by the diaries of:	Standard deviation (°C) of the sum of adjustment terms	Confidence interval (°C) of the sum of adjustment terms
Mo2, Kjellen (4.3a)	0.15	0.6
Groven, Kjellen (4.3b)	0.16	0.6
Storsjön, Groven, Kjellen (4.5)	0.22	0.9
Mo1, Kjellen (4.7)	0.17	0.7
Langland, Groven, Kjellen (4.9)	0.25	1.0

An error of the adjustment terms does not affect only individual cases, but all cases from a particular farm used in the reconstruction. Thus, these errors might also influence the long-term variability and trends in the reconstructed series. In the start of the series the data originate from Lake Storsjön district in Jämtland. Within the confidence interval the reconstructed temperature might be assessed 0.45 °C too high or too low according to the confidence interval.

The estimated errors of the adjustment terms were performed under the assumptions that the series of harvest dates are strictly homogenous. Though homogeneity is tested, the material of diaries is rather small and the overlapping varies in length. In particular the overlapping between the late 18th and the early 19th centuries is weak, comprising only 6 summers of the Kjellen and Groven farms. This overlapping is very crucial for the reconstruction of the 18th century temperatures.

To come closer to this problem of poor overlapping, the method is tested by using some long neighbouring series from various parts of the country. Periods of six summers were chosen for calibration of the differences between the series, whereas all remaining, overlapping summers were chosen as validation periods. For example the harvest dates from Vognill and Øyrønningen overlap during the period 1855 – 1894 by 27 summers. Among these 27 differences it is possible to select 4 periods of 6 consecutive summers, and derive 4 adjustment terms. The validation is performed on the remaining 21 summers. The positive, mean difference between observed and calculated harvest data is called the bias of the method. Altogether 44 calibration periods of 6 summers were available for testing.

The biases are shown in the histogram (figure 6.1). The mean bias is 2.5 days and the standard deviation is 2 days. This is quite acceptable as 2.5 days transformed into May – August temperature gives a bias of about 0.2 °C. It is, however, 3 cases (7 %) with biases of 0.5 °C or more, and if errors of this magnitude are present in the reconstruction, the real long-term temperature trend of the series will be jeopardized by the artificial trend. The largest bias (9.5 days or about 0.7 °C) is present when the harvest dates from Kjellen and Synstbø are compared, with the summers 1820 – 1825 as the calibration period. The distance between Kjellen and Synstbø is less than 150 km but the two farms are situated in different climate regimes, Dovre mountain areas and Trøndelag respectively. Real climate differences might be the reason for this large bias, which means that for this particular pair of farms the method should not be applied.

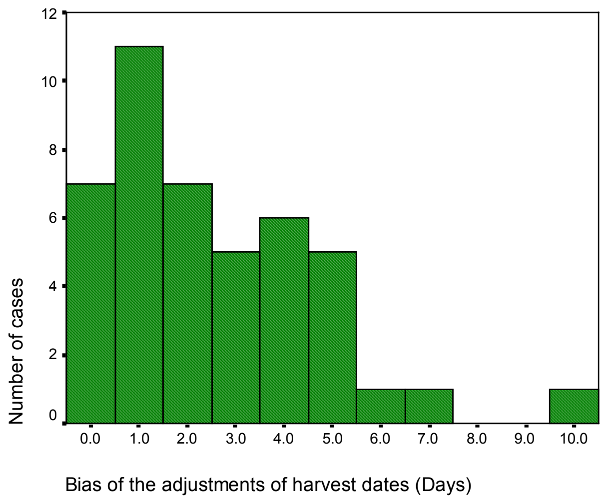

Figure 6.1 Biases of the adjustment terms based on overlapping periods of 6 summers. Further explanations are to be found in the text.

7 Discussion

The composite spring-summer temperature series of Trøndelag (proxy data 1701 – 1857, instrumental data 1858 – 2003) might be compared to the composite series of Vestlandet (proxy data 1734 – 1867, instrumental data 1868 – 2003) published by Nordli et al (2003). The Trøndelag series shows increased temperature during the data period, which comprises all years but 10 since AD 1701. But during the first century of the reconstruction (1701 – 1800), the temperature has decreased. Similar qualitative results can be seen for the Vestlandet series, which is based on diaries and historical, frontal glacial moraines, but this series is not available further back than AD 1734.

In both composite series (Trøndelag and Vestlandet) there are local maxima in the 1750s (figure 7.1a) followed by decreasing temperature towards the end of the century culminating with a cold spell in the beginning of the 19th century. The negative trend is also seen in instrumental data from Uppsala in Eastern Sweden during this period (figure 7.1b).

Comparing the reconstructions during the 18th century (or more precisely the period 1734 – 1800, where the composite series and the instrumental Uppsala series all are available) with the temperatures during the 20th century, both composite series show an increased temperature, whereas the Uppsala series shows a decreased temperature. The decrease of the Uppsala series is -0.2 °C according to the homogenisation of Moberg et al (2003). Compared to the increase of the Trøndelag series by 0.4 °C, there is a discrepancy of 0.6 °C.

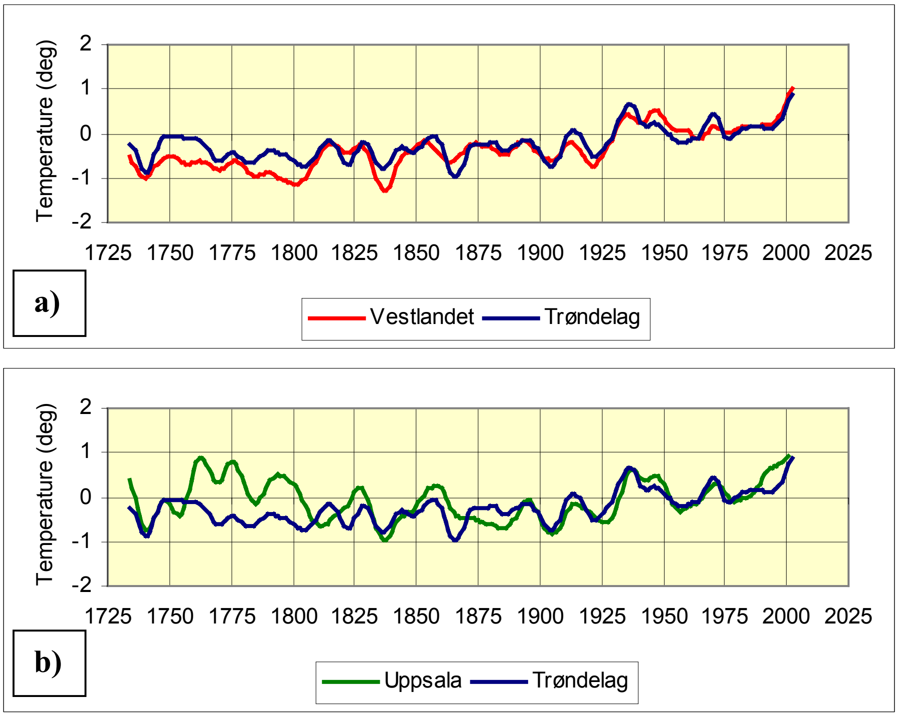

Figure 7.1 The Trøndelag series (instrumental since 1858) compared to the Vestlandet series (**a**) (instrumental since 1868), and Uppsala series (**b**) (all instrumental). All series are filtered by a Gaussian filter with standard deviation 3 years in its distribution during the period 1734 – 2000.

Different temperature evolution between Eastern Sweden and Trøndelag might occur, but the differences might also be caused by poor overlapping between the diaries at the end of the 18th century and the beginning of the 19th century. An investigation of the method using calibration and validation periods was performed. The result showed that in 3 out of 44 reconstructions (7 %) biases amounted to of 0.6 °C or larger (figure 6.1). Thus, the possibility that the difference between Eastern Sweden and Trøndelag is an artefact can not be excluded, but is not very likely.

During the 19th century the maxima and minima of the Trøndelag and Vestlandet series are located to the same decades. The maxima are situated around 1820, 1850s, 1870s, and 1890, whereas the minima are located to the first decade of the century, the late 1830s, 1860s, and

1880s. This correspondence, which previously only has been studied during the modern instrumental period, is also seen in the period of reconstruction, and seems to be stationary. However, the 1860s seem to have been much more severe in Trøndelag than in western Norway, whereas the late 1830s seem to have been less severe.

There exists also a tree ring series from the Femunden area, south eastern Trøndelag established by Brundin (1999). As the trees in the investigation were taken near the tree limit, their growth is strongly temperature dependant. Comparing the tree ring series to the Trøndelag series one should have in mind that the tree rings reflect July or perhaps also August temperatures only, whereas the Trøndelag series comprises the May – August period. However, the tree ring curve shows much of the same temporal variations as the grain harvest curve, with cold spells in the 1740s, first decade of 1800, and in the late 1830s. The cold spell of the 1860s is less pronounced in the tree ring data than in the harvest data.

The extraordinary warm summer of AD 1703 is confirmed also by the tree ring data, but no local maximum is seen in the filtered three ring curve during the first decade of the 18th century. The maximum of the Trøndelag series during those years might therefore be an artefact due to many missing harvest data. However, a maximum of the 1730s of the Trøndelag series is present also in the tree ring curve.

The Little Ice Age (LIA) was introduced as a period of far advanced glaciers compared with nowadays and earlier positions (Grove 1988). Temperature has been variable during the period, but mainly lower than at present (Jones and Bradley 1992). The Trøndelag series starts within the LIA, and shows mainly low temperatures during the 18th and 19th centuries and also in the first two decades of the 20th century. Thus, the LIA seems to be terminated in the 1920s by the so called "early 20th century warming". Exactly when the LIA ends has been disputed, but ending in the 1920s is rather late compared to the most common use of the term, i.e. AD 1800 - 1850 (Ogilvie and Jónsson 2001).

8 Conclusions

By use of a linear model, spring-summer temperature could be reconstructed for Jämtland and Trøndelag back to AD 1701, and the reconstruction was fitted together with the instrumental Trondheim (Værnes) series. The composite series was called the Trøndelag series due to the origin of the diaries from many sites mostly in Trøndelag. During the 19th century the method gave an RMSE error of 0.5 °C for the reconstructed, individual summers by "leaving one out cross-validation".

A significant, linear trend of the whole series was estimated to +0.6 °C (+0.2 °C per century). However, long-term trend estimation is hampered by poor overlapping between individual harvest series in between the 18th and the 19th centuries. A study of the method using all available diaries was performed. Errors of 0.5 °C or larger occurred in 3 out of 44 cases. Thus, there is a risk that this kind of errors can bias the long-term inter-centennial trends involving the 18th century.

The trends within individual centuries differ much from each others. During the 18th century the trend was negative (-0.4 °C), whereas the trends were positive during the 19th and 20th century, +0.3 °C and +0.5 °C respectively.

By using a Gaussian, decadal, low pass filter the Trøndelag series and an earlier derived Vestlandet series were compared. The maxima and minima in the two series were located in the same decades. Historically severe climatic decades described in narrative sources like the early 1740s, the first decade of the 19th century, the late 1830s, and the 1860s, also show low temperatures in the reconstructed series. The 1860s seem to have been much more severe in Trøndelag than in western Norway whereas the late 1830s seem to have been less severe.

Even if errors of the temperature reconstruction are taken into account, it might be concluded that the summer AD 2002 is the warmest ever since the start of the series 300 years ago.

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