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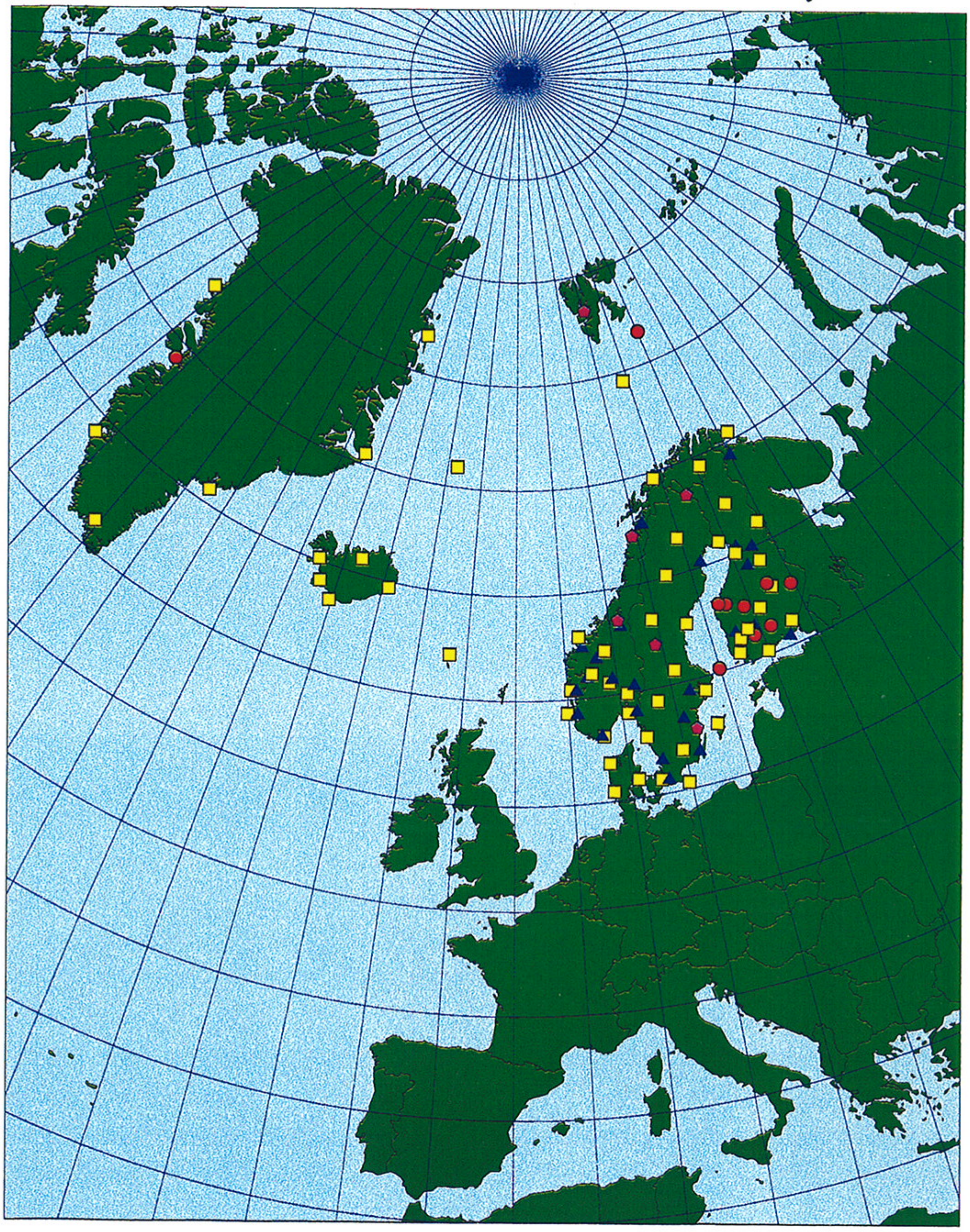
REWARD: - Relating Extreme Weather to Atmospheric circulation using a Regionalised Dataset.

Adjustment of Norwegian monthly means of daily minimum temperature

REPORT NR: 06/97

Per Øyvind Nordli



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Adjustments of Norwegian monthly means of daily minimum temperature

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ABSTRACT
At the Norwegian Meteorological Institute (DNMI) the procedure for calculation of mean monthly minimum temperature was changed 1 January in the years 1894 and 1938. By use of the old procedures on modern, digitised data and by internal testing by the Standard Normal Homogeneity Test, adjustment terms for old data were assessed. The adjustments varied by time of the year, latitude and climate (continental - maritime).

Procedure **prior to 1894**: For all stations the largest adjustments occurred in winter, at continental stations -3°C to -1.5°C, and at coastal or maritime stations about -1°C. The magnitude of the adjustments in summer was about -0.2°C, which is thought to be less than the influence of undetected inhomogeneities from other sources. Spring and autumn can be regarded as transition zones between the high adjustments in winter and the low ones in summer.

Procedure **1894 - 1937**: For all stations but one in Arctic, two local maxima occurred, one in spring being somewhat larger than the other one in autumn. The magnitude of the spring maximum was 1°C to 1.5°C at continental stations, 0.6°C to 0.8°C at stations situated in inner fjords, and 0.1°C to 0.5°C at stations situated in coastal districts. The magnitude of the summer minimum varied from zero to 0.3°C and the winter minima was near zero at all stations. In Arctic the adjustments seemed to be close to zero with an exception for the spring maximum at Svalbard Airport (0.5°C in April).

Changing procedures for calculating monthly mean of extreme temperatures may be a source of inhomogeneity in the series from several counties. Having been addressed by participants at IMO conferences at more than one occasion, it is very likely that this kind of inhomogeneity is not attributed to the Norwegian series only.

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Adjustments of Norwegian monthly means of daily minimum temperature

1 Introduction

The ongoing discussion in connection of the enhanced greenhouse effect on climate obviously has increased the interest for climatic time series. Most papers concerning climatic change deals with mean temperature. It has, however, been shown (e.g. Karl et al. 1993; Brázdil et al. 1996) that trends in the time series of maximum and minimum temperature do not correspond to those of mean temperature. Therefore a study of the time series of extremes increases our knowledge of climatic change.

Trends and variability may be masked by inhomogeneities of the series and consequently the series should be tested for inhomogeneity and if necessary adjusted. For Northern Europe this was done during the project period of the "North Atlantic Climatic Dataset (NACD)" (Frich et al. 1996). In the running REWARD project the test results from NACD will be adopted. However, special inhomogeneity problems of the extremes should be taken into account. One such problem is the changes of the observation hours of minimum temperature in the Norwegian network that took place in 1893-94 and 1 January 1938 which led to changed definition of the "minimum temperature day".

This report deals with approaches to quantify adjustments for these inhomogeneities in order to establish homogenised long-term series of minimum temperature.

2 Observational practise of minimum temperature in the Norwegian network

The minimum thermometer was introduced to all stations in the Norwegian network already in the autumn 1875. Before 1893 the index of the thermometer was set at 20^h and read at the morning observation at 8^h, local time or Christiania Time[1]. Thus the thermometer was not in operation the whole day and consequently daily minimum temperature was neither observed nor calculated. Only the nightly minimum temperature was observed.

However, mean nightly minimum temperature was not stored in the monthly summaries. A rather peculiar procedure, seen from the point of view of modern climatologists, was practised. Nightly minimum was only adopted in the summaries at the nights when the minimum temperature was lower than the evening and morning temperatures. If not, a graphical interpolated temperature was adopted as the "night" temperature. From the nightly minima and "night" temperatures an arithmetic mean was calculated called the mean monthly minimum temperature.

It is difficult to understand the reason for this practise. It can definitely not be understood by the concept of minimum temperature only. The practise seems to have been initiated by a desire of accurate mean temperature. The following reason is suggested: The two time intervals between the observation hours 8^h, 14^h and 20^h had equal length. The night interval, however, was twice as long as the other ones. This was (and is) obviously a problem for mean temperature calculations, not only because of its length but also because of the fact that the lowest temperature during the day tends to fall in this interval, making linear interpolations useless. Thus, the lowest temperature was measured by the minimum thermometer and if the minimum did not occur during night, temperature at the desired observation hour (2^h local time) was graphically interpolated. A passage in the preface of the yearbooks 1876 - 1890 strongly supports the interpretation made here, see e.g. Mohn (1878, page IX).

Compared to the present practise the minimum temperatures in the monthly summaries before 1893 are biased too high, as they do not consist of "real" daily minimum temperatures. Thus, time series should be negatively adjusted to obtain homogeneity if not larger adjustments for other reasons are required.

1 January 1893 the practise was changed. The index was set at the observation at 8^h. However, not all of the observers adopted this new practice at once, but from 1 January 1894 the new instructions were followed at all stations (Harbitz, 1963). Thus the daily minimum temperature was defined as the lowest temperature from 08^h one day to 08^h next day.

The new practise was not without weaknesses, especially at spring and autumn, as the minimum temperature often occurred near the hour of the morning observation. A cold night in between two milder ones contributed twice to the mean monthly

[1] Christiania time was local time at Christiania, a former name of Oslo. This city was founded around 1000 with the name Oslo, but the name was changed 1624 under the Danish government. In 1924 the city got back its original name.

minimum and a mild night in between two colder ones did not contribute at all. In Fig. 1 for example, the first cold night contributes to the daily minimum also the second day.

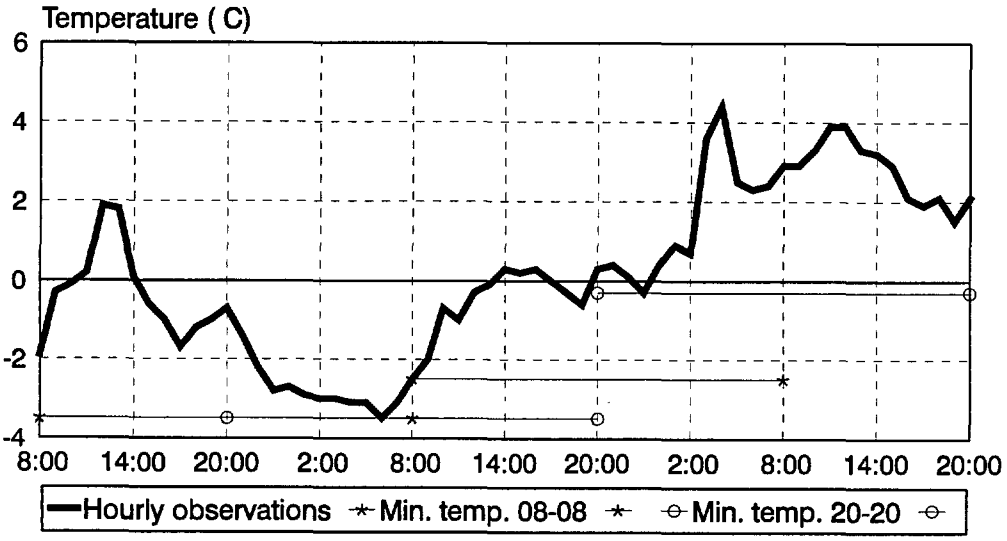


Fig. 1. Hourly observations 6 - 8 March 1994 from a test field for temperature at Dombås (62° N, 9° E). Two definitions of the minimum temperature day, 08 - 08 and 20 - 20, are illustrated by lines. Both definitions lead to equal results for 7 March which includes a cold night, but to different results the following day which includes a mild night.

There is historical evidence of opposition against termination of the day at the morning observation. To the International Meteorological Conference in Munich in 1891 (Scott 1893), Mr. A. L. Rotch from the Blue Hill Observatory in Readville, Mass., USA asked. "Is it not to be recommended that maximum and minimum thermometers should be generally set and read at an epoch when the temperature is as normal as possible; for example 6 p.m. and 9 p.m.?". Unfortunately the proposal was not approved by the conference, mainly due to practical difficulties in some countries. However, the conference stated "that it is of paramount importance to give in every case the hour at which the maximum and minimum thermometers are read and set".

It should last until the Warsaw Conference in 1935 before a change of practise was approved (IMO, 1935). "Extreme thermometers should be read at the morning and evening observations, but set only in the evening " (translated from German). Thus, the Norwegian practise was not in agreement with the resolution.

It is very likely that a change of practise in Norway, which took place 1 January 1937, was initiated by the resolution. The thermometer should now be read and set twice a day, at the morning and evening observations, i.e. 08^h and 19^h CET. The confusion of 1893 was avoided by following the old practise in the monthly summaries during 1937. But from 1 January 1938 also the definition of daily minimum temperature was changed. Now the daily minimum was taken as the lowest temperature in an interval starting at 19^h one day and ending at 19^h next day. This is also in agreement with the present definition.

If the occurrence of minimum temperature was randomly distributed throughout the day, a change of the observation hours would not cause any biases in the monthly mean minimum temperature. However, this is true (or almost true) only in the Arctic and in Northern Norway during winter. In Southern Norway and in the other seasons it is more likely that the daily minimum is located near the morning than the evening observation. Therefore the monthly mean minimum based on the daily interval from 8^h to 8^h is biased too cold compared to that from 19^h to 19^h. Thus, to homogenise minimum temperature series positive adjustment terms should be applied to the series in the period 1894 - 1937 if not adjustments for other reasons are required.

3 Previous definitions of minimum temperature day applied on modern data (PDMD).

It would have been desirable to apply the present algorithm also on the old part of the series and thereby eliminate one risk for homogeneity breaks. This is, unfortunately, not possible (except during 1937) because of the lack of evening observations. It would also have required digitised daily observations which are only available since 1957 for all stations and from 1951 for some long series.

It is, however, possible to do the opposite, to use the previous definitions on the latest parts of the series. Comparing the results to the official values would give adjustment terms that could be used on the old data. Ideally these adjustments should vary from year to year. However, based on data subsets of the series of 39 or 45 years, representative mean adjustments are expected to be found. Applying these to the old part of the series, the homogeneity would be appreciably improved. The method will hereafter be called PDMD (Previous Definitions applied on Modern Data).

The oldest procedure, used before 1894. A problem is immediate encountered by using the oldest procedure, - the lack of a precise guideline for the interpolation of the 2^h temperature. In the yearbooks Mohn (see e.g. 1878) used the term «interpolation» while Birkeland (1935) and Harbitz (1963) used «graphical interpolation». However, daily values from some stations are published in the yearbooks where the interpolated values are printed in italics. Some of these are closer to the evening temperature than to the morning temperature and vice versa. In some cases the deviations from linearly interpolated values may be large.

However, no apparently bias to linearity is seen in the material, and as a first approximation linear interpolation is used in the PDMD calculations. To come closer to this problem would require digitisation or manual calculations which is beyond the scope of this report

As nightly interval is used 19^h - 07^h CET. This does not exactly correspond to the most common interval 20^h - 08^h local time. Best correspondence is obtained for Karasjok (19^h18'- 07^h18'), poorest for Utsira (20^h40'- 8^h40').

The results obtained by using the oldest procedure are shown in Fig. 3 and in table 1. The series represent different climates and they are scattered from 58°N to 70°N. No series from Arctic areas is present due to the fact that no regular observations took place in the region before 1894.

The calculations reveal the same pattern for all stations, a minima during summer and a maxima during winter, Fig 3 a-d. During the summer months the adjustments for most of the stations are about -0.2°C, which are almost negligible compared to other reasons for inhomogeneity, e.g. relocations and changed environment (Nordli, 1996). However, for the two stations Færder and Vardø, the adjustments during

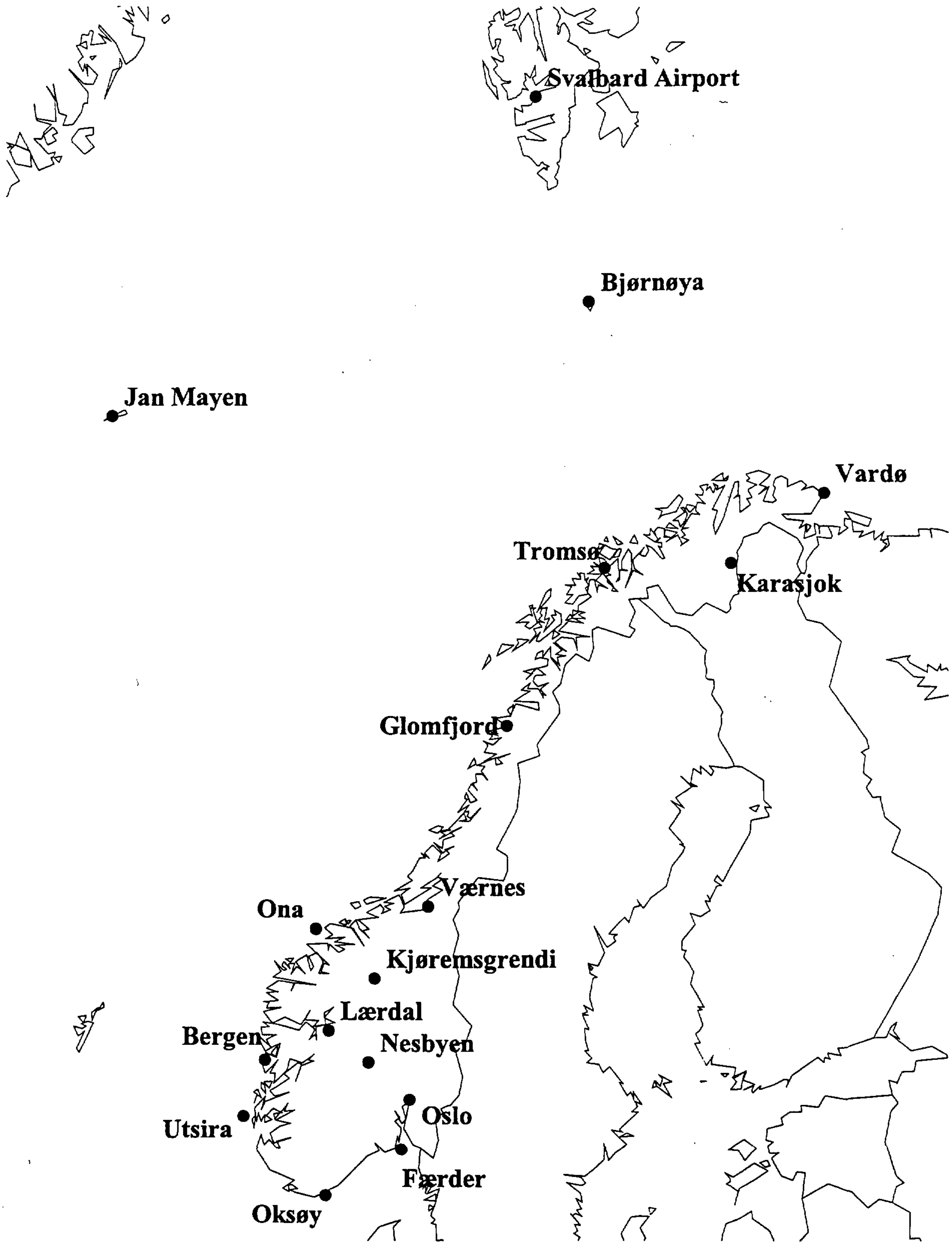
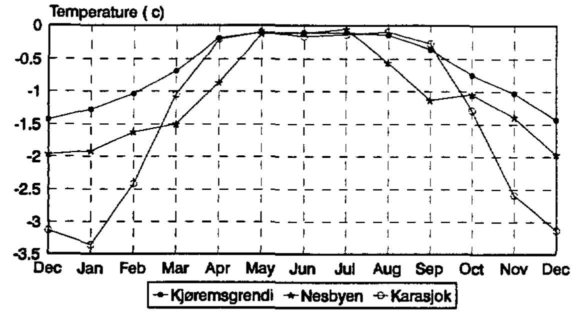
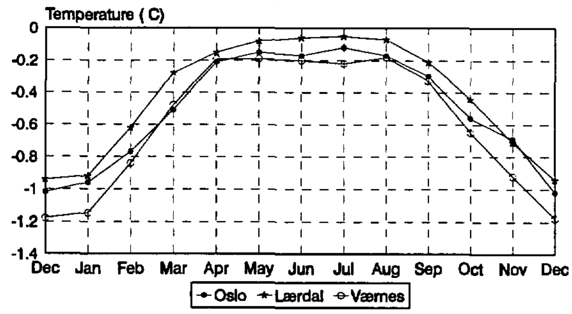


Fig. 1. Station map.

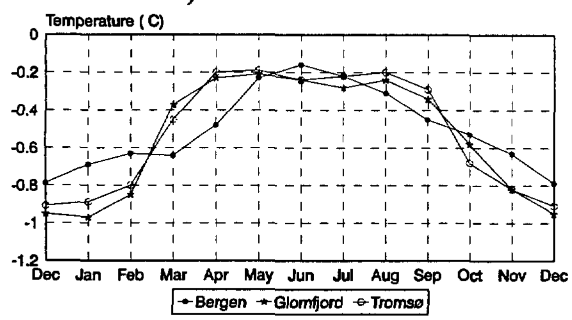
a) Continental stations



b) Inner fjord stations



c) Coastal stations



d) Stations on small islands

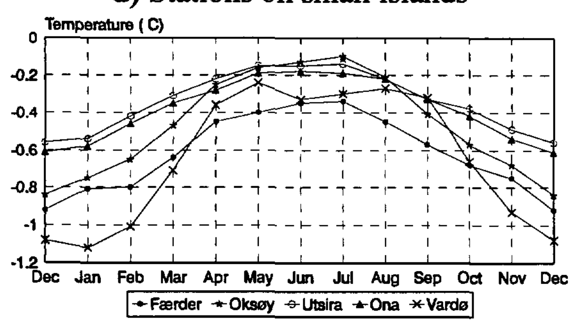
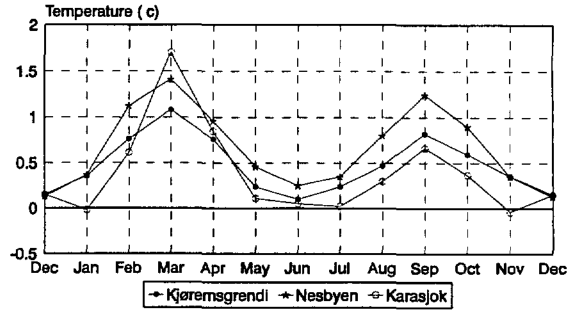
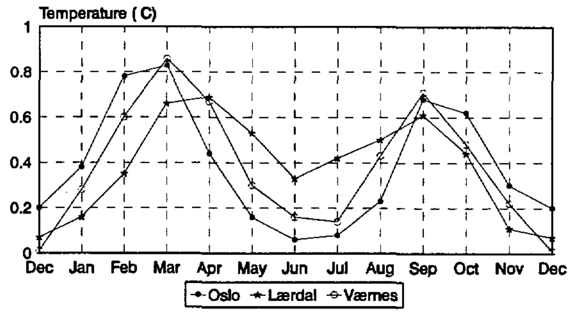


Fig. 3 Mean monthly differences between daily minimum temperature computed according to different definitions.
a - d) The present definition minus the one used prior to 1894.
e - i) The present definition minus the one used during the period 1894 - 1937.
Data coverage is 39 or 45 years.

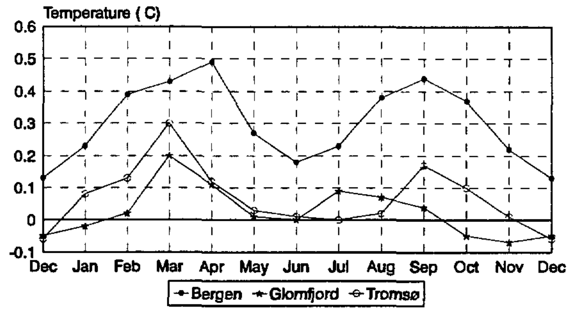
e) Continental stations



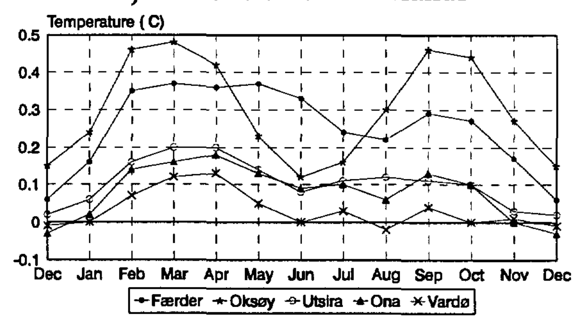
f) Inner fjord stations



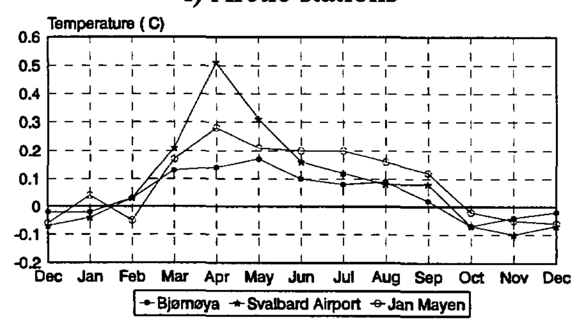
g) Coastal stations



h) Stations on small islands



i) Arctic stations



summer are somewhat larger, about -0.4°C in June. These stations are located on small islands.

Table 1 Mean differences between daily minimum temperature calculated according to the procedure in current use minus the one in use prior to 1894. Data coverage is 39 (1957 - 1995) or 45 (1951 - 1995) years. Std denotes the standard deviation of the mean value. All adjustments larger than ±0.1°C are significant (Student's T-test with significance level 0.05).

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kjørems-	Mean	-1.28	-1.04	-0.69	-0.19	-0.11	-0.11	-0.11	-0.15	-0.36	-0.75	-1.03	-1.43
grendi	Std	0.06	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.05
Oslo	Mean	-0.96	-0.77	-0.51	-0.21	-0.15	-0.17	-0.12	-0.17	-0.30	-0.56	-0.69	-1.02
	Std	0.04	0.04	0.04	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.03	0.05
Nesbyen	Mean	-1.92	-1.62	-1.50	-0.87	-0.13	-0.12	-0.06	-0.56	-1.14	-1.05	-1.39	-1.97
	Std	0.06	0.11	0.13	0.12	0.03	0.02	0.01	0.13	0.16	0.10	0.07	0.08
Færder	Mean	-0.81	-0.80	-0.64	-0.45	-0.40	-0.35	-0.34	-0.45	-0.57	-0.68	-0.75	-0.92
	Std	0.04	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04
Oksøy	Mean	-0.75	-0.65	-0.47	-0.25	-0.16	-0.13	-0.10	-0.21	-0.41	-0.57	-0.68	-0.84
	Std	0.04	0.05	0.04	0.03	0.02	0.02	0.01	0.02	0.04	0.04	0.03	0.04
Utsira	Mean	-0.54	-0.42	-0.31	-0.22	-0.15	-0.15	-0.14	-0.22	-0.33	-0.38	-0.49	-0.56
	Std	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Bergen	Mean	-0.69	-0.63	-0.64	-0.48	-0.23	-0.16	-0.22	-0.31	-0.45	-0.53	-0.63	-0.79
	Std	0.03	0.03	0.04	0.04	0.02	0.02	0.03	0.04	0.04	0.03	0.03	0.03
Lærdal	Mean	-0.92	-0.62	-0.28	-0.15	-0.08	-0.06	-0.05	-0.07	-0.21	-0.44	-0.71	-0.94
	Std	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.02	0.03	0.03	0.03	0.04
Ona	Mean	-0.58	-0.46	-0.35	-0.28	-0.19	-0.18	-0.19	-0.22	-0.33	-0.42	-0.54	-0.61
	Std	0.02	0.03	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03
Værnes	Mean	-1.15	-0.84	-0.48	-0.19	-0.19	-0.20	-0.22	-0.18	-0.33	-0.65	-0.92	-1.18
	Std	0.06	0.05	0.04	0.02	0.02	0.02	0.03	0.02	0.03	0.04	0.04	0.06
Glom-	Mean	-0.97	-0.85	-0.37	-0.23	-0.21	-0.24	-0.28	-0.24	-0.34	-0.58	-0.82	-0.95
fjord	Std	0.04	0.04	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.03	0.04	0.04
Tromsø	Mean	-0.89	-0.80	-0.45	-0.20	-0.19	-0.24	-0.22	-0.20	-0.29	-0.68	-0.82	-0.91
	Std	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.04	0.04
Kara-	Mean	-3.36	-2.42	-1.05	-0.21	-0.10	-0.17	-0.14	-0.10	-0.28	-1.29	-2.59	-3.13
sjok	Std	0.14	0.09	0.07	0.02	0.01	0.03	0.02	0.01	0.02	0.07	0.10	0.18
Vardø	Mean	-1.12	-1.01	-0.71	-0.36	-0.24	-0.33	-0.30	-0.27	-0.32	-0.66	-0.93	-1.08
	Std	0.04	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.04

In winter the magnitude of the adjustments differ considerably for individual stations, the major factor involved seems to be continentality. Thus, the series from the two stations situated on the floors of inland valleys, Karasjok and Nesbyen, are subject to huge adjustments. Large adjustments are also required at Kjøremsgrendi (Dombås), an inland station situated on the valley side. The adjustments at the other stations are smaller, about 1°C in midwinter for most of the stations, but only about 0.6°C at two stations situated on small islands in Western Norway, Utsira and Ona.

At the stations in Northern Norway, the transition zone in spring and autumn between small and large adjustments is more narrow than in Southern Norway.

The procedure in use 1894 - 1937 . The results obtained by using the procedure practised 1894 - 1937 are shown in Fig. 3, e - i. The adjustments follow a biannual cycle with the two local maxima in spring and autumn, the exception being the Arctic stations. The series from continental stations require the largest adjustments, about 1.5°C in March at Karasjok and Nesbyen and 1°C at Kjøremsgrendi. The adjustments are larger at inner fjord stations (Oslo, Lærdal and Værnes) than at coastal stations or at stations situated on small islands. Included in the latter categories are Glomfjord, Utsira, Ona and Vardø. The required adjustments to the series from these stations are only 0.2°C or less in all months.

Table 2 Mean differences between daily minimum temperature calculated according to the procedure in current use minus the one in use in the period 1894 - 1937. Data coverage is 39 (1957- 1995) or 45 (1951 - 1995) years. Std denotes the standard deviation of the mean value. All adjustments larger than ±0.1°C are significant (Student's t-test with significance level 0.05).

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kjørems-	Mean	0.36	0.76	1.08	0.76	0.24	0.10	0.24	0.47	0.82	0.59	0.36	0.15
grendi	Std	0.06	0.05	0.05	0.04	0.02	0.02	0.03	0.03	0.04	0.03	0.04	0.06
Oslo	Mean	0.38	0.78	0.83	0.44	0.16	0.06	0.08	0.23	0.68	0.62	0.30	0.20
	Std	0.03	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.04	0.04	0.03	0.04
Nes-	Mean	0.37	1.12	1.41	0.96	0.46	0.25	0.35	0.80	1.24	0.90	0.35	0.13
byen	Std	0.07	0.06	0.07	0.04	0.03	0.03	0.03	0.05	0.06	0.05	0.04	0.05
Færder	Mean	-0.16	-0.09	0.01	0.04	0.02	0.01	0.01	0.04	0.05	-0.04	-0.14	-0.17
	Std	0.12	0.11	0.08	0.05	0.02	0.02	0.03	0.03	0.05	0.07	0.09	0.11
Oksøy	Mean	0.24	0.46	0.48	0.42	0.23	0.12	0.16	0.30	0.46	0.44	0.27	0.15
	Std	0.03	0.04	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.03	0.03	0.03
Utsira	Mean	0.06	0.16	0.20	0.20	0.14	0.08	0.11	0.12	0.11	0.10	0.03	0.02
	Std	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Bergen	Mean	0.23	0.39	0.43	0.49	0.27	0.18	0.23	0.38	0.44	0.37	0.22	0.13
	Std	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
Lærdal	Mean	0.16	0.35	0.66	0.69	0.53	0.33	0.42	0.50	0.61	0.44	0.11	0.07
	Std	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.03	0.04
Ona	Mean	0.02	0.14	0.16	0.18	0.13	0.09	0.10	0.06	0.13	0.10	0.00	-0.03
	Std	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Værnes	Mean	0.28	0.60	0.86	0.67	0.30	0.16	0.14	0.43	0.71	0.48	0.22	0.01
	Std	0.05	0.05	0.05	0.03	0.03	0.02	0.03	0.03	0.03	0.04	0.04	0.05
Glom-	Mean	-0.02	0.02	0.20	0.11	0.01	0.00	0.09	0.07	0.04	-0.05	-0.07	-0.05
fjord	Std	0.04	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.03
Tromsø	Mean	0.08	0.13	0.30	0.12	0.03	0.01	0.00	0.02	0.17	0.10	0.01	-0.06
	Std	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.03	0.02	0.03	0.03
Kara-	Mean	-0.02	0.61	1.71	0.85	0.11	0.05	0.02	0.30	0.66	0.37	-0.04	0.15
sjok	Std	0.08	0.08	0.10	0.06	0.02	0.03	0.02	0.03	0.04	0.06	0.08	0.10
Vardø	Mean	0.00	0.07	0.12	0.13	0.05	0.00	0.03	-0.02	0.04	0.00	0.01	-0.01
	Std	0.03	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03
Bjørn-	Mean	-0.02	0.03	0.13	0.14	0.17	0.10	0.08	0.09	0.02	-0.07	-0.04	-0.02
øya	Std	0.05	0.05	0.05	0.04	0.02	0.02	0.02	0.02	0.02	0.04	0.03	0.04
Svalbard-	Mean	-0.04	0.03	0.21	0.51	0.31	0.16	0.12	0.08	0.08	-0.07	-0.10	-0.07
Airport	Std	0.06	0.06	0.05	0.04	0.02	0.02	0.02	0.02	0.03	0.03	0.05	0.05
Jan	Mean	0.04	-0.05	0.17	0.28	0.21	0.20	0.20	0.16	0.12	-0.02	-0.05	-0.06
Mayen	Std	0.03	0.05	0.04	0.03	0.02	0.02	0.01	0.02	0.03	0.03	0.04	0.04

The adjustments that should be applied to the Arctic series are 0.2°C or less for most of the months. The biannual cycle, present in the mainland, is not seen in the Arctic. The two stations exposed to maritime influence, Bjørnøya and Jan Mayen, have near constant adjustments from spring to autumn. The continental series Svalbard Airport, however, has a sharp peak in April (0.5°C). Similar results (0.4°C in April, not shown in Fig 3) are also obtained by using another station on Spitsbergen, Ny-Ålesund.

At the station Karasjok the maximum difference in spring is almost three times larger (1°C) than the one in autumn although the solar angle is about the same in both seasons. It is suggested that the reason for the discrepancy is the different diurnal temperature range (DTR) of the two seasons. The DTR is about 5°C larger in the spring than in the autumn at approximately the same solar angle. For Svalbard Airport the DTR in spring doubles that in autumn, i.e. 4°C larger, and the autumn maxima is not seen.

In winter negative adjustments are frequent in the Arctic and at the northernmost stations on the mainland. However, most of the adjustments are not significant. Some of them are slightly significant at significance lever 0.05 which is normal when tests are repeated several times. Negative adjustments should be rejected for climatological reasons. Therefore no adjustments should be applied to these series in winter.

4 Adjustments obtained from the Standard Normal Homogeneity Test (SNHT)

The SNHT test developed by Hans Alexandersson, has come into widely use as a general homogeneity testing method. It has for example been applied to precipitation data (Alexandersson, 1986; Hanssen-Bauer & Førland, 1994) and to temperature (Moberg, 1996). The normal use of the test has been to compare a test series to a group of homogeneous reference series. Nordli (1996) has applied the method also for "internal" testing, i.e. inter-comparison of extremes and observations at fixed hours, all data belonging to the same station. This application has for example shown to be an effective tool for detecting inhomogeneities caused by sunshine on wall cages.

Following the same idea, the test could also be used to detect inhomogeneities caused by changed definition of minimum temperature day. As a reference to the minimum temperature, the temperature at the morning observation should be chosen as it is better correlated to minimum temperature than that of the midday or evening observations. Long test periods are preferable to make the test as powerful as possible. On the other hand, the test is sensitive to various inhomogeneities in the series. These are more likely to be included the longer the test periods are. In practise the length of the test period should be a compromise between power of the test and homogenous reference series.

The oldest procedure, used before 1894. The period 1876 - 1909 was chosen for testing. The start coincides with the introduction of the minimum thermometer. The termination in 1909 was chosen because an inhomogeneity was introduced in 1910 when the time of observation for a group of stations was changed from Christiania Time to CET (the change did not affect another group where local time was used).

The results of SNHT are shown in table 3. All inhomogeneities detected during the time interval from1892 to 1895 are listed in the table, significant values are set in boldface. Inhomogeneities outside this interval, significant or not, are not shown. It is readily seen that the adjustments found by SNHT varies much more than those found by applying the previous definition to new data (PDMD), table 1. The reason may be that SNHT brings in more noise by the inclusion of the morning observation. At Karasjok, for example, a huge adjustment in February (-1°C) appears to be insignificant.

The results of the two methods are in good agreement for many of the stations. These are Kjøremsgrendi, Oslo, Færder, Oksøy, Lærdal and Værnes. Lærdal has obviously an inhomogeneity in 1883 which jeopardised the expected one in 1893. However, running the test once more, starting in 1884, the adjustments was in good agreement with the results from PDMD. In general adjustments in summer were too small to be detected by the SNHT, an exception being Færder where June and August adjustments were significant. Also applying SNHT to the Tromsø series showed significant results in summer, but these may have been obscured by a relocation 1895.

Table 3. Adjustments of mean monthly minimum temperature prior to 1894 detected by SNHT. As reference series are used the monthly mean temperatures observed at the morning observation. Significant adjustments are set in boldface. Only years of maximum t-value in the time interval 1892 - 1895 are listed.

Station/ Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kjøremsgrendi 1876 - 1909	**-0.87** **1893**	**-0.86** **1893**	-0.31 1894							**-0.61** **1893**	**-0.71** **1893**	**-0.50** **1893**
Oslo 1876 - 1909	**-1.05** **1894**	**-1.23** **1892**								**-0.53** **1893**	**-0.85** **1892**	**-0.68** **1893**
Færder 1886 - 1909	**-0.62** **1893**	**-0.80** **1892**				**-0.28** **1893**		**-0.35** **1893**	**-0.43** **1892**		**-0.66** **1893**	**-0.48** **1893**
Oksøy 1876 - 1909	**-0.75** **1894**	**-0.82** **1893**	-0.29 1992							**-0.48** **1893**	**-0.76** **1893**	
Utsira 1876 - 1909											-0.36 1895	-0.28 1895
Bergen 1876 - 1809		-0.35 1893										
Lærdal 1885-09	**-0.55** **1993**	**-0.76** **1994**	-0.54 1993						-0.50 1995		**-0.61** **1893**	**-0.53** **1893**
Ona 1876 - 1909												
Værnes 1876 - 1909	**-1.44** **1893**	**-1.24** **1893**	**-1.04** **1893**						-0.72 1894	**-0.95** **1893**	**-1.33** **1893**	**-1.44** **1893**
Bødø 1876 - 1909										**-0.43** **1895**		**-0.56** **1895**
Tromsø 1876 - 1909		**-0.48** **1893**	-0.35 1893		**-0.42** **1894**	**-0.49** **1893**			**-0.54** **1895**	-0.35 1894	-0.42 1893	-0.25 1895
Karasjok 1877 - 1909	**-1.71** **1893**	-1.01 1893								-0.35 1893	**-1.65** **1893**	**-1.57** **1893**
Vardø 1876 - 1909	**-0.62** **1893**										**-0.54** **1893**	

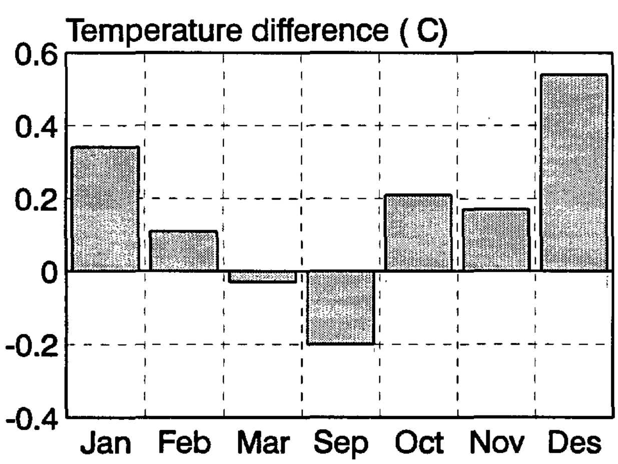


Fig. 4 Comparison of adjustments prior to 1894 obtained from different methods: Adjustments by PDMD minus those of SNHT.

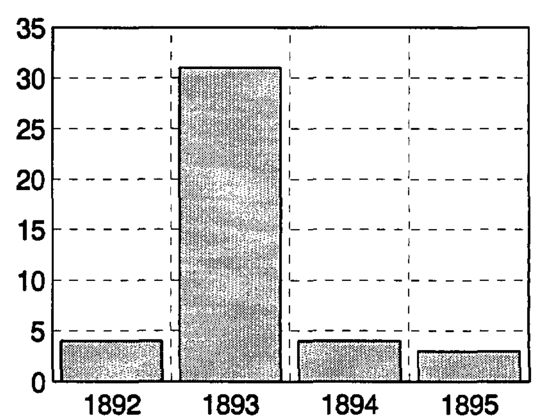


Fig. 5 Distribution of the years of break in daily minimum temperature detected by SNHT.

The adjustments detected at Utsira and Bergen are smaller than those found by PDMD, and for Ona no adjustment was significant. Also for the three northernmost stations on the mainland, the adjustments during winter were found to be smaller by SNHT than by PDMD, for example in Karasjok by a factor of about 0.5. However, running the test only from 1890, the adjustments in winter turned out to be about -3°C, which is in agreement with the figures in table 1. The inhomogeneity in the minimum temperature of Karasjok is also discussed by Nordli (1996).

In Fig. 4 the means of the adjustments obtained by PDMD minus those by the SNHT are shown. In late winter (Feb. - Mar.) and in autumn (Sep. - Nov.) the differences are in good agreement (within 0.2°C or less), but in midwinter (Dec. - Jan.) the values found from PDMD exceeds those found from SNHT.

There has been some doubt about the exact time for change of observation practise, see Ch. 2. Should 1893 be included in the period before or after the change. According to Harbitz (1963) the new procedure was introduced from 1893, but it was not before 1. January 1894 that it was completely adopted. The SNHT-program points out the greatest t-value and the corresponding year, i.e. the latest year before the break in the series. Because of the noise, the program may fail to point out the time for the break exactly, also one of the neighbouring years may be pointed out. However, an overwhelming majority of the tests points out the year 1893, see the distribution of the years before the breaks in Fig. 5. Thus, the new procedure has not (at least for a majority of the stations) been adopted before 1. January 1894.

The procedure in use 1894 - 1937. The test interval for SNHT should not be extended further than to the end of 1947, because in 1948 the hour for the morning observation was changed from 8^h to 7^h, i.e. 11 years after the break. The same time interval was also chosen on the other side of the break. Thus, the period of testing comprised the 22 years from 1927 to 1948.

In table 4 all breaks in the years from 1936 to 1938 are shown, significant results are set in boldface. In December and January no significant adjustments were found, in good agreement to the marginal adjustments found by PDMD. Adjustments found by PDMD had also a local minimum in summer, but in this season many large "adjustments" were detected by the SNHT, especially in June. These results, however, may be a consequence of other inhomogeneities in the series than changed minimum temperature day. At the stations Nesbyen and Karasjok the old wall cages were replaced by free-standing screens almost at the same time as the minimum temperature day was changed. From table 4 it is seen that the largest "adjustments" were detected at these stations. Also at some of the other stations screen changes occurred in the test period, i.e. Færder in 1930, Utsira in 1932, Kjøremsgrendi (Dombås) and Ona in 1933 and Oksøy in 1934. Also these changes may have obscured the results. The results are also dubious for the stations Oslo and Jan Mayen where large relocations took place in 1937 and 1940 respectively.

Table 4. Adjustments of mean monthly minimum temperature in the period 1894 - 1937 detected by SNHT. As reference series are used the monthly mean temperatures observed at the morning observation. Significant adjustments are set in boldface. Only years of maximum t-value in the time interval 1936 - 1939 are listed

Station/ Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kjøremsgrendi 1927 - 1948		**1.00** **1937**	**0.84** **1937**					**0.72** **1939**	**0.99** **1937**	**0 .75** **1937**		
Oslo 1927 - 1948										0.29 1937	0.16 1938	
Nesbyen 1927 - 1948		**1.04** **1937**	**1.31** **1937**			**1.00** **1936**	0.58 1936	**0.46** **1938**	**0.96** **1937**	**1.03** **1937**	0.32 1938	
Færder 1927 - 1948		0.34 1937				**0.45** **1936**	0.15 1936		0.21 1937			
Oksøy 1927 - 1948		0.35 1937			0.32 1936	**0.83** **1936**		**0.39** **1939**	**0.42** **1938**	**0.53** **1936**		
Utsira 1927 - 1948										0.27 1936		
Bergen 1927 - 1948			**0.46** **1939**						0.15 1937	**0.35** **1938**		
Lærdal 1927 - 1948									0.20 1937	0.27 1936		
Ona 1927 - 1948						**0.44** **1937**		**0.29** **1939**		0.26 1938		
Værnes 1927 - 1948						0.62 1937		0.51 1939				
Bodø 1927 - 1948		0.37 1938										
Tromsø 1927 - 1948				0.31 1937								
Karasjok 1927 - 1948	0.89 1936		**2.00** **1936**			**1.43** **1937**	**2.16** **1937**	**1.84** **1939**				
Vardø 1927 - 1948												
Bjørnøya 1927 - 1948						0.28 1937						
Svalbard A.p. 1927 - 1948												
Jan Mayen 1927 - 1948					0.23 1937	**0.33** **1938**						

The large adjustments in March found by PDMD at the continental stations are also confirmed by the SNHT. But somewhat smaller adjustments at Bergen, Lærdal and Værnes were not detected. For Vardø and Svalbard Airport no maximum t-value was detected in the interval 1936 - 1939.

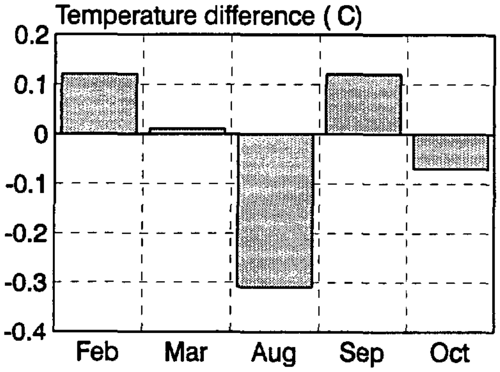


Fig. 6 Comparison of adjustments in the period 1894 - 1937 obtained from different methods: Adjustments by PDMD minus those of SNHT.

In the autumn there is good agreement between the results of the two methods if only significant results of SNHT are considered. But in September adjustments of 0.4 - 0.7°C at Bergen, Lærdal and Værnes found by PDMD, are not found to be significant by SNHT.

In Fig. 6 the mean differences of the results obtained by the two methods are shown for the spring and autumn local maxima. Tests results are included if SNHT showed the maximal t-value in the period 1936 - 1939, significant or not. Although large individual differences are included, the mean differences differed very little in all months except August.

5 A check of the robustness of the adjustments to minor changes of observation hours.

When the definition of the minimum temperature day was changed in 1938 the observation hours were 8^h, 14^h and 19^h. These differ from the present observation hours 7^h, 13^h and 19^h. In the simulations based on modern data (PDMD, see Ch. 3) daily minimum from 08^h - 08^h should have been compared to that obtained from 19^h - 19^h. As observation hour 08 does not exist any more, it was replaced in the simulations by the standard observation hour 07.

For most of the year the daily minimum is more likely to occur near 07^h than 08^h. The adjustments based upon a temperature day from 07^h - 07^h could therefore be somewhat exaggerated compared to those from 08^h - 08^h. However, a temperature rise during one hour (from 07 -08) might be too small to be of any importance compared to other sources of inhomogeneities. It is therefore essential to find out whether or not the adjustments found by the PDMD method need to be modified.

To come closer to the problem, observations from automatic stations with sufficient time-resolution were used. In the Norwegian network these are of types Campbell, Scanmatic and Vaisala. They observe "now values" every hour and minimum values in the period since the previous hour. Thus, it is possible to obtain minimum temperature during the day from 07^h - 07^h as well as from 08^h - 08^h. All stations with data coverage at least one year were used, i.e. 23 stations. The results for individual stations and groups of stations are shown in Appendix I.

The largest group comprises eleven continental stations in Southern and Eastern Norway (to the south of Trøndelag). The continentality varies within the group from the most extreme one, 10000 Tynset II (Østerdalen) to 18700 Oslo - Blindern (the inner part of the Oslo fjord). The monthly mean values of the group show similar annual distribution as the PDMD-calculations, i.e. local maxima in spring and autumn. In other seasons the differences (modifications) are zero or close to zero. As for PDMD the spring maxima is larger than the autumn maxima.

Values from Tynset II seem to be larger than from the other stations. This may be explained by the fact that Tynset is situated at a valley floor near the most continental area (the cold pole) in Southern Norway. However, a conclusion based upon only one station is not reliable because of noise in the data due to too small data samples. Thus, modifications of adjustments based upon one station only should be avoided.

To obtain larger samples, the mean modifications of all eleven automatic, continental stations were compared to the mean adjustments obtained from the PDMD-method for the four continental stations 16740 Kjøremsgrendi, 18700 Oslo, 24880 Nesbyen, and 97250 Karasjok, table 5. In winter and summer the adjustments found by PDMD were very small and in many cases insignificant and therefore omitted in the table. The modification of the adjustments in spring and autumn varied from 15 % to 26 %. Further, the mean modifications of the six automatic, coastal stations in southern Norway were compared to the adjustments from the five coastal stations 27250

Færder, 39100 Oksøy, 47300 Utsira, 50540 Bergen, and 62480 Ona, table 5. For these the relative modification varied more from month to month, from 5 % to 41 %. This might be due to a smaller data sample than for the continental stations.

Table 5 Ratio (%) of modification (obtained from automatic stations) to adjustments (from PDMD analysis). For information of the stations involved, see text.

Station category	Feb	Mar	Apr	Sep	Oct
Continental	20	25	23	15	26
Coastal	17	41	5	35	31

For the continental stations it seems reasonable to adopt a modification of the adjustments of about 20%, see table 5. For the coastal stations no monthly adjustment is larger than 0.5°C and the modification is less important than for the continental stations. For simplicity reasons the modification of 20% is adopted also for the coastal stations. For all stations the adjustments in winter and summer are so small that modifications are almost negligible. The modified adjustments are shown i table 6.

Table 6 Adjustments (°C) of monthly mean daily minimum temperature in the period 1894 - 1937. The adjustments found by the PDMD method are reduced by 20 %. Adjustments larger than 0.2°C are shaded.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kjøremsgrendi	0.3	0.6	0.9	0.6	0.2	0.1	0.2	0.4	0.7	0.5	0.3	0.1
Oslo	0.3	0.6	0.7	0.4	0.1	0.0	0.1	0.2	0.5	0.5	0.2	0.2
Nesbyen	0.3	0.9	1.1	0.8	0.4	0.2	0.3	0.6	1.0	0.7	0.3	0.1
Færder	0.1	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1
Oksøy	0.2	0.4	0.4	0.3	0.2	0.1	0.1	0.2	0.4	0.4	0.2	0.1
Utsira	0.0	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Bergen	0.2	0.3	0.3	0.4	0.2	0.1	0.2	0.3	0.4	0.3	0.2	0.1
Lærdal	0.1	0.3	0.5	0.6	0.4	0.3	0.3	0.4	0.5	0.4	0.1	0.1
Ona	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.0
Tromsø	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Karasjok	0.0	0.5	1.4	0.7	0.1	0.0	0.0	0.2	0.5	0.3	0.0	0.1
Vardø	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bjørnøya	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Jan Mayen	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0

It can not be expected that the adjustments should be accurately modified simply by a constant factor. On the other hand, individual data series from automatic stations are too short to be used without smoothing. By now it seems preferable to use the bulk of the stations rather than results of individual ones for calculating the modifications. The ratio between modification and adjustment varied from month to month largely caused by noise which jeopardised a possible systematically variation.

Therefore no better approximation to the real modification than a constant ratio is suggested. After all the magnitude of the modifications seldom exceeded 0.2°C which is small compared to other sources of inhomogeneity in the series of daily minimum temperature. For some of the stations the modifications should not be used on data before 1920. One of these are Karasjok which morning observation hour was 08^h local time = $07^h18'$ CET (Høgåsen 1996), which is close to the present observation hour used in PDMD calculations.

Modifying the adjustments before 1894 are very difficult because of the rather intrinsic procedure in use - not in all cases was the lowest minimum during night considered to be the nightly minimum temperature, ref. Ch. 2. In midwinter when the daily range is very small, the adjustments do not need modification and in summer the adjustments themselves are small, and the modifications are also likely to be small. Probably the adjustments during spring and autumn should have been modified. However, facing a calculation in which options are involved, it seems not to be worthwhile to carry out the calculations at this stage with very limited data samples available.

Data with sufficient time-resolution will, however, in the future be available when long series from automatic stations are established and both the procedure prior to 1894 and the one used during the period 1894 - 1937 can be applied on these data. But the problem with this direct method is to find automatic stations representative for each old data series.

Summary and conclusions

Historical sources tell that the Norwegian definition of the "minimum temperature day" was changed during 1893. Internal testing by "the Standard Normal Homogeneity Test" indicates, however, that for most of the stations the change took place 1 January 1894. A second change of the definition took place 1. January 1938. These changes bias the series of minimum temperature and the used of adjustment terms are necessary to keep the series homogenous.

In the present paper the procedure used for calculation of monthly means of daily minimum temperature before 1 January **1894** was applied on digitised daily data during the period 1951(1957) - 1995, in this report called the PDMD method. Thus, the results from the present procedure could be compared to the former one and the differences between them could be used as adjustment terms and applied to the old parts of the series. The method led to adjustment terms that differed by time of the year, latitude and climate (continental - maritime).

The largest differences were found at continental stations, especially Karasjok in winter, and the monthly mean of daily minimum temperature calculated by the former procedure, had to be adjusted about -3°C in the season November to January to equal the results obtained from the present one. For series from two other continental stations, Kjøremsgrendi and Nesbyen, adjustments of about -1.5°C were found during winter, and for series from coastal or maritime stations adjustments of about -1°C were found, all located to the winter season.

The magnitude of the adjustments in summer was about -0.2°C which is thought to be less than the influence of undetected inhomogeneities from other sources. Spring and autumn can be regarded as transition zones between the high adjustments in winter and the low ones in summer.

The change of the definition of minimum temperature day in **1938** led to adjustments depending on month, latitude and climate, like the change in 1894. Also in this case the greatest adjustments should be applied to the series from the continental stations. At all series from the Norwegian mainland two local maxima were found, one in spring and the other one in autumn, the spring maximum being without exceptions the largest one. In March it amounted to about 1.5°C for the Karasjok and Nesbyen series and to about 1°C for the series from Kjøremsgrendi. Series from stations situated in inner fjords needed maximum adjustments of 0.6°C to 0.8°C (Oslo, Lærdal, Værnes), and at the coastal districts no series needed adjustments larger than 0.5°C. For most stations situated at the outer islands the adjustments were only 0.2°C or less. In Arctic the adjustments seemed to be close to zero with an exception for the spring maximum at Svalbard Airport (0.5°C in April).

By use of automatic stations with sufficient time resolution it was found that the above adjustments could be biased too large due to changed observation hour in the morning. In the period 1894 - 1937 the minimum temperature day was defined from 08^h to 08^h (local time or Christiania time, since 1920 CET) while in the calculations based on digitised, daily data it was defined from 07^h to 07^h (CET). The automatic stations which could be used, had very short series of observation, and the results were subject to much noise. To operate with individual reduction factors seemed unrealistic, and all adjustments were reduced 20 %. Only for the continental stations the modifications amounted to 0.2°C or more. Compared to other sources of undetected inhomogeneity, the use of this modification factor therefore seemed not to be important.

Adjustments were also assessed by internal use of the SNHT on monthly basis. The mean of the daily minimum temperature was compared to the mean of the morning observation, both temperatures originated from the same station. The results from the SNHT method differed a lot from those of the PDMD for individual months. This was considered to be caused by inhomogeneities in the data brought in by the SNHT method. The two methods gave approximately the same results for mean values obtained from the whole station network, i.e. the difference being 0.3°C or less in all months but one.

Search in the archive at DNMI has revealed that the temperature day of extreme temperature was debated during conferences of the International Meteorological Organisation (IMO) before 1893 and 1938. Thus, it is very likely that this kind of inhomogeneity is not attributed to the Norwegian series only. It may be a source of inhomogeneity in the series from several countries. The change which took place in Norway in 1938, seems to have been initiated by a recommendation of the Warsaw Conference in 1935.

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Appendix I

*Differences of daily minimum temperature (unit = 0.1°C) calculated for different definitions of temperature day (day 08^h - 08^h minus day 07^h - 07^h). The calculations are done on data from automatic stations with data coverage between one and three years. The two last columns in the tables show the number of days for the month of maximum (*Max*) and minimum (*Min*) data coverage.*

Continental stations, Southern and Eastern Norway

No.	Name	J	F	M	A	M	J	J	A	S	O	N	D	Max	Min
10000	Tynset II	1	4	8	4	1	1	0	1	3	2	0	-1	84	29
11500	Apelsvoll	-1	1	2	1	1	0	0	0	0	2	1	0	62	28
12560	Kise på Hedmark	0	2	3	1	0	0	0	0	1	3	1	1	92	76
12680	Lillehammmer	0	3	3	2	1	0	1	0	2	1	-1	1	61	27
13160	Kvitfjell	0	1	1	1	1	1	1	1	1	1	1	0	62	29
18700	Oslo - Blindern	1	2	3	1	0	0	1	0	2	1	0	-1	59	25
23510	Løken i Volbu	0	1	4	3	1	0	0	1	2	1	0	1	62	28
25830	Finsevatn	0	1	3	2	2	0	0	0	1	1	-2	0	85	44
33890	Vågsli	1	2	3	1	0	0	0	0	0	2	0	0	56	29
40880	Hovden - Lundane	1	1	4	2	0	0	1	0	1	3	0	1	55	20
46510	Midtlæger	0	0	1	1	1	1	1	0	1	1	0	0	81	53
Mean		**0**	**2**	**3**	**2**	**1**	**0**	**0**	**0**	**1**	**2**	**0**	**0**		

Coastal stations, Southern Norway

No.	Name	J	F	M	A	M	J	J	A	S	O	N	D	Max	Min
17000	Strømtangen fyr	-1	0	2	0	0	1	0	1	1	1	0	-1	78	29
34130	Jomfruland	0	1	1	1	0	1	0	0	1	2	0	-1	86	56
42161	Lista fyr	0	0	2	0	0	0	0	0	0		1	0	50	18
44081	Obrestad fyr	1	1	1	0	1	0	-1	0	1	1	-1	0	82	20
52531	Hellisøy fyr	0	1	0	0	0	0	1	0	1	1	0	0	124	76
56430	Furneset	0	0	2	0	0	1	0	1	2	-1	1	0	93	85
Mean		**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**		

Coastal stations, Trøndelag and Northern Norway

No.	Name	J	F	M	A	M	J	J	A	S	O	N	D	Max	Min
69150	Kvithamar	0	1	2	2	0	1	0		3		0	-1	62	19
71000	Steinkjer - Egge	1	2	2	1	0	0	0	1	1	2	1	-1	99	62
71990	Buholmråsa fyr	0	0	1	0	0	1	0	0	1	0	0	0	90	57
76540	Tjøtta	0	0	1	0	0	1	1	2	0	1	1	1	62	18
82230	Bodø - Vågøynes	0	1	2	0	1	0	1	1	1	1	1	0	62	18
90400	Tromsø - Holt	1	1	3	0	1	1	1	1	1	1	1	1	62	18
Mean		**0**	**1**	**2**	**0**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	**0**		