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TITLE

## The early 20th century warming
### Daily observations at Grønfjorden and Longyearbyen on Spitsbergen
### (2nd edition)


AUTHORS

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PROJECT CONTRACTOR

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SUMMARY

The oldest regular temperature time-series from Svalbard, the Green Harbour record (December 1912 - September 1930, observations at Finneset in Grønfjorden), has thus far only been available digitally in the form of monthly mean values. Likewise the oldest part of the Longyearbyen series (November 1916 – August 1923) also lacked digitalisation for daily data. ACIA (Artic Climate Impact Assessment) funded the digitisation of the two series for three main daily observations, permitting quality control of the series. In addition, measurements from a German-Austrian scientific overwintering expedition (1911-1912) have been digitised.

Analysis of the Green Harbour data shows that for some periods, particularly in the early part of the series, the monthly data have not been of top quality. This resulted in a few corrections to mean monthly values. However, correcting the original series does not change the annual or seasonal trends, and the steep rise in temperature at the beginning of the series (1911-1920), known in high northern latitudes as the early 20th century warming, is maintained. Two-thirds of this temperature increase could be explained at Green Harbour by an increase in winter (December-March) cloud cover.

The composite Svalbard Airport series (including also Green Harbour and Longyearbyen data) was revised and reanalysed for trends by the Mann-Kendall test. For the annual values a positive trend was detected significant at the 5 % level for the whole observational period. In summer (JJA) a positive trend is also significant at the 5 % level, whereas a positive trend in autumn (SON) is not significant at this level. For the spring (MAM) a positive trend is highly significant, whereas in winter (DJF) there is no trend for the whole period.


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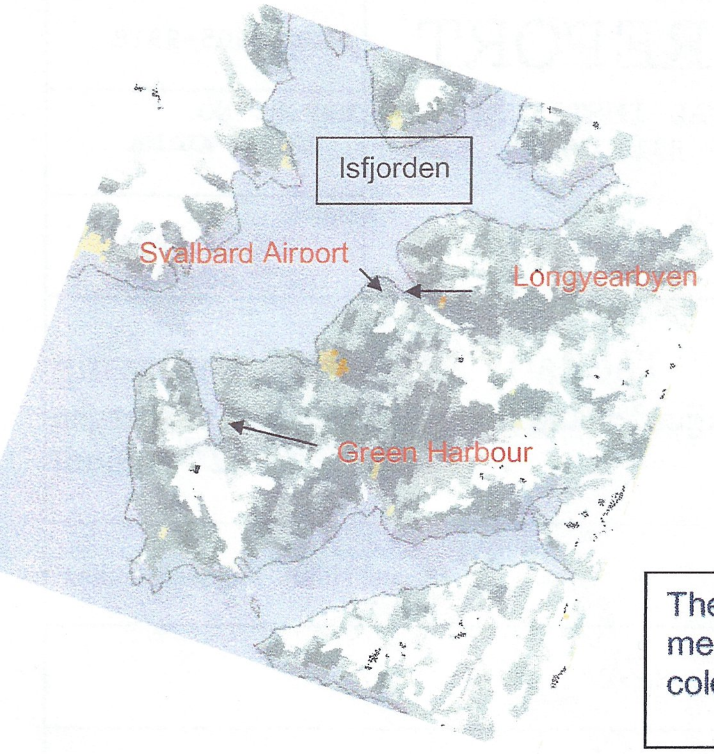


The Isfjorden area with the measuring sites typed in red colour

The Svalbard Islands

# The early 20th century warming

## Daily observations at Grønfjorden and Longyearbyen on Spitsbergen
## (2nd edition)

by

Øyvind Nordli[1] and Jack Kohler[2]

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**Abstract**

The oldest regular temperature time-series from Svalbard, the Green Harbour record (December 1912 - September 1930, observations at Finneset in Grønfjorden), has thus far only been available digitally in the form of monthly mean values. Likewise the oldest part of the Longyearbyen series (November 1916 – August 1923) also lacked digitalisation for daily data. ACIA (Artic Climate Impact Assessment) funded the digitisation of the two series for three main daily observations, permitting quality control of the series. In addition, measurements from a German-Austrian scientific overwintering expedition (1911-1912) have been digitised.

Analysis of the Green Harbour data shows that for some periods, particularly in the early part of the series, the monthly data have not been of top quality. This resulted in a few corrections to mean monthly values. However, correcting the original series does not change the annual or seasonal trends, and the steep rise in temperature at the beginning of the series (1911-1920), known in high northern latitudes as the early 20th century warming, is maintained. Two-thirds of this temperature increase could be explained at Green Harbour by an increase in winter (December-March) cloud cover.

The composite Svalbard Airport series (including also Green Harbour and Longyearbyen data) was revised and reanalysed for trends by the Mann-Kendall test. For the annual values a positive trend was detected significant at the 5 % level for the whole observational period. In summer (JJA) a positive trend is also significant at the 5 % level, whereas a positive trend in autumn (SON) is not significant at this level. For the spring (MAM) a positive trend is highly significant, whereas in winter (DJF) there is no trend for the whole period.

## 1. Introduction

The homogenised Svalbard Airport temperature record, starting in December 1911, is one of only a few long-term (>65 yr) instrumental temperature series from the high Arctic (Nordli et al. 1996). As such, it is an important record for interpreting present Arctic meteorological trends in terms of past behaviour.

The series start with an abrupt temperature change at about 1920. The sudden temperature increase, known as the early 20th century warming, is seen in all long-term Norwegian series. The warming is particularly strong in the Nordland region and coastal areas of Finnmark (Hanssen-Bauer and Nordli 1998), but is also seen in the artic series of Greenland and series from stations adjacent to the Arctic such as Iceland, Faeroes, and northern Finland (Førland et al. 2002). Polyakov et al. (2003) analysed artic and sub-arctic temperatures north of 62 °N, and found rapid early 20th century warming in all seasons but summer, in particular during the period 1918 – 1922 in winter.

The early 20th century warming was especially pronounced in the Svalbard Airport series, so much so that the reliability of the instrumentation was questioned already at an early stage (Birkeland 1930). Hanssen-Bauer and Førland (1998) found that the positive trend in the Svalbard Airport record could not be explained by circulation changes only, and suggested that the varying extent of sea ice could have contributed to this abrupt shift in climate. Analysis by Benestad et al. (2002) further supported this suggestion.

Recently, the homogenized Svalbard Airport series was compared to three proxy records: ice-core oxygen isotope data from the high-resolution 1997 Lomonosovfonna ice core; the Barents Sea ice-edge record, and the Vardø Norway temperature record (Kohler et al. manuscript in preparation). Regression relations developed for the period 1912-2000 between the proxies and the Svalbard Airport series were used to convert the proxies to Svalbard temperatures. In addition, meteorological data from over-wintering hunting expeditions in the period 1898-1911 have been digitised and used to check the reliability of the proxies. Most of over-wintering data compare well with the three proxy series. The observed and proxy series compare well in the period after 1920, but in the early period 1912-1919 the Svalbard Airport series is consistently colder than the other series would indicate.

In this study we used newly digitised daily values from Green Harbour (in Grønfjorden a tributary fjord to Isfjorden) as well as German-Austrian scientific expedition data (1911-1912) from Longyearbyen to shed light on the early part of the Svalbard Airport temperature series. The newly digitised daily data makes it possible to study the data quality more explicitly than before when only monthly summaries were available.

In the period Nov. 1916 to Aug. 1923 meteorological observations were carried out three times daily at Longyearbyen by the mining company Store Norske Spitsbergen Kulkompani. Thus, also these observations overlap the observations from Green Harbour. The original observations were digitised and controlled, and also used in a new homogenised Svalbard Airport series.

## 2. Data

Observation times at Green Harbour were 08, 14, 20 Central European Time (CET) until 1 July 1920, when they changed to 08, 14, 19 CET. In all years minimum daily temperatures were recorded, but no maximum temperature. These measurements are all recorded on standardized forms. In addition, a thermograph has been running at the station. Hourly observations were extracted from the charts and used in the yearbooks published by the institute to form daily values, as well as monthly summaries. Thus, there exist two available sources for digitization, the yearbooks and the original forms. In order to avoid possible printing errors in the yearbooks, our choice was the original forms. For a few months, however, the forms were not easy readable, and for these periods digitization was from the yearbooks.

In general, minimum temperatures recorded in the original form were lower than in the thermograms, for days with the lowest temperatures. In the yearbooks, the minimum temperature readings from the thermometer are adjusted by data from the thermograms. The readings of the thermometer might be wrong, but to adjust it from the thermograms is also problematic. The difference is largest at low temperatures, at which the reliability of the thermograph might be questioned.

The data quality of the series is variable, but tends to improve toward the end of the series. Occasionally during the early years, temperatures were recorded as integer values, although as longs as the nearest whole degree was noted correctly, this does not affect the monthly mean temperature significantly. In periods of increasing temperature, the minimum thermometer reading showed higher temperatures compared to the previous fixed hour observation done with the main thermometer. However, the observers are not much to blame for this. Due to the time lag of the thermometer screen, the air inside the screen becomes colder than the ambient air in such situations. Correcting this, however, is rather easy as the minimum temperature can be interpreted to equal the previous reading of the main thermometer. These cases are picked up and corrected by a data program running logical tests. Every large correction was manually checked before adopted in the database.

In some months we find significantly different mean temperatures, when compared to the previous values published by met.no. One reason may lie in the different methods of obtaining the minimum temperature. Another reason may be that the diurnal temperature range was poorly known on Svalbard when the observations started in 1911, which meant the weighting factors to be used for calculating mean temperatures from the fixed observation times (irregularly distributed over the course of a day) were poorly known. The largest differences between the old manually calculated monthly mean temperature and the new ones based on the newly digitized data are listed in table 2.1.

Table 2.1 The 5 largest positive and negative differences between the old and new values of monthly mean temperature at Green Harbour.

| Year.month | Largest positive difference | Year.month | Largest negative difference |
|---|---|---|---|
| 1928.03 | 3.06 | 1921.04 | -0.67 |
| 1912.11 | 0.83 | 1917.01 | -0.47 |
| 1919.04 | 0.57 | 1919.03 | -0.37 |
| 1917.04 | 0.56 | 1921.05 | -0.31 |
| 1917.03 | 0.54 | 1921.02 | -0.30 |

The largest positive difference of 3.06 °C was caused by a digitizing error in the old data set, while the most negative difference of -0.67 was caused by a calculation error. The mean difference was 0.1 °C and the standard deviation was 0.27 °C.

Although there are periods of the series where the data are not of top quality, the irregularities found in the data are far from sufficient to question the temperature increase during the observational period. The data control thus supports the conclusions of Birkeland (1930) and Steffensen et al. (1996).

During the period September 1911-June 1912 a German-Austrian scientific expedition over-wintered at Longyearbyen, and carried out meteorological observations (Rempp and Wagner 1921). Their base station was situated at Longyearbyen, which at that time was also called Advent Bay. The thermometer screen was described as being situated on a flat plain, 33 m ASL, at the valley side near the mouth of the Longyear valley, a tributary valley to Adventdalen. This is very near the altitude (37 m) of the last meteorological station run in Longyearbyen by The Norwegian Meteorological Institute. There are no other flat areas in the valley side at that elevation, near the bay. Thus, the two sites of measurements must have been situated close to each other, at a distance not more than 100 m.

Thermographs were also located at Platåberget, 420 m ASL about 2 km to the west of the base station, and at Nordenskiöldfjellet, 1050 m ASL about 7 km south-west of the base station. (In the text Platåberget is said to be situated to the north of the base station and Nordenskiöldfjellet to the west of the base station, but this is certainly wrong). The observations at Nordenskiöldfjellet were suspended during mid winter, from 26th of October to 18th of February.

The German-Austrian scientific, expedition data are important because the measurements were performed at three different altitudes, and because the relation between Green Harbour and Longyearbyen temperature is important for homogenization of the Svalbard Airport series.

In the period Nov. 1916 to Aug. 1923 meteorological observations were carried out at Longyearbyen by the mining company *Store norske Spitsbergen Kulkompani*. Thus, also these observations overlap the observations from Green Harbour. The daily observations were digitised and controlled and ready for use in 2004. These observations had earlier been available in digital form only as monthly mean values. Only minor differences were discovered between the new monthly values based on digitised observations and the old manually calculated monthly values. For annual means no difference was larger than 0.1 °C.

## 3. Distributions of air temperature in the cold and warm phase of Green Harbour observations

The temperature series of Green Harbour was grouped by season (Dec.-Feb., Mar.-May, Jun.-Aug., Sep.-Nov.) during the cold and warm phases of Green Harbour temperature. The cold phase was defined from the start of the station in December 1912 to November 1919, and the warm phase was defined from December 1919 to the termination of the station September 5, 1930. Distributions of temperature were calculated within each season and period. The differences of the distributions are shown at various percentiles of the distributions in Figure 3.1. In all seasons but summer the differences between the distributions are most predominant at the low percentiles (low temperatures), while in the other end of the distributions (high temperatures) the differences are much smaller. During summer, differences between the two phases are largest at high percentiles, while at the 5 percentile, for example, the difference is negligible.

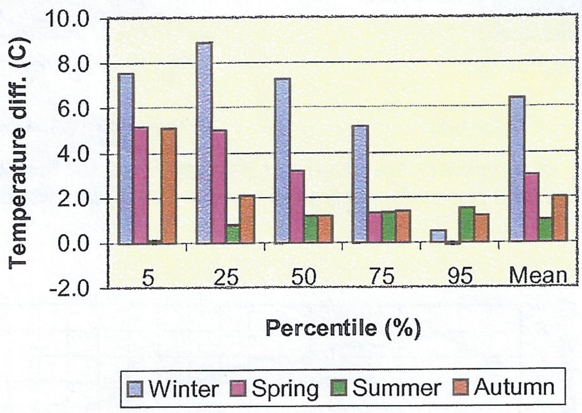


Figure 3.1 Differences at fixed percentile points between the warm phase (1912-1919) and cold phase (1920-1930) of Green Harbour temperature grouped by four seasons defined in the text. For comparison the differences of the mean value are also shown. The observation hours were 08, 14 and 20(19) CET.

March is a cold month on Svalbard; the lowest temperature (-49.4 °C) recorded at an official Norwegian meteorological station at Svalbard occurred on March 28th 1917. Thus, there are good reasons for including March among the winter observations. With this alternative definition of winter (Dec.-March) the distributions for Green Harbour were calculated for the cold and warm phases (figure 3.2a and 3.2b, respectively). The temperature distribution in the cold phase is very near a normal distribution with the skewness parameter = 0.1, whereas in the warm phase the distribution is skewed to the low temperature side, with the skewness parameter = -0.3.

The differences between the two distributions were also calculated at fixed percentile points (figure 3.3). The maximum difference, about 8 °C, occurs at the 20th percentile, but the difference remains high also in the interval 5 - 60 %, whereas the decrease is rapid for the higher percentiles, and the difference is below 1 °C at the 95 percentile.

During winter in inland areas of Scandinavia the distributions are skewed with a long tail to the cold side of the distribution. This is in contrast to the situation in the cold phase at Green Harbour where the distribution is nearly normal. This suggests a higher frequency of inversions at Green Harbour during the cold phase, generating a greater variety of low temperature events. In the warm phase, the distribution is skewed, more like that of present-day continental Scandinavia, corresponding to less frequent inversions. The mean difference between the warm and cold phases is about 6 °C, and due to the absence of the most extremely low temperature, the standard deviation is a bit lower in the warm phase than in the cold phase, 9.3 °C and 11.0 °C, respectively.

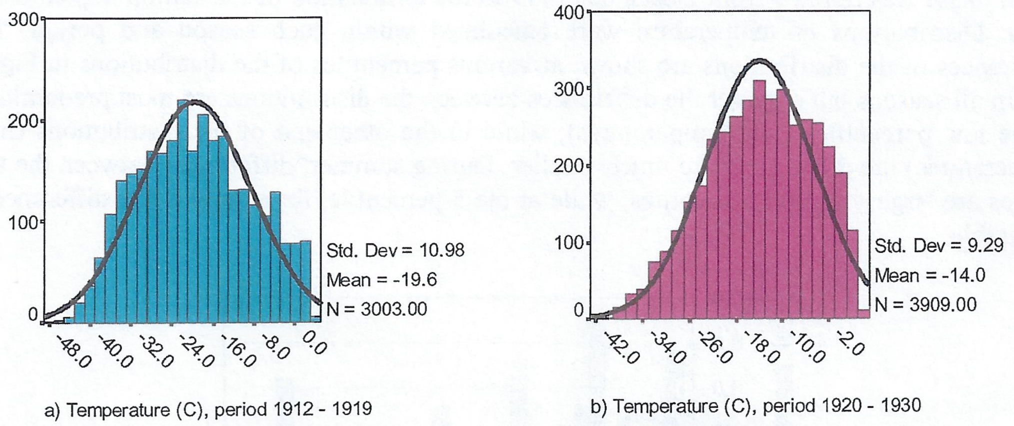


Figure 3.2 Distributions of temperature at fixed observation times for the station Green Harbour in its cold phase (a) and in its warm phase (b) during the season December-March.

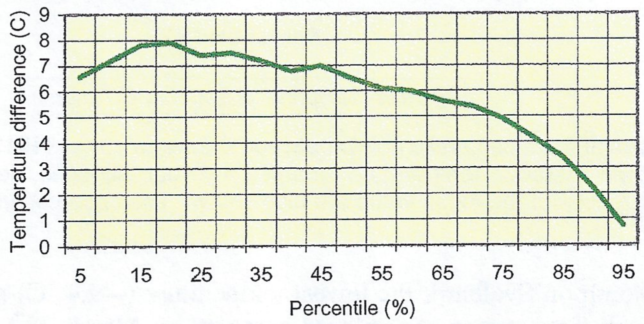


Figure 3.3 Winter (Dec.-March) temperature difference between warm and cold phases of Green Harbour observations at fixed percentile points.

During winter, clouds prevent loss of heat from the ground, such that there is a positive correlation between cloud cover and temperature. For Green Harbour this correlation is 0.61 and is highly significant. The distribution of cloud cover is U-shaped with most observations concentrated in either groups 0 and 10. Cloud cover increased from the cold phase to the warm phase, from a mean value of 5.2 tenths of the sky covered to 6.6. The question is then whether this increase in cloud cover alone could explain the temperature increase from the cold to the warm phase.

Temperatures were grouped by cloud cover and the two phases compared within each of the 10 cloud cover groups (figure 3.4). In each group, the temperature in the warm phase is higher than in the cold phase, with temperature differences that are highly significant. Thus, the temperature difference between the two phases cannot be explained entirely by changes in cloud cover. However, cloud cover is at least partly responsible for the temperature increase, since there is a larger temperature difference under clear sky conditions than overcast sky (figure 3.4).

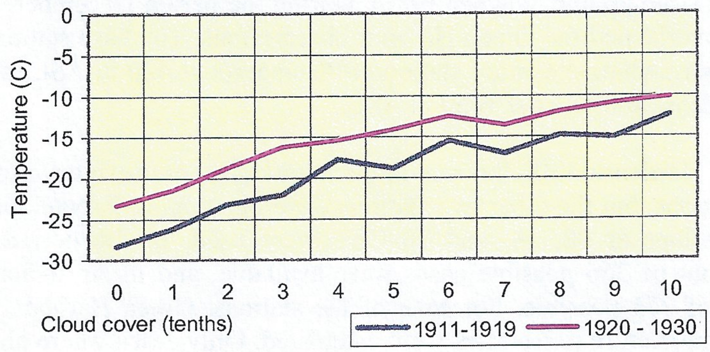


Figure 3.4 Mean Green Harbour temperature at the warm (1920-30) and cold (1911-19) phases during the season December-March. Observations are grouped by cloud cover.

The effect of the cloud cover increase on the temperature difference of the two phases was subject for a closer study. If the number of cloudy days in the cold phase had been larger, the temperature would have been higher. The effect of the cloud cover might be assessed by replacing the cloud cover distribution of the cold phase with that of the warm phase. Thus:

$$T_W = \frac{1}{N}\sum_{i=1}^{10} T_{Ci} w_i \,, \qquad (1)$$

where $T_W$ is the simulated mean temperature of the cold phase given the cloud cover distribution of the warm phase, $N$ is the total number of cases in the warm phase, $T_{Ci}$ is the mean temperature in the cold phase of cloud cover class $i$, and $w_i$ is the number of occurrences in the warm phase of cloud cover in class $i$

This resulted in a simulated mean temperature of the cold phase 3.8 °C warmer than the observed temperature of the cold phase, whereas the mean difference between the warm and cold phases based on observations is 6 °C. That means that about 2/3 of the temperature increase from the cold to the warm phase is caused by increased cloud cover.

## 4. Temperature variations with altitude based on measurements at Longyearbyen

The Austrian-German expedition performed measurements during the winter 1911-1912 in Longyearbyen (Rempp and Wagner 1921). During the period December 1911-June 1912 the observations overlapped the Green Harbour observations. The base station was situated at 33 m ASL, an intermediate-elevation station at Platåberget at 420 m ASL, and a high-elevation station at Nordenskiöldfjellet at 1050 m ASL.

The station at Nordenskiöldfjellet was inoperative during mid-winter, probably due to harsh weather conditions, but the other two stations were functioning throughout this period. In this study, observations at 08, 14, and 20 CET were used. In the periods December-March (DJFM) 299 out of 366 possible cases were available, and in April-June (AMJ) 246 were available out of 273 possible. For each of the stations, Green Harbour, Longyearbyen and Platåberget, temperature percentiles were calculated. Only cases where all of the stations had data were included. For each fifth percentile the temperature differences between Platåberget and the two other stations were calculated for the seasons DJFM (figure 4.1a) and AMJ (figure 4.1b). Basic statistics of the observations are given in table 4.1.

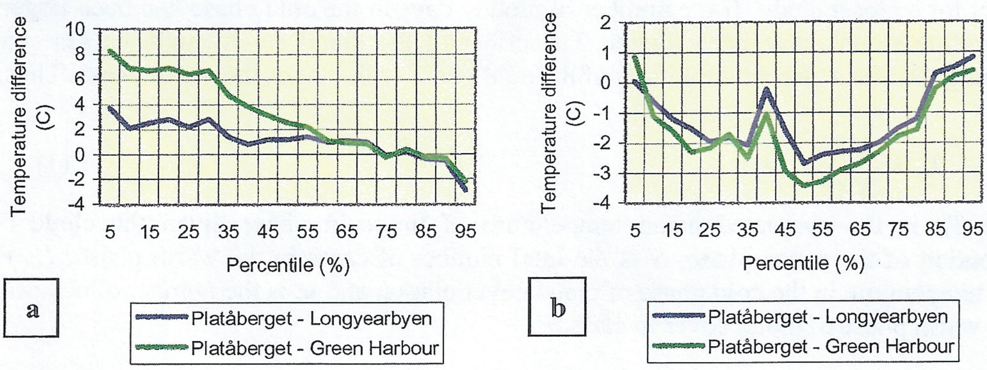


Figure 4.1. Differences at fixed percentile points between temperature distributions of Green Harbour, Longyearbyen, and Platåberget, a) for the period December 1911-March 1912, and b) April-June 1912.

Table 4.1. Statistics for observed temperature at Green Harbour, Longyearbyen, and Platåberget December 1911-June 1912.

| | December 1911– March 1912 | | | April 1912-June 1912 | | |
|---|---|---|---|---|---|---|
| | Green Harbour | Longyearbyen | Platåberget | Green Harbour | Longyearbyen | Platåberget |
| Mean | -19.6 | -17.7 | -16.6 | -5.0 | -5.5 | -6.6 |
| Median | -20.6 | -19.3 | -18.1 | -0.6 | -1.3 | -4.0 |
| Standard dev. | 11.5 | 10.0 | 8.4 | 8.8 | 8.7 | 8.6 |

Winter (DJFM) temperatures are lower at Green Harbour and Longyearbyen than at Platåberget for all percentiles up to about the 70th percentile. For percentiles between 70 and 90 the distributions are almost equal, while Platåberget is coldest at the very end of the distribution. However, there are also large differences between Green Harbour and Longyearbyen for low percentiles. Low temperatures are much more frequent at Green Harbour than at Longyearbyen. The low temperatures at Green Harbour strongly influence the mean difference in this period, as well as the larger standard deviation.

These results may again attribute to the frequent inversions that occur during the Artic winter. Near the ground, temperature increases with height. Thus, the lowest lying station, Green Harbour at 7 m ASL, experiences the lowest temperatures in these situations. The difference in altitude between Longyearbyen and Green Harbour is only 26 m, which seems too small to account for the differences observed between the stations at the lowest temperatures. Strong catabatic winds, however, might be present near Longyearbyen more often than at Grønfjorden where Green Harbour was situated.

Because of its higher altitude, temperatures at Platåberget are lower than at the two other stations when there are no inversions, on days with cloudy skies or high temperatures. This is not enough to compensate for the higher temperatures at the cold end of distribution, and the mean temperature of Platåberget remains higher than at the two other stations (table 4.1).

The cloud cover at Green Harbour and Longyearbyen do not differ systematically from each other; for 228 comparative observations the mean difference is only 0.1 tenths cloud cover, less than the biases that might be present among different observers. Mean temperature differences between the two sites are therefore not due to different cloud cover.

In the season April-June the inversions are weaker and less frequent. The standard deviations are about equal for the three stations, and now the temperature at Platåberget is lower that at Longyearbyen and Green Harbour due too its larger altitude. The temperature at Green Harbour is also higher than at Longyearbyen, so the situation is changed from winter (figure 4.1b).

For the period when the station at Nordenskiöldfjellet was operative, from 19 February to 31 March, there are 123 simultaneous observations at all stations (31 March was missing at Platåberget). The altitude of Nordenskiöldfjellet is 1050 m, which we assume was the approximate altitude also for the meteorological station (1055 m is given as the station altitude in Rempp and Wagner (1921)). Only for the coldest weather situations is the temperature higher at the mountain station than at the base station in the valley of Longyearbyen (figure 4.2). Compared with Green Harbour, however, the ground station is coldest for about 2/3 of the lowest percentile points. Comparison of Nordenskiöldfjellet and Platåberget shows that inversions seldom reached above the level of the Platåberget station (figure 4.2).

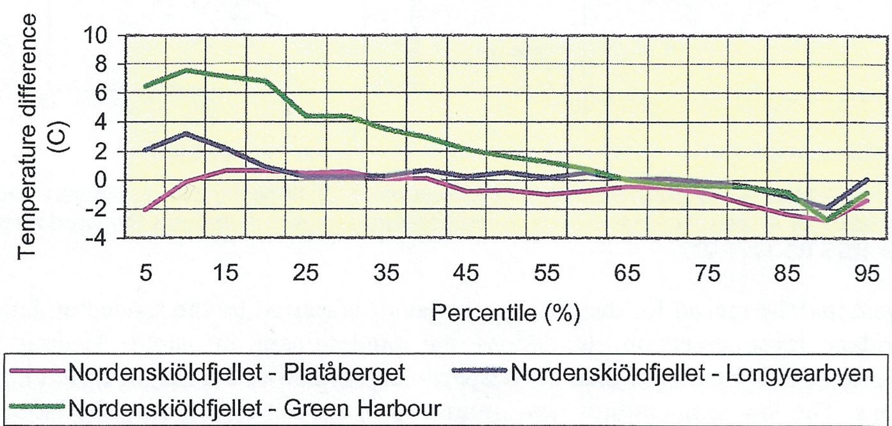


Figure 4.2. Differences at fixed percentile points between temperature distributions of Nordenskiöldfjellet and Green Harbour, Longyearbyen, and Platåberget for the period 19 February-30 March 1912.

**5. Daily minimum temperatures, Longyearbyen and Svalbard Airport (1975-1977).**

From the preceding discussion, it is clear that inversions can result in significant temperature differences between stations at even slightly different elevations, with the largest differences occurring in the daily minimum temperatures. Therefore, this weather element was used for further study of the spatial differences for the modern period at Longyearbyen and Svalbard Airport. The data used were for the two-year period with simultaneous measurements, 1975.08-1977.07.

In some weather situations the minimum temperature differed between the stations. This occurred mainly when wind disturbed the boundary layer of cold air over the more rugged terrain in Longyearbyen, while the cold air layer was maintained at Svalbard Airport. These situations were taken out of the data sample if the difference exceeded three times the difference between the median value and the 75th or 25th percentiles.

On average, Longyearbyen was warmer than Svalbard Airport for all months, with differences ranging from 0.4 °C warmer in September to 1.5 °C in January and intermediate values in other months. The differences were significantly affected by temperature itself in some of the months.

The regression lines between the difference and mean minimum temperature for February, March, April and December have negative slopes, while for September, October and November slopes are positive. For the remaining months, January, April, June, July and August, the slopes of the lines are not significantly different from zero ($p > 0.05$). The months February and October are shown as examples (Figure 5.1).

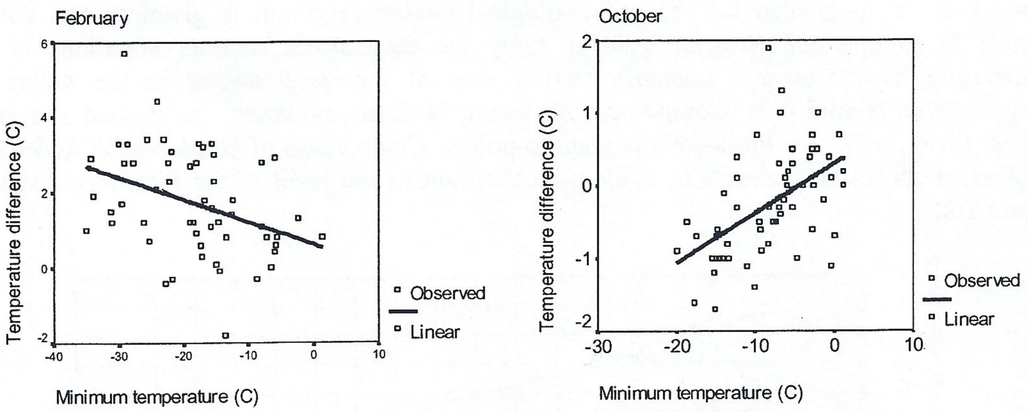


Figure 5.1. Difference of daily minimum temperature ( °C) between Longyearbyen and Svalbard Airport as function of average daily minimum temperature Longyearbyen and Svalbard Airport ( °C) in the period 1975.08-1977.07.

We suggest that the reason for the different behavior is caused by the sea ice on Isfjorden and the boundary layer inversion. Inversions are predominant in Arctic leading to higher temperatures at Longyearbyen than at Svalbard Airport due to the height difference between the stations. The low temperatures near ground level are not affected by the Isfjorden water when the fjord is frozen. At low air temperatures in situations with open fjord, the lower air layers are heated by the fjord. Thus, we see positive slope lines in the autumn, whereas the slopes are negative during winter. During summer, the air temperature does not drop much below zero, and the fjord does not affect air temperature much. This is consistent with no significant slope of the regression line during summer.

We conclude that adjustments of Longyearbyen temperatures to Svalbard Airport should be temperature-dependant for some of the months.

**6. Revision of the Svalbard Airport long-term series**

A homogenized temperature series for Svalbard Airport has already been established back to December 1911 by including also other series from regular stations around Isfjorden (Nordli et al. 1996). The other series originate from Longyearbyen, Green Harbour, and Barentsburg, all covering the period prior to August 1975. After that date, all data originates from Svalbard Airport. A few gaps are also filled in by data from Isfjord Radio and there are some interpolations during WW II. In cases of overlapping data, the first priority was given to the Svalbard Airport series and the second priority to the Longyearbyen series.

The rationales for revising the long-term series now are the improvements of values as a result of further digitization and quality control of the Green Harbour and Longyearbyen series. An even more important reason is the increased understanding of the climate variability and spatial differences within the Isfjorden areas due to the availability of more daily data.

The recently digitized German-Austrian scientific expedition data from Longyearbyen make it possible to check the former adjustments of the Green Harbour series, which was applied to make it homogenous with the Longyearbyen series. The overlapping comprises the period from Dec. 1911 to June 1912. On average for these months the adjusted series differed by only 0.3 °C (colder) compared to the observed one. For the Dec. - March, where the variability of temperature is larger than in other seasons, the corresponding difference was assessed about 1 °C too cold. This check indicates that the former adjustments are reliable, taking into account the different climate at those sites during inversion situations, in which reliable adjustments are hard to find. This is particularly true for the winter 1911-12, which was extraordinary cold.

The German observational site in Longyearbyen was near the same site used for the later Norwegian observations (Ch. 2). These data are therefore assumed to be homogenous with the later Norwegian data from Longyearbyen. Thus, the regression analysis between the Green Harbour observations and the Longyearbyen observations were carried out with all available data, Norwegian as well as German. The overlapping period was thus from Dec. 1911 to Aug. 1923, but in the Longyearbyen series there is many gaps.

The temperature differences between Longyearbyen and Green Harbour seem to vary with temperature. The first approach for checking these variations was to use simple regression analysis individually for each month with the resolution of daily mean temperature (figure 6.1, table 6.1). The data fit the linear model well though with varying regression correlation from month to month, being highest in winter (0.98 in January) and poorest in summer (0.85 in August). The standard errors of the estimate were larger in winter than in summer due to the much larger variability in winter (note for example the scale differences of the diagrams 6.1 January and 6.1 July). Thus, in February the standard error is estimated to 2.9 °C, whereas in August this amounts only to 1.1 °C. The number of data points in the analyses vary from 123 (October) to 216 (March).

The Longyearbyen data need to be adjusted to the Svalbard Airport site (see also Ch. 5). However, the equations developed in Ch. 5 are valid only for minimum temperature. Another set of regression equations were therefore established using daily mean temperatures during the interval of parallel measurement (August 1975-July 1977). Less data were available for analysis (only two years) than for the regression between Green Harbour and Longyearbyen.

Tentatively the regression analysis was performed individually for each month. However, due to the similarities of the regression equations for December and January the two months were joined and the number of data points doubled. Likewise the months February and March were joined. The standard errors of these estimates were about 1 °C. For the rest of the year, April – November, the Longyearbyen monthly temperatures were adjusted to Svalbard Airport conditions by temperature independent adjustment terms based on the parallel measurements for each month.

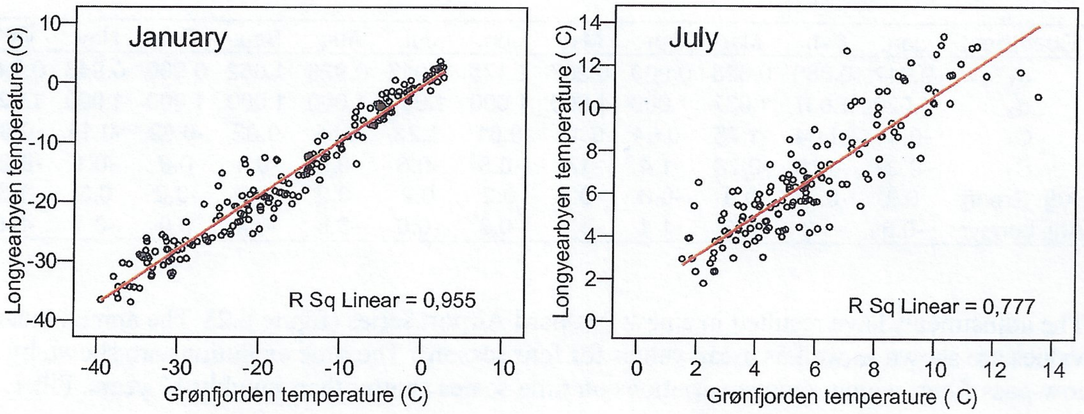


Figure 6.1 Mean daily temperatures at Longyearbyen and Green Harbour plotted for the months January and July during the years 1911-1923. In the period there are many missing values.

The errors of the monthly mean values are smaller than the errors for individual days. Under the assumption of randomness the errors of monthly means are reduced to 0.2 – 0.5 °C, but it is not proved that the parallel measurements represent unbiased samples for the period 1911-1975. Therefore the figures above should be regarded as a lower limit of the real error.

The procedure for establishing the adjustments can be formalized as follows. The estimated temperatures at Longyearbyen, $T_L$, and Svalbard Airport, $T_S$, may be written:

$$T_L = \alpha_1 T_G + C_1 \qquad (2)$$

$$T_S = \alpha_2 T_L + C_2 \qquad (3)$$

where $T_G$ is the temperature at Green Harbour, and $\alpha_1$, $\alpha_2$, $C_1$ and $C_2$ are constants (Table 6.1) established by regression analysis. Adjustments to make Green Harbour temperatures valid for Svalbard Airport are obtained by combining equations (2) and (3).

$$T_S = \alpha_1 \alpha_2 T_G + \alpha_2 C_1 + C_2 \qquad (4)$$

During the months April-November the adjustments for Longyearbyen are simply the mean differences between the series. Formally the regression equations may be used for these months too by setting the coefficients $\alpha_2 = 1$.

The winter temperatures (Dec. – March) for Green Harbour have to be positively adjusted to be valid for Svalbard Airport (table 6.1; Adj. Grønfj.). When it comes to spring (April – May) the situation is very different, and negative adjustments have to be used. During the rest of the year only small adjustments are needed. Negative adjustments of the Longyearbyen series (table 6.1; Adj. Longyr.) are needed except during late autumn (Oct. – Nov.), where practically no adjustments are necessary.

Table 6.1 Coefficients $\alpha_1$, $\alpha_2$, $C_1$ and $C_2$ for use in equations (2) and (3) for adjustments of the temperature series from Green Harbour and Longyearbyen to be valid for the Svalbard Airport series. The adjustments listed in the table (Adj. Grønfj. and Adj. Longyr.) are those to be used for the standard normal period 1961-1990.

| Coefficient | Jan. | Feb. | Mar | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\alpha_1$ | 0.917 | 0.880 | 0.823 | 0.900 | 0.987 | 1.175 | 0.943 | 0.926 | 1.052 | 0.906 | 0.948 | 0.840 |
| $\alpha_2$ | 1.020 | 1.037 | 1.037 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.020 |
| $C_1$ | -0.44 | -1.04 | -1.75 | -0.54 | 0.14 | 0.61 | 1.22 | 0.65 | 0.02 | -0.69 | -0.14 | -0.99 |
| $C_2$ | -0.29 | -0.78 | -0.78 | -1.4 | -1.0 | -0.8 | -0.6 | -0.5 | -0.4 | 0.0 | -0.1 | -0.29 |
| Adj. Grønfj. | 0.9 | 0.7 | 0.9 | -0.8 | -0.8 | 0.2 | 0.2 | -0.2 | -0.3 | -0.2 | 0.3 | 1.3 |
| Adj. Longyr. | -0.6 | -1.3 | -1.3 | -1.4 | -1.0 | -0.8 | -0.6 | -0.5 | -0.4 | 0.0 | -0.1 | -0.6 |

The adjustments have resulted in a new Svalbard Airport series (figure 6.2). The annual mean values are shown as well as mean values for four seasons. The time evolutions are shown by a low-pass filter, which remove variations on time-scales shorter than roughly 10 years, Filt.1.

Looking first at the individual mean values (annual or seasonal), the lowest temperatures are usually found in the early part of the series, except for autumn, in which the coldest years are in the late 1960s. On a decadal scale (red curve) the 1930s and the 1950s were particularly warm in all seasons. At present (2004), the Spitsbergen climate is in a warm phase, which is seen in all seasons. The filtered curves are higher at present than in any earlier period for the annual mean values as well as for the seasons, spring, summer and autumn. For winter, however, the temperature now is lower than during the maximum in the 1930s analyzed on the decadal scale.

The most pronounced cold phases of the series are in the 1910s and in the 1960s. These decades were cold for all seasons. Also the period around 1980 was cold during winter and summer, but local minima for these years are hardly seen in the intermediate seasons, spring and autumn.

The trends of the series were tested for significance by the non-parametric Mann-Kendall test (Sneyers 1990). An annual positive trend is significant at the 5 % level. Significant trends are also present in spring and summer, but not in winter and autumn. At the 0.01 significance level the positive trend is significant in spring, but not in the other seasons, whereas at the 10 % level the positive trends in all seasons but winter are significant (table 6.2).

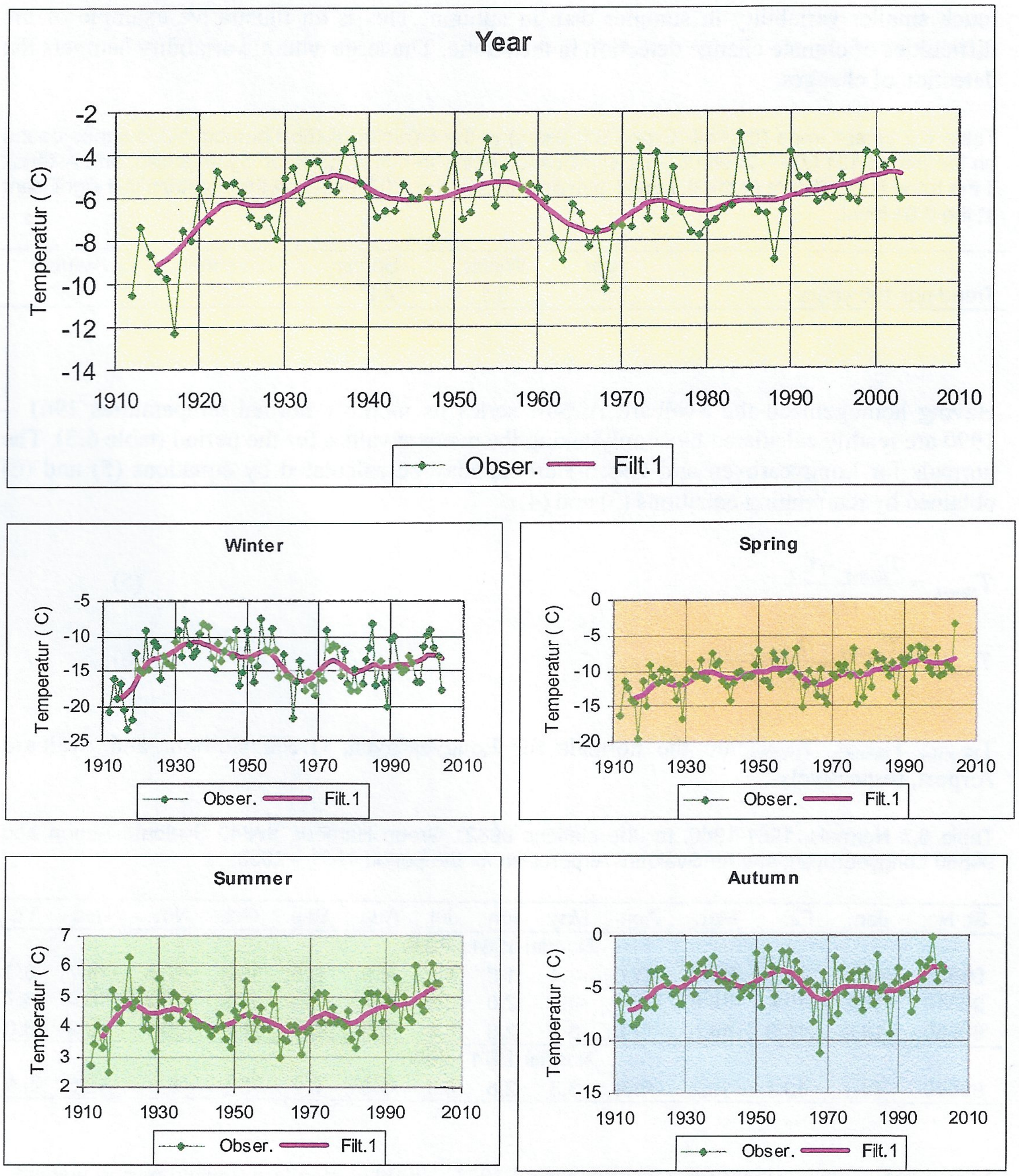


Figure 6.1 The Svalbard series homogenized to be valid at Svalbard Airport in the period September 1911 – August 2004 for (**a**) annual values, (**b**) winter (DJF), (**c**) spring (MAM), (**d**) summer (JJA), (**e**) autumn (SON). Individual years are represented as dots in the diagrams. The individual years are filtered by a Gaussian low-pass filter with standard deviations of 3 years (Filt.1), corresponding to a rectangular filter of about 10 years.

The combined Svalbard Airport series was also tested for trends by linear regression analysis for annual values as well as seasonal values (table 6.2). The significance of the regression coefficient is indicated by asterisks. In autumn the trend is 1.3 °C per 100 years but is not significant at the 0.05 level, whereas a smaller trend in summer of 0.7 °C is significant due to much smaller variability in summer than in autumn. This is an illustrative example of the difficulties of climate change detection in the Arctic. The large natural variability hampers the detection of changes.

Table 6.2 Linear trend (degree °C per 100 years) in the Svalbard Airport homogenized series based on the period 1911.09 – 2004.08. The significance of the trends is indicated by asterisks, one asterisk if the trend is significant at the 0.1 level, two asterisks at the 0.05 level and three asterisks if significant at the 0.01 level.

| | Year | Winter | Spring | Summer | Autumn |
|---|---|---|---|---|---|
| Trend per 100 years | 1.6** | 0.1 | 4.2*** | 0.7** | 1.3* |

Having homogenized the Svalbard Airport series its monthly normal temperatures 1961 – 1990 are readily calculated by simply taking the average values for the period (table 6.3). The normals for Longyearbyen and Green Harbour may be calculated by equations (5) and (6) obtained by rearranging equations (3) and (4)

$$T_{NormL} = \frac{T_{NormS} - C_2}{\alpha_2} \quad (5)$$

$$T_{NormG} = \frac{T_{NormS} - \alpha_2 C_2 - C_1}{\alpha_1 \alpha_2} \quad (6)$$

$T_{NormL}$, $T_{NormG}$, $T_{NormS}$ are the normals for Longyearbyen, Green Harbour and Svalbard Airport, respectively.

Table 6.3 Normals, 1961-1960, for the stations 99821 Green Harbour, 99840 Svalbard Airport and 99860 Longyearbyen, and for Svalbard Airport also for the period 1971 – 2000.

| St. No. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec | Yr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Normal 1961 - 1990 | | | | | | | | | | | | | |
| 99821 | -16.1 | -17.1 | -16.7 | -11.6 | -3.4 | 1.8 | 5.6 | 4.9 | 0.6 | -5.3 | -10.6 | -14.7 | -6.9 |
| 99840 | -15.2 | -16.4 | -15.8 | -12.4 | -4.2 | 2.0 | 5.9 | 4.7 | 0.3 | -5.5 | -10.3 | -13.4 | -6.7 |
| 99860 | -14.6 | -15.0 | -14.5 | -11.0 | -3.2 | 2.8 | 6.5 | 5.2 | 0.7 | -5.5 | -10.2 | -12.9 | -6.0 |
| Normal 1971 - 2000 | | | | | | | | | | | | | |
| 99840 | -14.1 | -15.1 | -13.7 | -11.4 | -3.8 | 2.5 | 6.1 | 5.0 | 0.7 | -5.5 | -9.3 | -12.6 | -5.9 |

Many meteorological institutes use the period 1971 – 2000 as standard normal period instead of 1961 – 1990, which is in use at the Norwegian Meteorological Institute. For Svalbard Airport the latest period is 1°C warmer for the annual value and up to 2 °C warmer in late winter. No monthly value is colder. The increased values are due to the replacements of the cold 1960s by the mild 1990s in the normals. This shows that there might be large differences between standard normal periods in Arctic due to pronounced decadal variability.

## 7. Summary and conclusion

As discussed in the introduction, the early 20$^{th}$ century warming was especially pronounced in the Svalbard Airport series (1911.09 – 2004.08), so much so that the reliability of the instrumentation was questioned already at an early stage (Birkeland 1930). A recent comparison of the homogenized Svalbard Airport series to three proxy records (discussed in the introduction) shows that the observed and proxy series compare well in the period after 1920, but that in the early period 1912-1919 the Svalbard Airport series is consistently colder than the proxy series would indicate (Kohler et al. manuscript in preparation).

The present analysis shows that although the Green Harbour series has not always been of top quality, nothing is found to indicate so large errors that the low temperature in the 1910s should be doubted. As much as 2/3 of the warming from the 1910s to the 1920s during winter can be explained by an increase of cloud cover that has taken place.

Analyses of contemporarily observations at different altitudes in Longyearbyen show that both Green Harbour and Svalbard Airport represent areas with frequent inversions. During cold spells the local climate at Svalbard Airport will experience much lower temperatures than higher-altitude sites. Inversions are local phenomena, which will not translate to the proxy data. Thus, the poor fit of the Lomonosovfonna ice-core proxy data during the 1910s might be due to more frequent inversions, which will not be recorded at the high-altitude of the ice-core drilling site. The correlation of other proxy data to Svalbard Airport data could also potentially be poorer when there are more frequent inversions at Svalbard, since the proxy data are obtain from comparatively distant sites.

For the annual values a positive trend is detected in the Svalbard Airport series significant at the 5 % level for the whole observational period. In summer (JJA) a positive trend is also significant at the 5 % level, whereas a positive trend in autumn (SON) is not significant at this level. For the spring (MAM) a positive trend is highly significant, whereas in winter (DJF) there is no trend for the whole period.

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