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THE SVALBARD AIRPORT TEMPERATURE SERIES

Abstract: In the Isfjorden region of Spitsbergen in the Svalbard archipelago, the air temperature has been observed continuously at different sites since 1911 (except for a break during WW II). The thermal conditions at these various sites turned out to be different so that nesting the many series together in one composite time series would produce an inhomogenous long-term series. By using the SNHT (Standard Normal Homogeneity Test) the differences between the sites were assessed and the series adjusted accordingly. This resulted in an homogenised, composite series mainly from Green Harbour (Finneset in Grønfjorden), Barentsburg (also in Grønfjorden), Longyearbyen and the current observation site at Svalbard Airport.

A striking feature in the series is a pronounced, abrupt change from cold temperature in the 1910s to warmth in the 1930s, when temperature reached a local maximum. This event is called the early 20th century warming. Thereafter the temperature decreased to a local minimum in the 1960s before the start of another increase that still seems to be ongoing. For the whole series, statistically significant positive trends were detected by the Mann-Kendall test for annual and seasonal values (except for winter).

Quite often the Norwegian Meteorological Institute receives queries about long-term temperature series from Svalbard. Hopefully, the Svalbard Airport composite series will fulfil this demand for data. It may be downloaded free of charge from the Institute’s home page: http://sharki.oslo.dnmi.no and should be used with reference to this article.

Key words: Arctic, Svalbard, long-term temperature series

Introduction

The Svalbard Airport temperature series, starting in September 1911, is one of only a few long-term (~ 100 yr) instrumental temperature series from the high Arctic (Nordli et al. 1996). As such, it is an important record for interpreting current Arctic temperature trends in terms of past behaviour. It is a composite series consisting of shorter series from the Isfjorden area (Fig. 1), all of them homogenised to be valid for the Svalbard Airport site. The airport is situated near Longyearbyen (Fig. 1), the main Norwegian settlement on Svalbard.

The observations at the airport started in 1975, whereas at Longyearbyen observations started as early as 1911, if we take into account observations made by a German-Austrian scientific expedition as the start of the series. The starting year for more permanent observations was 1916, but the problem with the Longyearbyen series is that it has many gaps. Other important observation sites from which the data for the composite series were taken are Green Harbour for the early period and Barentsburg, the main Russian settlement on Svalbard, for the later period.

There were earlier attempts to homogenise the Svalbard Airport series (Nordli et al. 1996; Nordli and Kohler 2004), which resulted in slightly different adjustments. The main reason for this was the ongoing digitalisation

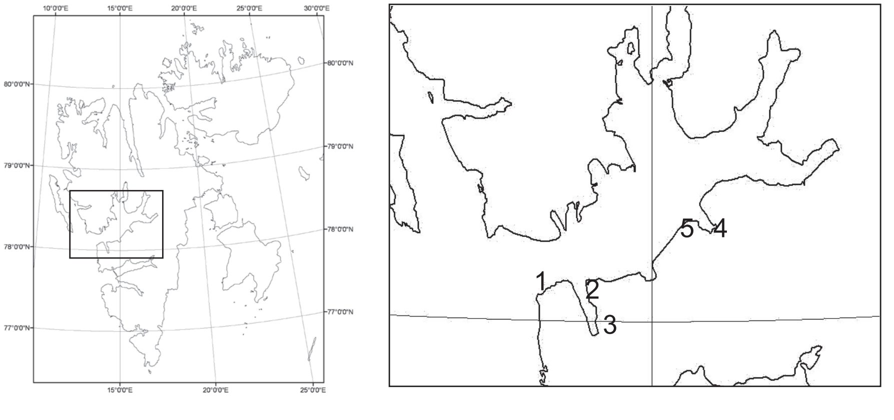


Fig. 1. Map of Svalbard with the Isfjorden area enlarged (right). The location of the stations giving data to the Svalbard Airport composite series are numbered: 1) Isfjord Radio, 2) Barentsburg, 3) Green Harbour, 4) Longyearbyen, 5) Svalbard Airport

Table 1. Series included in the composite Svalbard Airport series with given periods for the inclusion

National Station No.	Name	Whole period of observations	Inclusion in the composite series
99860	Longyearbyen	1911.09.-1977.07 (there are many gaps)	1911.09–1912.06 1916.11–1919.09 1919.11–1920.05 1921.09–1923.08 1930.09–1934.08 1935.01–1935.09 1936.11–1939.06 1945.09–1946.08 1957.01–1975.07
99821	Green Harbour	1911.12–1930.08	1912.07–1916.10 1919.10–1919.10 1920.06–1921.08 1923.09–1930.08
99820	Barentsburg	1933.02 -present	1934.09–1934.12 1935.10–1936.10 1939.07–1941.08 1948.01–1948.08 1948.10–1956.12
99790	Isfjord Radio	1934.09–1976.07	1946.09–1947.12 1948.09–1948.09
99840	Svalbard lufthavn	1975.08-present	1975.08–2010.02

of the Svalbard data that made it possible to use more daily data for the calculation of the adjustments.

The different sources of data for the series are listed in Table 1 and are described in some detail in section 2. The homogenisation of the series is described in section 3 together with the calculation of the adjustments that are necessary to obtain homogeneity.

Data and methodology

First the individual series are homogenised using the Standard Normal Homogeneity Test (SNHT) introduced by Alexandersson (1986). This is a relative homogeneity test that requires data from reference stations for comparison. However, the number of reference stations on Svalbard is sparse, so it was important to take metadata into account.

The significance of the trends in the series were tested using the Mann-Kendall test (e.g. Sneyers 1990; Nordli et al. 2008). As it is a rank test it can be used without knowing the distribution of the variable being tested.

Except for a break during WW II there have been continuous measurements in the area around Isfjorden since 1911. The locations of the many series that have contributed to the composite long-term series are listed in Table 1, with their national station number and names. They are briefly described below.

Svalbard Airport

As the name implies, the station is situated at the airport of Svalbard, which in Norwegian is called *Svalbard lufthavn*, and this is the name used in Norwegian station lists. It is located near the outer part of Adventfjorden, a bay of Isfjorden (Fig. 1). Measurements began in August 1975 using the MI-33 screen pattern, which is the standard Norwegian screen for harsh weather conditions (cf. Nordli et al. 1997). The station is still running (cf. Table 1).

The temperature measurements proceeded in the same screen throughout the measurement period, up to 5th October 2010, when the screen was changed to a pattern MI-74 and relocated to a site further away from the runway of the airport. This was done in order to minimise the thermal influence on the measurements by an area which had been cleared for airport purposes. The sparse grass growing on the area was replaced by sand, and in late July or early August 2010 was covered with asphalt. Measurements are performed both on the new and the old sites.

Longyearbyen

The series consists of three main series, one run by Store Norske Spitsbergen Kulkompani and two other by the Norwegian Meteorological Institute. There are also three shorter series. However, the sites of the main series as well as the shorter series are all located near each other and are considered to be homogenous. A description of the sites and the homogeneity testing is given by Nordli et al. (1996). A brief outline is given below, first for the three main series and then for the three shorter series:

Store norske Spitsbergen Kulkompani. In the period between November 1916 and August 1923 meteorological observations were carried out three times a day at Longyearbyen by a mining company *Store Norske Spitsber-*

gen Kulkompani. The daily observations were digitised and controlled, and were 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 greater than 0.1°C.

The Norwegian Meteorological Institute series. The institute carried out observations at Longyearbyen during two periods, the first one from September 1930 to June 1939 (period I), and from January 1957 to July 1977 (period II). During both periods observations were carried out according to the rules established by the Institute with observation times at 7.00, 13.00, 18.00 UTC (period I) and 6.00, 12.00, 18.00 UTC (period II). The standard screen for harsh weather conditions was used during both periods, i.e. type MI-33 .

The German-Austrian scientific expedition. In the period between September 1911 and June 1912 a German-Austrian scientific expedition overwintered 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 a.s.l., in the valley side near the mouth of the Longyear valley, a tributary valley to Adventdalen. The last meteorological station run in Longyearbyen by the Norwegian Meteorological Institute (period II) was located at almost the same altitude (37 m). There are no other flat areas in the valley side at that elevation, near the bay. Thus, the two sites where the measurements were taken must have been situated close to each other, at a distance of no more than 100 m.

German observations during WW II. In the period between December 1941 and June 1942 observations were carried out at Longyearbyen by German military forces. The location was presumably near the period II site.

Post war observations. In the period between September 1946 and December 1947 observations were carried out by Norwegians. These observations are reported to have been performed at a distance of 250 m NNW of the period II site. Using a modern map the direction seems rather to have been NNE.

Green Harbour

Observations at Green Harbour (between December 1911 and August 1930) were carried out according to the Norwegian standards, i.e. observation times were 7.00, 13.00, 19.00 UTC until 1 July 1920 and then changed to 7.00, 13.00, 18.00 UTC; daily minimum temperatures 08h – 08h, but no maximum temperature. The quality of the data 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. However, as long as the nearest whole degree was read correctly, this did not affect the monthly mean temperature significantly. Further information on the quality of the series is given by Nordli and Kohler (2004).

In some months we find significantly different mean temperatures, when compared to the previous values published by the Norwegian Meteorological Institute (for details see Nordli and Kohler (2004)). One reason for that was the use of different sources for obtaining the minimum temperature data (the readings were taken from a thermometer or alternatively from thermographs). Another reason could be that the diurnal temperature range was poorly known on Svalbard when the observations started in 1911, i.e. the weighting factors (Nordli and Tveito 2008) used for calculating mean temperatures from observations irregularly distributed over the course of the day, were poorly known.

Barentsburg

Barentsburg is a Russian meteorological station located only 2 km to the north of Green Harbour (Fig. 1). The station is still running, but the latest data available for this article is from December 1990. The measurements started in 1933 when the station was moved to Barentsburg from Grumantbyen, where it was located from 1931. In July 1941 observations were interrupted, due to WW II,. They were resumed in 1947. Unfortunately, our knowledge of the metadata from the station is incomplete. The following is entirely based upon work conducted by Rudolf Brázdil from Brno University, Czech Republic (pers. comm.); more complete information can be found in Nordli et al. (1996).

Metadata from about 1963: The meteorological station is located in northeastern part of the village, approximately 500 m from the shore line. To the north and northwest of the station is a deep valley. The nearest buildings (each 6 m high) are located at a distance of 50 m and 80 m (old consulate building) from the measuring site.

Metadata January 1978 to January 1984: Due to the construction of a 5-floor building 40 m to the south of the station and plans for a new consulate building, the station was moved to the location of the aerological station (22 m a.s.l.). Because of the lack of facilities for the installation of the instruments, not all of them were moved. The air temperatures and humidity could in this period have been influenced by streams of warm water from the dining room or agriculture building (located at a distance of about 10 m).

Measurement at the current location started on 1 February 1984. Homogeneity testing by the SNHT did not detect any inhomogeneities in the series (Nordli and Kohler 2004).

Isfjord Radio

The station was situated on Cape Linné at the mouth of Isfjorden, established on 1st September 1934 (Fig. 1). It was destroyed in the war in September 1941 but was re-established at the same place after the war. From August 1946 observations were resumed, but from 30 June 1976 the station was no longer used for climatological purposes.

The radiation screen was being altered between the patterns of 1930 and 1933. The station started by using an MI-30, which was changed to an MI-33 in 1939, which reverted to an MI-30 in 1946 and and which changed again to MI-33 on 20 August 1951. Since then it has remained unchanged.

The homogenization of the Svalbard Airport long-term series

A meteorological observation station was established at Svalbard Airport the 1st of August 1975 (Table 1, Fig. 1). Later it was defined as a Climate Reference Series (RCS) by the Norwegian Meteorological Institute and was taken as the principal series for a homogenised, composite long-term series of Svalbard. This means that all other series will be adjusted to be valid for the Svalbard Airport series. Thus, observations from the airport can be included in the composite series without any adjustments, whereas all other series have to be adjusted.

The series at the airport is situated in the main settlement of Longyearbyen at a distance of only 15 km. For the construction of the composite series the Longyearbyen series has a key role as it overlaps both with the oldest series on Spitsbergen and with the Svalbard Airport series.

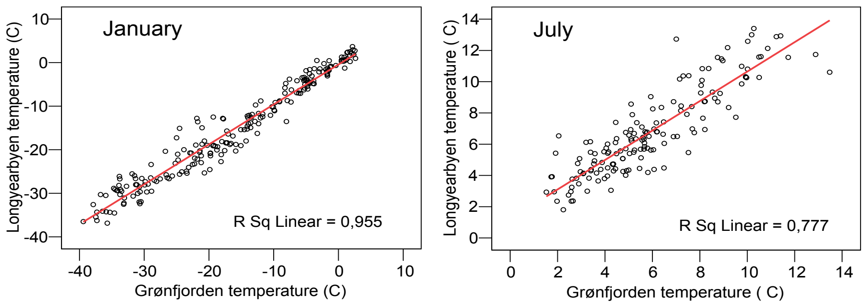
The adjustment of the Longyearbyen series

To adjust the Longyearbyen series, linear regression analysis was performed with the Longyearbyen temperature used as the predictor and the Svalbard Airport temperature as the predictant using the daily mean temperature during the interval of parallel measurements (November 1975-July 1977). Tentatively the 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 thus 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 regression equations showed that the adjustments within each month varied very little with temperature, so for simplicity's sake the Longyearbyen series was adjusted not by regression analysis but by temperature-independent adjustment terms. These were calculated as differences between the two stations. The differences varied from month to month, from -1.4 °C in April to 0.0 °C in October (ref. C_2 in Table 2).

The adjustment of the Green Harbour series

The temperature differences between Longyearbyen and Green Harbour seem to vary with temperature. The first approach to checking these variations was to use simple regression analysis individually for each month with the resolution of daily mean temperature (Table 2 and Fig. 2). The data fit the linear model well, though with varying regression correlation from month to month, which was highest in winter (0.98 in January) and lowest 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 the scale differences of the diagrams in Fig. 2 for January and July). For example in February the standard error is estimated to be 2.9°C, whereas in August it amounts only to 1.1°C. The number of data points in the analyses vary from 123 (October) to 216 (March).

The errors of the monthly mean values are smaller than the errors of individual days. If we assume randomness, the errors of monthly means are reduced to 0.2–0.5°C, but it is not proved that the parallel measurements



Green Harbour Green Harbour

Fig. 2. Mean daily temperatures at Longyearbyen and Green Harbour plotted for January and July during the years 1911–1923. In the period there are many missing values

Table 2. Coefficients α_1, α_2, C_1 and C_2 for use in equations (1), (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.
α_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
α_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

represent unbiased samples for the whole 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:

$$T_L = \alpha_1 T_G + C_1 \qquad (1)$$

$$T_S = \alpha_2 T_L + C_2 \qquad (2)$$

where T_G is the temperature at Green Harbour, and α_1, α_2, C_1 and C_2 are constants (Table 2) established by regression analysis. The adjustments necessary to make Green Harbour temperatures valid for Svalbard Airport are obtained by combining equations (1) and (2).

$$T_S = \alpha_1 \alpha_2 T_G + \alpha_2 C_1 + C_2 \qquad (3)$$

For 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 coefficient $\alpha_2 = 1$.

The winter temperatures (December-March) for Green Harbour have to be positively adjusted to be valid for Svalbard Airport (Table 2: Adj. Grønfj.). When it comes to spring (April-May) the situation is very different, and negative adjustments need to be made. During the rest of the year only small adjustments are needed. Negative adjustments of the Longyearbyen series (Table 2: Adj. Longyr.) are needed for all months except for late autumn (October-November), where practically no adjustments are necessary.

The adjustment of the Barentsburg series

The Longyearbyen series has gaps which have partly been filled by the Barentsburg series, from which only monthly means are available for the Norwegian Meteorological Institute. Alternatively the Isfjord Radio series could have been used, but the Barentsburg series needs lesser adjustments than Isfjord Radio to fit into the composite series. This is the main reason for the choice of priority. The mean differences between the Svalbard Airport and the Barentsburg series are shown as a curve in Figure 3 together with the adopted adjustments, shown as steps.

The Barentsburg data are included in the combined series mainly for the period 1948–1956, and also for some years in the 1930s (Table 1).

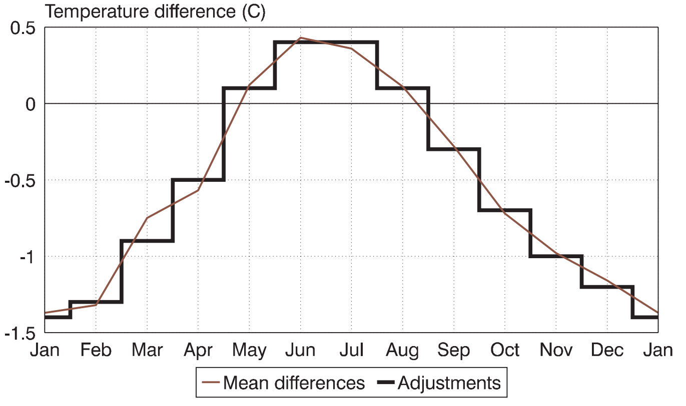


Fig. 3. Mean differences (curve) between Svalbard Airport and Barentsburg series, August 1975– December 1990. The step function is the adopted adjustments applied to the Barentsburg series to make it valid for Svalbard Airport

The adjustment of the Isfjord Radio series

During the period September 1946 to December 1947 none of the adjusted series mentioned so far have data coverage. The only alternative is Isfjord Radio, which is not an ideal series to be used as the station is influenced by the open water west of Spitsbergen to a much larger extent than Svalbard Airport. Thus, in the season December-February the adjustments are between -3 and -4 °C (Nordli et al. 1996), whereas in the season June-August the adjustments are slightly positive (cf. Nordli et al. 1996).

Interpolations during WW II

Interpolations of missing mean monthly temperatures in the series from Isfjord Radio were performed by the use of regression analysis (Steffensen 1969). Temperature data from Jan Mayen and the Russian station Bukta Tikhaya on Franz Josef Land were chosen as predictors, as well as pressure data from Isfjord Radio, Jan Mayen, Vardø, Røst and Bergen.

The standard deviation of the residuals varied from about 0.5 °C in August to about 2°C in March. The interpolations were later adjusted to the Svalbard Airport series (Nordli et al. 1996).

Results

Having calculated the adjustments that should be applied to every individual series, and following the priority of the series outlined in the previous chapter, the homogenised, composite series is readily available, as shown in Figure 4.

Looking first at the individual mean values (annual or seasonal), the lowest temperatures are usually observed in the early part of the series, except for autumn, when the coldest years are in the late 1960s. The highest temperatures, however, are usually found in the later years; for example the three warmest years occurred consecutively in the period 2005–2007. Among these, 2006 peaks out as a particularly warm year. This is when the highest ever seasonal temperature means for winter and spring were also recorded. In the year 2000 the autumn was particularly warm. Warm years also occurred in the 1930s although they were colder than the modern extremes. The summer of 1922 was exceptionally warm, exceeded nominally only by 2006 and 2007.

On a decadal scale (Gaussian filter curve in Fig. 4) the 1930s and the 1950s were particularly warm for all seasons. At present (2010), the climate of Spitsbergen is in a warm phase, which is seen for all seasons. The filtered curves are now higher than in any earlier period since systematic observations began in 1911.

The most noticeable 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 spring and summer, whereas local minima for these years are hardly seen in winter and autumn.

The trends of the series were tested for significance. The result was that the composite Svalbard Airport series has a positive trend significant to the level of 1%. Using the same analysis for the seasonal temperatures, the test showed positive significant trends to the level of 1% in spring, summer and autumn, but for winter the trend was not significant.

The composite Svalbard Airport series was also tested for trends by linear regression analysis for annual as well as seasonal values (Table 3). The trend in winter is much steeper than in summer, but the variability is also greater so that trends are not so easily detected during winter. Generally this is an illustrative example of the difficulties of climate change detection in the Arctic. The high natural variability hampers the detection of changes.

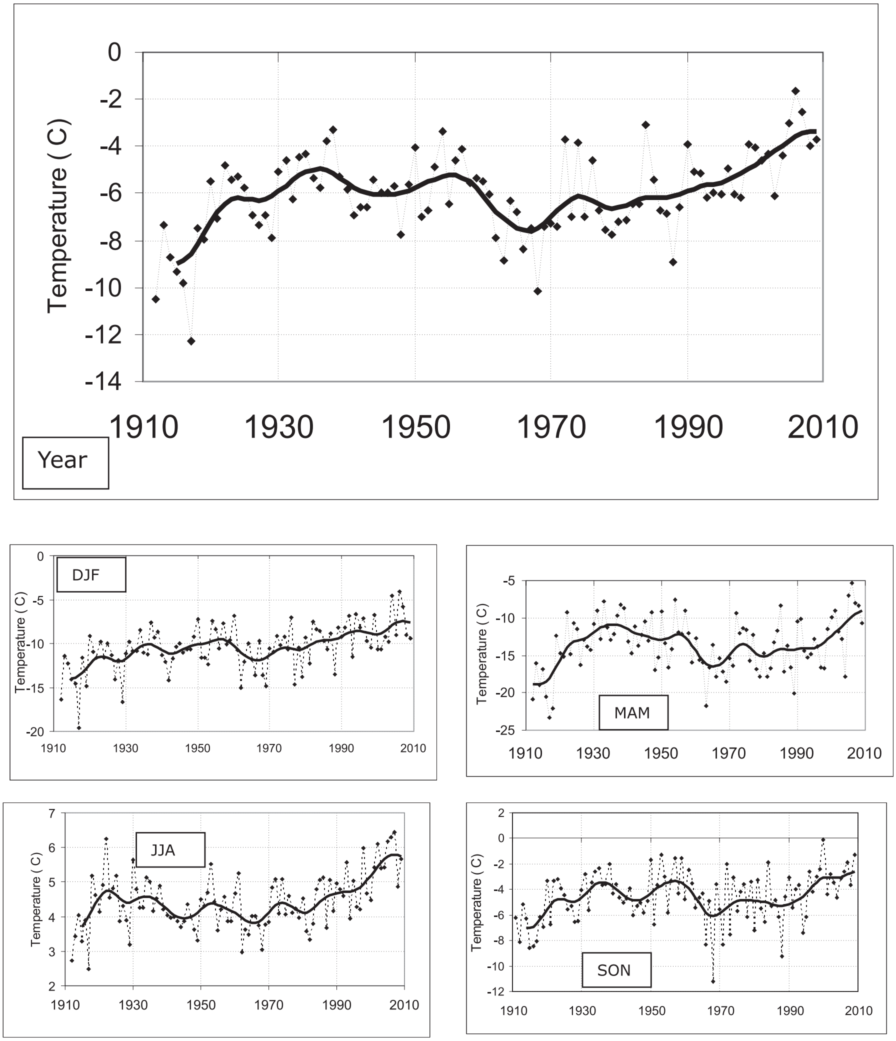


Fig. 4. The homogenised Svalbard Airport series during the period September 1911 to December 2010 for annual values (Year), winter (DJF), spring (MAM), summer (JJA), and autumn (SON). Individual years (dots) are filtered by a Gaussian low-pass filter (curve) with a standard deviation of 3 years in its distribution, corresponding to a rectangular filter of about 10 years

Table 3. Linear trend (degree °C per 100 years) in the Svalbard Airport homogenised series based on the period September 1911 – February 2010. The significance of the trends is indicated by asterisks (Mann-Kendall test) – one asterisk if the trend is significant to the level of 0.05, two asterisks if it is significant to the level of 0.01

	Year	Winter	Spring	Summer	Autumn
Trend per 100 years	2.4**	2.5	4.4**	1.1**	1.7**

Having homogenised the Svalbard Airport series, its monthly standard normal temperatures for the period 1961–1990 can be easily calculated by simply taking the average values for the period (Table 4). The standard normals for Longyearbyen and Green Harbour may be calculated by using equations (4) and (5) obtained by rearranging equations (2) and (3)

$$T_{NormL} = \frac{T_{NormS} - C_2}{\alpha_2} \qquad (4)$$

$$T_{NormG} = \frac{T_{NormS} - \alpha_2 C_2 - C_1}{\alpha_1 \alpha_2} \qquad (5)$$

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

Meteorological institutes may use the normal periods 1971–2000 and 1981–2010 instead of the standard normal period 1961–1990, which is currently in use at the Norwegian Meteorological Institute. For Svalbard Airport the period 1971–2000 is 0.8°C warmer than the standard normal 1961–1990 period (Table 4). No monthly value is lower. The warmer character of the 1971–2000 normal period is a result of the presence of the warm 1990s, which replaced the cold 1960s in the standard normal period.

An even larger difference is expected when the 1981–2010 normal period is being used. For all months the temperature values in this latest normal period are higher than those in the 1971–2000 normal period. However, the standard normal 1931–1960 that includes the mild 1930s and 1950s is also higher than the standard normal period 1961–1990 that includes the cold 1960s. In late autumn and early winter the temperature for the 1931–1960 period is still higher than for 1981–2010 (2009), but not for annual values. This shows that there might be large temperature differences between normal periods in Arctic due to clearly indicated decadal variability and/or large trends in the series.

Discussion

The most striking feature of the Svalbard series is the very low temperatures at the start of the series and the rapid warming during the 1910s, which resulted in a local maximum on the annual temperature curve in the 1930s. This warming was later known as "the early 20th century warming".

Understanding the very rapid temperature increase has historically been a challenge for climatologists. In 1928 the reliability of the measurements was questioned even by the most distinguished Norwegian climatologist B.J. Birkeland (Steffensen et al. 1996) in a letter to the Geophysical Institute in Tromsø, which is resposible for carrying out Norwegian meteorological measurements on Spitsbergen. Later Birkeland accepted the measurements and published the results (Birkeland 1930). At the beginning of the 1930s it was recognised by climatologists that a climatic fluctuation that even had substantial social and economic impact had occurred (Wood and Overland 2009).

Although being particularly strong on Svalbard, the early 20th century warming was also strong in the northernmost part of Norway, in the Nordland region and coastal areas of Finnmark (Hanssen-Bauer and Nordli 1998). It is also visible in the arctic series from Greenland and in the series from stations adjacent to the Arctic such as Iceland, the Faroes, 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 except for summer, particularly strong in winter in the period 1918–1922.

Nordli and Kohler (2004) found that increased cloud cover associated with the warming could have had an important feedback effect on the temperature measured at Green Harbour. Increased cloud cover reduces the net loss of radiation from the ground during winter and thus hampers the build up of surface inversions. This might be very important for a time series from a low level station near the ice-covered fjord like Green Harbour, which also is indicated by comparison with the Longyearbyen data (Table 4). The

Table 4. Standard normals 1961–1960, for the stations 99821 Green Harbour, 99840 Svalbard Airport and 99860 Longyearbyen as well as standard normal 1931–1960 and normals 1971–2000 and 1981–2010 for the Svalbard Airport series (as far as these are known). Values in *italic* comprise averages for the period 1981–2009

St. No.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Yr.
Standard normals 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
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
Standard normal 1931–1960													
99840	-12.2	-13.7	-14.9	-11.5	-3.9	2.3	5.9	4.7	0.5	-4.4	-7.8	-10.1	-5.4
Standard normal 1961–1990													
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
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
Normal 1981–2010 and average 1981–2009													
99840	-12.9	-13.6	-13.3	-10.2	-2.8	2.9	6.5	5.4	1.1	-5.0	*-8.1*	*-11.3*	-5.1

increased cloud cover is in line with the increased southerly winds and a greater number of storms penetrating the Arctic in connection to the warming (Hesselberg and Johannessen 1958). Also Wood and Overland (2009) found that circulation changes are very important for arctic temperature. They defined two meridional indices MI3 and MI2, which they showed to account for as much as 40–60% of the variance of the wintertime surface air temperature in the area between Iceland and Svalbard in the period 1851–2006. It is important to note that in this area the NAO index is practically uncorrelated with temperature (Wood and Overland 2009).

Johannessen et al. (2004) by the use of simulations with ECHAM4 and HadCM3 coupled atmosphere-ice-ocean models found that the early 20th century warming was within the natural internal climate-system variability, whereas the arctic warming during the last two decades is a response to anthropogenic forcing. This is also in line with previous results obtained by Hanssen-Bauer and Førland (1998) who 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. The analysis carried out by Benestad et al. (2002) further supported this suggestion.

There is no significant correlation between the NAO index and the Svalbard temperature (Hanssen-Bauer 2007) in contrast to the correlations with temperature on the Norwegian mainland (positive) and with Greenland (negative). Nevertheless, there is a common pattern of trends for the entire Atlantic Arctic area with positive trends for the 1910–1945 period, negative for 1946–1975, and again positive for 1976–1999 (Førland et al. 2002). A characteristic feature of the Svalbard Airport series is that the trends are here steeper (positive or negative) than most of the other temperature trends in Greenland, Faroes, Iceland, and northern Norway. The Svalbard Airport series might thus be regarded as a fingerprint of the long-term variability for the Arctic Atlantic area.

In the Atlantic area there are low frequency variations in the Sea Surface Temperature (SST) called the Atlantic Multidecadal Oscillation (AMO) index. These are possibly related to fluctuations in the thermohaline circulation (e.g. Polyakov and Johnson 2000). In the positive phase of AMO the SSTs in the North Atlantic tend to be higher than in the negative phase. Its positive phase occurred in the period 1930–1960 and in 2000–2010, during which periods the Svalbard Airport temperature was also in a warm phase (Fig. 4). As the Svalbard series is short (~ 100 years) it is not easy to assess how strongly the AMO and the Svalbard Airport series are related on those time scales. For annual values, however, they correlate rather poorly, $r = 0.29$ in the period 1912–2009.

In recent years the Svalbard Airport series have been particularly warm, such as in the period 1995–2005. For this period Przybylak (2007) analysed Arctic temperature series in different sectors. For the Atlantic sector the mean anomaly was 0.98 ^{o}C with reference to the 1951–1990 average, which is considerably less than for Svalbard Airport, where the anomaly was 1.5 ^{o}C taken from the present compilation.

The last 30 years of the Svalbard series (1981–2010) are only slightly warmer than the standard normal period 1931–1960. However, this is an effect of the long-term variability rather than lack of a significant trend. The period 1931–1960 is the warmest thirty-year period in the 20th century in contrast to the next standard normal period, 1961–1990, which is very nearly the coldest. During the 1931–1960 period it was the late autumn and early winter that were extremely mild.

During the first decade of the 20th century there were very few stations in operation in the Arctic (Przybylak et al. 2009) except for those in Greenland. There are some data for Svalbard for the period 1898–1913 from hunting expeditions, which were equipped with standard instruments from the Norwegian Meteorological Institute. They certainly cannot be incorporated in the Svalbard Airport series without adjustments as they are located far from the Airport. The adjustments are, however, difficult to assess without adequate reference series for comparison. This is solved by a project funded by the Polish-Norwegian Research Fund and Norway Grants, i.e. the AWAKE project. The necessary reference will be established by a re-opening of the old meteorological stations at the sites of the hunting expeditions. Thus, there will be measurements on the old sites parallel to the present stations on Svalbard, which will be of particular interest the Svalbard Airport station.

One long series that has been very seldom used in the composite Svalbard Airport series is the Isfjord Radio series (Table 1, Fig. 5). It is warmer than the Svalbard Airport series due to the influence of open water off the west Spitsbergen coast during winter. The Longyearbyen series is also warmer than the Svalbard Airport series, but this must be due to its location in the valley side in contrast to the flat area on the airport where measurements are taken today.

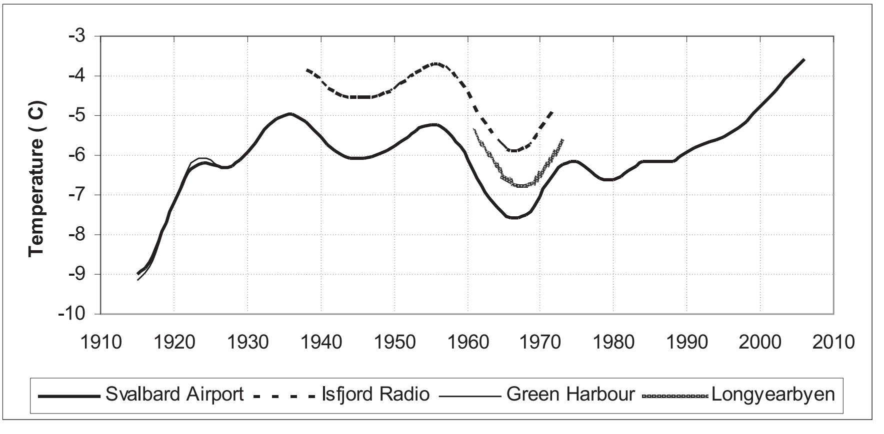


Fig. 5. Annual values of the composite Svalbard Airport series and three other series from the Isfjorden area. Individual years (not shown) are filtered by a Gaussian low-pass filter (curves) with a standard deviation of 3 years in its distribution, corresponding to a rectangular filter of about 10 years. Three years at the end of each curve are omitted

The huge ongoing research activity on Svalbard often requires information on long-term temperature variability and trends, for example in the fields of paleoclimate, oceanography, glaciology and biology. Thus, it is expected that the Svalbard Airport series may satisfy the necessary data demands for many research fields. The series is included in the data base on the website of the Norwegian Meteorological Institute from where the data may be downloaded free of charge.

Conclusion

Since radio connections were established at the Norwegian meteorological stations on Svalbard, synoptic data have been sent to the world's meteorological institutes. If temperatures from those stations are nested together in one series, the result is very inhomogenous. The long-term Svalbard Airport composite series is adjusted for the purposes of obtaining homogeneity. After homogenisation the linear trends for the whole period of the composite series, September 1911 to February 2010, are (in ^{o}C per decade): year 0.24, spring 0.44, summer 0.11, and autumn 0.17, for all values $p < 0.01$. The trend for winter, 0.25, is not significant.

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