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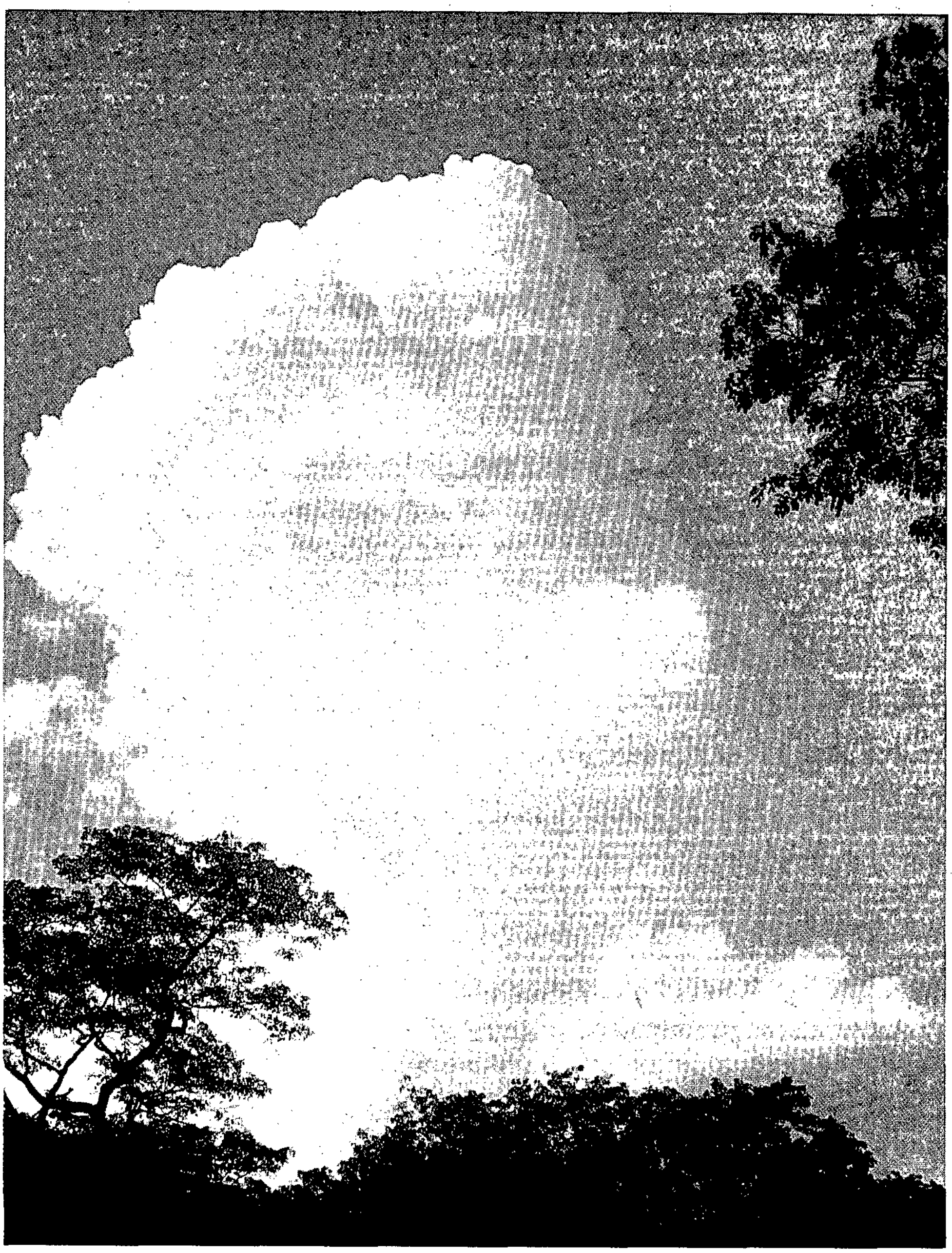
HOMOGENEITY ANALYSES OF TEMPERATURE AND PRECIPITATION SERIES FROM SVALBARD AND JAN MAYEN

P.Ø. Nordli, I. Hanssen-Bauer, E.J. Førland

REPORT NO. 16/96 KLIMA



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Homogeneity analyses of temperature and precipitation series from Svalbard and Jan Mayen

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PROJECT CONTRACTORS

Norwegian Research Council and Norwegian Meteorological institute.

Abstract

A short survey of the history of the Norwegian Arctic stations is presented. It is mainly based on inspection reports stored in DNMI's archives.

By use of the Standard Normal Homogeneity Test (SNHT) climatic series in the Norwegian Arctic are tested for inhomogeneities. Several inhomogeneities are found in the precipitation series. All precipitation series except those from Hornsund and Svalbard Airport are inhomogeneous and should be adjusted. On the other hand all temperature series but Jan Mayen are found to be homogeneous. The inhomogeneities detected in the Norwegian series can be attributed to physical changes which are reported in the station history archives.

Homogeneous, temperature and precipitation series valid for Svalbard Airport are established back to 1911. For Ny-Ålesund a temperature series from 1934 is obtained. Means and normals of these series are presented in Appendix.

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1 Introduction

Global surface temperatures have increased by about 0.3 to 0.6°C since the late 19th century (IPCC, 1996). Scenarios based on further increase in greenhouse gases imply that in the middle of the 21st century, the winter temperature in Northern Europe will increase by 2.5 - 4°C and in summer by 1 - 3°C. Precipitation will increase in both winter and summer by 5-15%. Most of the general climate models indicate that the Arctic areas are especially vulnerable to climate change caused by increased greenhouse effect. It is therefore crucial to monitor the long-term variations of temperature and precipitation in the Arctic.

The present report is written as a part of the project "Climate studies in Norwegian Arctic areas", which includes analyses of long-term climate series from these areas. Earlier studies have revealed that inhomogeneities in meteorological elements often are of the same magnitude as typical long-term climatic trends (Hanssen-Bauer and Førland, 1994), (Nordli et al., 1996). Real climatic trends may thus be masked or amplified when analyses are based upon inhomogeneous series, and it is important to adjust series for inhomogeneities before they are used in studies of long-term climate variations.

Unfortunately it is not easy to establish reliable long-term climatic series from Arctic areas. Weather observations in the Arctic are primarily aimed for forecasting purposes, and usually little care is taken to prevent inhomogeneities caused by relocations, changed environment (buildings etc.) and instrumental improvements. The harsh weather conditions in the Arctic increase dramatically the measuring errors for precipitation. Small changes at the Arctic measuring sites may accordingly cause substantial changes in the measuring conditions. In addition the station network in the Arctic is sparse, so it is often difficult to find reference series for use in homogeneity studies.

In order to overcome these difficulties and to homogenise meteorological time series from the Norwegian Arctic, data from several countries have been used in homogeneity testing of these series. Data from parallel measurements and metadata archives have been used as supplementary information. The present report summarises this work. The conclusions may be questioned in the future, if even more detailed homogeneity studies are carried out using additional data and/or better time resolution. However, we believe that our conclusions are optimal when using the present dataset.

2. Stations and data coverage.

2.1 Stations

This report includes homogeneity studies of meteorological series from 9 Norwegian stations, 1 Russian and 1 Polish station in the Norwegian Arctic. The stations and their geographical co-ordinates are listed in table 2.1. In cases of relocation, the table gives the co-ordinates of the last location.

Fig. 3.2 shows the positions of the stations Bjørnøya, Hopen, Jan Mayen, Svalbard Lufthavn and Ny-Ålesund. This figure also shows the positions of some stations which were used as reference stations in the homogeneity studies (see chapter 4.). Fig. 3.3 shows the positions of all the Spitsbergen stations, which include Hornsund, Sveagruva, Isfjord Radio, Barentsburg/Green Harbour and Longyearbyen in addition to Svalbard Lufthavn and Ny-Ålesund.

In connection with the establishing of the "North Atlantic Climatological Dataset" (NACD) (Frich et al., 1996), the metadatafiles for the Norwegian Arctic stations were studied. The history of these stations was then published in Norwegian (Steffensen et al., 1996). Chapter 3 in the present report gives a short English summary of these metadata, as well as some metadata from Barentsburg, which were kindly delivered by Dr. R. Brázdil, University of Brno, Check Republic.

Table 2.1 Meteorological stations studied in the present report.

Station no.	Station name	Nationality	Latitude	Longitude
99710	Bjørnøya	Norwegian	74° 31'N	19° 01'E
99720	Hopen	Norwegian	76° 30'N	25° 04'E
99750	Hornsund	Polish	77° 00'N	15° 34'E
99760	Sveagruva	Norwegian	77° 54'N	16° 48'E
99790	Isfjord Radio	Norwegian	78° 04'N	13° 38'E
99821	Green Harbour	Norwegian	78° 05'N	14° 14'E
99820	Barentsburg	Russian	78° 07'N	14° 13'E
99840	Svalbard Airport	Norwegian	78° 15'N	15° 28'E
99860	Longyearbyen	Norwegian	78° 13'N	15° 35'E
99910	Ny-Ålesund	Norwegian	78° 55'N	11° 56'E
99950	Jan Mayen	Norwegian	71° 01'N	08° 40'W

2.2 Data

The present study includes air temperature (T) and precipitation (R) during the period from the start of observations through 1995. Input data were monthly means of T and monthly sums of R. An overview of the observing periods and data coverage at the different stations is given in table 2.2.

From the Norwegian stations, daily values of the elements are available in digital form from 1956, and monthly values were calculated from these. Before 1956 only monthly values are available. However, additional statistical material was digitised within the NACD-project. Data control was performed by comparing annual values with the sum (for R) or mean (for T) of 12 monthly values. Monthly mean temperatures were recalculated on the basis of monthly clock means to ensure unity of formulas and to correct former calculation errors. Old interpolations of monthly mean temperatures were removed from the datafiles, except the interpolations done for the missing values during World War II. Monthly data from Barentsburg were supplied by Dr. R. Brázdil, while similar data from Hornsund were delivered by Dr. M. Mietus, Inst. of Meteorology and Water Management, Gdynia, Poland.

Table 2.2 Observing periods at the Arctic stations.

Station	El.	Period of obs.	Missing values
99710 Bjørnøya	T R	1920.02-present 1920.01-present	1920.08-1920.08, 1941.08-1945.10 1941.07-1945.10
99720 Hopen	T R	1944.11-present 1945.10-present	1945.08-1945.10 None
99750 Hornsund	T R	1978.07-present 1978.07-present	1981.08-1982.07, 1995.07-present 1981.08-1982.07, 1995.07-present
99760 Sveagruva	T R	1978.05-present 1978.05-present	None None
99790 Isfjord Radio	T R	1934.09-1976.07 1934.09-1976.06	1941.07-1946.08 1941.07-1946.08
99821 Green Harbour	T R	1911.12-1930.08 1911.12-1930.08	None None
99820 Barentsburg	T R	1933.02 -present 1933.03 -present	1938.11-1938.12, 1941.08-1947.12, 1949.06-1949.09, 1957.01-1957.12, 1991.01-present 1941.08-1947.12, 1990.08-present
99840 Svalbard Airport	T R	1975.08 -present 1975.08 -present	None None
99860 Longyearbyen (Also called Advent Bay and Svalbard Radio)	T R	1916.11-1977.07 1916.11-1977.07	1920.06-1921.09, 1923.09-1930.08, 1934.09-1934.12, 1935.10-1936.10, 1939.07-1941.11, 1942.07-1945.08, 1946.09-1956.12 1920-06-1921.09, 1923.06-1930.08, 1934.09-1956.12
99910 Ny-Ålesund	T R	1969.01 -present 1969.01 -present	None None
99950 Jan Mayen	T R	1921.09 -present 1922.01 -present	1940.09-1941.04, 1942.06-1942.07 1941.01-1941.04, 1942.06-1942.07

3 A short history of the Norwegian meteorological stations in the Arctic

The following short summary in English is based on a metadata report in Norwegian (Steffensen et. al., 1996).

99710 Bjørnøya

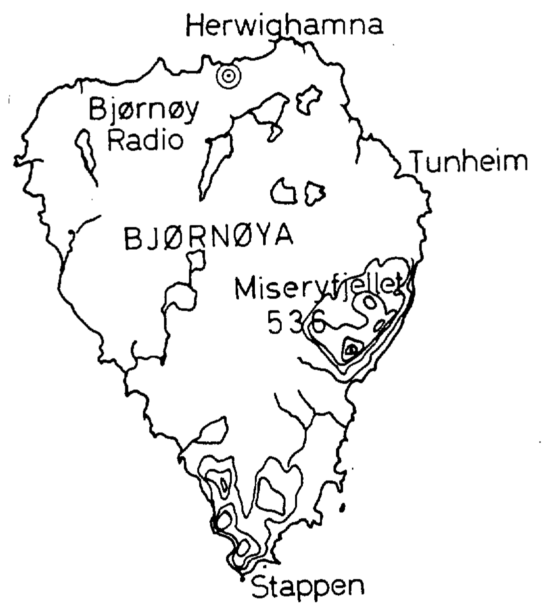


Fig. 3.1 Bjørnøya

Bjørnøya (Bear Island) is situated halfway between the southern tip of Spitsbergen and the coast of Finnmark, Fig. 3.2, but is considered as one of the Svalbard Islands. The weather station was established in 1920 at Tunheim in the North-eastern part of the island, Fig. 3.1. Temperature was during the first two years measured in two wall screens, but in August 1922 the instruments were moved into a single louvered free standing screen of the Edlund pattern (conc. different screens, cf. Nordli et. al., 1996). At the same time the precipitation gauge was equipped with a wind shield.

In 1929 there was a small relocation that altered the station's height from 38 m a.s.l to 29 m a.s.l and in 1933 there was a change of screen type, from the Edlund pattern to the pattern of 1930 (MI-30).

In August 1941 the station was destroyed by war actions, but rebuilt in 1945 at a site about 90 m ENE at the old one. The observations were resumed on 25 August that year, now with a radiation screen of pattern 1933 (MI-33). The station height was further reduced to 23 m.

On 12 July 1947 the station was moved 7.5 km to Herwigshamna on the Northern side of the island and the station height reduced to 15 m a.s.l. In 1969 a new station was ready for use and the precipitation gauge and radiation screen were moved 82 m and 77 m respectively, to E. The height of the station remained approximately the same. In inspection reports the new and old measuring sites for precipitation were not considered to be identical, see Ch. 5.

99720 Hopen

The weather station at Hopen, Fig. 3.2, was established by German soldiers in November 1944 and operated through July 1945. The radiation shield of the German type Johannes Blume was in decay and the inner cage was lost. The barometer is reported to have had a rather bad position in the house. Precipitation was not observed.

On 14 October 1945 the station was re-established at Hopen Radio by the Norwegian Marine and has been situated on this place since then. However, there has been some changes of instrument types. In 1945 the radiation screen MI-30 replaced the German type and in 1948 MI-33 replaced MI-30. In 1948 the precipitation gauge was equipped with a shield.

In the years 1957 to 1976 there were changes of the station buildings. About 1970 a building was removed and replaced by a much lower one which might have reduced the lee turbulence effect at the site of the precipitation gauge, see Ch. 4.2.

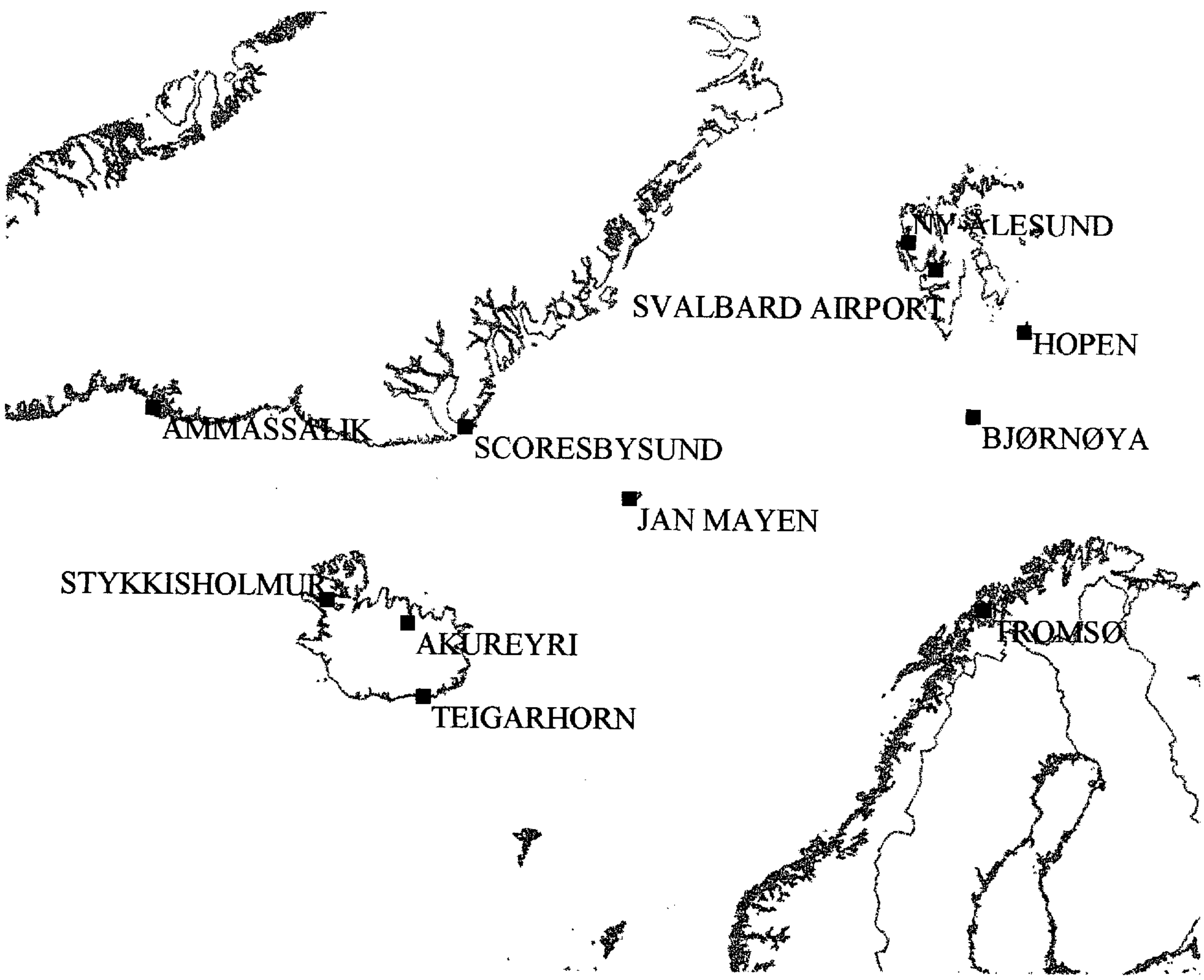


Fig. 3.2 Some important stations within the area for homogeneity testing.

99750 Sveagruva

Observations at Sveagruva, Fig. 3.3, started in May 1978. In the summer 1981 the radiation screen and the precipitation gauge were moved about 100 m NW to an area also used for permafrost measurements.

99790 Isfjord Radio

The station was situated on cape Linné at the mouth of Isfjorden, Fig. 3.3, established 1 September 1934. It was destroyed by war actions in September 1941 but re-established at the same place after the war. From August 1946 observations were resumed, but from 30 June 1976 the station was taken out of the official network, observation program reduced, and data not any longer controlled and stored in the files of DNMI.

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

On 15 August 1939 the precipitation gauge was equipped with a wind shield.

In 1958 the radiation screen and precipitation gauge were moved to another site about 60 m to NW. The precipitation gauge was again moved 15 m further in the same direction on 22 August 1966. In the inspection report of 1967 the new site was judged to be far better with respect to drifting snow.

99821 Green Harbour

The station was established at Grønfjorden on 1 December 1911 and is thus the oldest of the regular stations on Spitsbergen, Fig. 3.3. The equipment for temperature and precipitation measurements were not of conventional type. It consisted of four 3 m • 3 m walls mounted together so that their lower borders were 85 cm above the ground. As there was no roof over the walls, they could serve as a combined shield for precipitation and temperature. The thermometers got additional screening by an inside cage.

The precipitation gauge should have been placed on the top of the shield, but the observers found it more convenient to move it down to a lower position inside this construction. It is documented that this was sometimes done. Its upper surface was then 1.1 m lower than the upper edges of the walls. In 1924 the precipitation gauge was moved 1.9 m from its original site and equipped with a wind shield of conventional type.

On request in 1928 from N.J. Føyn (Steffensen et. al., 1996), the director of the Geophysical Institute in Tromsø, Prof. Krognæs, could state that the temperature equipment remained at its old site and had been unchanged (Birkeland, 1930). It is thus very likely that the situation had not changed during the remaining years before the station was closed on 27 August 1930.

Fig. 3.3 Map of Spitsbergen showing the locations of meteorological stations

99820 Barentsburg

Barentsburg is a Russian meteorological station located only 2 km to the north of Green Harbour, Fig. 3.3. The station is still running, but the latest data available to us 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, in connection with World War II, observations were interrupted. They were resumed in 1947, see table 2.2.

The following metadata survey is entirely based upon R. Brázdil (pers. comm.).

Information from about 1963:The meteorological station is located in north-eastern 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 (6 m height) appear at distances of 50 m and 80 m (old consulate building) from the measuring site.

Later information: Due to construction of a 5 floors building 40 m to the south of the station and plans for a new consulate building, the station was moved to the place of the aerological station (22 m a.s.l.). The station consisted only of 2 meteorological screens and a precipitation gauge and operated between 1 June 1978 and 31 January 1984. Because of the lack of facilities for installation, not all of the instruments were moved.

Measurement on the current position started 1 February 1984.

During the period between 1 June 1978 and 31 January 1984, air temperatures and humidity could have been influenced by a stream of warm water from the dining room or agriculture building (distance about 10 m).

From 1963 the hours of observation are 00, 03, 06, 09, 12, 15, 18, 21 h of Moscow time, i.e. the corresponding time belt + 1 hour. Concerning hours of observation before 1963, we have no available information. Daily values are computed from all hours of observation starting with 00 hour Moscow time.

Table 1.1 Heights (m) above sea level of the station and the barometer at Barentsburg.

Date	Station	Barometer
1951.09.14	70	64.9
1971.10.10	70*	
1978.06.01 - 1984.01.31	22	
1984.02.01 -	73	74.5

*Remained probably unchanged up to 1978.05.31

Precipitation Gauges:
1963: Tretyakov , 2 m above the ground
1978: Tretyakov 0-1 precipitation gauge, 1.7 m above the ground

Precipitation is corrected for wetting from 1966, but before 1966 the precipitation sums are not corrected. Corrections are:

- 0.2 mm for liquid precipitation
- 0.2 mm for mixed precipitation
- 0.1 mm for solid precipitation and when the amount is smaller than 0.5 mm.

99840 Svalbard Airport

In Norwegian the station's name is «Svalbard lufthavn». It is situated near the outer part of Adventfjorden, a branch of Isfjorden, Fig. 3.3. Measurements began in August 1975. The station is still running (cf. table 2.2).

There has not been any changes at the station that could be expected to influence measurements.

99860 Longyearbyen

At Longyearbyen, about 4 km Southeast of Svalbard Airport, Fig. 3.3 and 3.4, observations begun in November 1916. The observations stopped in July 1977, and there have been several long interruptions.

<u>Period 1911.12 - 1923.08</u>: The station in Longyearbyen was during this time administrated by a mining company called «Store Norske Spitsbergen Kulkompani». Our knowledge of the metadata is rather sparse; there exist only three inspection reports for the whole period, dated 1920, 1922 and 1924. The last one was thus performed after the station's closure and an effort to resume was obviously in vain.

In the inspection reports the name used was Advent Bay. However, from the descriptions it is clear that the location was Longyearbyen which at that time was more commonly known as Longyear City. In 1920 the observations were made at the hospital. During the inspection that year a free standing screen with double louvered walls replaced the wall screen. The measuring site was moved about 50 m. At the same time the precipitation gauge was also moved about the same distance. Its site was before the relocation «too close to the hospital».

The hospital was situated in the former Longyearbyen which was mostly destroyed during World War II. The hospital, however, survived the war (Arlov, 1991) but was later removed. According to personal communication with Susan Barr on the Norwegian Polar Institute the site was located at position 1 in Fig. 3.4. Looking at the map it should be kept in mind that the former buildings are others than the present ones. The station's height at that time was 50 m a.s.l. defined by the precipitation gauge.

As a private station the data has not been published in DNMI's yearbooks.

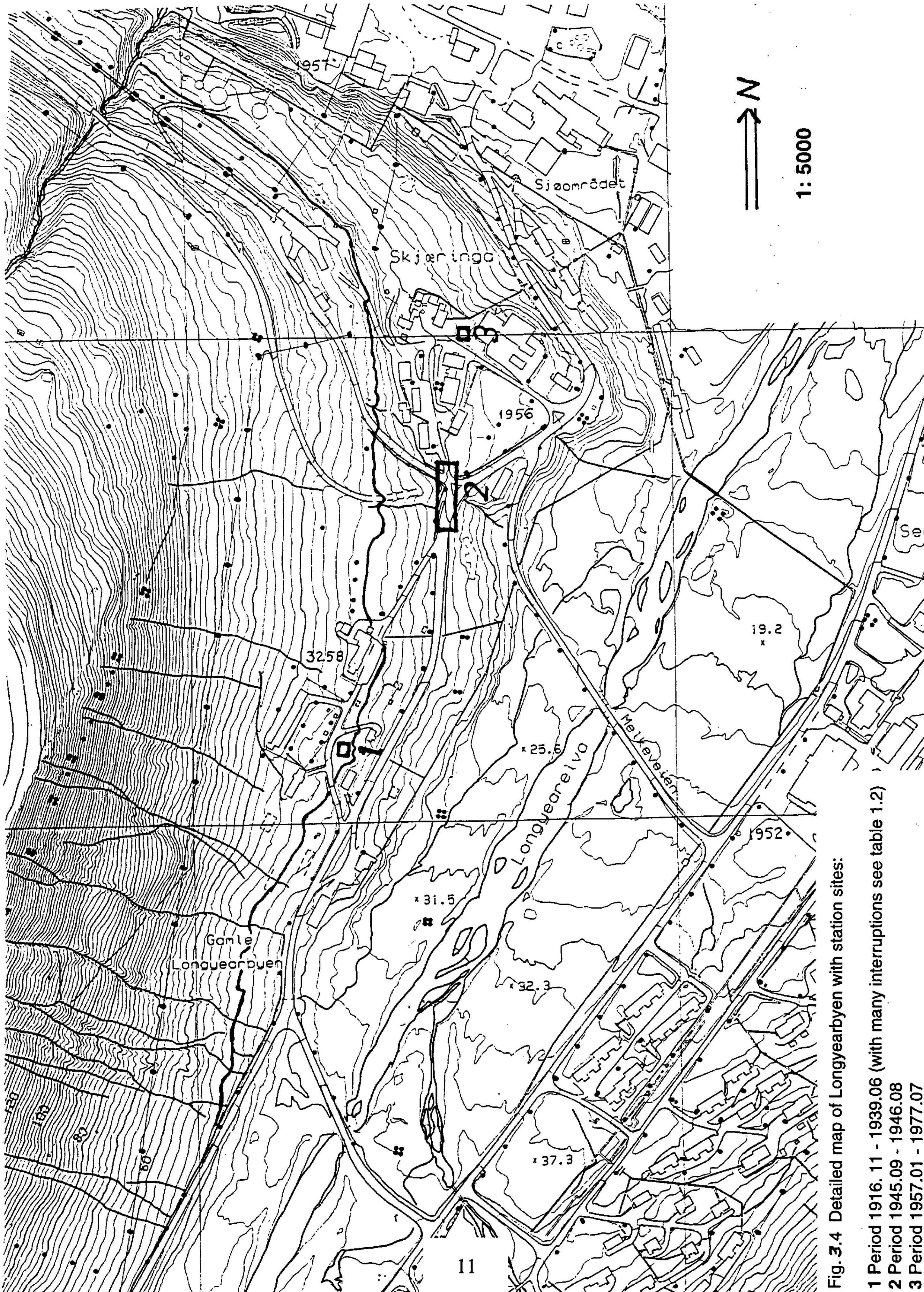


Fig. 3.4 Detailed map of Longyearbyen with station sites:

1 Period 1916. 11 - 1939.06 (with many interruptions see table 1.2)
2 Period 1945.09 - 1946.08
3 Period 1957.01 - 1977.07

Period 1930.09 - 1939.06: Under the administration of DNMI observations were continued at Svalbard Radio. The site was close to the former place, but 3 m larger station height indicates a minor relocation.

From the inspection in 1930 there exist photos. Judged from the photos the radiation screen seems to be of the Edlund pattern, i.e. single louvered. The precipitation gauge is not equipped with a wind shield. The 1930 inspection is the only one before the war.

World war II: There exist some German observations during World War II and some Norwegian observation in 1945/46. The Norwegian observations are reported to have been made at a distance of 250 m NNW from the former station at Svalbard Radio, site 2 in Fig. 3.4. Using a modern map the direction seems rather to have been NNE. After the closure of the station in 1946 there is a long gap in the series until January 1957.

Period 1957.01 - 1977.07: The new place is plotted in Fig. 3.4, site 3. It is located about 450 m NNE of the old hospital building and the first station.

In 1964 the radiation screen and precipitation gauge were relocated 61 m S and 68 m SSE respectively. The station's height was reduced from 38 m to 37 m.

Conclusion. The station has been located in an area which we may call old Longyearbyen - Skjæringa situated at the western slope of the Longyear valley. The maximum length between the sites was 450 m. The height above sea level has varied from 37 m to 53 m. The site between 1916 and 1920 is most probably the same as at the time of the inspection in 1920, but this is not documented.

99100 Ny-Ålesund

Ny-Ålesund, Fig. 3.2 and 3.3, was a mining settlement which nowadays has changed into a research station. The meteorological station was established in January 1969, but relocated already in August 1974 to a lower site, 8 m a.s.l. Vertical and horizontal distances between the two sites are 34 m and 1.6 km respectively.

99950 Jan Mayen

The meteorological station has always been located in the middle of the island, and except for the period of World War II either at the NW or SE shores. It was established in September 1921 on the SE shore, position 1 in Fig. 3.5. It is known that the radiation screen in 1928 was of the Edlund type which on 27. August 1933 was replaced by the single louvered MI-30. In 1938 an extra wall was set up to the north of the screen to protect it from drifting snow. In 1932 a wind shield for precipitation was mounted.

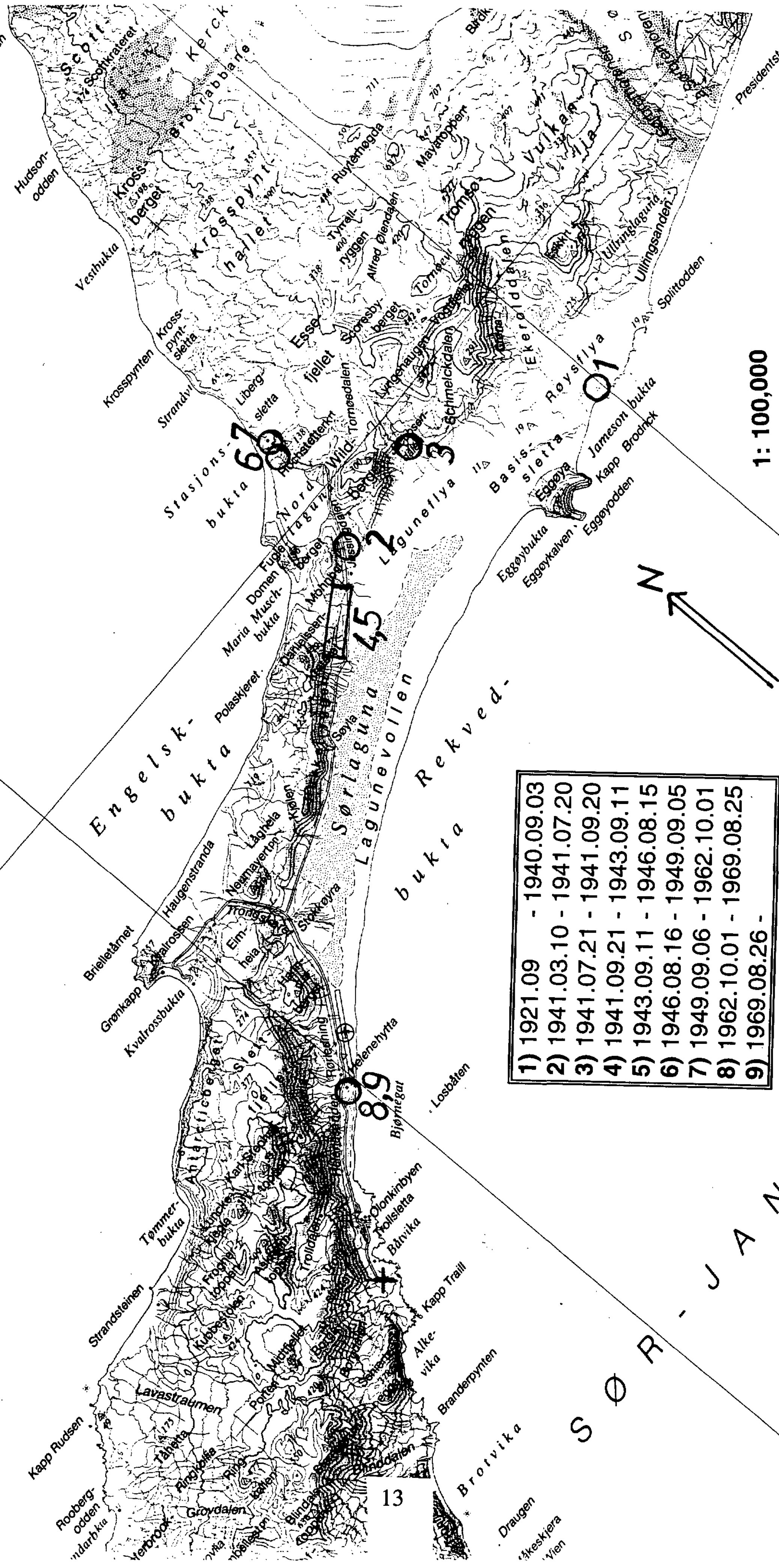


Fig. 35 Map of the central part of Jan Mayen with station sites.

In September and October 1940 the station was hit and at last destroyed by war actions. But already in March 1941 a Norwegian expedition established a temporary station in a valley about 500 m from the SE-shore, since then called Jøssingdalen, position 2 in Fig. 3.5. During the period from 1941 to 1949 the station was located at five different sites, positions 2 - 6. However, from 5. September 1949 to 1. October 1962 it remained at the same position (7) on the NW shore.

1. October 1962 the station was again moved to the SE shore, 11.3 km to a more southern position (8) than where it started in 1921. On 25 August 1969 there was a minor relocation of the station to its present position (9).

For the whole period after World War II the same type of radiation screen , MI-33, has been used.

During the period November 1959 to May 1962 parallel measurements were performed on each side of the island. The official observations at the NW-shore could be compared with observations at Båtvika (marked with + in Fig. 3.5) on the SE-shore, 15.5 km apart, Ch. 4.1.

4 Homogeneity testing of the time series

4.1 Method

The homogeneity testing was performed using the Standard Normal Homogeneity Test (SNHT) (Alexandersson, 1986). The method has been used at DNMI since 1990 (Hanssen-Bauer et al., 1991). The test has proved to be useful for investigating homogeneity of precipitation series (Hanssen-Bauer and Førland, 1994) and air temperature series (Nordli, 1996). It was also widely used in establishing homogeneous series in the NACD (Frich et al., 1996).

The principal of the SNHT is to compare data from a test station to data from a group of homogeneous reference stations. In the Arctic, the distances between neighbouring stations can be large. This causes some difficulties. One problem, which especially concerns precipitation, is that the correlation between test and reference series drops rapidly as the distance between the stations increases. This implies that the "noise level" of the test increases, and the "threshold" for detecting inhomogeneities increases similarly. The consequence is that inhomogeneities are more difficult to detect.

A more serious problem connected to large distances between test and reference stations, is that long-term changes in circulation patterns may affect the climate at the stations differently. Real climatic variations may consequently lead to virtual inhomogeneities when the series are compared. To avoid adjusting for such virtual inhomogeneities, two precautions were taken. Firstly, all series were tested against several reference series, if possible against series from stations in different directions from the test station. Secondly, metadata were used in addition to the test results.

4.2 Temperature

The SNHT was performed on seasonal data: Winter (Dec - Feb), spring (Mar - May), summer (Jun - Aug), and autumn (Sep - Nov). These definitions are used for simplicity; they are not in agreement with climatic definitions of seasons. For example summer does not exist in the Arctic.

An overview of the test results from the SNHT are shown in table 4.1. Due to variation of correlation coefficients from test to test, the threshold for detecting inhomogeneities also varies. In general, correlations in summer are poor compared to the other seasons. Best correlated are the Spitsbergen series after 1978 when a denser network of stations was established.

Fortunately most of the test results reveal homogenous series even for tests involving the best correlations between the test station and reference group. There are in Arctic measuring conditions of great benefit for homogeneous series, i.e. high frequencies of fog, high cloudiness and strong wind. Moreover, the environment near the screen is not affected by growing vegetation.

Table 4.1 Test results obtained by the SNHT method for homogeneity testing of temperature applied on seasonal data. The results are presented in the following order: Winter (Dec - Feb), spring (Mar - May), summer (Jun - Aug), and autumn (Sep - Nov).

Explanation to the columns:

- No.: Test number
- Test station: Station number and name of the test station.
- Period: The period for the test
- Corr.: Correlation coefficient (multiplied by 100) of the highest correlated reference station which covers the entire test period.
- Results: H denotes homogeneous, B (break) inhomogeneous series.
- Ref. stations: The station numbers of the reference stations. (Station number 99840* denotes the combined Svalbard Airport series).

List of reference stations:
90450 Tromsø
98550 Vardø
98400 Makkaur fyr
98700 Ekkerøy
99860 Longyearbyen
Sty - Stykkisholmur
Teig - Teigarhorn
Sco - Scoresbysund
Am - Ammassalik

No.	Test station	Period	Corr.	Results	Ref. stations
1		1920 - 1994	95 91 86 96	B H H H	98400 99720 99840 99950
2	99710 Bjørnøya	1924 - 1994	57 73 72 67	B H H H	90450 98550 98700
3		1946 - 1994	95 91 86 96	H H H H	99720 99840
4		1945 - 1994	96 91 86 97	B H B H	99710 99750 99760 99840
5	99720 Hopen	1945 - 1994	96 91 86 97	B H H H	99710 99840
6		1945 - 1994	96 91 86 97	H H H H	99710
7		1945 - 1994	96 91 86 97	H H H H	99840
8	99750 Hornsund	1979 - 1994	99 97 86 99	H B H H	99710 99720 99760 99840
9	99760 Sveagruva	1979 - 1994	99 97 89 99	H H H H	99710 99720 99750 99840
10		1935 - 1975	99 99 91 99	H H H H	99710 99820 99860
11	99790 Isfjord Radio	1935 - 1975	92 85 62 95	H H H H	99710 99860
12		1935 - 1975	92 85 62 95	H H H H	99710
13		1920 - 1940	81 89 49 86	B H H H	99710
14		1921 - 1938	90 90 57 87	B H H H	99710 99860
15		1935 - 1975	99 99 91 99	H H H H	99710 99790 99860
16	99821 Green Harbour	1935 - 1975	99 99 91 99	H H H H	99710 99790
17	and	1935 - 1975	91 84 56 94	H H H H	99710
18	99820 Barentsburg	1978 - 1990	99 97 97 98	H H H H	99760 99840 99910
19		1978 - 1990	99 97 97 98	H H H H	99840 99910
20		1978 - 1990	99 97 97 98	H H H H	99840
21		1976 - 1994	98 96 94 98	H H H H	99710 99720 99820 99910
22	99840 Svalbard Airport	1976 - 1994	98 96 94 98	H H H H	99720 99910
23		1976 - 1994	98 96 94 98	H H H H	99820 99910
24		1920 - 1938	93 73 33 73	H H H H	99710
25	99860 Longyearbyen	1922 - 1975	93 85 57 94	H H H H	99710
26		1937 - 1975	99 98 91 99	H H H H	99710 99790
27		1969 - 1994	98 99 84 97	H H H H	99720 99820
28	99910 Ny-Ålesund	1969 - 1990	98 99 84 97	H H H H	99820
29		1969 - 1994	92 81 28 96	H H H H	99720
30		1922 - 1990	75 66 60 73	H H B H	99710 99840 Sty Teig Sco Am
31		1922 - 1990	74 41 49 66	H B B H	99710 99840
32	99950 Jan Mayen	1922 - 1990	62 58 60 64	B H B H	Sty Teig
33		1922 - 1990	75 66 46 73	H H H H	Sco Am
34		1922 - 1990	75 66 60 73	H H B H	99710 Teig Sco
35		1922 - 1990	69 55 56 58	H H B H	99840 Sty Am

Homogeneity testing of the time series

99710 Bjørnøya.

The station is tested during the period 1946-1994 against the reference stations Hopen (highly correlated) and Svalbard Airport, test 3. The series is homogeneous during the period.

Tests No. 1 and 2 reveal inhomogeneities in winter, but the test results are not consistent. The years of the breaks are different and the signs are opposite.

Conclusion: The station is homogeneous during the whole period.

99720 Hopen

When Bjørnøya and the combined series valid for Svalbard Airport are used in the reference group, the test gives a significant break in winter season in 1957 or 1958 (tests 4 and 5), with indicated adjustment 1.1°C. When splitting up the reference group (tests 6 and 7) almost the same results are found in both cases, though not significant. These test results are contradicted by station history; nothing seems to have changed at the station that should result in inhomogeneities of the temperature series. The t-values, however, is close to the 5 % significant level.

Conclusion: The station is considered to be homogeneous.

99750 Hornsund

The station is owned by The Polish Academy of Science and has been in operation since July 1978 without interruptions.

It is possible to establish a reference group (test 8) which correlates well with the test series. A significant break is detected in spring 1983. As the t-value is close to the 5 % limit and the break is located near the start of the series, this test result is discarded.

Conclusion: Hornsund is considered to be homogeneous.

99760 Sveagruva

The series correlates well with the reference group and no significant break is detected.

Conclusion: Sveagruva is homogeneous.

99790 Isfjord Radio

In all seasons the series correlates well with Barentsburg series. All tests reveal homogeneous results.

Conclusion: The station is homogeneous during the whole period.

99821 Green Harbour and 99820 Barentsburg

The two sites are situated in the same fjord, Grønnefjorden, only 2 km apart from each other. They are therefore tested as one data series. The first part of the series can not be tested by SNHT because of lack of reference stations.

Up to 1920 the series consists of a pronounced overrepresentation of below normal temperatures which has led to doubt about the homogeneity of the series. This question was discussed already by Birkeland (1930) who applied Helmert's and Abbe's one parameter tests on the series. Both tests led to rejection of the hypothesis of randomness.

The station was administrated by the Geophysical Institute in Tromsø, which according to Birkeland stated that no change of site or observational procedure has taken placed at the station, Ch. 1. He therefore concluded that the series was homogeneous and that the virtual break in 1920 was caused by climatic variation.

Returning to the testing by the SNHT, inhomogeneities in winter are detected by tests 13 and 14. The results are consistent, revealing the same year for the break, 1930. Since no data is available in the period 1931 to 1933 the year coincide with the change from Green Harbour to Barentsburg. The adjustment needed is 2.2°C, i.e. Green Harbour is colder than Barentsburg. Physically this may be explained by the change of station height, from 4 m in Green Harbour to probably 70 m in Barentsburg. Winter inversion is predominating in the area.

Conclusion: There is a break in the series in the winter season in connection with the change from Green Harbour data to Barentsburg data (1930). No significant breaks are detected by SNHT in the other seasons or other years. Thus the Green Harbour and Barentsburg series should be considered as two separate homogeneous series.

99840 Svalbard Airport

The series is tested against a reference group consisting of the four nearest stations, test 21, and also against two subgroups of them, tests 22 and 23.

Conclusion: Svalbard Airport is homogenous.

99860 Longyearbyen

The three tests 18-20 are performed against reference groups consisting of Bjørnøya and Isfjord Radio. All tests indicate homogeneous series. It should be stated, however, that in summer before 1937 this result is only nominal because of poor correlation with reference station Bjørnøya.

Conclusion: The station is considered homogeneous.

99910 Ny-Ålesund

The series is tested against Hopen and Barentsburg and found homogeneous in all seasons, tests 27-29. The station was relocated in 1974 when the station height was reduced from 42 m to 8 m. Considering the results from the series Green Harbour - Barentsburg an inhomogeneity caused by the relocation should be expected in winter.

Further investigation about the effect of the relocation is done by the more powerful Student's t-test. The test is applied to the difference of mean temperature between Ny-Ålesund and Barentsburg. Two partly overlapping seasons are chosen, January - February and November - March. No significant break in the difference is detected.

During the period Nov. 78 - Jan. 84 Barentsburg has probably had a lower position 22 m a.s.l. only. Therefore this period is omitted and the same test applied again. The result, however, remains the same - no significant break in the difference between the stations in connection with the relocation.

Conclusion: Ny-Ålesund is homogeneous during the whole length of the series.

99950 Jan Mayen

Steffensen (1969) compared observation at the ordinary site on the NW shore with extra observations at Båtvika on the SE shore at the period of overlapping. The results quoted from her publication are shown in table 4.2.

Table 4.2 Monthly mean temperature differences: Ordinary site - Båtvika, from Steffensen (1969).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1960	0.4	0.0	0.2	0.2	0.5	0.2	-0.2	-0.1	0.2	-0.4	-0.1	0.0
1961	0.0	0.4	0.0	-0.1	0.0	-0.2		0.0	0.1	0.3	0.1	-0.1
1962	-0.2	-0.5	-0.2	-0.3								
Mean	0.1	0.0	0.0	-0.1	0.3	0.0	-0.2	0.0	0.2	0.0	0.0	0.0

The mean value of the differences is only 0.01°C and the standard deviation 0.2°C. An annual cycle of the differences is not seen. These results are promising concerning the homogeneity as the station has changed its position several times between the two shores.

Tests results against reference stations in Svalbard (Bjørnøya and Svalbard Airport), Iceland (Stykkisholmur and Teigarhorn), and Greenland (Ammassalik and Scoresbysund) are listed in table 4.1. On seasonal basis the correlation coefficients varies between 0.74 and 0.41, being largest in winter and autumn. Some significant breaks are detected in all seasons but most of them are not maintained when tested against other groups of reference stations.

A significant break in summer season is found 1939 when compared with all reference stations. Its magnitude is -0.6°C, i.e. the first part of the series being too warm compared with the later one. The year of the break is very close to the end of the station's first stable period on the SE shore. The inhomogeneity occurs most significantly when tested against the Icelandic stations (test 32) while tested against the Greenlandic stations (test 33) it is not significant at the 5% level. Further testing is performed where each of the regions Svalbard, Iceland and Greenland is represented by one station only, tests 34 and 35. Again both tests reveal significant breaks in nearly the same years,1939 and 1940.

Finally the SNHT method is used for internal testing, i.e. the mean temperature at fixed hours are tested against each others and against the daily minimum temperature. Relative to the observations at 07^h, 19^h and minimum, the observation at 13^h was warmer before 1941 by 0.4°C. The tests indicate that the inhomogeneity is affecting just the day time observations.

Jan Mayen have professional observers and a climate which should favour homogeneous series. In summer the average cloud cover is almost 7 oktas and windy weather is frequent. The station has been moved between the two shores but as we have seen at one occasion the mean temperature difference was zero. One should therefore be reluctant to accept even significant test results as the reference stations may contain inhomogeneities too. However, these breaks in summer appear stable when different reference stations are used and the year for the break coincides closely to a larger relocation. Therefore the break in the series was adjusted for.

The Danish Meteorological Institute has informed us that the Greenlandic series undergo further homogeneity testing. Possible adjustments of the Greenlandic series should influence the reference group for Jan Mayen and probably also the test results. Therefore our conclusion at this stage is preliminary.

Preliminary conclusion: The series is inhomogeneous in summer season with a break in 1940 when the station was relocated for the first time.

Preliminary adjustments: The series is adjusted on the basis of the reference group in test No. 30 containing all of the six reference stations used in the test. When the year 1940 is added to the period before the break, the adjustments turn out to be -0.5°C in summer. Although not significant, a tendency of too high temperature before 1940 is also detected in late spring. It is interpreted to be related to the overheating in summer. Therefore also spring temperatures are adjusted, by -0.4°C in May and by -0.3°C in April.

4.3 Precipitation

The homogeneity testing of precipitation series was performed on seasonal as well as annual precipitation sums. The seasons were defined in the same way as for temperature (section 4.2). Each series was tested against several reference series. The reference series were chosen from the other series included in the present analysis, and/or from 04063 Akureyri in Iceland, 04339 Scoresbysund in Greenland, and 90450 Tromsø at the Norwegian mainland. The positions of these additional stations are shown in Fig. 3.2.

During the testing, the series from Green Harbour and Barentsburg were joined together. Likewise, the series from Longyearbyen and Svalbard Airport were coupled. Table 4.3 shows the correlation matrix for annual precipitation at the resulting 9 stations and the 3 additional stations. Similar matrixes based upon seasonal precipitation show more or less the same picture, though the seasonal correlation coefficients in most cases are slightly lower. The correlations in table 4.3 are generally poor, except from those between some of the Spitsbergen series. This implies that only major inhomogeneities will be detected. Test results indicate that changes in precipitation of less than 10-15% in most cases may be hidden by noise.

Still, one should expect to find several inhomogeneities in the Arctic series, as minor changes in the exposure of a precipitation gauge may lead to considerable changes in the gauge catch under weather conditions which govern these areas. For example, the DNMI gauge during snowfall and strong winds will catch less than 50% of the real precipitation (Førland et al., 1996). On the other hand, drifting snow may contribute more than 60 mm during one day. Such amounts of drifting snow should be detected during routine data control, however these routines have been manual, and they may have changed throughout the years.

Table 4.3 Correlation coefficients between series of annual precipitation from 9 stations in the Norwegian Arctic and 3 additional stations.

	99710	99720	99750	99760	99790	99820	99840	99910	99950	04063	04339	90450
99710	1.00	0.27	0.24	0.04	0.24	0.20	0.38	0.38	0.27	0.01	0.30	0.22
99720	0.27	1.00	0.13	-0.47	0.42	0.25	0.01	-0.22	0.14	0.41	0.37	0.40
99750	0.24	0.13	1.00	0.36	.	0.62	0.43	0.32	0.16	0.34	-0.10	0.25
99760	0.04	-0.47	0.36	1.00	.	0.67	0.70	0.57	-0.11	-0.03	-0.24	-0.33
99790	0.24	0.42	.	.	1.00	0.86	0.74	0.79	0.31	0.41	0.66	-0.04
99820	0.20	0.25	0.62	0.67	0.86	1.00	0.68	0.72	0.27	0.28	0.09	0.10
99840	0.38	0.01	0.43	0.70	0.74	0.68	1.00	0.82	0.31	0.15	-0.01	-0.21
99910	0.38	-0.22	0.32	0.57	0.79	0.72	0.82	1.00	0.51	0.15	-0.01	-0.28
99950	0.27	0.14	0.16	-0.11	0.31	0.27	0.31	0.51	1.00	0.20	0.15	0.12
04063	0.01	0.41	0.34	-0.03	0.41	0.28	0.15	0.15	0.20	1.00	0.27	0.03
04339	0.30	0.37	-1.10	-0.24	0.66	0.09	-0.01	-0.01	0.15	0.27	1.00	0.08
90450	0.22	0.40	0.25	-0.33	-0.04	0.10	-0.21	-0.28	0.12	0.03	0.08	1.00

A summary of the final results from the homogeneity testing of precipitation series is given in table 4.4, while adjustment factors for the detected inhomogeneities are given in table 4.5. It should be emphasised that several tests were run in addition to those referred to in table 4.4. The final conclusions concerning homogeneity of the series were thus drawn from more information than the test results given in this table. In the following paragraphs the test results are commented for each series separately.

Table 4.4 Main results from homogeneity testing of Arctic precipitation series.
Column 1: The station which is tested. Column 2: Status of the tested data. O=original, A=adjusted once, 2A=adjusted twice, ... Column 3: Test period. Column 4: Test results for annual , winter, spring, summer and autumn precipitation. H=homogeneous, B=inhomogeneous at the 10% level. Column 5: Reference stations. Column 6: Conclusion. H=homogeneous, B=inhomogeneous / year for break / reason for break E=environments, R=relocation, S=windshield, ?=uncertain.

Test station	Dat.	Period	Results	Ref. stations	Concl.
99710 Bjørnøya	O	1957-1995	H HHHH	99720 99840 99950 90450	H
	O	1948-1995	H HHBH	99720 99790 99840 99950 90450	H
	O	1948-1995	B HHHH	99720 99790 99820 99840 90450	H
	O	1926-1995	B BHHB	99820 99950 90450	B 1947 R
	A	1922-1995	H BHHB	99820 99950 90450	B 1926 S
	2A	1922-1995	H HHHH	99820 99950 90450	H
99720 Hopen	O	1948-1995	B BBHB	99710 99790 04063 90450	B 1974 E
	A	1948-1995	H HHHH	99710 99790 04063 90450	H
99750 Hornsund	O	1978-1995	H HBHH	99760 99820 99840 99910	H
99760 Sveagruva	O	1978-1995	B BBHH	99750 99840 99910	B 1981 R
	A	1978-1995	H HBHH	99750 99840 99910	H
99790 Isfjord Radio	O	1948-1966	B HBBH	99710 99720 99820 04063	B 1958 R
	O	1957-1976	B HBHH	99710 99820 99840 04339	B 1967 R
	2A	1948-1976	H HHHH	99720 99820 99840	H
	2A	1934-1976	B BHBH	99710 99820 99950	B 1939 S
	3A	1934-1976	H HHBH	99710 99820 99950	H
99821+99820 Green Harbour/ Barentsburg	O	1978-1990	B BHBH	99720 99790 99840 99910	B 1984 R
	A	1957-1990	B BBBB	99720 99790 99840 99910	B 1978 R
	2A	1957-1990	H HHHH	99720 99790 99840 99910	H
	2A	1948-1990	B BBHH	99720 99790 99840 99910	B 1956 ?
	3A	1925-1990	B HBHH	99710 99790 99950	B 1930 R
	4A	1911-1990	B HBHB	99710 04063 90450	B 1924 S
	5A	1911-1990	H HBHH	99710 04063 90450	H
99860+99840 Longyearbyen/ Svalbard Airport	O	1957-1975	H BHHH	99710 99790 99820	H
	O	1975-1995	H HHHH	99710 99760 99910	H
	O	1957-1995	H HBHH	99710 99790 99820 99910	H
	O	1917-1995	B HBHH	99710 99840 99950	B 1924 R
	A	1917-1995	H HHHH	99710 99840 99950	H
99910 Ny-Ålesund	A	1968-1995	B HHHH	99820 99840	B 1974 R
	O	1968-1995	H HHHH	99710 99820 99840	H
99950 Jan Mayen	O	1933-1995	B BBHH	99820 99840 04063 90450	B 1946 R
	A	1933-1995	B HBBB	99710 99820 99840 04063 90450	B 1940 R
	2A	1933-1995	H HHHH	99710 99820 99840 04063 90450	H
	2A	1922-1995	B HBBB	99710 99820 90450	B 1932 S
	3A	1922-1995	H HHHH	99710 99820 90450	H

Table 4.5 Adjustment factors for inhomogeneities found in precipitation series from the Norwegian Arctic.

Station\period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
99710												
1920.01-1926.07	1.05	1.05	0.98	0.90	0.85	1.00	1.00	1.00	1.00	1.02	1.04	1.05
1926.08-1947.07	0.75	0.75	0.75	0.75	0.85	1.00	1.00	1.00	0.90	0.85	0.80	0.75
99720												
1948.01-1974.07	1.40	1.40	1.40	1.40	1.40	1.20	1.00	1.00	1.00	1.10	1.20	1.40
99760												
1978.05-1981.08	0.75	0.70	0.70	0.70	0.75	0.90	1.00	1.00	1.00	0.90	0.75	0.75
99790												
1934.09-1939.07	1.30	1.30	1.35	1.10	1.19	1.39	1.39	1.45	1.33	1.33	1.32	1.46
1939.08-1958.07	1.00	1.00	1.00	1.00	1.08	1.27	1.27	1.32	1.21	1.16	1.10	1.13
1958.08-1966.08	0.80	0.80	0.80	0.80	0.90	1.10	1.15	1.20	1.15	1.10	1.00	0.90
99820+99821												
1911.12-1924.07	1.42	1.42	1.41	1.31	1.20	1.00	1.06	1.19	1.31	1.40	1.42	1.42
1924.08-1930.08	0.82	0.82	0.84	0.84	0.92	0.96	1.06	1.19	1.19	1.19	1.12	0.96
1933.02-1956.07	1.10	1.10	1.10	1.10	1.10	0.96	0.96	1.08	1.08	1.08	1.20	1.20
1956.08-1978.07	0.84	0.84	0.88	0.88	0.96	0.96	0.96	1.08	1.08	1.08	1.04	0.98
1978.08-1984.01	0.60	0.60	0.70	0.70	0.80	0.80	0.80	0.90	0.90	0.90	0.80	0.70
99840+99860												
1916.11-1923.05	1.40	1.40	1.30	1.30	1.20	1.20	1.20	1.20	1.30	1.30	1.40	1.40
99910												
1969.01-1974.07	1.30	1.30	1.30	1.30	1.30	1.20	1.10	1.10	1.00	1.00	1.10	1.30
99950												
1921.09-1932.07	1.25	1.25	1.25	1.56	1.44	1.44	1.44	1.44	1.44	1.71	1.56	1.25
1932.08-1940.12	0.96	0.96	0.96	1.20	1.20	1.20	1.20	1.20	1.20	1.32	1.20	0.96
1941.05-1946.08	1.20	1.20	1.20	1.20	1.20	1.10	1.10	1.10	1.10	1.20	1.20	1.20

99710 Bjørnøya

The test results from Bjørnøya revealed two inhomogeneities. The first one is connected to the installation of a windshield in 1926. Precipitation then increased during winter, while the summer precipitation was not affected. The second one is attributed to the relocation in 1947 (see chapter 3). Apparently this relocation led to decreased precipitation during winter, while the summer precipitation was not affected.

In addition, it should be mentioned that when the Bjørnøya series is tested against series from Spitsbergen (Isfjord Radio/Barentsburg) an inhomogeneity significant on the 1% level is found in 1957/58. However, this is not found when testing against other stations, and no reason for such an inhomogeneity is found in the metadata. It may be caused by real differences in the climate evolution on Bjørnøya and Spitsbergen (cf. Ch. 4.1), and it is not adjusted for.

The test results do not indicate any influence on the measurements of the relocation in 1968. However, as there are no really good reference stations for Bjørnøya, parallel measurements were, as a part of the present project, run during 2 years in order to study the difference between the two locations closer. The results are documented in chapter 6, where it is concluded that there is some effect on solid precipitation of this relocation. However, as the environments at the old site were different in 1968 and in 1993, it is not possible to quantify it. Further, as there is no trace of this relocation in the standard normal homogeneity test, no adjustment is made for the relocation.

99720 Hopen

The series is tested from 1948, when it was relocated and windshield was installed. An inhomogeneity significant on the 1% level is found in 1974. This was probably caused by several changes in the environments during 1971-1975. Old building were removed and new ones built during this period, and the exposure of the precipitation gauge was certainly affected by these changes.

As for Bjørnøya, some tests against Spitsbergen precipitation series indicate an inhomogeneity around 1957. Again, however, this is not found in tests against other series, and no adjustment is made.

99750 Hornsund

Test results indicate that there may be an inhomogeneity in 1993, which eventually has led to larger gauge catch. However, we have no metadata for Hornsund. Further, 1993 is close to the present end of the series, and one should wait for additional data before drawing the final conclusion.

99760 Sveagruva

An inhomogeneity significant on the 1% level is found in 1982. According to the metadata, the station was relocated in 1981, and the inhomogeneity is probably a consequence of this.

99790 Isfjord Radio

Three inhomogeneities are found in the precipitation series from Isfjord Radio. The installation of a windshield in 1939 increased the gauge catch in all seasons, but mostly during winter. A relocation in 1958 apparently also led to increased gauge catch, though this may partly be caused by increased influence of drifting snow. A relocation in 1966 led to increased gauge catch during summer, but reduced measured precipitation during winter. The new location is reported to be less affected by drifting snow, which explains the reduced winter precipitation. The gauge catch during summer is increased, as the new position is less wind exposed than the old one.

99821 Green Harbour and 99820 Barentsburg

This series ends up with 5 adjustments. The Green Harbour gauge was relocated and equipped with a windshield in 1924. This leads to increased gauge catch during all seasons except summer. The series is adjusted for this, however, the data from the years before 1924 are not as reliable as data from later years because of the quite awkward installation of the gauge during the earlier years (see chapter 3).

The joining of the Green Harbour and the Barentsburg series leads to an inhomogeneity. During winter, the gauge catch in Barentsburg is lower than that in Green Harbour, while during summer it is slightly higher.

An inhomogeneity in 1956 significant at the 1% level is revealed. The metadata for Barentsburg (chapter 3) includes no information which can explain this break, but the information is sparse. Also, the statistical evidence for an inhomogeneity is strong, as it is indicated by tests against all series with data covering the actual period. The series is thus adjusted for this inhomogeneity.

Two more inhomogeneities are revealed by the test, one in 1978 and one in 1984. Both of them can be explained by relocations of the gauge.

99840 Svalbard Lufthavn and 99860 Longyearbyen

In spite of several relocations, only one inhomogeneity is found in the Longyearbyen precipitation series. This is connected to the relocation from the "Advent Bay" to "Svalbard Radio" (chapter 3), which leads to increased gauge catch.

No inhomogeneity is found in the series from Svalbard Airport, and neither when the two series are joined together. This is not quite in agreement with the 1961-1990 precipitation normals which have been estimated for both locations (Førland, 1993). According to these, the gauge catch during winter is lower at the airport than in Longyearbyen. This might also be expected, as the airport position probably is less sheltered against the wind than the earlier position. However, parallel measurements during 1974-1976 indicate that the airport position also may catch more drifting snow.

99910 Ny-Ålesund

One inhomogeneity is found, which could be explained by the relocation in 1974. The gauge catch was increased after this relocation, especially during winter and spring.

99950 Jan Mayen

The installation of a windshield led to increased gauge catch from 1932. This inhomogeneity, as well as inhomogeneities in 1940 and in 1946 are revealed during the testing. The latter inhomogeneities were caused by relocations. The measurements between 1940 and 1946 should be used with care as there also were several relocations during this period.

General comments to the homogenised series

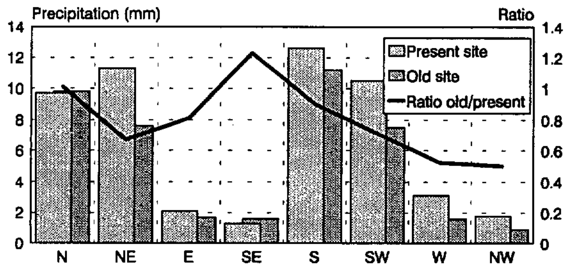
The reliability of the resulting series is variable. Up to 5 adjustments have been introduced in one series. As the adjustments always are somewhat uncertain, the quality of a series with several adjustments is bound to be reduced compared to series where no adjustments are needed.

There are also time periods where the data from all stations are questionable. According to metadata, the reliability of data from before 1924 is lower than for data from later periods. Further, no station has measured continuously and without relocations throughout the second world war. Finally, all Spitsbergen stations experienced changes during the 1970s. Consequently, the adjusted series are still not necessarily homogeneous. However, the good correspondence which exists between test results and metadata certainly indicates that the adjustments which have been accomplished have improved the series.

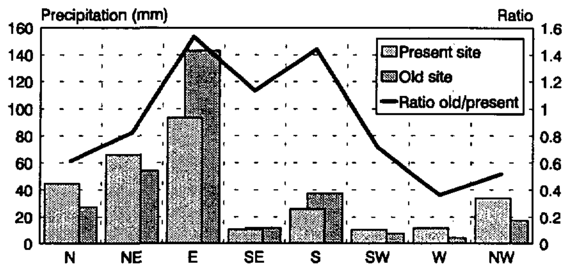
5 Parallel measurements of precipitation at Bjørnøya

In June 1969 the precipitation gauge at Bjørnøya was moved 82 m in easterly direction. The reason was that the former location in inspection reports was considered as unsatisfactory as the gauge "stood on the top of a slope. Moreover, there were also lee-effects from the houses". The new place was later reported to be "better". An inhomogeneity of the precipitation series was thus forecasted.

In order to investigate this possible inhomogeneity, parallel measurements were performed from July 1993 to October 1995. The former site was identified from a station map and a precipitation gauge was set up. The extra measurements were performed by the ordinary staff at the meteorological station at hours 07 and 19. The results are given in Fig. 5.1 and 5.2, grouped by 8 wind directions.



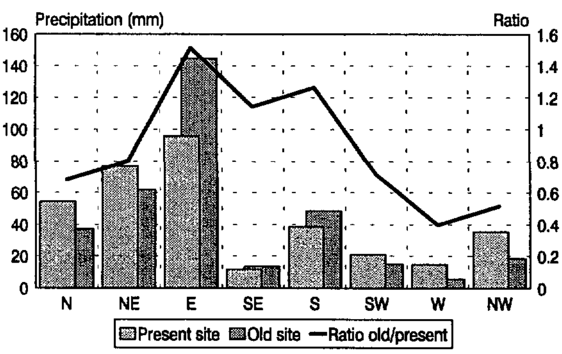
a)



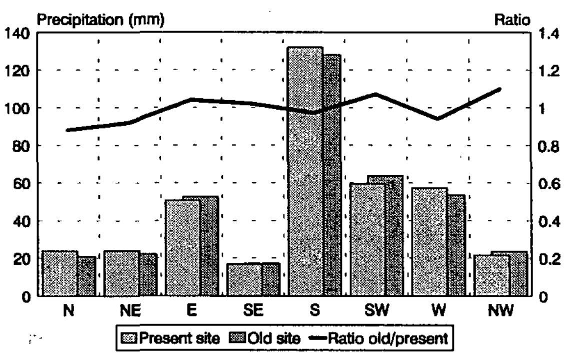
b)

Fig 5.1 Parallel precipitation measurements on Bjørnøya during the period 1993.07 - 1995.10. Solid or mixed precipitation under wind condition a) < 5 m/s and b) ≥ 5 m/s grouped by 8 wind directions.

Fig. 5.1a comprises observations of snow or mixed precipitation for wind speed less than 5 m/s, and Fig. 5.1b wind speed ≥ 5 m/s. It is seen by comparing the figures that most of the precipitation (in fact 85%) occurred for wind ≥ 5 m/s. The distribution of the total solid and mixed precipitation in Fig. 5.2a does consequently not differ much from that in Fig. 5.1b. The difference of liquid precipitation between the two sites is not significant (Fig. 5.2b).



a)



b)

Fig 5.2 Parallel precipitation measurements on Bjørnøya during the period 1993.07 - 1995.10 grouped by 8 wind directions. a) Total amount of solid or mixed precipitation. b) Liquid precipitation

The total amounts of solid and mixed precipitation during the period are approximately the same, the difference being only 4 mm or 1%. But looking at the ratios at the 8 sectors, they are far from equal. Precipitation in the sector from W to NE is more effectively caught at the present site than at the old one. This should be expected, as wind from this direction has an upslope motion before it reaches the old site. In addition, the new site is somewhat sheltered against winds from NW, N and NE by the new station building. The ratio between the gauge catch at the old and the new location for sector W - NE is 0.59.

In the eastern sector the catch efficiency is greater at the old site than at the new one. This sector counts heavily in the statistics because it is the far most common wind direction during solid precipitation. The difference between the sites can not be explained by the terrain in that sector, because it appears flat and uniform seen from both sites. On the other hand, the new station building is located only 60 m from the old site in easterly direction. Lee-effects from the building probably have lead to increased catch efficiency at the old site relatively to the new one. This building was, however, not present during 1947-1969, and the parallel measurements are thus not representative for the old measurements under easterly winds. The results from the parallel measurements should therefore be discarded for that sector. For all other wind sectors, the parallel measurements are assumed to be representative for the old measurements. This is assumed because, with exception of the new station building, the environments at the old measuring site are unchanged relatively to the period 1947-1969.

To assess the effect of the new station building is far from simple. The problem was approached by assuming that:

- there is no difference between the old and the new site for winds from sector E
- there is no difference between the two sites for liquid precipitation
- the differences in the other sectors for solid and mixed precipitation are as shown in Fig. 5.2a

This leads to an adjustment factor of 1.22 for solid and mixed precipitation, and zero adjustment for liquid precipitation. For the total precipitation amount the adjustments are given in table 5.1.

Table 5.1 Adjustment factors for the period 1947.09 - 1969.07 deduced from parallel measurements.

Winter	Spring	Summer	Autumn
1.14	1.18	1.01	1.05

These adjustments are not supported by the test results found by SNHT method (chapter 4.3). There is not necessarily any contradiction in this, as the lack of well-correlated neighbouring stations (table 4.3) makes it impossible to detect small inhomogeneities by the SNHT. However, an approximately 15% increase in winter and spring precipitation should be expected to cause a local maximum in the SNHT test statistics, even if it was not statistically significant. This was not the case, and the question is how to weight the results from the parallel measurements against those of the SNHT.

The parallel measurements at Bjørnøya **proves** that there are differences in catch efficiency at the old and the new site, and that the differences are dependent on wind direction. But in order to **quantify** these differences, it was necessary to make some **assumptions**. One or more of these may be wrong. First, the catch efficiency at the old site under easterly winds may differ from those at the new one. Very small differences in the wind field may affect the catch efficiency of a precipitation gauge. For instance, in the present case the slope directly west of the old site may create turbulence which affects the gauge catch during periods of easterly wind. Secondly, the precipitation was measured by intervals of 12 hours and wind direction may have varied during the intervals. Therefore lee-effects from the new building may have affected catch efficiency also for precipitation grouped in other sectors than the eastern one. The differences in other sectors may thus be underestimated in Fig. 5.2a. Finally, the adjustment factors given in table 5.1 are valid for a specific period (1947-1969) only if the frequency distribution of wind direction during precipitation for the parallel measurements is representative for this period. This is not necessarily the case.

In the present work we conclude that no adjustment should be made for the relocation in 1969 at the present stage. There is a difference in measured precipitation at the two places. It is, however, dependent on wind direction and it is not quantified in a satisfactory way for the wind direction which is the most common under solid precipitation.

6 Establishing temperature and precipitation series from Spitsbergen

6.1 Temperature series valid for Svalbard Airport

The data used in the combined series from Svalbard Airport consists of several shorter series. Each of them have shown to be homogeneous according to the SNHT method, Ch. 4. Some of the series are partly overlapping and will be used in the combined series by the following priority: 1) Svalbard Airport, 2) Longyearbyen, 3) Barentsburg and Green Harbour, 4) Isfjord Radio. On the basis of overlapping periods, adjustment terms are calculated which should be added to the series to obtain homogeneity.

In the following we will use the notation T_X for the average value of the mean monthly temperature for station X. The station is denoted by the first letter in the station's name. If stations X and Y have an overlapping period, the average monthly difference during the whole period is $(T_X - T_Y)_{xy}$ where the double index xy denotes the overlapping period.

Step 1: Svalbard Airport series: The series is complete since the start in August 1975 and is used in the combined series without adjustments.

Step 2: Longyearbyen series: For two years, from August 1975 to July 1977 parallel measurements were performed at Longyearbyen and Svalbard Airport. The differences between them during that period was

$$\textbf{(1)}\quad \Delta_P = (T_S - T_L)_{sl}$$

where T_S and T_L (following the convention) are the average temperature during the overlapping period for Svalbard Airport and Longyearbyen. The difference varied from -1.4°C in late winter to near zero in October, Fig. 6.1.

Another estimate of the difference between Svalbard Airport and Longyearbyen, Δ_B, can be calculated by the Russian Barentsburg series.

$$\textbf{(2)}\quad \Delta_B = (T_S - T_B)_{sb} - (T_L - T_B)_{lb} = \Delta_{sb} - \Delta_{lb}$$

where indices B and b denotes Barentsburg. The mean differences between Svalbard Airport and Barentsburg (Δ_{sb}) and between Longyearbyen and Barentsburg (Δ_{lb}) are calculated for the periods August 1975 to December 1990 and from February 1933 to July 1977 respectively. There exist, however, large gaps in the Longyearbyen series. Therefore the number of years for comparison is reduced to 22 - 26 depending on the month. The average differences calculated by formula (2) that makes use of the Barentsburg series, are shown in Fig. 6.1. Because of different years included in the average values, Δ_B will not take exactly the same values as Δ_P.

The two sets of differences, Δ_P and Δ_B, may be taken as estimates for the adjustments which should be applied on the Longyearbyen series to make it valid for Svalbard Airport. The two sets almost coincide for some months but in the late winter the two terms differ, in March almost 0.8°C, Fig. 6.1.

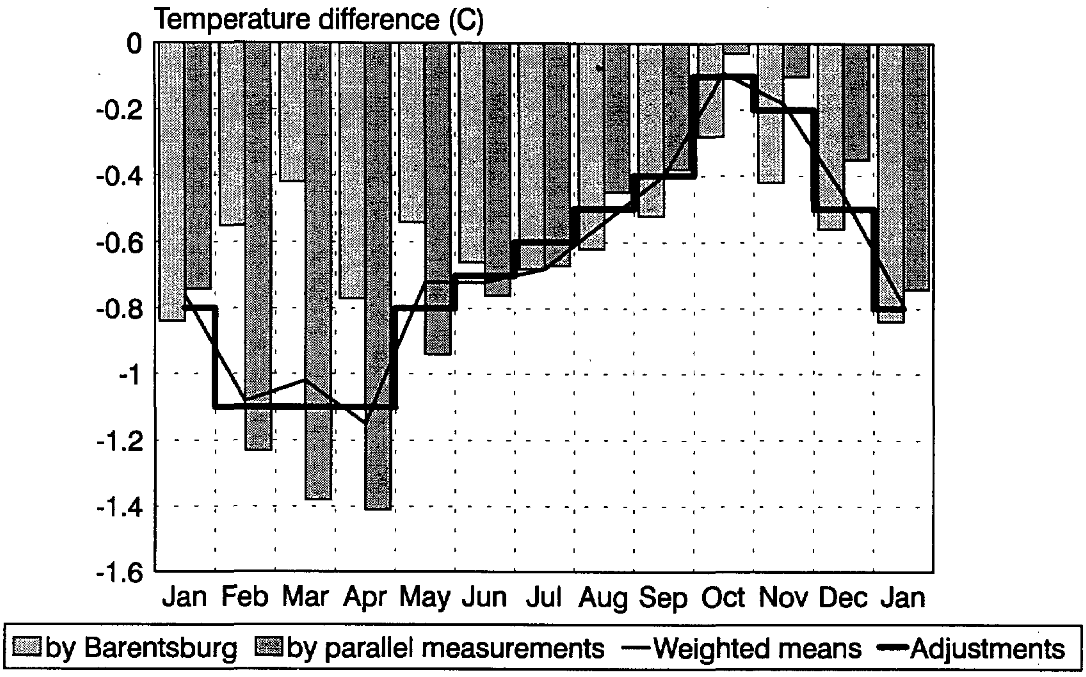


Fig. 6.1 The difference between Svalbard Airport and Longyearbyen found by use of Barentsburg, Δ_B, and parallel measurements, Δ_P. The resulting weighted means and adjustments of the Longyearbyen series to make it valid for Svalbard Airport, are also shown.

There are both advantages and disadvantages of using the Barentsburg series in the comparison; longer overlapping periods can be used but in doing so additional noise is induced in the differences. It is, however, suggested that the best estimates for the «true» adjustments will be found by using information from both Δ_B and Δ_P. A weighted average, Δ, of the two terms is therefore chosen:

$$\textbf{(3)}\quad \Delta = w\Delta_P + (1-w)\Delta_B, \text{ where } 0 \le w \le 1$$

Now, the temperature differences Δ_B and Δ_P are assumed to belong to different normally distributed populations, having the same mean value but different standard deviations. The standard deviation (s_P) of the mean difference Δ_P is calculated from the daily mean temperature differences which have standard deviation s:

$$\textbf{(4)}\quad s_P = \frac{s}{\sqrt{n_e}}, \qquad n_e = n\frac{1-\rho}{1+\rho}$$

where n is the number of days and ρ is the coefficient of auto-correlation of the daily differences (Mitchell et. al, 1966) (Matalas & Langbein, 1962). Thus in an auto-correlated series the «effective» number of observations, n_e, is reduced compared to a random series. In the dataset the largest reduction occurred in April, from 60 to 23.

The standard deviation, s_B, of Δ_B is calculated by the general formula for a difference provided that the two terms are normally distributed.

$$\textbf{(5)}\quad s_B = \sqrt{s_{sb}^2 + s_{lb}^2}$$

where s_{sb} and s_{lb} denotes the standard deviations of Δ_{sb} and of Δ_{lb} respectively. These standard deviations of the mean values for the entire overlapping periods are calculated on the basis of the distributions of the monthly mean temperature differences.

Again assuming normal distributions the standard deviations, s_Δ, of the weighted means, Δ, are given by

$$\textbf{(6)}\quad s_\Delta = \sqrt{w^2 s_P^2 + (1-w)^2 s_B^2}$$

By differentiation of s_Δ by the weight, w, the minimum value of the standard deviation is calculated. Minimum standard deviation occurs when

$$\textbf{(7)}\quad w = \frac{s_B^2}{s_P^2 + s_B^2}$$

Substituting w from (7) into (3) and (6) one has:

$$\textbf{(8a)}\quad \Delta = \frac{s_B^2 \Delta_P + s_P^2 \Delta_B}{s_P^2 + s_B^2} \qquad \textbf{(8b)}\quad s_\Delta = \frac{s_B s_P}{\sqrt{s_B^2 + s_P^2}}$$

The results from calculations of the weighted means from formula (8a) are shown in Fig. 6.1 and s_Δ in table 4.2. In late winter s_B is much larger than s_P and consequently the mean differences of the parallel measurements are more heavy weighted than the mean differences of the comparisons with Barentsburg involved. The adopted adjustments are smoothed within the limit of 0.1°C difference to the weighted means.

<u>Step 3: Barentsburg series</u>: The Longyearbyen series has gaps which partly have been filled by the Barentsburg series. Alternatively the Isfjord Radio series could have been used. The Barentsburg series, however, acquires lesser adjustments than Isfjord Radio to fit into the combined series. This is the main reason for the choice of priority.

The mean differences between Svalbard Airport and Barentsburg (Δ_{sb}) in formula (2)) are shown as a curve in Fig 6.2 together with the adopted adjustments shown as steps.

The Barentsburg data are included in the combined series mainly in the period 1948 - 1956, but also some years in the 1930s are represented by Barentsburg, Appendix 1, table I.

<u>Step 4: Green Harbour series</u>: The series overlaps with the Longyearbyen series from November 1916 to August 1923. There are however gaps in the Longyearbyen series that reduce the number of overlapping years to 4-6 depending on the month, table 2.2. The series is fitted into the combined series by

$$\text{(9)} \quad \Delta_G = (T_S - T_L)_{sl} - (T_G - T_L)_{gl}$$

where G and g denote Green Harbour. The mean differences Δ_G seems to vary rather unsystematically during the year as shown as a curve in Fig. 6.3. Because of the limited number of overlapping years, the extremes in May, June, and December are somewhat reduced in the adopted adjustments, the steps in Fig. 6.3.

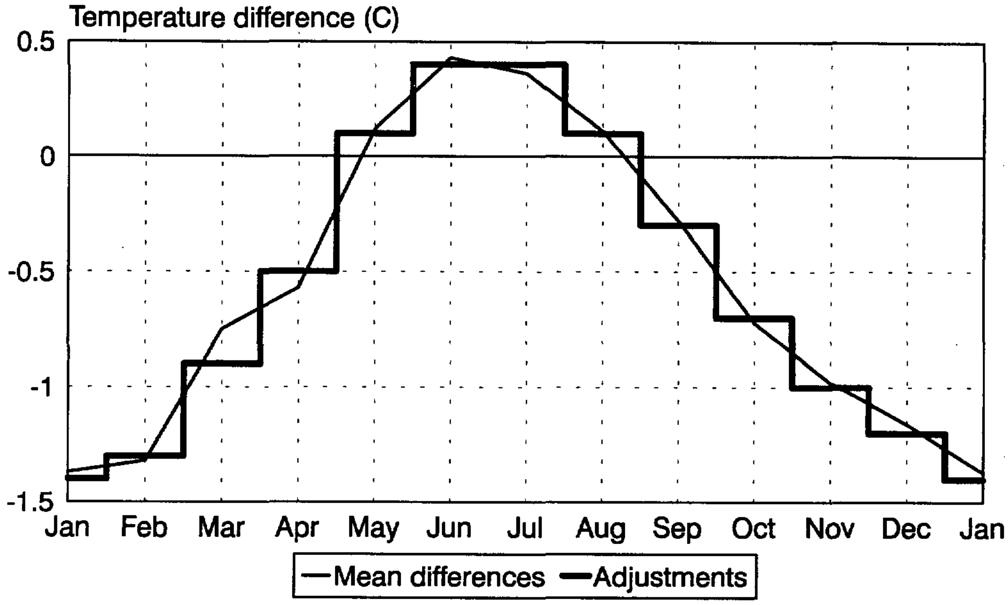


Fig. 6.2. Mean differences between Svalbard Airport and Barentsburg, 1975.08 - 1990.12. The step function is the adopted adjustments applied to the Barentsburg series to make it valid for Svalbard Airport.

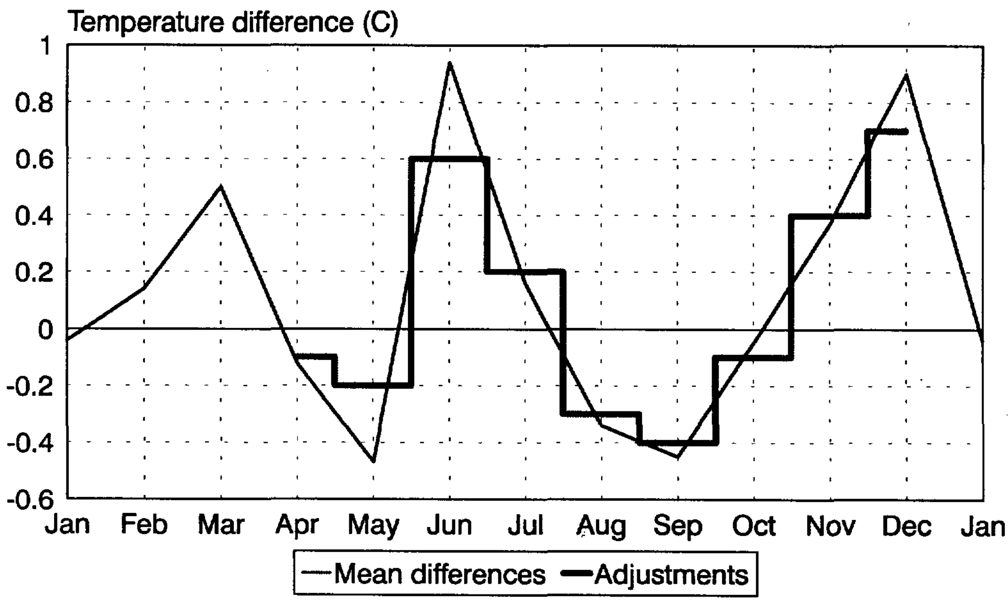


Fig. 6.3. Mean differences between Svalbard Airport and Green Harbour. The step function is the adopted adjustments applied to the Green Harbour series to make it valid for Svalbard Airport.

In winter the difference between Green Harbour and Longyearbyen depended on temperature. Large negative differences were likely to occur in cold winters. Linear regression analysis was therefore applied on the data in the season January - March, the coldest months in the year (Nordli, 1995) (Tuomenvirta & Alexandersson, 1995). About 40% of the variance was explained by the regression

$$\textbf{(10)}\quad (T_G - T_L)_{gl} = 0.1024T_G + 0.65$$

which was substituted into (9) for the months January, February and March.

Green Harbour is the oldest regular series on Spitsbergen and are included in the combined series in the period December 1911 to October 1916 where no other station was in operation. It also fills two gaps in the Longyearbyen series from June 1920 to September 1921 and from September 1923 to August 1930.

Step 5: Isfjord Radio: In the period September 1946 to December 1947 Isfjord Radio is included in the combined series as the only station in operation on Spitsbergen. The difference between Svalbard Airport and Isfjord Radio may be expressed by

$$\textbf{(11)}\quad \Delta_I = (T_S - T_L)_{sl} - (T_I - T_L)_{il}$$

where I and i denote Isfjord Radio. The differences are shown as a curve in Fig. 6.4 together with the adopted adjustments shown as steps.

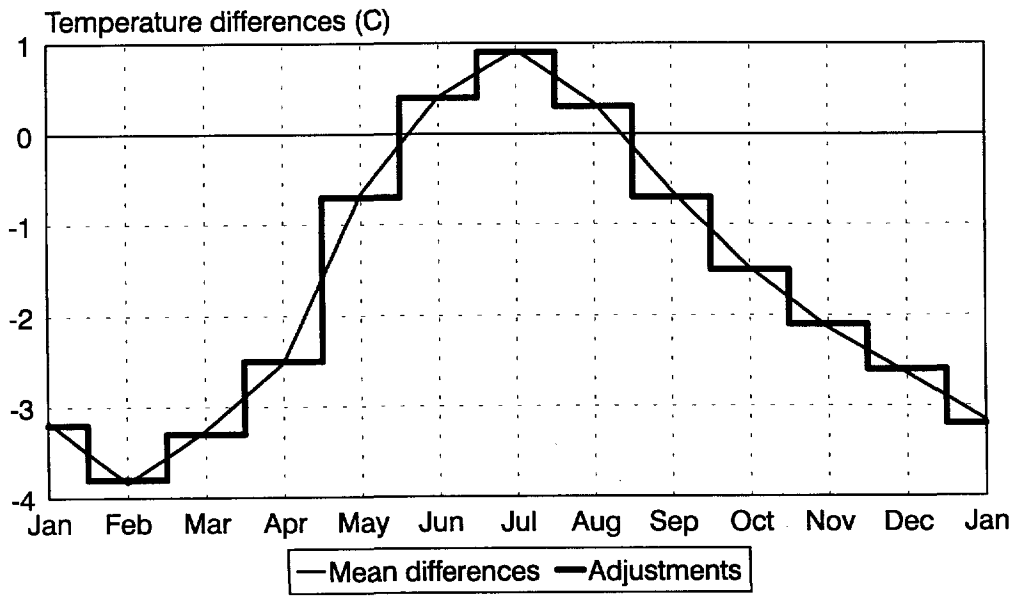


Fig. 6.4. Mean differences between Svalbard Airport and Isfjord Radio. The step function is the adopted adjustments applied to the Isfjord Radio series to make it valid for Svalbard Airport.

Step 6: Interpolations during World War II: By use of regression analysis interpolations of missing monthly mean temperature in the series from Isfjord Radio have been performed (Steffensen, 1964). As predictors were chosen temperature data from Jan Mayen and the Russian station Bukta Tikhaya on Franz Josefs Land, and 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 could probably be improved by using daily circulation maps, but that would be beyond the scope of the this report. Therefore the previous interpolations are maintained and transferred to Svalbard Airport by equation (11).

By these methods a complete series from December 1911 to December 1995 is obtained on the basis of raw data and adjustments given in Fig. 6.1 to 6.4. A previous combined series valid for Svalbard Airport was published by Hanssen-Bauer et. al. (1990). Our present work differ from the work of 1990 by the use of the Barentsburg series to establish a better relationship between the Longyearbyen series and the Svalbard Airport series. In addition the Barentsburg series has replaced the Isfjord Radio series when possible so that only 16 months in the combined series originates from Isfjord Radio. The mean annual difference between the two versions of the combined series during the years 1912-1974 is only 0.1°C, but there are seasonal differences, i.e the newly homogenised series is warmer in spring (+0.6°C in May) and colder in autumn and early winter (-0.3°C in December).

In table 6.1 the standard deviations of the adjustments are shown. In winter the adjustments based upon data from Barentsburg and Green Harbour are quite scattered. The digit giving the degree is quite certain but the decimal fraction is only nominal. In summer the uncertainties are less, ±0.5°C.

The standard deviations for the comparison between Svalbard Airport and Longyearbyen are of the order 0.1°C, computed by formula (8b). Although the Longyearbyen series are judged homogeneous, it may still contain inhomogeneities exceeding 0.1°C.

Table 6.1 Standard deviations for the adjustments in the combined Svalbard Airport temperature series

Adjustments	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$T_S - T_L$	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
$T_S - T_B$	0.7	0.9	0.6	0.7	0.3	0.3	0.2	0.2	0.4	0.4	0.5	0.6
$T_S - T_G$	0.6	1.2	1.3	1.0	0.6	0.4	0.4	0.5	0.1	0.4	0.6	1.3

Monthly temperature normals (1931-1960) (1961-1990) as well as mean values for the entire period (1912-1995) are published in Appendix I, table I.

6.2 Temperature series valid for Ny-Ålesund

In the coastal districts of Spitsbergen the two series Isfjord Radio and Ny-Ålesund are combined into one homogeneous series valid for Ny-Ålesund. The method used is the same as for Svalbard Airport; comparison of the series during overlapping periods. The series overlaps from January 1969 to June 1976. The differences are shown as a curve in Fig 6.5 together with its standard deviations. The adopted adjustments are shown as steps. Again we see that the largest uncertainties occur in winter, ±1°C, and the smallest ones in early summer about ±0.3°C. Possible correlation between the temperature differences and the temperature itself was examined during the season January - March, but no significant correlation was found.

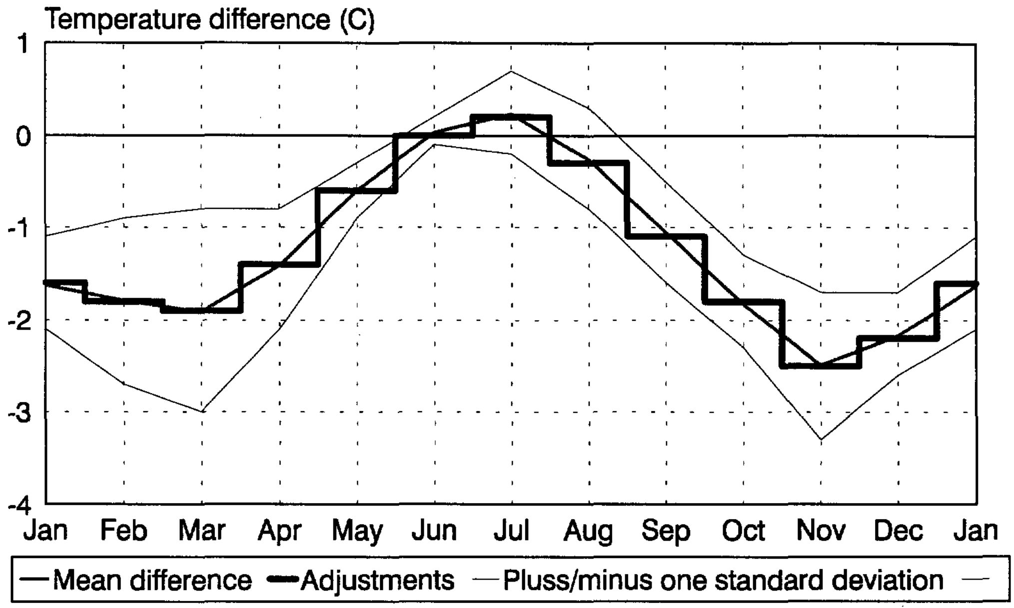


Fig. 6.5. Mean differences between Ny-Ålesund and Isfjord Radio. The step function is the adopted adjustments applied to the Isfjord Radio series to make it valid for Ny-Ålesund.

Monthly temperature normals (1961-1990) and mean values for the entire period (1935-1995) are published in Appendix I, table II.

6.3 Precipitation series valid for Svalbard Airport

The homogenised precipitation series from Svalbard Airport/Longyearbyen and Green Harbour/Barentsburg were combined in order to give a precipitation series valid for Svalbard Airport for the period 1911-1995. Data from the period 1971-1990 were used to calculate the ratios between average monthly precipitation sums at the two locations, using the formula:

$$\textbf{(12)} \quad \alpha_m = R_{Sm} / R_{Bm}, \quad m = 1,\dots,12$$

where m is month (1=Jan, .., 12=Dec) , R_m is average precipitation sum in month m, and subscript S or B denotes if it is measured at Svalbard Airport /Longyearbyen or at Green Harbour/Barentsburg, respectively.

Table 6.2 Ratios (∝) between monthly precipitation sum at Svalbard Airport and in Barentsburg.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
α	0.35	0.35	0.35	0.37	0.40	0.50	0.55	0.50	0.40	0.35	0.30	0.35

The monthly ratios were adjusted slightly to show a smooth seasonal variation (Table 6.2). Monthly precipitation at Svalbard Airport may now be estimated by the formula:

$$(13)\ R_{Sm} = R_{Bm} \cdot \alpha_m$$

Data from the period 1957-1970 were used in order to test the model. The correlation coefficient between observed and estimated monthly precipitation sums is 0.74.

As the Svalbard Airport /Longyearbyen series of annual precipitation according to table 4.3 is better correlated to the Isfjord Radio series than to the Barentsburg series, one might expect estimates based upon measurements from Isfjord Radio to be superior to those found by (13). To test this hypothesis, ratios between monthly precipitation at Svalbard Airport and at Isfjord Radio were calculated from the official 1961-1990 precipitation normals (Førland, 1993). Estimates for precipitation at Svalbard Airport during the period 1957-1970 were made by multiplying these ratios by monthly precipitation at Isfjord Radio. The correlation coefficient between the Svalbard Airport series and these estimates is 0.59 for the period 1957-1970. It is thus the estimates made from the Barentsburg series which are used to fill the gaps in the Svalbard Airport/Longyearbyen series. The series covers the period 1911-1995 with exception of World War II. Precipitation normals (1961-1990) are given in Appendix I, table III.

7 Summary and conclusion

Mainly on the basis of inspection reports stored in DNMI's archives, a short survey of the history of the Norwegian Arctic stations is presented. Special attention is given to changes at the stations that might have influenced the homogeneity of temperature and precipitation measurements.

Results from homogeneity testing of the temperature and precipitation series using the Standard Normal Homogeneity Test (SNHT) are presented. For mean temperature the stations 99710 Bjørnøya, 99720 Hopen, 99760 Sveagruva, 99790 Isfjord Radio, 99821 Green Harbour, 99840 Svalbard Airport, 99860 Longyearbyen and 99910 Ny-Ålesund turned out to be homogeneous. The last one has earlier been considered inhomogeneous as a result of a relocation. Also the Russian series from Barentsburg and the Polish series from Hornsund were found to be homogeneous. In the series from Jan Mayen, however, a break was detected, possibly caused by a major relocation in 1940.

The temperature series from the near by stations Green Harbour and Barentsburg were linked together and tested for homogeneity. The combined series was found to be inhomogeneous in winter (Dec - Feb). In the rest of the year, however, no break was detected.

Several inhomogeneities were found in the precipitation series. This is what one should expect, as gauge catch for snow under windy conditions is sensitive to minor changes in environments, exposure or instrumentation. Actually, all series except those from Hornsund and Svalbard Airport are inhomogeneous and should be adjusted. All inhomogeneities detected in the Norwegian series can be attributed to physical changes which are reported in the station history archives. The only inhomogeneity found by the SNHT which is not explainable by information in the metadata is one in the Barentsburg series in 1956. However, the metadata from this station are probably not complete.

The homogenised time series from Spitsbergen were finally used in order to create series of temperature and precipitation of maximum length. On the basis of parallel measurements at Svalbard Airport and Longyearbyen and overlapping periods for various series, a combined temperature time series valid for Svalbard Airport was achieved. The series starts in December 1911. This series is mostly based upon the continental stations in the Isfjorden area.

The temperature series from Isfjord Radio was adjusted and linked together with the Ny-Ålesund series to form a homogeneous coastal series valid for Ny-Ålesund. It starts in September 1934. Except for some years in connection with World War II the two long combined series originate from different stations.

A precipitation series starting in 1911 valid for Svalbard Airport was achieved by using measurements from Svalbard Airport, Longyearbyen, Barentsburg and Green Harbour .

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Appendix I

The tables contain standard normals and means for the long series on Spitsbergen.

Svalbard Airport temperature series.

Table I Temperature normals (°C) for the homogenised series valid for Svalbard Airport as well as the means (°C) of the entire length of the series.

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Means 1912-95	-14.4	-15.5	-15.9	-12.1	-4.2	2.3	5.9	4.7	0.3	-5.4	-9.6	-12.0	-6.3
Normal 1931-60	-12.4	-13.6	-14.9	-11.3	-3.8	2.3	5.9	4.6	0.7	-4.4	-7.8	-10.1	-5.4
Normal 1961-90	-15.3	-16.2	-15.7	-12.2	-4.1	2.0	5.9	4.7	0.3	-5.5	-10.3	-13.4	-6.7

The origin of the Svalbard Airport temperature series is:
1911.12 - 1916.10 : Green Harbour
1916.11 - 1920.05 : Longyearbyen
1920.06 - 1921.09 : Green Harbour
1921.10 - 1923.08 : Longyearbyen
1923.09 - 1930.08 : Green Harbour
1930.08 - 1934.08 : Longyearbyen
1934.09 - 1934.12 : Barentsburg
1935.01 - 1935.09 : Longyearbyen
1935.10 - 1936.10 : Barentsburg
1936.11 - 1939.06 : Longyearbyen
1939.07 - 1941.08 : Barentsburg
1941.09 - 1941.11 : Interpolations
1941.12 - 1942.06 : Longyearbyen
1942.07 - 1945.08 : Interpolations
1945.09 - 1946.08 : Longyearbyen
1946.09 - 1947.12 : Isfjord Radio
1948.01 - 1956.12 : Barentsburg
1957.01 - 1975.07 : Longyearbyen
1975.08 - 1995.12 : Svalbard Airport

Ny-Ålesund temperature series

Table II Temperature normals (°C) of the homogenised series valid for Ny-Ålesund as well as the means (°C) of the entire length of the series.

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Means 1935-95	-12.7	-13.5	-13.9	-10.7	-3.8	1.7	5.0	4.0	0.0	-5.4	-9.3	-11.3	-5.2
Normal 1961-90	-13.9	-14.6	-14.2	-11.1	-4.0	1.5	4.9	3.9	-0.3	-5.7	-10.0	-12.5	-5.7

The origin of the Ny-Ålesund temperature series is:
1934.09 - 1941.06: Isfjord Radio
1941.07 - 1946.08: Interpolations
1946.09 - 1968.12: Isfjord Radio
1969.01 - 1995.12: Ny-Ålesund

Svalbard Airport precipitation series.

Table III Precipitation normals (mm) for the homogenised series valid for Svalbard Airport as well as the means (mm) of the entire length of the series.

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
* Means1912-1995	16	19	18	10	7	9	14	21	17	14	16	19	180
Normal 1961-1990	15	19	22	11	6	10	18	23	20	14	15	16	190

* The period 1941.08 - 1945.08 is missing.

The origin of the Svalbard Airport precipitation series is:
1911.12 - 1916.10 : Green Harbour
1916.11 - 1920.05 : Longyearbyen
1920.06 - 1921.09 : Green Harbour
1921.10 - 1923.08 : Longyearbyen
1923.09 - 1930.08 : Green Harbour
1930.09 - 1934.08 : Longyearbyen
1934.09 - 1941.07 : Barentsburg
1945.09 - 1946.07 : Longyearbyen
1946.08 - 1947.12 : Isfjord Radio
1948.01 - 1956.12 : Barentsburg
1957.01 - 1975.12 : Longyearbyen
1976.01 - 1995.12 : Svalbard Airport