Supplementary file for: Gjelten H.M., Nordli Ø., Isaksen K., Førland E.J., Sviashchennikov P.N., Wyszynski P., Prokhorova U.V., Przybylak R., Ivanov B.V. & Urazgildeeva A.V. 2016. Air temperature variations and gradients along the coast and fjords of western Spitsbergen. *Polar Research 35.* Herdis Motrøen Gjelten, Norwegian Meteorological Institute, P.O. Box 43 Blindern, NO-0313 Oslo, Norway. E-mail: herdismg@met.no

Metadata and gap filling

Most of the old time series of Spitsbergen are characterized by large gaps that hamper their usefulness in climate analysis. In recent years we see an increased interest for the old climate series both from the Norwegian Meteorological Institute and Arctic and Antarctic Research Institute. It has resulted in re-establishment of the stations Isfjord Radio (stopped in 1976, re-established 2014) and Pyramiden (stopped in 1957, re-established 2011). The gaps have been filled by interpolated values established by linear regressions for each month with neighbouring stations as predictors; see Eqn. 1. The time scale was daily mean temperature.

Further information about the interpolations is shown in Supplementary Table S1. The structure of Supplementary Table S1 is as follows:

Line 1: Month of the year.
Line 2: predictand series – predictor series, overlapping periods.
Line 3: regression coefficient, α, in Eqn. 1 in the main text. If $\alpha > 1$ the variability of the predictand is greater than the predictor, and vice versa if $\alpha < 1$.
Line 4: the constant term in Eqn. 1 in the main text.
Line 5: the Sum of Squares of the Regression (SSR) divided by the Sum of Squares of the Total (SST) is a measure of the skill of the regression, here in %. This measures is often also referred to as the "percent explained by the regression", but it is better to use the phrase "accounted for" as the regression only shows relationships without giving causes for this relationship.
Line 6: the uncertainty (RMSE or the standard deviation of the residuals) in the interpolated daily mean temperatures.

Supplementary Table S1. Regressions on daily values: α and C are coefficients in Eqn. 1, SSR/SST is the regression sum of squares divided by the total sum of squares in % (variance accounted for by the regression), RMSE (°C) is the root square mean of the residuals.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Isfjord Radio – Barentsburg (1940-1941; 1947-1976)												
α	0.875	0.870	0.872	0.869	0.877	0.800	0.751	0.816	0.883	0.887	0.885	0.883
C	0.24	0.17	0.21	0.91	0.14	0.25	0.65	0.63	0.56	0.51	0.43	0.35
SSR/SST (%)	96	95	95	96	97	91	74	85	92	97	97	97
RMSE (°C)	1.4	1.5	1.4	1.1	0.6	0.6	0.9	0.7	0.7	0.8	1.0	1.1
Isfjord Radio – Ny-Ålesund (1974-1976; 1997-2002)												
α	0.858	0.878	0.864	0.804	0.819	0.760	0.740	0.716	0.737	0.780	0.837	0.882
C	0.19	0.21	0.40	0.46	-0.09	0.87	1.58	1.92	1.40	0.70	0.54	0.65
SSR/SST (%)	94	94	94	93	92	81	62	64	89	93	94	95
RMSE (°C)	1.5	1.5	1.5	1.3	0.9	0.9	1.0	1.0	0.8	1.1	1.2	1.4
Barentsburg – Isfjord Radio (1940-1941; 1947-1976)												
α	1.091	1.093	1.090	1.104	1.108	1.113	0.974	1.005	1.046	1.090	1.095	1.097
C	-0.94	-0.93	-0.98	-0.55	-0.31	-0.21	0.77	0.12	-0.59	-0.80	-0.79	-0.79
SSR/SST (%)	96	95	95	96	97	91	74	85	92	97	97	97
RMSE (°C)	1.6	1.7	1.6	1.3	0.7	0.8	1.0	0.8	0.8	0.9	1.1	1.3
Barentsburg – Svalbard Airport (1975-2014)												
α	0.865	0.868	0.869	0.883	0.903	0.878	0.842	0.840	0.860	0.856	0.865	0.880
C	-0.82	-0.88	-1.01	-0.75	-0.62	-0.27	0.58	0.52	0.13	-0.35	-0.62	-0.52
SSR/SST (%)	94	94	93	94	95	90	83	88	93	94	95	95
RMSE (°C)	1.8	1.8	1.9	1.4	0.8	0.7	0.8	0.7	0.8	1.1	1.3	1.5
Hornsund – Isfjord Radio (1997-2002; 2011-2014)												
α	1.055	1.033	1.082	1.070	1.005	0.729	0.652	0.641	0.862	0.970	1.048	1.042
C	0.00	-0.12	0.26	0.07	-0.13	0.10	0.88	0.78	0.18	0.18	0.52	-0.18
SSR/SST (%)	93	93	93	90	86	71	57	66	88	91	93	93
RMSE (°C)	1.9	1.7	1.8	1.8	1.2	0.9	0.9	0.8	0.8	1.2	1.3	1.7
Hornsund – Svalbard Airport (1975-2014)												
α	0.834	0.790	0.805	0.824	0.825	0.573	0.405	0.533	0.727	0.817	0.864	0.874
C	0.35	0.18	0.01	-0.04	-0.25	0.30	1.81	1.20	0.67	0.85	0.90	0.70
SSR/SST (%)	92	91	89	89	87	67	43	66	87	89	93	93
RMSE (°C)	2.0	2.0	2.1	1.8	1.2	1.0	1.0	0.9	1.0	1.4	1.5	1.8
Svalbard Airport – Longyearbyen (1975-1977)												

α	1.018	1.038	1.036	1.023	1.049	0.976	1.022	0.929	0.970	0.968	0.971	1.023
C	-0.52	-0.68	-0.88	-1.13	-1.10	-0.87	-1.01	-0.26	-0.57	-0.21	-0.36	-0.04
SSR/SST (%)	99	99	99	98	98	96	90	92	97	99	99	98
RMSE (°C)	0.7	0.9	1.1	0.8	0.6	0.6	0.7	0.5	0.4	0.5	0.6	1.2
Svalbard Airport – Barentsburg (1947-1976)												
α	1.088	1.088	1.070	1.060	1.048	1.026	0.948	1.042	1.081	1.097	1.095	1.081
C	0.13	0.23	0.17	0.17	0.49	0.56	0.55	0.14	-0.05	0.09	0.24	0.04
SSR/SST (%)	97	97	96	97	97	95	91	94	96	97	97	98
RMSE (°C)	2.0	2.0	2.1	1.5	0.9	0.8	0.9	0.8	0.9	1.2	1.5	1.7
Pyramiden – Barentsburg (1948-1959; 2011-2014)												
α	1.039	1.055	1.068	1.087	1.047	0.991	0.905	0.940	1.030	1.115	1.098	1.110
C	-1.34	-0.76	-0.96	-0.15	0.27	0.91	1.68	1.03	0.13	-0.39	-0.54	-0.42
SSR/SST (%)	94	94	94	93	94	90	78	84	91	91	96	94
RMSE (°C)	2.0	2.0	2.0	1.7	1.0	0.8	0.9	0.8	1.0	1.4	1.5	1.8
Pyramiden – Svalbard Airport (2011-2014)												
α	1.005	1.027	0.959	1.023	0.942	0.980	0.858	0.849	1.033	1.061	1.063	0.992
C	-1.29	-0.72	-1.52	-0.82	-0.54	-0.06	1.37	0.87	-0.44	-0.52	-0.97	-0.70
SSR/SST (%)	92	97	93	93	90	86	86	70	85	92	94	92
RMSE (°C)	1.6	1.1	1.6	1.5	1.2	0.8	0.7	0.7	0.9	1.0	1.3	1.5
Ny-Ålesund – Isfjord Radio (1969-1976)												
α	1.077	1.067	1.043	1.070	1.100	1.074	0.853	0.959	1.229	1.197	1.138	1.082
C	-1.09	-1.05	-1.41	-0.77	-0.20	-0.36	0.85	-0.28	-1.55	-1.14	-1.19	-1.25
SSR/SST (%)	94	93	92	90	90	83	62	70	88	93	93	94
RMSE (°C)	1.9	1.9	2.0	1.8	1.1	1.0	1.1	1.1	1.1	1.3	1.5	1.6

Supplementary Table S2. Pyramiden, average mean temperature difference in the period 23.07.2011–31.12.2014 between estimated and observed values. The estimates are based on regression with Barentsburg as predictor in the period 01.01.1948-15.05.1957.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean	0.0	-0.1	0.2	0.5	0.1	0.0	0.0	0.4	0.5	0.3	0.3	-0.1	0.18
RMSE	1.5	1.5	1.6	1.6	1.0	0.7	0.8	0.8	1.0	1.1	1.4	1.6	1.26

The gaps in the time series are in most cases filled by data from more than one predictor station. Our first choice is the station with the greatest amount of variance accounted for, but due to different periods of observation it has been necessary to also use the second best station. More detailed information is given in the text below.

99754 Hornsund: The meteorological station is located in the outer part of the Hornsund fjord (Fig. 1b) and belongs to the Institute of Geophysics of the Polish Academy of Science. It lies about 200 m from the coast. The first meteorological observations were conducted in the International Geophysical Year 1957/58; however, regular measurements began in July 1978.

No official meteorological observations were carried out at Hornsund in the period 27.07.1981–31.08.1982, but thanks to volunteers from Wroclaw University some measurements of air temperature and humidity were made. Based on thermograms Przybylak (1992) filled the gap, so the series might be considered to be complete since the beginning in 1978. In this study, daily data for the station has been reconstructed back to the start of the Isfjord Radio series, i.e., September 1934. Isfjord Radio was used as predictor as long as the station was in operation, until 30.06.1976. As no observations were carried out neither at Isfjord Radio nor at Hornsund in the period 01.07.1976–30.06.1978, this gap had to be filled by use of another predictor. The choice fell on Svalbard Airport, but this resulted in a larger RMSE than with Isfjord Radio as predictor (Supplementary Table S1). A multiple regression approach was also tested. One of the predictors was Bjørnøya, but the uncertainty was not reduced significantly (not shown).

99790 Isfjord Radio: This Norwegian meteorological station was established on 1 September 1934 and is situated on cape Linné at the mouth of Isfjorden (Fig. 1b). It was destroyed by actions of war in September 1941 but re-established at the same place in July 1946. The official station was closed down on 1 July 1976. In September 2014 a new automatic weather station was established at the same site.

Recently digitized data from Isfjord Radio were tested against the neighbouring station Barentsburg for inhomogeneities by the standard normal homogeneity test (Alexandersson 1986). No inhomogeneity was detected during an early overlapping period 01.12.1947–30.06.1976 (not shown). There were also two shorter overlapping periods: 01.01.1997–05.02.2002 and 20.06.2002-06.12.2004, when a logger of the type Aanderaa was in operation at Isfjord Radio. So the question arises: are the later automatic observations biased compared with the early manual ones? In order to answer this question regression analysis was performed with Barentsburg as predictor. The coefficients α and C were calculated for each month in the early period (training period), whereas the regressed values were calculated for the later periods (validation periods) and then compared to the observed values. The biases varied from −0.09 °C in June and July to −0.02 °C in April. This is of the same magnitude as the accuracy of the thermometers or sensors. Therefore the regression estimates were considered to be unbiased and the early manual observations at Isfjord Radio were joined with the new automatic ones without adjustments.

Three stations were tested as predictors for filling of the large gaps in the series: Hornsund, Barentsburg and Ny-Ålesund. The reconstructions by Barentsburg had lower uncertainty compared to the two other stations except for February (Supplementary Table S1), i.e., a larger fraction of the variance was accounted for by the regression and the RMSE was smaller. In particular this is true for the summer months. Therefore Barentsburg was our first choice for gap filling. Ny-Ålesund gave only slightly lower RMSE than Hornsund (not shown) and was therefore used in periods where Barentsburg were missing data.

99820 Barentsburg is a Russian meteorological station that is still in operation, located in Grønfjorden, a branch of Isfjorden (Fig. 1b). Measurements began in 1933 when the station was moved ca. 25 km to Barentsburg from Grumantbyen (the first Russian station in Svalbard was located there at the end of 1931). The station has been relocated three times which has resulted in a changed altitude (Table 1; Nordli et al. 2014). Daily mean temperatures from the station for the period 1940–2014 have been downloaded from the web page www.meteo.ru/climate/. However, monthly means from the 1930s are also used. They have been in the possession of the Norwegian Meteorological Institute for a considerable time and have been tested and found reliable.

Gaps in the series (Table 1) were filled by Isfjord Radio (1940–1975) and by Svalbard Airport (1976–2014; Supplementary Table S1). The RMSE is slightly less for Isfjord Radio as predictor than for Svalbard Airport. During the period 1940–2014 the gaps amounted to 5 % of the observations (the period 08.1941–09.1946 was not counted).

99840 Svalbard Airport: As the name suggests, the station is situated at Svalbard Airport (in Norwegian, Svalbard lufthavn, which is the name used in Norwegian station lists). It is located near the outer part of Adventfjorden, a branch of Isfjorden (Fig. 1b). In 2010 the sparse grass growing near the site of measurements was replaced by sand, and in late July or early August 2010 covered with asphalt. The station was relocated on 5 October 2010 in order to prevent thermal influences on the measurements associated with the area cleared for airport purposes, see Table 1. Double measurements showed no homogeneity break due to the relocation (Nordli et al. 2014). Daily data for the station were reconstructed back to 1957 by regression analysis with Longyearbyen as a predictor (Supplementary Table S1). The uncertainty (RMSE) in the reconstructed monthly means was 1°C or less and for the winter months about 99 % of the variance was accounted for by the regression (Supplementary Table S1). The low RMSE is very likely due to the short distance between the measuring sites, about 5 km.

99860 Longyearbyen: The series consists of three main series, one conducted by the northernmost coal-mining company, Store Norske Spitsbergen Kulkompani, and the two other by the Norwegian Meteorological Institute (Steffensen et al. 1996). Here we only use the last series for prolonging the Svalbard Airport series back to 1957; see above.

99880 Pyramiden: Among the stations along Isfjorden this station is the innermost situated at Mimerdalen in the Billefjorden branch of Isfjorden (Fig. 1b). The measurements at this Russian meteorological station began in 1948 and ended in 1957. No changes affecting the temperature measurements occurred (Ivanov et al. 2014). A new automatic weather station was established at the same site by the Norwegian Meteorological Institute in 2011. This continuation of the Pyramiden station involved a change of screen and also a change from manual to automatic observation procedures. The homogeneity of the new series compared with the old one was tested by the use of the long term Barentsburg series that overlaps both series. Regression coefficients were calculated for the old (training) period and applied to the new (validation) period (Supplementary Table S2). The estimated monthly means were generally close to the observed ones. The bias was only 0.18 °C for the annual mean, but amounted to 0.5 °C in April and September.

No adjustments were made in the series as the new part seemed to be too short for any conclusion to be made about the homogeneity. Consequently the whole series was considered to be homogenous. The large gap in the series between the end of the Russian series and the beginning of the Norwegian one was filled by regression analysis using Barentsburg as predictor (Supplementary Table S1).

99910 Ny-Ålesund: The Norwegian meteorological station at Ny-Ålesund was relocated in 1974 when the station was moved from the small nearby airport to the settlement, see Table 1. However, homogeneity testing did not detect inhomogeneities in mean temperature due to the relocation (Nordli et al. 1996).

Mean daily temperatures were reconstructed using Isfjord Radio back to 1934. The uncertainty in the daily mean temperatures was slightly larger than for the reconstruction of Hornsund temperatures (Supplementary Table S1).

Short description of screens

MI-1930: Norwegian single louvered screen with an inner cage for the instruments (Nordli et al. 1997).

MI-1933: Norwegian double boarded wall, screen for harsh weather conditions (Nordli et al. 1997).

MI-1946: Norwegian double louvered wall east and west, double boarded wall north and south (Nordli et al. 1997).

MI-1974: Norwegian cylindrical double louvered screen (Nordli et al. 1997).

MI-2001B: Norwegian cylindrical double louvered screen.

Selianinov screen: Standard Russian double louvered screen (Ivanov et al. 2014).

Vaisala, DTR13: Cylindrical single louvered screen (Nordli et al. 1997).

Wavelet analysis

The filtered curves in Fig. 2 in the main text show the variability in the time series on a decadal time scale. An additional way to display the variability in the time series is through wavelet analysis (see the methods section in the main text). Spectrograms from wavelet analysis show the variability in the time series on different time scales, short-term to long-term (Supplementary Fig. S1). The spectrograms were very similar for the six stations (not shown) therefore only spectrograms of Barentsburg are included in Supplementary Fig. S1. Supplementary Fig. S1a displays the spectrogram for the monthly reconstructed series from Barentsburg during the period 1948–2014. Three main oscillating patterns were detected. There are as expected short-term fluctuations reflecting the annual cycle of the data with a period less than one year (not easily seen because of the small scale in the figure). The second type of fluctuations is medium-term fluctuations with a period between 1 and 10 years, and the third type is long-term fluctuations with a period between 10 and 25 years. In the medium-term oscillations, fluctuations with a 1–5 year period have weakened while the fluctuations with a 5–10 year period have strengthened. The long-term fluctuations show a clear decrease in intensity from around 1980.

Seasonal differences were also analysed. A spectrogram for January in Supplementary Fig. S1b represents the cold season while the warm season is represented by a spectrogram for July in Supplementary Fig. S1c. For July, the long-term fluctuations with a period larger than 20 years are the more pronounced ones. They also seem to have a strengthening signal. We see that the summer season gives little contribution to the variability in the time series, as little of the patterns in the July spectrogram can be found in the “annual” spectrogram (Supplementary Fig. S1a). For January, the fluctuations with a 3–5 year period and 10–20 year period are weakening. The fluctuations with a 5–10 year period are strengthening. Winter contributes much to the variability in the annual spectrogram, as the pattern in the spectrograms for January and the “annual” spectrogram is similar.

Supplementary Table S3. Linear trend (°C/decade) for the reconstructed temperature series for the period 1948–2015. Numbers in boldface denote a trend significant at a 5 % level.

Station	1948–2015				
	Year	DJF	MAM	JJA	SON
Hornsund	**0.38**	**0.65**	**0.48**	**0.19**	0.20
Isfjord Radio	**0.31**	**0.43**	**0.40**	**0.21**	0.18
Barentsburg	**0.35**	**0.57**	**0.44**	**0.21**	0.18
Svalbard Airport	**0.45**	**0.71**	**0.55**	**0.28**	0.24
Pyramiden	**0.36**	**0.60**	**0.45**	**0.19**	0.16
Ny-Ålesund	**0.34**	**0.54**	**0.40**	**0.18**	0.21

Supplementary Table S4. Calculated 1961–1990 temperature normals (°C).

	Hornsund	Isfjord Radio	Barents-burg	Svalbard Airport	Pyramiden	Ny-Ålesund
Jan	−12.5	−12.1	−14.1	−15.3	−16.0	−13.9
Feb	−12.8	−12.4	−14.7	−16.2	−16.4	−14.6
Mar	−12.6	−12.0	−14.5	−15.7	−16.4	−14.2
Apr	−10.1	−9.5	−11.4	−12.2	−12.6	−11.1
May	−3.6	−3.2	−4.1	−4.1	−4.1	−4.0
Jun	1.3	1.6	1.6	2.0	2.5	1.5
Jul	4.1	4.8	5.5	5.9	6.6	4.9
Aug	3.6	4.2	4.5	4.7	5.2	3.9
Sep	0.9	0.6	0.5	0.3	0.6	−0.3
Oct	−3.6	−4.0	−4.9	−5.5	−5.9	−5.7
Nov	−8.0	−8.0	−9.5	−10.3	−11.0	−10.0
Dec	−11.2	−10.6	−12.3	−13.4	−14.1	−12.5
Annual	−5.4	−5.1	−6.1	−6.7	−6.8	−6.3

Supplementary Table S5. 1986–2015 average temperature (°C).

	Hornsund	Isfjord Radio	Barents -burg	Svalbard Airport	Pyramiden	Ny-Ålesund
Jan	−9.5	−9.3	−11.0	−11.7	−12.7	−11.0
Feb	−10.0	−10.2	−12.1	−12.9	−13.6	−12.2
Mar	−10.1	−10.0	−11.8	−12.6	−13.7	−12.0
Apr	−7.8	−7.8	−9.2	−9.6	−10.2	−9.3
May	−2.4	−2.4	−3.0	−2.6	−2.9	−2.8
Jun	2.2	2.5	2.6	3.3	3.5	2.5
Jul	4.5	5.4	6.1	6.6	7.2	5.4
Aug	4.3	5.2	5.3	5.8	6.0	4.5
Sep	1.8	1.9	1.4	1.6	1.4	0.6
Oct	−2.9	−3.2	−4.4	−4.6	−5.4	−5.1
Nov	−5.8	−6.0	−7.4	−7.8	−8.8	−7.9
Dec	−8.5	−7.9	−9.8	−10.5	−11.3	−10.2
Annual	−3.7	−3.5	−4.4	−4.6	−5.0	−4.8

Supplementary Table S6. The 1961–1990 normal of number of days per year with daily mean temperature below or above different temperatures. The difference between the 1986–2015 average and the 1961–1990 normal is also shown.

Station	T < –15° C		T < –10 °C		T > 0 °C		T > 5 °C	
	1961-90	Δ	1961-90	Δ	1961-90	Δ	1961-90	Δ
Hornsund	56	–22	105	–30	126	18	11	12
Isfjord Radio	48	–21	101	–28	123	14	27	14
Barentsburg	71	–27	121	–28	116	14	33	14
Svalbard Airport	84	–30	131	–32	118	18	37	16
Pyramiden	89	–28	135	–25	119	11	48	11
Ny-Ålesund	72	–24	122	–26	116	10	27	10

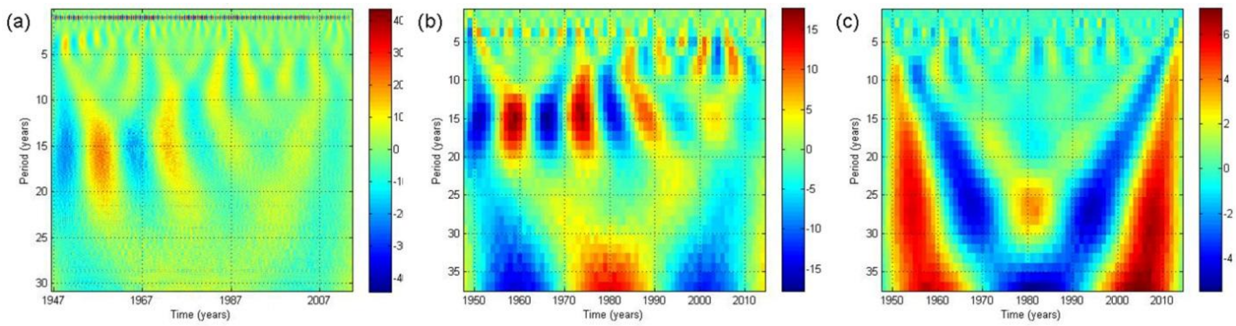
Supplementary Table S7. Linear trends (°C/decade) of annual mean temperature (T_m), annual mean maximum temperature (T_{max}) and annual mean minimum temperature (T_{min}) from Hornsund, Barentsburg, Svalbard Airport and Ny-Ålesund in the period 1979–2015. Numbers in boldface denote a trend significant at a 5 % level. The average linear trend of each parameter is also included.

Station	T_{max}	T_m	T_{min}
Hornsund	**0.88**	**1.03**	**1.21**
Barentsburg	**0.75**	**1.06**	**1.19**
Svalbard Airport	**1.03**	**1.29**	**1.41**
Ny-Ålesund	**0.86**	**0.96**	**1.06**
Average	0.88	1.09	1.22

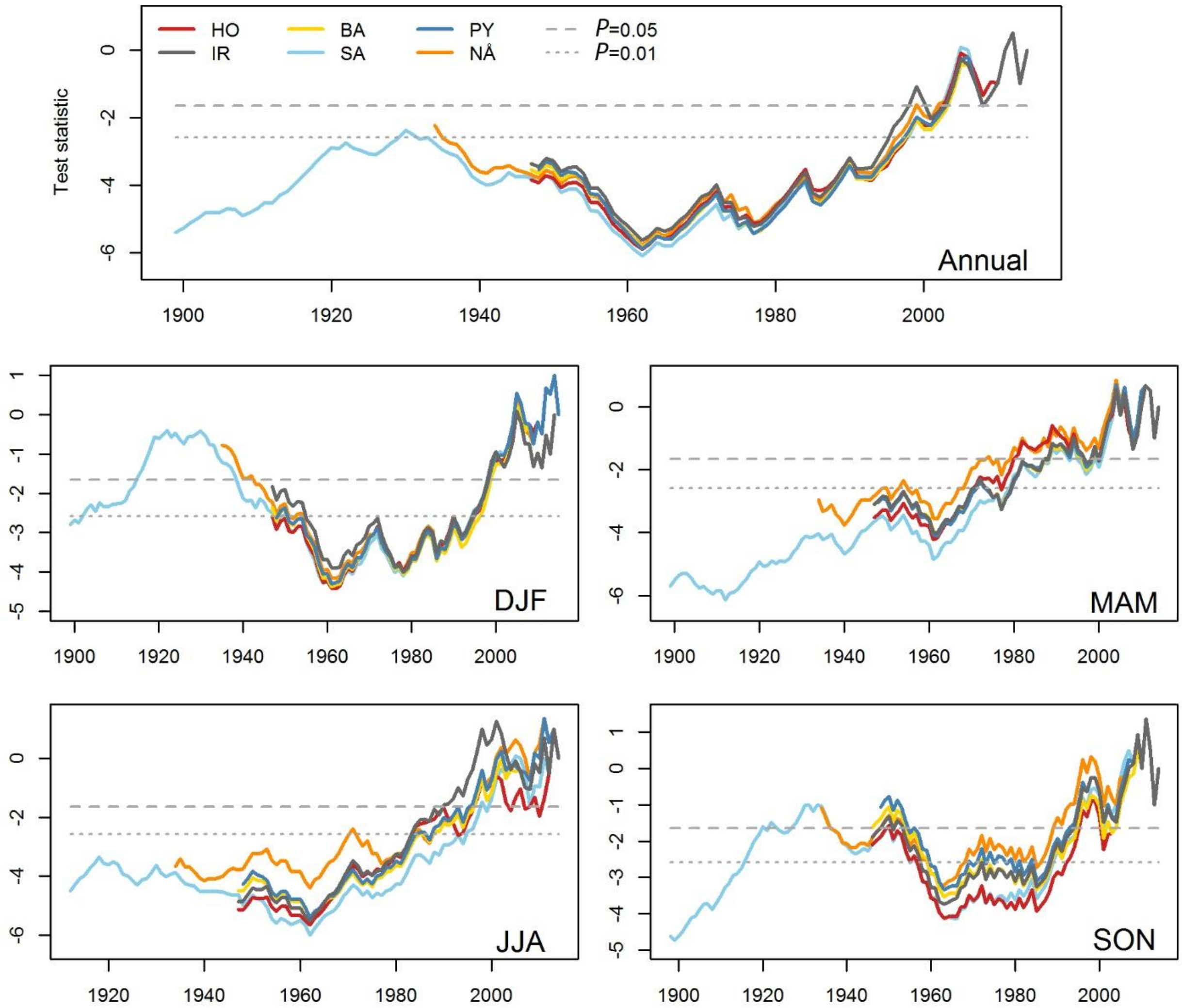
Supplementary Table S8. Mean K-index (%) for the reconstructed series in different periods.

Period	Hornsund	Isfjord Radio	Barentsburg	Svalbard Airport	Pyramiden	Ny-Ålesund
1951-1960	32.0	32.1	38.6	42.1	46.2	36.8
1961-1970	39.9	38.9	47.0	51.9	54.0	43.5
1971-1980	35.0	34.2	41.1	45.8	47.9	39.9

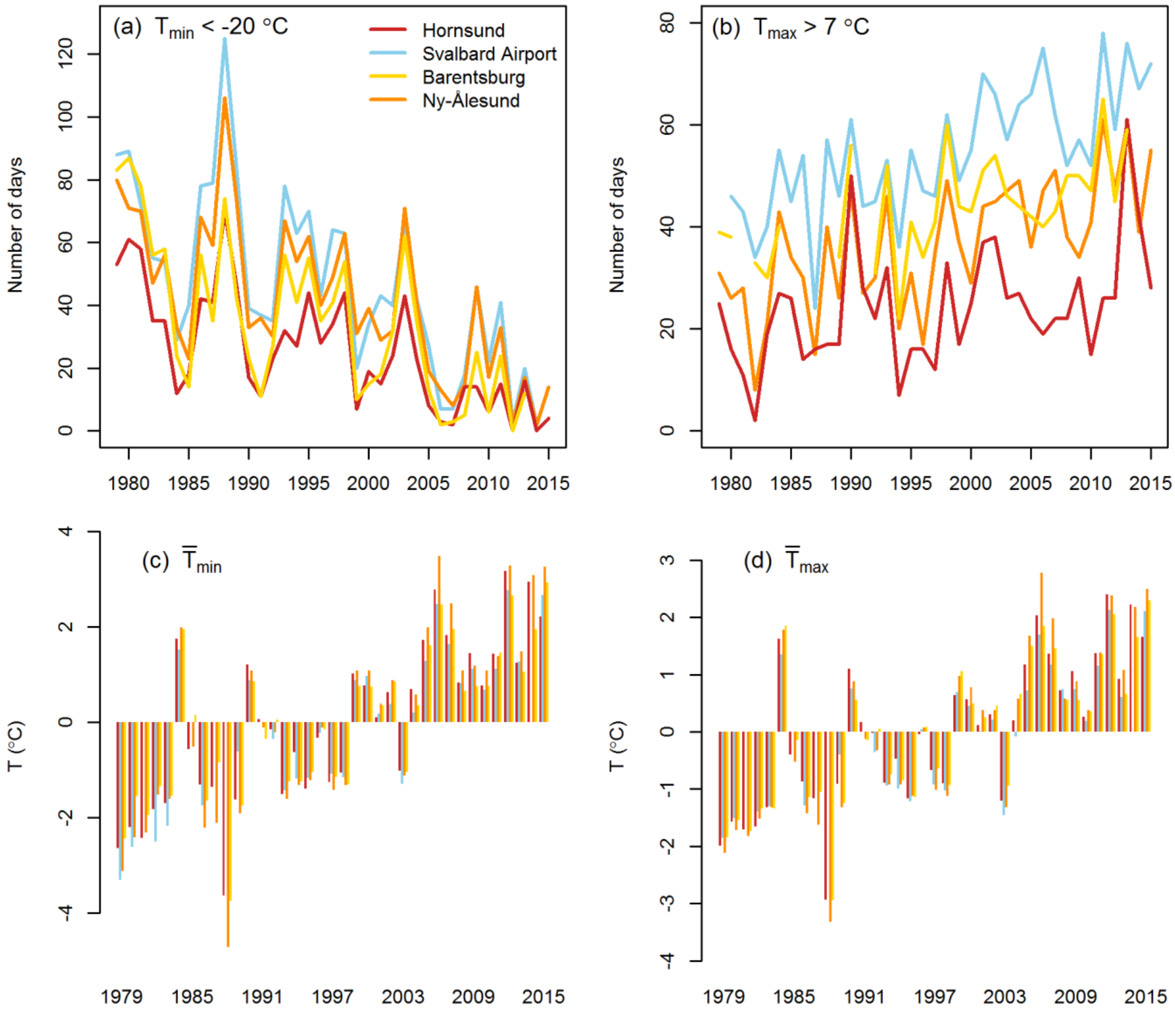
1981-1990	34.0	35.3	41.9	45.7	48.9	41.8
1991-2000	31.5	32.1	38.2	41.5	44.4	35.8
2001-2010	30.8	31.6	37.9	42.3	44.3	36.5
1948-2014	33.3	33.4	40.1	44.2	46.9	38.5



Supplementary Fig. S1. Spectrograms from the wavelet analysis of the Barentsburg series (1948–2014) of (a) the monthly reconstructed series, (b) January mean temperature and (c) July mean temperature. The units for the colour scales are °C*(month)$^{1/2}$.



Supplementary Fig. S2. Test statistic of sequential Mann-Kendall test of annual and seasonal temperature means. Beginning at the end of the time series, the test statistic is recalculated for every year added to the time series. Two horizontal lines showing the significance levels 5 % and 1 % is also included.



Supplementary Fig. S3. Daily extreme values from Hornsund, Barentsburg, Svalbard Airport and Ny-Ålesund in the period 1979–2015. (a) Number of days per year with minimum temperature lower than −20 °C. (b) Number of days per year with maximum temperature higher than 7 °C. (c) The annual mean minimum temperature anomaly compared to the mean of the 1979–2015 period. (d) The annual mean maximum temperature anomaly compared to the mean of the 1979–2015 period.

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