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Relocation of the Svalbard Airport temperature sensor

On 18 September 2016, the measuring site at Svalbard Airport was relocated to make room for an expansion of the airport. Beforehand, the Norwegian Meteorological Institute (MET Norway) started campaign measurements to examine how temperatures varied between three possible relocation sites for the temperature sensor. These sites are numbered 2, 3 and 4, whereas the official sensor was located at site 1 (see Fig. 1c in the main article). The radiation screens at the four measuring sites were all of the MI-2001B type, a screen constructed by MET Norway for use in the country's official station network. At sites 2 and 3 the sensors were of the UTL-3 type manufactured by Geotest, and at site 4 there was a a Tinytag Plus2 sensor manufactured by Omni Instruments. The campaign lasted from 22 September 2015 to 20 July 2016, which amounts to 80% of one year, totalling 6997 hourly observations. Figure 1b in the main article shows the terrain around the airport and the Longyearbyen settlement.

The results show that the mean temperature did not differ from the official one for site 3, whereas the two others were slightly colder (Supplementary Table S1). For site 2 the mean difference was –0.14°C, which is of the same magnitude as the calibration uncertainty of the sensors. The area around the airport is very flat, so this result was to be expected. For practical reasons MET Norway chose site 2 as the new official measuring site; all the sites were acceptable from a meteorological point of view. Position 3 could be too near to future infrastructure, whereas position 4 was considered too remote.

Supplementary Table S1. Mean temperature difference (°C) between test sites and the official measuring at Svalbard Airport for the period 22 September 2015 to 20 July 2016. Standard deviations for hourly observations are given in the bottom row. Altogether, there were 6997 hourly observations at each site.

Measuring sites	Site 2, new site	Site 3	Site 4
Possible corrections	–0.14	–0.01	–0.18
Standard deviations	0.27	0.26	0.36

The differences between the new (site 2) and old (site 1) show a systematic pattern over the year, with largest absolute values in late winter and early spring, whereas the values during summer are close to zero (Supplementary Table S2). During most of the year the temperature did not differ more than could be expected from the uncertainties of the sensors, but in late winter and early spring the chosen site was about 0.25°C colder than the old one.

We considered correcting for this, but did not find it feasible, mostly because the differences are small, but also because it could have been due to special measuring conditions at the sites that particular winter: it is not obvious that the result would have been the same if the measurements had continued for more than one winter.

Supplementary Table S2. Differences (°C) between test values at the new site (site 2) and the old site (site 1) during the parallel measurements from 22 September 2015 to 20 July 2016. August is missing, and for July and September the data coverage was 65% and 30%, respectively. There are also some small gaps in March and April.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Sep	Oct	Nov	Dec
Difference	–0.15	–0.25	–0.26	–0.26	–0.10	0.00	0.06	–0.05	–0.13	–0.13	–0.18

The difference between the new and old Svalbard Airport composite series

The methods employed to establish the Svalbard Airport daily series are the same as used by Nordli et al. (2014) for the monthly series. However, additional digitization of data sources and longer overlapping periods with Svalbard Airport series have led to some differences compared with the original series. The causes of the differences are listed below (for details see Supplementary Table S3).

In the original article (2014) the series ended in 2012, whereas the present series ends in 2018. Therefore, increased overlapping periods were possible, so for the stations Akseløya, Sørkappøya and Isfjord Radio, prolonged overlapping periods were used. For most of the months, this has not changed the results much, but there are some exceptions, as follows.

Akseløya: for most of the years the new compilation shows lower temperatures in January and February, whereas the values in April are higher (Supplementary Table S3).

Sørkappøya: the station contributes to the composite series for one winter only. The mean value in December and February has become lower, while March is higher. The rest of the months have not changed much (Supplementary Table S3).

Isfjord Radio: available parallel measurements with Svalbard Airport have led to higher values during winter 1947/48 and lower values during summer 1948 (Supplementary Table S3).

Colleagues at the Arctic and Antarctic Research Institute in St. Petersburg have given us reliable daily data from Barentsburg, from which we have generated improved monthly data. However, we detected only small differences, except for January 1935 (Supplementary Table S3).

Recent digitization of daily data from Longyearbyen for some time intervals in the periods 1916–1946 has led to the correction of some monthly values. Our monthly means had until now been taken from the protocols, i.e., they were manually calculated. We have detected a few errors. Constants in Köppen’s formula (Köppen 1888; Nordli & Tveito 2008) have led to some adjustments to the old monthly means. Only one large error was detected

(Supplementary Table S3).

We were not able to reproduce the equations for Svarttangen for the months March, April and May in 1907. These are errors in the original Svalbard monthly series.

Supplementary Table S3. Monthly mean temperature differences between the new and old Svalbard series (new – old). Only differences larger than 1°C are listed.

Year	Month	New value	Difference	Predictor
1898	12	–16.4	–1.4	Akseløya
1899	1	–14.8	–1.1	
1899	4	–15.6	2.3	
1900	12	–18.2	–1.5	
1901	4	11.5	1.4	
1902	12	–14.3	–1.2	
1903	1	–15.6	–1.1	
1903	4	–9.8	1.0	
1904	12	–22.3	–1.8	
1905	1	–21.7	–1.6	
1905	4	–10.6	1.1	
1907	3	–10.6	2.3	Svarttangen
1907	4	–7.9	1.1	
1907	5	–5.1	1.6	
1908	12	–14.2	–1.4	Sørkappøya
1909	2	–19.7	–1.4	
1909	3	–21.2	3.9	
1910	12	–17.1	–1.4	Akseløya
1911	4	–9.7	1.1	
1925	6	4.0	1.3	Green Harbour
1935	1	–14.2	1.2	Barentsburg
1938	3	–13.9	–1.3	Longyearbyen
1946	12	–7.0	1.3	Isfjord Radio
1947	2	–13.8	1.5	
1947	3	–17.9	1.2	
1947	6	2.5	–1.9	
1947	7	4.4	–2.0	
1947	8	5.1	–1.0	

Bias due to different climate? Test of a regression model, a case study

Data from Isfjord Radio were grouped by time. One group contained historical data (August 1975 – July 1976; September 1996 – December 2004) and the other one recent data (September 2014 – December 2018). Regression with Svalbard Airport was performed with further grouping by months so that 12 pairs of regression equations were established—one pair for each month. Both pairs of regressions were tested against each other on real Isfjord Radio data, i.e., the data that were included in the Svalbard Airport composite series (see Fig. 2 in the main article, yellow colour).

Supplementary Table S4. Differences between regressed temperatures at Svalbard Airport by pairs of regression equations, one regression based on a recent period (September 2014 – December 2018) and the other one based on a historical period (August 1975 – July 1976 ~~1975.08–1976.07~~; September 1996 – December 2004), recent – historical. Predictors from Isfjord Radio were used for certain intervals (Table 1 in the main article, Inclusion).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Tn[a]	–16.5	–23.7	–22.4	–21.4	–6.5	–2.0	1.9	5.7	–4.8	–14.2	–16.4	–19.9	
Diff.	–0.5	0.1	0.8	–0.9	0.3	0.8	0.7	0.3	–0.2	0.6	0.9	0.6	0.3
Tm[b]	–4.6	–12.1	–15.5	–9.0	–2.1	1.9	5.1	4.6	1.3	-3.3	-7.8	-7.6	
Diff.	-0.3	0.4	0.5	0.2	0.2	0.7	0.4	0.1	0.2	0.1	0.4	0.2	0.3
Tx[c]	1.9	0.5	-5.1	0.8	2.4	4.2	8.6	10.0	6.7	3.2	1.0	2.4	
Diff.	-0.1	0.7	0.2	1.2	0.1	0.6	0.1	1.0	0.6	-0.3	-0.1	-0.1	0.3

[a] Lowest daily mean temperature for the interval. [b] Mean temperature for the interval.
[c] Highest daily mean temperatures for the interval.

The mean difference for all months was only 0.3°C for the estimates based on the recent data minus the estimates based on the historical data (Supplementary Table S4). For the mean values it varies from –0.3 °C (January) to 0.7 °C (June), whereas the variations for the extremes are somewhat larger. In April the slopes of the two regression lines are quite different, resulting in opposite signs for the highest and lowest temperatures, whereas the difference for mean temperature is small. The reason for the different slopes might be the small number of low temperatures in the recent period. However, for the final regression all available double measurements between the Svalbard Airport and Isfjord Radio were used.

The small differences in most of the months indicate that the regression model is robust for climate variations. Moreover, for Crozierpynten, Akseløya, Sørkappøya and Svarttangen, where only recent parallel measurements with Airport are available, at least one cold winter is included (2010/11). If this winter had been included in the case study, the differences would probably have been even smaller.

The Svalbard series compared to other Arctic series in the North Atlantic/Barents Sea regions

The new Svalbard Airport composite series was compared to other series available for the southern part of the Arctic in the Atlantic sector and the Barents Sea within a common data period 1921–2018. The series are Bjørnøya (74°31' N, 19°00' E) to the south of Spitsbergen, Vardø (70°22' N, 31°6' E) north-eastern Norway, Jan Mayen (70°56' N, 8°40' W) to the north of Iceland and Malye Karmakuly (72°22' N, 52°42' E) in Novaya Zemlya. Inter-correlations between the stations and linear trends were studied for the whole period and for sub-periods. The sub-periods are: the Early 2oth Century Arctic Warming (1921–1950), the Last Cold Period (1951–1980) and the Recent Arctic Warming (1981–2010). The sub-periods are the same as used by Przybylak (2016). Such periods were also detected by the Rodionov test, although the borders between them differed slightly. For this study, we have added an update, the period 1991–2018, i.e., the time after the last standard normal period.

We found that Svalbard Airport had positive correlations with the other stations in the area. For the annual mean temperatures and almost all seasonal means, the correlations were significant at the 0.05 level (Supplementary Table S5; see also figure 1.2 in Przybylak 2016). As expected, taking into account the distances between the stations, the highest correlations occurred with data from Bjørnøya. This is true for the entire common data period, as well as for all sub-periods. In spring, we noticed that Svalbard Airport correlated very closely with Vardø—far more so than with Jan Mayen or Malye Karmakuly (for further details see figures 2 and 4 in Przybylak 1997). The smallest spatial coherency of air temperature occurred in summer. This might be due to weaker large-scale atmospheric circulation, leaving a comparably greater influence on local climate.

Some poor and even insignificant correlations occurred in the periods 1921–1950 and 1981–2010 (Supplementary Table S5). For the interpretation of this result, we need also to bear in mind non-climatological reasons, i.e., poorer data quality during the Second World War and, for Malye Karmakuly, the breakdown of the Soviet Union. Moving the time window to 1991–2018 the correlations increase.

Supplementary Table S5. Correlation coefficients between prolonged series of seasonal and annual air temperatures at the Svalbard Airport and nearest long-term meteorological stations for the warm (1921–1950, 1981–2010 and 1991–2018), cold (1951–1980) and entire common (1921–2018) periods. Correlation coefficients in boldface indicate significance at $p \leq 0.05$.

Station	DJF	MAM	JJA	SON	Year
1921–1950					
Bjørnøya	**0.87**	**0.78**	**0.72**	**0.85**	**0.90**
Jan Mayen	**0.58**	0.30	0.32	**0.56**	**0.58**
Vardø	0.33	**0.55**	**0.53**	**0.62**	**0.64**
Malye Karmakuly	0.25	**0.54**	**0.42**	**0.39**	**0.44**
1951–1980					

Bjørnøya	**0.91**	**0.86**	**0.60**	**0.96**	**0.93**
Jan Mayen	**0.68**	**0.52**	**0.58**	**0.62**	**0.74**
Vardø	**0.58**	**0.63**	**0.47**	**0.60**	**0.63**
Malye Karmakuly	**0.58**	**0.52**	**0.45**	**0.47**	**0.63**
1981–2010					
Bjørnøya	**0.94**	**0.86**	**0.60**	**0.92**	**0.94**
Jan Mayen	**0.83**	**0.62**	**0.71**	**0.58**	**0.84**
Vardø	**0.48**	**0.64**	**0.44**	**0.48**	**0.67**
Malye Karmakuly	**0.45**	0.35	**0.37**	0.27	**0.46**
1991–2018					
Bjørnøya	**0.94**	**0.87**	**0.50**	**0.94**	**0.94**
Jan Mayen	**0.81**	**0.56**	**0.61**	**0.70**	**0.80**
Vardø	**0.52**	**0.73**	**0.48**	**0.62**	**0.75**
Malye Karmakuly	**0.62**	**0.46**	**0.51**	**0.60**	**0.69**
1921–2018					
Bjørnøya	**0.93**	**0.87**	**0.68**	**0.94**	**0.94**
Jan Mayen	**0.76**	**0.57**	**0.66**	**0.69**	**0.81**
Vardø	**0.56**	**0.74**	**0.56**	**0.63**	**0.75**
Malye Karmakuly	**0.54**	**0.60**	**0.50**	**0.49**	**0.66**

Trends in the updated Svalbard Airport series compared to other Arctic stations

The effect of the inclusion of the new data into the Svalbard Airport composite series differs between sub-periods (Supplementary Table S6). The new series shows greater warming in winter and spring during the warm period 1921–1950 compared to the original series, and greater cooling in summer. Differences in trends were absent or negligible in all other analysed sub-periods. Also with respect to the other Artic series in the Atlantic region, the inclusion of the recent data period 2013–2018 increased the trends. As a result, the majority of them are statistically significant in the long-term period 1921–2018, except for winter. The greatest warming occurred in spring (Supplementary Table S6). In the recent period (1991–2018) the greatest warming occurred in winter for all stations except Vardø.

During the period 1951–1980 the Atlantic part of the Arctic and the Barents Sea area cooled, especially during winter. Because of the large variability in the winter climate, this cooling was not statistically significant, although Malye Karmakuly cooled more than 1°C.

Supplementary Table S6. Linear trends (°C/decade) in the new and previous version (Nordli et al. 2014) of Svalbard Airport (SA) composite series of air temperature, and in air temperatures from the nearest meteorological stations. Numbers in boldface denote a trend significant at the 5% level.

Station	DJF	MAM	JJA	SON	Year

1921–1950					
New SA series	0.16	0.63	–0.18	0.20	0.18
Original SA series	0.12	0.60	–0.11	0.20	0.18
Bjørnøya	–0.18	0.34	–0.07	0.38	0.11
Jan Mayen	–0.63	–0.14	0.11	0.35	–0.05
Vardø	–0.06	0.01	–0.11	0.23	0.03
Malye Karmakuly	–0.31	0.88	–0.47	0.14	0.08
1951–1980					
New SA series	–0.82	–0.35	–0.11	–0.87	–0.59
Original SA series	–0.82	–0.35	–0.10	–0.87	–0.58
Bjørnøya	–0.57	–0.01	0.07	–0.56	–0.31
Jan Mayen	–0.78	–0.09	–0.04	**–0.71**	–0.42
Vardø	–0.13	0.01	0.00	–0.23	–0.09
Malye Karmakuly	–1.07	–0.32	–0.35	–0.45	–0.54
1981–2010					
New SA series	**2.31**	0.76	**0.65**	**1.00**	**1.14**
Original SA series	**2.31**	0.75	**0.65**	**1.00**	**1.14**
Bjørnøya	**1.62**	0.49	**0.51**	**0.72**	**0.80**
Jan Mayen	**1.10**	**0.79**	**0.74**	**0.63**	**0.80**
Vardø	**0.71**	0.43	**0.40**	**0.52**	**0.50**
Malye Karmakuly	0.97	0.44	0.07	0.48	0.48
1991–2018					
New SA series	**3.19**	**1.05**	**0.66**	**1.65**	**1.66**
Bjørnøya	**1.91**	**0.80**	**0.40**	**1.21**	**1.09**
Jan Mayen	**1.04**	**0.58**	**0.66**	**0.84**	**0.78**
Vardø	0.36	**0.57**	**0.50**	**0.95**	**0.60**
Malye Karmakuly	**2.07**	0.90	0.68	**1.45**	**1.30**
1921–2012					
New SA series	0.03	**0.43**	**0.11**	0.08	**0.16**
Original SA series	0.03	**0.42**	**0.11**	0.08	**0.16**
Bjørnøya	0.02	**0.31**	**0.09**	0.07	**0.13**
Jan Mayen	–0.02	0.10	0.06	0.03	0.05
Vardø	0.03	**0.17**	0.06	0.07	**0.08**
Malye Karmakuly	–0.13	**0.24**	0.03	0.00	0.04
1921–2018					
New SA series	0.23	**0.49**	**0.15**	**0.19**	**0.27**
Bjørnøya	0.15	**0.34**	**0.12**	**0.14**	**0.19**
Jan Mayen	0.07	**0.14**	**0.11**	**0.11**	**0.11**
Vardø	0.08	**0.20**	**0.09**	**0.11**	**0.12**
Malye Karmakuly	0.00	**0.30**	0.08	0.07	**0.12**

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