Testing the homogeneity of climate series of surface air temperature in Barentsburg (Svalbard)

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Abstract

Observations on surface air temperature in the Barentsburg (Svalbard) are one of the longest on the Svalbard. They started in 1932 (with a break between 1941 and 1947). In this study, we checked the homogeneity of this series, because the measurement site of Barentsburg meteorological station was relocated twice (in 1978 and 1984). The station relocation might be a cause of inhomogeneities in temperature data sets. During the 2nd measurement series (June 1978 – January 1984) microclimatic features were revealed, caused by the closer position of the measurement site to the fjord and its lower altitude than the former site had. However, the inhomogeneities on the boundaries of this period were not found by several statistical tests. Therefore, this series can be used in its original form without introducing any corrections to study the climate of Svalbard. The resulting composite series (1932-2023) contains the largest amount of direct instrumental observation data compared to similar series obtained at other weather stations of the archipelago.

Key words: Svalbard, Barentsburg, Arctic climate, climate change, surface air temperature, instrumental data series, homogenization, microclimate

List of abbreviations: SAT – surface air temperature, MS – meteorological station, a.s.l. – above sea level, AS – aerological station, SNHT – Standard Normal Homogeneity Test, BRT – Buishand Range Test, PT – Pettitt Test, VNRT – Von Neumann Ratio Test

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Introduction

Instrumental meteorological records on Svalbard have a long history, starting from the end of the 19^{th} century. However, the earliest of them were episodic (during scientific and commercial expeditions, overwinterings). There were about 30 stationary meteorological stations (MSs) that have worked and are working at different times on Svalbard. A number of MSs operating at the beginning of the 20^{th} century were subsequently closed or changed their location. Observations at some MSs were conducted with long-lasting breaks (up to tens of years). Data from most MSs, due to their short observation periods, are unsuitable for studying climate change in the region.

Some authors (Vikhamar-Schuler et al. 2019) take into account the data of 18 MSs, including MS "Bjornoja" and "Hopen", located 100-240 km away from the archipelago. Most of the 18 presented MSs have short series of observations, and in addition, short-term observations (several years) on 2 MSs were carried out only in the 20^{th} century, and observations on 7 MSs began only in the 21^{st} century (after 2007). Other researchers, for example (Hanssen-Bauer et al. 2019), rely on data from only 7 MSs, including MS "Bjornoja" and "Hopen". The above-mentioned authors did not use in their studies a rather long series of instrumental observations on MS "Sveagruva" (1978–present). In according to (Vikhamar-Schuler et al. 2019), the weather station was established at Sveagruva in 1978 and is still operative. Because of data gaps, re-locations and instrumental changes, the temperature and precipitation series from Sveagruva are not analyzed since it can not be considered homogeneous. At the same time, the mentioned authors used data from the MS “Isfjord Radio”, despite the significant missing data in 1976–2014, as well as the absence of data at most stations during II World War.

Summarizing the above, we believe that only the following MSs are of interest for climate studies of Svalbard (Table 1).

Meteorological station	Period of observations
Barentsburg	1932–1941, 1947–present *
Horsund	1978–present
Isfjord Radio	1934–1941, 1946–1976, 2014– present
Ny-Alesund	1969–1974 (relocation), 1974–present
Pyramiden	1948–1956, 2012–present
Svalbard Airport	1975–present
Sweagruva	1978–present

Table 1. Meteorological stations suitable for climate research and its periods of work.
Note: * – transfers of this MS are analyzed in this work

The longest series of instrumental records of surface air temperature (SAT) on the archipelago was obtained in the Russian settlement of Barentsburg. It began in 1932 (Second International Polar Year), and after a break between 1941 and 1947 (Second World War) continues to the present day. Moreover in 1911-1930, the Norwegian MS Green Harbor operated in 1.5 km from the current position of the MS Barentsburg. This opens up some prospects for creating a composite series of SAT_{mon} starting from 1911 using data from the Green Harbor and Barentsburg. The majority of this series will consist of original (instrumental) data. But, in the studies of the climate of the archipelago, in most cases, the data from the MS Svalbard Airport (Longyearbyen) are used. MS Svalbard Airport is included in the Global Climate Observing System[1]. Data of the average monthly SAT (SAT_{mon}) at the Svalbard Airport have been available for analysis since 1898. However, regular instrumental records have only been carried out here since August 1975. Earlier SAT values were calculated based on data from other MSs, including the Barentsburg MS (Nørdli 2010, Nørdli et al. 2020). Such calculations are always accompanied by the appearance of certain errors. The SAT ratio at the MSs does not remain constant and changes depend on the macrocirculation conditions and uneven climate changes in the region. For this reason, one cannot be sure that the relationships established in a certain period of time (and often this is only a few years of parallel measurements) were similar in the past. Other operating Svalbard MSs involved in the analysis of climate change are located in the Norwegian village of Ny-Alesund (records have been carried out since 1969, the measurement site was moved in 1974) and at the Polish research station Horsund (records have been carried out since 1978).

The main problem with using the Barentsburg MS data is the transfers of the measurement site that took place in 1978 and 1984 (Demin et al. 2020). They occurred within the village, but theoretically could have led to a violation of the homogeneity of the climate series.

The aim of this work is to check the homogeneity of the SAT_{mon} series at the MS Barentsburg and the capability of using them to solve climate problems.

Material and Methods

We used the monthly average SAT values obtained for the Barentsburg MS for the periods August 1932 – June 1941 and December 1947 – December 2023 from archive of the Russian Research Hydro-Meteorological Institute - World Data Center (RIHMI-WCD) in Obninsk. In addition we used data from the Svalbard Airport MS from the Norwegian Meteorological Institute and Historical Arctic Rawinsonde Archive, 1947–1996[2].

History of meteorological observations in Barentsburg

Regular meteorological observations in Barentsburg began in August 1932. The measuring site was located on the northeastern outskirts of the village, at an altitude of about 70 m above sea level (a.s.l.), 450 m from the eastern shore of the Green Fjord (*see* Fig. 1).

Since June 1, 1978, due to the construction of new buildings near the measuring site (position 1), meteorological observations were moved to a narrow coastal terrace (position 2), located 70-80 m from the fjord at an altitude of 22 m a.s.l. The second and last relocation took place in February 1984. Since then, meteorological observations have been conducted on the southern outskirts of the village at a distance of 320-340 m from the fjord and at an altitude of 74 m a.s.l.

Fig. 1. Barentsburg settlement[3]; the numbers indicate the positions of the measuring site of Barentsburg MS: 1 – 1932-1978, 2 – 1978-1984, 3 – 1984-2023; number 4 shows the position of Green Harbor MS (operated 1911-1930).

Microclimatic features of the locations of measurement sites in the settlement of Barentsburg

The main requirements imposed in climatology on observation series: the characteristics of the series should change only in accordance with the natural variability of macroprocesses and should not contain effects caused by a change in the measurement methodology, types of measuring instruments, a relocation of the measuring site or artificial changes in the surrounding area.

Theoretically, we can assume the existence of two potential moments in time when a violation of the methodical homogeneity of the SAT series at the Barentsburg MS could have been observed. These are 1978 and 1984, when the measurement site was moved. The first factor that could lead to a violation of homogeneity was a change in the distance from the measurement site to the shore of the Green Fjord. The second was a change in the altitude of the measurement site a.s.l. A more critical circumstance could be a change in the forms of the surrounding relief. However, the entire territory of the Barentsburg settlement is located at the foot of the mountains on a steep slope. Therefore, the surrounding relief remained more or less same and could not be consider as a major factor affecting data homogeneity. The cold air formed on the slopes moves freely down to the fjord, spreading over its vast water area. There are no conditions for air accumulation in any places of measurement sites.

Due to the relocations of the measurement sites of the Barentsburg MS, the SAT data series was divided into three series. The series obtained at each site in the text are marked with numbers: No. 1, No. 2, No. 3 (the numbers correspond to the marks in Fig. 1).

In the area of the measurement site No. 2 (*see* Fig. 1), the Barentsburg aerological station (AS) operated from 1973 until its relocation in 1987. The data there included SAT observations at a level of 2 m at the point of the radiosonde release. This allows to estimate possible differences in the thermal characteristics of the measurement site No. 2 from the measurement sites No. 1 and No. 3. However, the

SAT data obtained at the AS turned out to be very incomplete. The probes were not launched every day and not at all standard times (only 00 and 12 UTC). The number of day and night releases differed by more than 2 times in some months. Because of that, we analyzed not SAT_{mon}, but daily average SAT values (SAT_{dl}), which were calculated as the average of two times: 0 and 12 UTC.

Results and Discussion

Fig. 2 shows the distributions of the differences in the SAT_{dl} values obtained in different months between positions No. 1 (January 1973 – June 1978) and No. 3 (February 1984 – August 1987) and the position of the AS (position No. 2), respectively. There were large differences in SAT_{dl} between points located only hundreds of meters apart (*see* Fig. 2). It might happened due to small number of daily observations, when a pronounced short-term deviation in SAT or even an erroneous record could greatly affect the final calculated average value. For this reason, not only mean differences in SAT_{dl} were used in the data comparison, but also their medians, which are less sensitive to outliers.

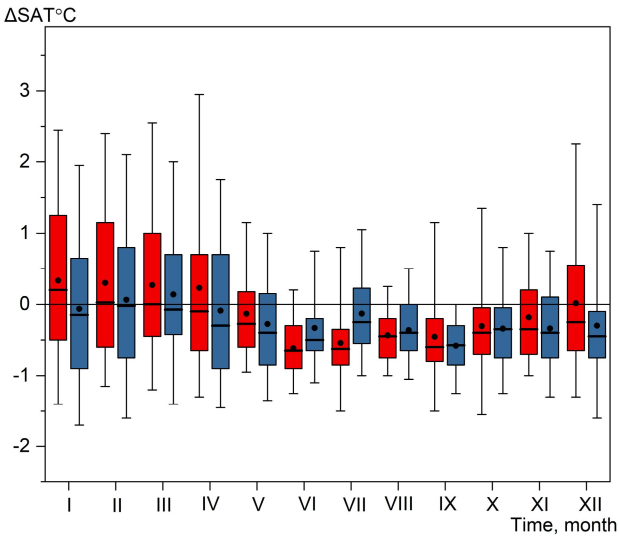


Fig. 2. Box diagram of the distribution of differences of SAT_{dl} in different months: No. 1-No. 2 (red), No. 3-No. 2 (blue): box – 25-75%, whiskers – 5-95%, the black dots marks the mean value, the lines - the median.

Based on the averaged monthly differences of SAT_{dl}, we concluded that site No. 2 differs from sites No. 1 and No. 3 by higher SAT_{dl} values in the summer period (by 0.3-0.5°C). This is due to the lower altitude of site No. 2 on the slope and the warming effect of the fjord, which was seen in an increase in the minimum SAT_{dl} values. This warmer SAT_{dl} at No. 2 remained in the fall and early winter, but changed sign since January (*see* Fig. 2). Apparently, the formation of a stable ice cover (fast ice) in the Green Fjord limits the flow of oceanic heat into the atmosphere (Makshtas 1991, Zhuravskiy et al. 2012). The effect of inverse temperature distribution begins to manifest itself precisely during this period of the year. The higher location of sites No. 1 and No. 3, compared to site No. 2, caused slightly higher SAT_{dl} values, by 0.2-0.3°C. At the same time, this effect was practically absent when the median values of the differences were considered. This indicates that the effect (differences) did not manifest itself in all years and depended on the characteristics of the vertical distribution of air temperature in current synoptic conditions, the thermal regime of the waters of the fjord and its ice conditions.

The average differences of SAT_{dl} between points No. 1-No. 2 and No. 3-No. 2 differed statistically significantly in June, July, and December (the parametric Student's T-test and nonparametric Mann-Whitney test were used to compare the averages). It looks like point No. 3 was warmer than point No. 1 in June and July and colder in December (*see* Fig. 2). The situations were considered individually (*see* Fig. 3). As follows from the Fig. 3, the difference in June has arisen since 1986, in July - since 1977, in December - since 1976. These dates do not coincide with the dates of the measurement site relocations. Consequently, the change in the differences of SAT_{dl} had a natural rather than a methodological cause. Site No. 2 was in slightly different microclimatic conditions compared to sites No. 1 and No. 3. Microclimatic inhomogeneities appeared here under certain meteorological conditions (wind speed and direction, amount and type of clouds, *etc.*). Depending on the frequency of these conditions, determined by synoptic processes, inhomogeneities were more pronounced or practically not observed. Sea surface temperatures, heat content of the upper mixed layer, ice cover of the Green Fjord, which also have variability on different time scales, can affect the difference of SAT values between sites No. 1-No. 2 No. 3-No. 2. All this can lead to small variations in the average monthly differences of SAT. Considering that there were no statistically significant differences in the average differences of SAT_{dl} between points No. 1-No. 2 and No. 3-No. 2 in other months, we consider the local temperature conditions of sites No. 1 and No. 3 as identical. The series before June 1978 and from February 1984 should be attributed to one sample. Consequently, we need to adjust the SAT_{mon} data only for the period June 1978 – January 1984.

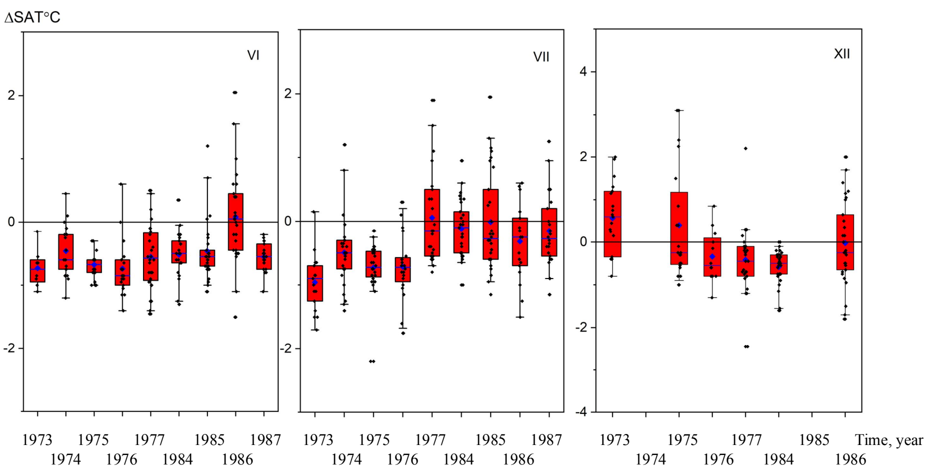


Fig. 3. Box diagrams of the distribution of differences of SAT_{dl} on sites No. 1-No. 2 and No. 3-No. 2 (the parameters of the box diagram are the same as in Fig. 2, the dots indicate the measurement results).

For each month, linear regression equations were calculated relating the SAT_{dl} at sites No. 1 and No. 3 with the SAT_{dl} at the AS for the periods 1973 – May 1978 and February 1984 – August 1987. By applying these equations to the SAT_{dl} values obtained at the MS located at site No. 2, the SAT_{dl} values were adjusted for the period June 1978 – January 1984, which combine series 1 and 3 of measurements into a continuous series.

The adjusted SAT_{mon} values for the period June 1978 – January 1984 differs little from the measured SAT_{mon} values at site No. 2 and do not change practically the trends in recent climate change determined from the original SAT_{mon} series compiled from individual observation series at three sites (*see* Table 2). To illustrate this, we used two main periods for comparative assessments. The first period began in 1976, which is the conventional date for the beginning of recent global warming (Report on Climate Features on the Territory of the Russian Federation in 2016[4]). The second period began in 1968: it is the date of the end of the previous cooling period observed in the study region since the late 1930s, and it is characterized by a change in the sign of the trend (Demin et al. 2023).

Period\Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
1968-2023	1.34	1.30	0.88	1.10	0.45	0.43	0.38	0.39	0.47	0.68	1.18	1.34	0.81
1968-2023 correction	1.32	1.28	0.87	1.09	0.46	0.46	0.40	0.42	0.51	0.70	1.20	1.34	0.84
1976-2023	1.87	1.69	0.96	1.10	0.55	0.53	0.42	0.38	0.59	0.69	1.04	1.45	0.97
1976-2023 correction	1.84	1.65	0.93	1.08	0.56	0.60	0.46	0.43	0.66	0.73	1.08	1.44	0.96

Table 2. Trends in SAT_{mon} (°C/10 years) based on original and adjusted series.

Since the corrections to the SAT_{mon} had virtually no effect on the estimates of the rate of recent warming, and the correction period itself (June 1978 – January 1984) was quite short, it is advisable to preserve the original data. Moreover, the aerological data that were used to detect the microclimatic differences between the section No. 2 and the sections No. 1 and No. 3 of our series were characterized by significant incompleteness. In addition, as can be seen from the example of Fig. 3, the established relationships between the sections No. 2-No. 1 and No. 2-No.3 can vary significantly from year to year depending on meteorological conditions and ice-hydrological processes in the fjord. The SAT values from section No. 2 obtained after using corrections may not reflect their real value in a particular year. Obviously, the condition for maintaining the original values obtained in the period June 1978 – January 1984 in the SAT_{mon} series is the absence of methodological inhomogeneities in the series at the boundaries of this period.

Homogeneity test

The homogeneity of the SAT series in Barentsburg for the periods 1935-1975 and 1978-1990 was investigated in the work (Nørdli et al. 1996). The Standard Normal Homogeneity Test (SNHT)(Alexandersson 1986) was applied to the differences in the synchronous SAT values measured at the Barentsburg MS and at the nearest MSs: Svalbard Airport, Sveagruva, Ny-Alesund, Isfjord Radio, Bjørneøya. The SAT series in Barentsburg for the above periods were found to be homogeneous. However, these studies do not provide information on the preservation of homogeneity during the station relocation in 1978. Verification by the difference method in this case is very difficult due to the absence of nearby MSs with sufficiently long measurement periods before and after 1978; at the MS closest to Barentsburg (37 km to the northeast) – "Svalbard Luftvan", measurements have been conducted only since August 1975 and the short period of synchronous operation before the first transfer in 1978 (no more than 3-4 years) does not allow obtaining reliable statistical estimates. At the other nearby Ny-Alesund MS, homogeneous series are guaranteed only since 1974 (the year of transfer at this MS). In addition, Ny-Alesund MS is poorly suited for the role of a reference, because it is located 110 km from Barensburg MS, while climate changes in the region occur spatially unevenly (Gjelten et al. 2016, Ivanov 2019, Dahlke et al. 2020, Isaksen et al. 2022, Rantanen et al. 2022).

To check the homogeneity, we used the original SAT_{mon} series. The main difficulty in using such series is that changes in their characteristics can occur not only due to methodological reasons (relocation of a measurement site, change of instrument, *etc*.), but also due to natural factors, namely climate change. One solution to the problem is to divide the main series into shorter segment, and study each of them independently. Another solution is to detect breaks in short segments (windows), when long-term climate changes do not have time to lead to a noticeable change in the characteristics of the series.

First, we divided the SAT_{mon} series for the period December 1947 – December 2023 at the Barentsburg MS into two large overlapping series: December 1947 – February 1984 and June 1978-December 2023. Each of them contains only one possible methodological inhomogeneity (measurement site replacements). The need for such a division is due to the fact that existing statistical tests are effective in finding only one violation of homogeneity. However, with such a division, the series are quite long (>40 years) and under conditions of a changing climate, the series are almost guaranteed to be inhomogeneous. This forced us to select shorter periods within them: January 1969 – February 1984 and June 1978 – 1993. We did not include data before 1969 and after 1993 in testing - a change in the trend of SAT changes can be observed within longer periods. According to the work (Demin et al. 2023), in 1968 the region experienced a change in trend from cooling to warming, and between 1988 and 1994 the rate of warming increased sharply.

Within the selected series, testing was carried out in several overlapping subseries of different duration. To test the homogeneity of the series after the replacement of the measurement site in 1978, six subseries were considered: sequentially from January 1969, 1970, 1971, 1972, 1973, 1974 to January 1984. To test the homogeneity after the replacement of the measurement site in 1984, six subseries were also sequentially studied from June 1978 to 1988, 1989, 1990, 1991, 1992, 1993, respectively. We chose this approach based on the following considerations. To avoid the effects created in the SAT_{mon} series by natural climate changes, the periods for homogeneity analysis should be sufficiently short, thus, we used periods not more than 15 years. In short series, even one anomalous value can significantly affect the test result. But the dates of inhomogeneities created by anomalous weather conditions of individual years will obviously change depending on the selected series length. We think that by multiple testing over periods of different lengths methodological inhomogeneities could be separated from inhomogeneities of a natural nature. Inhomogeneity of a methodological nature, as we believe, should manifest itself constantly in most of the selected subseries. Additionally, in such a testing scheme, the points of possible violation of homogeneity (~1978 and 1984) were consistently shifted from the end/beginning of the series to its middle (and vice versa). This increased the reliability of testing, since statistical tests do not uniformly detect shift points located at the ends or in the middle of the series under study (Yozgatligil 2016).

According to accepted international practice, the simultaneous use of several tests is the best strategy for testing meteorological series for homogeneity. For example, in several works (Kobysheva 2008, ECA&D 2013[5]), it was proposed to use four statistical tests sequentially: SNHT, Buishand Range Test (BRT), Pettitt Test (PT), and Von Neumann Ratio Test (VNRT). The series is considered homogeneous if only one of the four tests fails and questionable if such a result is achieved by two tests. Of the mentioned tests, only the SNHT, BRT and PT were used in the work, since they not only detect inhomogeneity, but also indicate the year of its occurrence.

The results of testing all the selected subseries for SAT_{mon} are shown in Fig. 4. We took into account the results obtained for the statistical significance level (α) equal to 0.10. We took into account the inhomogeneity only if it is indicated by 2 or 3 tests. In addition, the results were compared with the metadata. As noted above, the relocation of the measurement site in 1978 was a relocation closer to the shore of the fjord and to a lower position a.s.l. The relocation in 1984 was a relocation further from the fjord and to a higher altitude. In this regard, in the studied SAT series, the methodological inhomogeneity associated with the relocation of the measurement site should manifest itself simultaneously near both 1978 and 1984.

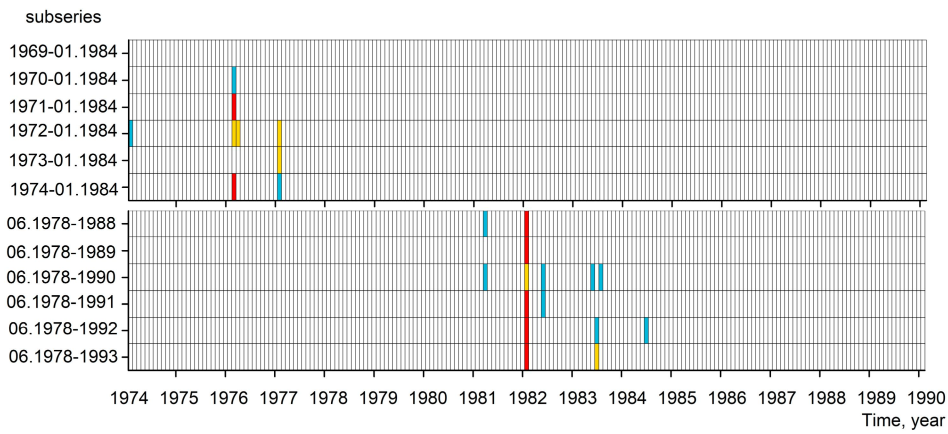


Fig. 4. Dates of detection of inhomogeneities (horizontal axis) in different subseries of SAT_{mon}: blue color if the inhomogeneity was detected by only one test, yellow and red – by 2 and 3 tests, respectively.

In the period from January 1969 to January 1984 there were some indications (not all tests and not in all subseries) of inhomogeneity in 1976 (February, March) and in 1977 (January). All inhomogeneities appeared before the relocation of the measurement site. In the period from June 1978 to 1993 inhomogeneity was confidently (2-3 tests) revealed only in January 1982 – also far from the date of the second relocation. Only in June two tests indicated inhomogeneity at the boundary of 1983 and 1984 (relocation of site from point No. 2 to No. 3). However, it is difficult to assume that methodological inhomogeneity appeared only in one month, without affecting at least the neighboring months of the same season and only in one of the six analyzed subseries (June 1978–1993).

Therefore, based on the combination of tests (and in most cases, on each test separately), we had no reason to reject the null hypothesis about the homogeneity of the series in the period 1969–1993.

As an independent check of the entire 1969–1993 series, we used the RHtest package, widely used in climatology to detect multiple breaks and homogeneity tests (Wang et al. 2007, Wang 2008). In automatic mode, RHtest did not detect any breaks that could be expected when replacements of the measurement site occurred in the period 1969–1993. The SAT_{mon} series for this period should be considered homogeneous.

We studied the time distribution of structural shifts in SAT_{mon} series over the entire period from December 1947 to 2023 using the SNHT test. In the SNHT test, the meteorological value series $Y_1, \ldots, Y_n$ is divided into 2 parts containing k and $n–k$ terms. Then the value T_k is calculated:

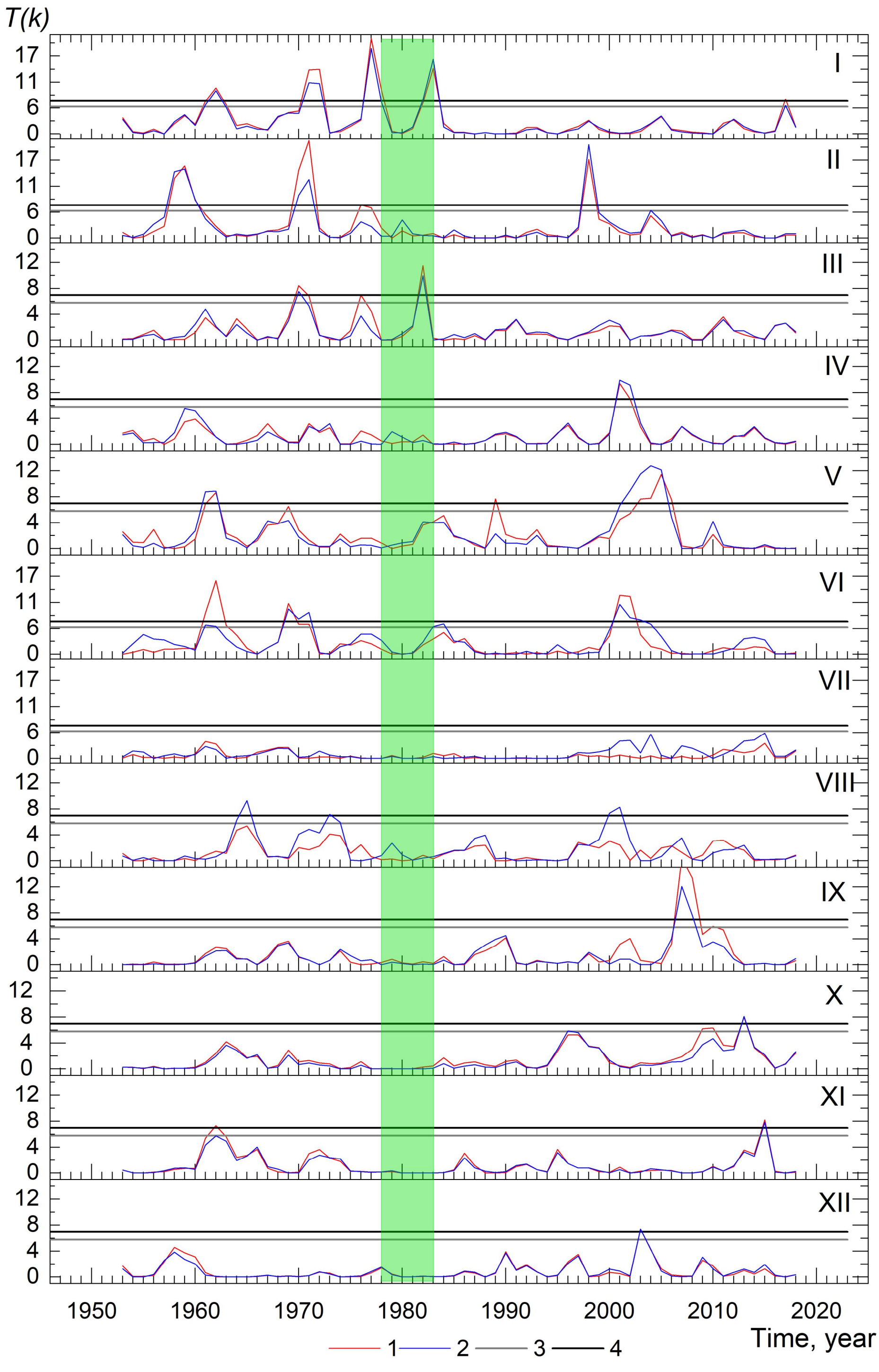
$$T_k = k(\overline{z_1})^2 + (n-k)(\overline{z_2})^2,$$

where $$\overline{z_1} = \frac{1}{k}\frac{\sum_{i=1}^{k}(Y_i - \overline{Y})}{s}, \quad \overline{z_2} = \frac{1}{n-k}\frac{\sum_{i=k+1}^{n}(Y_i - \overline{Y})}{s}, \quad s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(Y_i - \overline{Y})^2, \quad \overline{Y} = \frac{1}{n}\sum_{i=1}^{n}Y_i$$

If there is a shift at the moment K, the T_k function reaches its maximum value near $k=K$. The null hypothesis (the series is homogeneous) is rejected if T_{max} is higher than some critical value determined over the entire length of the given sample.

Fig. 5 shows the variations of the T_k parameter in a sliding 11-year window. The choice of the 11-year window was due to the number of available SAT_{mon} values between the measurement site relocations in 1978 and 1984 (5-6 values for different months). This ensured the maximum sensitivity of the test, since the values from the third series were not included in the T_k calculation at the boundaries of the first and second series, and the first series at the boundaries of the second and third series also were not included in the calculation. In addition, 10 years period is the minimum recommended period length for the SNHT test.

Fig. 5.► Variations of the T_k parameter in sliding 11-year windows for the Barentsburg MS (1) and the Svalbard Airport MS (2), horizontal lines are the critical values of T_k for α=0.05 (3) and α=0.01 (4), respectively; the period June 1978 – January 1984 is highlighted in green.


T(k)
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
1950
1960
1970
1980
1990
2000
2010
2020
Time, year
1
2
3
4

As follows from Fig. 5, no matter what duration of the period we chose (even within guaranteed methodically homogeneous sections: before June 1978 and from February 1984), individual months with signs of inhomogeneity were almost always detected. These inhomogeneities were caused by climate variations. It can be assumed that the same inhomogeneities due to climate changes may accidentally appear near the dates of the MS transfer (be falsely confirmed by metadata). The example in Fig. 5 shows the need to involve various methods of analysis before concluding on the inhomogeneity.

In the case of Barentsburg, an additional sign of methodological inhomogeneity may be extremes of the T_k parameter simultaneously near 1978 and 1984. Indeed, the transfer of MC in 1978 is a transfer closer to the gulf and to a lower altitude. The transfer in 1984 is a transfer further from the gulf and to a higher elevation. Therefore, the effects of the transfers in 1978 and 1984 are opposite in sign, but most likely close in magnitude.

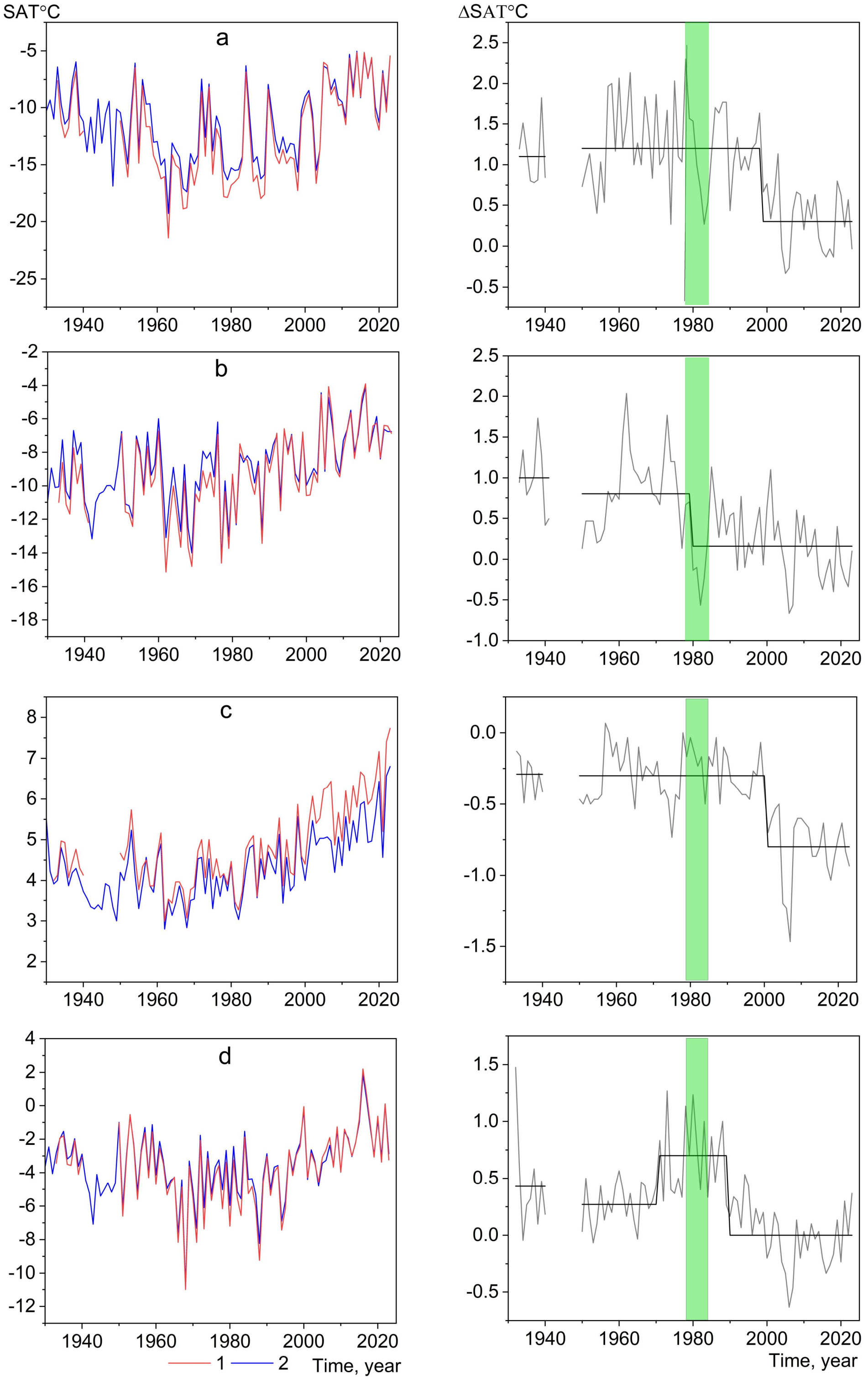
Simultaneous peaks of the T_k parameter near 1978 and 1984, but with an obvious time shift, were observed in January and March. The dates did not coincide with the dates of the measurement site relocations. The natural character of the detected variations was evidenced by the fact that similar T_k variations were also detected in homogeneous series of SAT_{mon} at MS Svalbard Airport. For the entire period under study (1948–2023), T_k variations at the Barentsburg and Svalbard Airport MSs occurred almost synchronously, indicating the natural character of the SAT_{mon} changes. All the tests we used, in general, confirmed the homogeneity of the data obtained at the Barentsburg MS, which allows them to be used for various climate calculations.

Comparison of the SAT_{mon} time series at the Barentsburg and Svalbard Airport MSs

Currently, the SAT_{mon} time series obtained at the Svalbard Airport MS is used as a reference series for climate studies in Svalbard (Nørdli 2010). However, regular instrumental observations at the measurement site at the airport in Longyearbyen (Svalbard Airport MS[6]) began only in August 1975. Before that, observations were carried out at several sites in the territory of Longyearbyen itself (in the inner part of the Advent Fjord, 3 km from the airport). In the first years, observations at the airport were carried out over a natural soil surface, but now the measurement site has a concrete base. Using data from other MS and reanalysis data, this series was reconstructed up to 1898. The history of meteorological observations and the procedure for creating a composite SAT_{mon} series at the Svalbard Airport MS were described in detail in several papers (Nørdli 2010, Nørdli et al. 2020).

The SAT values at the Barentsburg and Svalbard Airport MS were compared and the changes in the corresponding average seasonal (calendar) evalueated as shown in Fig. 6. The distance between these MSs is about 35 km. This determines the very close nature of the SAT changes in all seasons and months. The correlation coefficients of the SAT values during the period of parallel measurements (from August 1975) took values from 0.95 (August) to 0.99 (December).

Fig. 6. ► On the left are changes in the average seasonal (calendar) values of SAT at MSs Barentsburg (1) and Svalbard Airport (2); on the right are changes in their differences and the average level of differences: a - winter, b - spring, c - summer, d - autumn; the period June 1978 – January 1984 is highlighted in green.


SAT°C
ΔSAT°C
a
b
c
d
1
2
Time, year
Time, year

At the same time, there were also important differences in the series. The average values of the SAT differences did not remain constant. In all seasons of the year, starting from the 1980s, it has become noticeably warmer at the Svalbard Airport MS compared to the Barentsburg MS. This occurred during the period of already guaranteed methodically homogeneous SAT series at both MS. It can be assumed that the recorded changes in the differences were due to the different nature of climate change at both observation points. Both MSs are in different microclimatic conditions, which also affects the SAT difference between them depending on the features of synoptic processes in a particular macrocirculation epoch. It is possible that seasonal and interannual changes in sea surface temperature and ice conditions occur differently in different water areas of Isfjorden (Green Fjord, Advent Fjord). For example, Skogseth et al. (2020) provides information on a close relationship between the variability of the SAT and the influx of Atlantic water into different parts of Isfjorden. Thus, in conditions of complex surface relief, the presence of fjords of different lengths and depths, various ice conditions and the changing sea currents, it is not reasonable to use only one reference series to correct and supplement the series (restoring gaps) at other MSs of the archipelago. When the SAT series at MSs Svalbard Airport and Barentsburg are analyzed jointly, they allow a more correct and objective assessment of the observed changes and variability of the climate of Svalbard.

Conclusions

Regular instrumental meteorological observations in Barentsburg began in August 1932, and have been continuous since December 1947. Due to the relocation of the measurement site in 1978 and 1984, the SAT_{mon} series were divided into three fragments (3 series). There were no differences in the thermal regime between the measurement sites during the 1st (before June 1978) and 3rd (since February 1984) SAT series. Microclimatic features were detected during the 2nd measurement series (June 1978 – January 1984), and were caused by the closer position of the measurement site to the shore of the fjord and its lower altitude. However, various statistical tests and procedures did not reveal any inhomogeneities in the series combined from 3 series that could be linked to the dates of the measurement site relocations. This may be due to the fact that the microclimatic differences at the measurement sites were smaller than the natural interannual variations in the SAT_{mon}, as well as the relatively short period of the MS's stay at site No. 2 from June 1978 to January 1984. The SAT_{mon} data at the Barentsburg MS are available in their original form at climate centers and can be used to assess climate change in the region.

References

ALEXANDERSSON, H. (1986): A homogeneity test applied to precipitation data. *Journal of Climatology*, 6: 661-675. doi: 10.1002/joc.3370060607

DAHLKE, S., HUGHES, N., WAGNER, M., GERLAND, S., WAWRZYNIAK, T. and MATURILLI, M. (2020): The observed recent surface air temperature development across Svalbard and concurring footprints in local sea ice cover. *International Journal of Climatology*, 40: 12. doi: 10.1002/joc.6517

DEMIN, V. I., IVANOV, B. V. and REVINA, A. D. (2020): Reconstruction of air temperature series at Russian Station in Barentsburg (Svalbard). *Russian Arctic*, 9: 30-40. (In Russian).

DEMIN V., IVANOV B, KARANDASHEVA T. and REVINA, A. (2023): Determining the breaking points of the trend in long-term changes of air temperature in Barentsburg (Svalbard). *Czech Polar Reports*, 13(2): 197-209. doi: 10.5817/CPR2023-2-16

GJELTEN, H. M., NØRDLI, Ø., ISAKSEN, K., FØRLAND, E. J., SVIASHCHENNIKOV, P. N., WYSZYNSKI, P. , PROKHOROVA, U. V. , PRZYBYLAK, R., IVANOV, B. V. and URAZGILDEEVA, A. V. (2016): Air temperature variations and gradients along the coast and fjords of western Spitsbergen. *Polar Research*, 35: 29878. doi: 10.3402/polar.v35.29878

HANSSEN-BAUER, I., FØRLAND, E. J., HISDAL, H., MAYER, S., SANDØ, A. B. and SORTEBERG, A. (eds.) (2019): Climate in Svalbard 2100 – a knowledge base for climate adaptation. NCCS report 1/2019.

ISAKSEN K., NØRDLI, Ø., IVANOV, B., KØLTZOW, M. A., AABOE, S., GJELTEN, H. M., MEZGHANI, A., EASTWOOD, S., FØRLAND, E. J., BENESTAD, R. E., HANSSEN-BAUER, I., BRÆKKAN, R., SVIASHCHENNIKOV, P., DEMIN, V., REVINA, A. and KARANDASHEVA, T. (2022): Exceptional warming over the Barents area. *Scientific Reports*, 12: 9371. doi: 10.1038/s41598-022-13568-5

IVANOV, B. V. (2019): Comparing the «earlier» and the «modern» warming in West Arctic on example of Svalbard. *IOP Conference Series: Earth and Environmental Science. Turbulence, Atmosphere and Climate Dynamics*, 231: 012023. doi: 10.1088/1755-1315/231/1/012023

KOBYSHEVA, N. V. (Ed.) (2008): Guide to specialized services to the economy with climate information, products and services. *Centr nauchno-informacionnyh tekhnologij "Asterion"* [Center for Scientific and Information Technologies "Asterion"], Saint-Petersburg, 336 p. (In Russian).

MAKSHTAS, A. P. (1991): The heat budget of Arctic ice in the winter. Ed. by E.L. Andreas. U.S. Army Cold Research and Engineering Laboratory. Hanover. New Hampshire 03755. Publ. by International Glaciology Society. Cambridge CB2 1ER U.K., 77 p.

NØRDLI, Ø., HANSSEN-BAUER, I. and FØRLAND, E. J. (1996): Homogeneity analysis of temperature and precipitation series from Svalbard and Jan Mayen. *Norwegian Meteorological Institute DNMI KLIMA,* report 16/96.

NØRDLI, Ø. (2010): The Svalbard Airport temperature series. *Bulletin of Geography, Physical Geography Series*, 3: 5-25. doi: 10.2478/bgeo-2010-0001

NØRDLI, Ø., WYSZYŃSKI, P., GJELTEN, H. M., ISAKSEN, K., ŁUPIKASZA, E., NIEDŹWIEDŹ, T. and PRZYBYLAK, R. (2020): Revisiting the extended Svalbard Airport monthly temperature series, and the compiled corresponding daily series 1898–2018. *Polar Research*, 39. doi: 10.33265/ polar.v39.3614

RANTANEN, M., KARPECHKO, A.Y., LIPPONEN, A., NORDLING, K., HYVÄRINEN, O., RUOSTEENOJA, K., VIHMA, T. and LAAKSONEN, A. (2022): The Arctic has warmed nearly four times faster than the globe since 1979. *Communications Earth & Environment*, 3: 168. doi: 10.1038/s43247-022-00498-3

SKOGSETH, R., OLIVIER, L. L. A., NILSEN, F., FALCK, E., FRASER, N., TVERBERG, V., LEDANG, A. B., VADER, A., JONASSEN, M. O., SØREIDE, J., COTTIER, F., BERGE, J., IVANOV, B. V. and FALK-PETERSEN, S. (2020): Variability and decadal trends in the Isfjorden (Svalbard) ocean climate and circulation – An indicator for climate change in the European Arctic. *Progress in Oceanography*, 187: 102394. doi: 10.1016/j.pocean.2020.102394

VIKHAMAR-SCHULER, D., FORLAND, E. J., LUTZ, J. and Gjelten, H. M. (2019): Evaluation of downscaled reanalysis and observations for Svalbard. Background report for Climate in Svalbard 2100. NCCS – report 4/2019.

WANG, X. L., WEN, Q. H. and WU, Y. (2007): Penalized maximal t test for detecting undocumented mean change in climate data series. *Journal of Applied Meteorology and Climatology*, 46(6): 916-931. doi: 10.1175/JAM2504.1

WANG, X. L. (2008): Accounting for autocorrelation in detecting mean-shifts in climate data series using the penalized maximal t or F test. *Journal of Applied Meteorology and Climatology*, 47: 2423-2444.

YOZGATLIGIL, C. (2016): Comparison of homogeneity tests for temperature using a simulation study. *International Journal of Climatology*, 36: 62-81. doi: 10.1002/joc.4329

ZHURAVSKIY, D., IVANOV, B. and PAVLOV, A. (2012): Ice conditions at Gronfjorden Bay, Svalbard, from 1974 to 2008. *Polar Geography*, 35(2): 169-176. doi: 10.1080/1088937X.2012.662535

Web sources / Other sources

[1] Global Climate Observing System: https://ww.gcos.dwd.de/DWD-GCOS

[2] Historical Arctic Rawinsonde Archive, 1947-1996, Version 1: https://nsidc.org/data/nsidc-0008/versions/1

[3] Fig.1 photo by Bjørn Christian Tørrissen: https://commons.m.wikimedia.org/wiki/File:Barentsburg-Overview.jpg

[4] Report on Climate Features on the Territory of the Russian Federation in 2016 (2017), Roshydromet, Moscow, 70 p. (In Russian).

[5] European Climate Assessment & Dataset (ECA&D) (2013): Algorithm Theoretical Basis Document (ATBD). ECA&D: Project number: EPJ029135. Royal Netherlands Meteorological Institute KNMI. Version: 10.7. URL: https://www.ecad.eu/documents/atbd.pdf

[6] Svalbard Airport MS data: Norwegian Meteorological Institute: https://www.met.no