Newly discovered series of meteorological measurements in SW Greenland (Nuuk) in the period 1806–13

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Abstract. The article presents a description of a newly discovered, unique series of meteorological measurements in SW Greenland (Godthåb [now Nuuk]) from the beginning of the 19th century (1 November 1806 to 16 August 1813), for scientific climatological research. The series is the longest available from before 1840, not only for Greenland but also for the entire Arctic. The handwritten meteorological register was found in the archives of the Royal Society in London (MA/154). The meteorological observations were carried out by the German mineralogist Dr Charles Lewis Giesecke. The observations include measurements, taken two to three times per day, of air temperature, atmospheric pressure and wind direction. In addition, the meteorological register briefly describes the weather conditions for each day. In the article, we present a detailed analysis of thermal conditions for the period covered by a complete series of measurements (Aug 1807–Jul 1813). The analysis of air temperature clearly shows that the study period was one of the coldest periods (possibly the coldest) in the past two millennia. A cooling of this severity in the first decades of the 19th century for the study region, encompassing the whole of Greenland and the entire Arctic, has also been previously reconstructed by other scientists using different proxy data and models. Among the available reconstructions that use different proxy data or that use climate models for this purpose, most of the reconstructions of air temperature are almost fully consistent with the available results of meteorological observations for this period.

Keywords: Arctic, Greenland, historical climatology, data rescue, climate records, temperature

1. Introduction

The main aim of historical climatologists in recent decades has been to reconstruct the climate on different spatial scales – from global to regional and local – for the last centuries. For this purpose, documentary evidence is used from before the beginning of regular meteorological observations (Pfister et al., 1999; Brázdil et al., 2005), which is usually taken as the year 1850, except for Africa and the Arctic (for which 1890 is the usual start point) (Brönnimann et al., 2019). One type of very useful information about past weather and climate is an early, irregular, isolated series of meteorological measurements. Recently, an initiative was created to inventory all available data of this type (including existing databases) for the whole world, including the Arctic, and then make it available in digital form (Brönnimann et al., 2019; Lundstad et al., 2023). This activity has found recognition and interest among many scientists and has been called “data rescue activity”. For the Arctic as a whole and for its different regions (Canadian Arctic, Greenland, Svalbard and Novaya Zemlya), a summary of existing meteorological measurements was conducted by Przybylak and Vizi (2005), Vinther et al. (2006), Przybylak et al. (2010, 2016, 2018), and Przybylak and Wyszyński (2017). Queries conducted in many European and Canadian archives and libraries allowed the collection of 118 series of average monthly air temperature values from the years 1801–1920 (for details, see Table I in Przybylak et al. 2010), with the greatest amount dating from after the 1st International Polar Year 1882/83. The majority of the gathered series (77.1%) cover periods of less than two years; however, series of one year or less dominate (58.5%) (Przybylak et al., 2010).

Meteorological data from prior to 1850 are rare and mainly available for Europe and eastern North America (see Fig. 2a in Brönnimann et al. 2019). According to the map presented in this article (Fig. 2a), such a series for Greenland exists only for the south-western coast. Detailed descriptions of the observations available for this time are provided in papers by Vinther et al. (2006) and, recently, for the late 18th century by Demarée et al. (2020), Demarée and Ogilvie (2021) and Przybylak et al. (2024). According to these publications, the oldest series of observations of about one year or more is that for Neu-Herrnhut (now Nuuk) for the period Sep 1767–July 1768. All known meteorological observations made here in the late 18th century were usually performed by the Moravian missionaries (for more information about their activity, see, e.g., Lüdecke (2005), Demarée and Ogilvie (2008), or Demarée et al. (2020). They are usually available in the form of tables with meteorological data. Some have survived and are available in archives in Germany (Moravian Archives Herrnhut), the UK (The Library and Archives of the Royal Society and Moravian Church Archive and Library in London) and the USA (Moravian Archives Bethlehem) (see Demarée and Ogilvie [2008] for more details). Others have been included in texts of reports, usually prepared for each month of the year, and most often sent annually by ship to Europe (diaries handwritten in English or Old German). The latter sources, which contain only sparse and irregular measurement data relating to only a few parameters, have been assessed in terms of their utility in application to climate studies (particularly for the study of weather extremes in SW Greenland) by Kodzik (2019) and Borm et al. (2021). Any new data series from the early instrumental period, especially for the Arctic (including Greenland), is very precious for calibrating proxy-based climate reconstructions from so-called natural archives (ice cores, tree rings, lacustrine sediments, etc.). Vinther et al. (2006) document this fact very clearly, showing a strong correlation (0.6–0.7) between reconstructed SW Greenland winter temperatures and ice-core winter-season proxy. Although they did extensive work rescuing a large amount of early instrumental data for SW Greenland, they found neither the reportedly oldest meteorological data series for Nuuk, relating to September 1767–July 1768 (see their Fig. 2, where the series starts at 1784), nor the series analyzed by us for 1806–13. This latter, entirely new series contains complete data from six years of observations and is the longest series available for the Arctic (including Greenland) for the period before 1840. The Arctic is defined as the region after *Atlas Arktiki* (Treshnikov, 1985; see also Fig. 1.1 in Przybylak, 2016). For the 1840s and 1850s, ~~we have~~ a continuous series of data is available for Illulisat (Jacobshavn) (Vinther et al., 2006) and probably also for Lichtenau (1843–51) and Neu-Herrnhut (1843–60) according to Table 2 (Lüdecke et al., 2005). To check the completeness of the last two series, we need to have access to the so-called Lamont collections (kept at the Chair of Ecoclimatology at the Technical University of Munich). ~~Despite numerous requests, the owner of the collection does not want to make it available to us.~~

From this brief review of the state of knowledge about early meteorological observations available for Greenland, it is clear that many exist. Despite many years of searches for such observations by many Danish and UK scientists (Vinther et al., 2006) and by Polish researchers and climatologists (Przybylak et al., 2010), no one has managed to obtain information about the existence of a long-term continuous series of daily and sub-daily meteorological observations at Nuuk for the period between 1806 and 1813. While searching the Royal Society archives in London ~~archives~~ for early instrumental meteorological observations by the Moravian Brethren, we happened upon this series. Therefore, the main goal of this article is to present this newly discovered series of observations to a broader audience of scientists and to present the first results of climate analysis. This analysis is limited, however, to a description of conditions and changes in air temperature in Nuuk at that time. (Descriptions of other parameters will follow in future publications.) The secondary goal is to compare air temperatures in the study period against earlier temperature observations from the late 18th century (Przybylak et al., 2024) and with later records, including modern observations from 1991–2020.

2. Area, data and methods

The meteorological observations analyzed here were made at the beginning of the 19th century in the territory of present-day Nuuk (Danish name *Godthåb*, φ= 64° 11' 0.49" N, λ= -51° 43' 17.65" W; see also Fig. 1), the capital and largest city of Greenland. Currently, they are available in the manuscript MA/154 in the Library and Archives of the Royal Society in London. The title of the manuscript is: *Meteorological observations at Godthåb [Nuuk], Greenland, by Charles Lewis Giesecke*. More details about this source are available at https://catalogues.royalsociety.org/CalmView/Record.aspx?src=CalmView.Catalog&id=MA%2f154&pos=1. According to the title page of the manuscript and the Royal Society catalogue describing the source, the scientist responsible for making them was the German mineralogist

Dr Charles Lewis Giesecke (born Johann Georg Metzler [1761–1833]) (Fig. 2). However, given the numerous biographical accounts of his stay in Greenland (e.g., Monaghan 1993; Jørgensen, 1996; Wyse Jackson, 1996; Whittaker, 2001), there is some doubt as to whether he conducted the meteorological observations alone; he may have had help from the local Inuit community and Moravian missionaries.

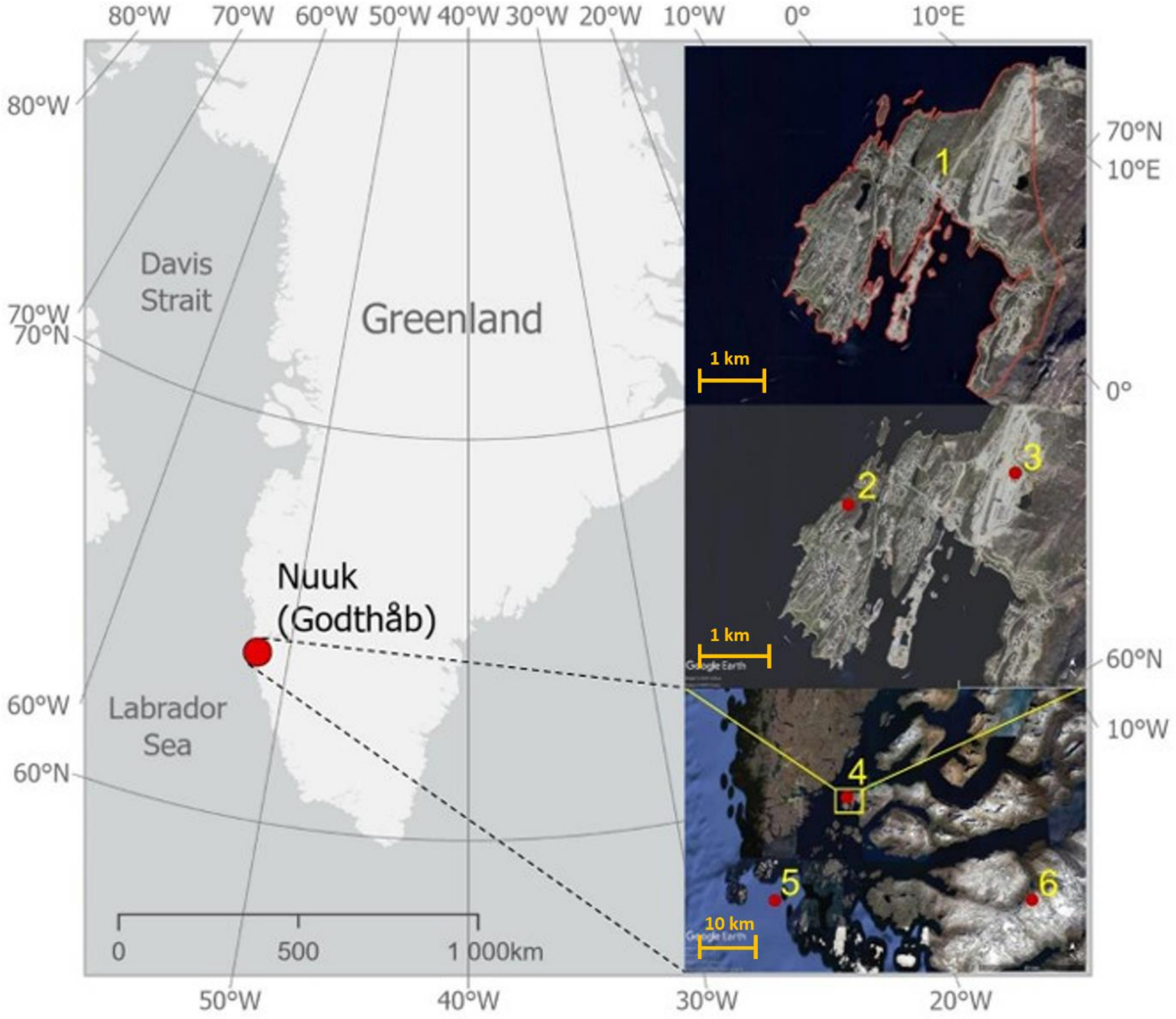

Fig. 1. Location of historical and contemporary sites of meteorological measurements in SW Greenland. Explanation: 1 – historical site Godthåb (1806–13, the exact location is unknown); 2 – 4250 Nuuk (1991–2020); 3 – 4254 Mittarfik Nuuk (2001–20), 4 – ModE-RA (1806–13), 5 – 20CRv3_C (1806–13, coastal grid point), 6 - 20CRv3_T (1806–13, terrestrial grid point). Map data for location of sites: © Google Earth; images © U.S. Geological Survey, © IBCAO, © 2025 Maxar Technologies, © 2025 Airbus and © 2025 Asiaq

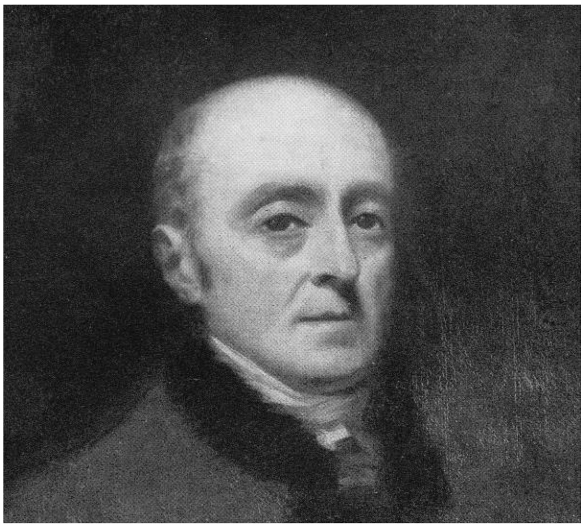

Fig. 2. Portrait of Sir Charles Lewis Giesecke (1761–1833) painted by the Scottish painter Raeburn in 1817 (after Whittaker, 2001)

Dr Charles Lewis Giesecke arrived at Friederichshaab in Greenland on May 31, 1806 (Whittaker, 2001). The primary purpose of his research visit and stay in SW Greenland, which was planned to last for one to two years, was to conduct a geological reconnaissance, particularly in search of new minerals. We know that the meteorological observations he began on November 1, 1806, continued regularly until April 1807. From then until August of the same year, the observations were intermittent and irregular. Therefore, he likely carried out most of his geological research from June to October 1806 and then from May to July 1807. There is also evidence that he conducted studies of minerals in the summers of 1808 and 1809 (Whittaker, 2001); however, these trips were likely shorter. During this time, he organized research expeditions along the south-western coast of Greenland, from Upernavik in the north to Cape Farewell in the south (Whittaker, 2001). To reach these places, he mostly used boats, but also sledges and travelled on foot. Due to the onset of the Napoleonic War in 1807, much of Europe was occupied by French troops. Thus, Giesecke could not return to Denmark and decided to stay in Greenland until the political situation changed and allowed him to return (Whittaker, 2001). This fact likely led to the initiation of systematic meteorological observations, which were conducted over six years (Aug 1807 – Jul 1813), resulting in the almost-complete series of observations made three times a day (morning, midday and evening). The gaps occur in September 1807 and cover 18th–19th for all measurement times, plus 22nd–30th for midday measurements and 21st–30th for evening. The gaps were filled using data from the same days of the year, but from the years 1808–12. These data were used to calculate the differences between noon/evening observations and morning observations—for which data from September 1807 are available. The resulting five-year average differences were added to the morning observation data from the period of September 20–30, 1807. On the other hand, missing data from September 18 and 19 were reconstructed using average values calculated from ten temperature values measured at the same observation time on adjacent days. The data used in this study were taken from the manuscript MA/154 found in the Archives of the Royal Society in London (Fig. 3). The original manuscript is available in Copenhagen Diamond Library (Mineralogisches Reisejournal über Grönland gehalten 1806-1813. (I Nr. 323 a: Tägliche Wetter-Beobachtungen in Godthaab von 1. Nov. 1806 - 16. Aug. 1813: 323 b: Nogle Ord om og til Grønlands Opkomst Hans Kgl. Majest. allerunderdanigst tilegenet; ogsaa paa Tysk.) 9 Bd. Karl Ludwig Giesecke 1761-1833 mineralog (DBL)1806-1813. As mentioned above, it is possible that, for these measurements, especially during his exploratory travels, he involved Inuits and (especially) the Moravian missionaries. These latter were already present in the area and had extensive experience in conducting meteorological observations (see e.g., Demarée and Ogilvie 2008; Przybylak et al., 2024).

As Fig. 3 shows, Giesecke conducted measurements and observations of the following meteorological variables: atmospheric pressure (morning and evening), air temperature (morning, midday and evening) and wind direction (morning and evening). The precise times of observations are not given. In addition to the meteorological data available in the meteorological registers, he provided brief descriptions of the weather conditions for each day. At the end of each month, he also included a short summary of the weather conditions (at the bottom of the table of meteorological data). Unfortunately, the register does not provide information about the units used for the measurements or details about the thermometer's exposure. It is assumed that the thermometer was placed on the north-facing wall outside Giesecke's building. However, in the Arctic, where there is polar day during summer months, such placement does not eliminate the influence of solar radiation unless the thermometer is adequately shielded. The detailed location of the place where observations were probably done (whether it was near the sea or at some distance from the sea, its elevation, etc.) is also unknown.

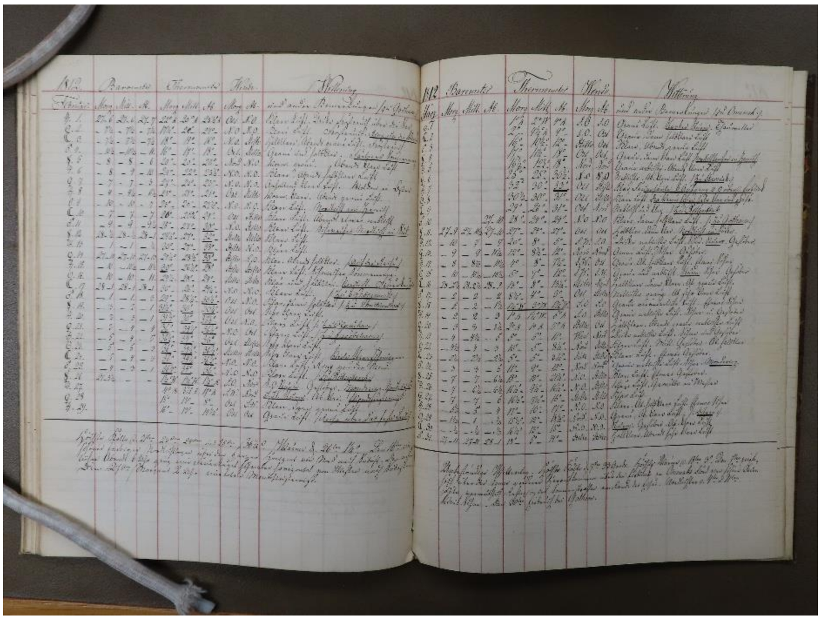

Fig. 3. Example of a manuscript presenting meteorological observations in Godthåb (1 Feb 1806–16 Aug 1813) (data presented in the manuscript: 1 February 1812 to 31 March 1812, source – The Library and Archives of the Royal Society in London, MA/154)

In the article, we present an analysis limited to air temperature – the most important variable in every climate analysis. We first verified all transcribed data against the source data. In the next step, these data ~~All source data~~ were quality-controlled first by (i) visual inspection and then (ii) by the method recommended by WMO (Aguilar et al. 2003). ~~, and no incorrect or suspect data were found~~. All sub-daily series of temperature (morning, midday and evening) were analyzed, looking for data exceeding 3–4 SD. We found only a few such cases, all of which we analyzed using air pressure and wind direction (atmospheric circulation) in terms of the probability of occurrence (determining the cause and consistency with the course of the aforementioned meteorological elements). For this purpose, we also used the descriptions written by Giesecke, who regulary indicated high/low values and large day-to-day fluctuations (and explained them, giving the reasons). We did not find any erroneous temperature values. We also calculated the differences between observations taken at noon and in the morning, at noon and in the evening, and in the evening and in the morning. We also checked several values exceeding 3–4 SD, and all of them were deemed correct. We performed a similar test for day-to-day changes and again did not find any changes that aroused doubts. All these methods demonstrated that the data are of good quality and homogeneous. Our comparison with present values (see results part) also support this favourable assessment, as did comparison with parallel observations available for Nuuk for the years 1811–12.

As we wrote earlier, the unit in which air temperature measurements are presented in the meteorological register is not given. To determine which unit was likely used in Giesecke's measurements, we compared his results with parallel temperature observations available for another location in Godthåb during 1811–12 (Vinther et al., 2006). Based on these, we concluded that temperatures were measured in degrees Celsius. Although the exact times of air temperature measurements are unknown, we calculated mean daily air temperature (MDAT) using a weighted average: (Tmorning + Tmidday + 2 × Tevening) / 4. To assess the probable biases in the calculation of MDATs, we used hourly air temperature data from the Nuuk 4250 station from 2010 to 2020 (Drost Jensen, 2022). We calculated MDATs according to eight different formulas:

$$\mathrm{MDAT1} = (T1 + T2 + T3, \dots , T24)/24 \tag{1}$$

$$\mathrm{MDAT2} = (T6 + T12 + T18)/3 \tag{2}$$

$$\mathrm{MDAT3} = (T7 + T13 + T19)/3 \tag{3}$$

$$\mathrm{MDAT4} = (T8 + T14 + T20)/3 \tag{4}$$

$$\mathrm{MDAT5} = (T8 + T14 + 2*T20)/4 \tag{5}$$

$$\mathrm{MDAT6} = (T8 + T14 + 2*T21)/4 \tag{6}$$

$$\mathrm{MDAT7} = (T6 + T12 + 2*T20)/4 \tag{7}$$

$$\mathrm{MDAT8} = (T6 + T12+ 2*T21)/4 \tag{8}$$

where MDAT1 is calculated from 24 hourly measurements per day (the “real daily average”).

In the next step, we compared the MDAT1 results against those obtained using all other formulas (MDAT2–MDAT8, which rely on only three measurement times per day) (see Table 1). Analysis shows that, in the cold half-year (Oct–Mar), the maximum bias reaches 0.1 °C, whereas in summer the bias is highest but does not exceed 0.5 °C. The formulas MDAT6, MDAT7, and MDAT8 are closer to MDAT1, with a bias typically of 0.0 °C, except in June, July, and August, when the bias reaches a maximum of 0.2 °C.

Table 1. Mean monthly and annual differences in air temperature (°C) between MDATs calculated according to formulas MDAT2–MDAT8 in comparison to the average calculated using the MDAT1 formula

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
MDAT2-MDAT1	0.0	0.0	0.1	0.1	0.3	0.3	0.4	0.3	0.1	0.1	0.0	0.0	0.15
MDAT3-MDAT1	0.0	0.1	0.0	0.1	0.3	0.4	0.5	0.3	0.1	0.1	0.1	0.0	0.17
MDAT4-MDAT1	0.0	0.1	0.0	0.2	0.3	0.4	0.5	0.4	0.2	0.1	0.0	0.0	0.18
MDAT5-MDAT1	0.0	0.1	0.0	0.1	0.3	0.4	0.5	0.3	0.2	0.1	0.0	0.0	0.17
MDAT6-MDAT1	0.0	0.1	0.0	0.1	0.1	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.07
MDAT7-MDAT1	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.06
MDAT8-MDAT1	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.1	0.0	0.0	0.0	-0.04
Max bias	**0.0**	**0.1**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.4**	**0.2**	**0.1**	**0.1**	**0.0**	**0.18**

None of the possible biases in air temperature measurements that are associated with the type and accuracy of the thermometer used or its exposure can be estimated due to the lack of relevant information. However, the exposure bias should be minimal or zero for the polar night due to the absence of solar radiation at such times. However, we must add here that scientists at that time (approximately the late 18th century) were familiar with methods of meteorological measurement. Knowledge about the appropriate placement and protection of thermometers was common. During the period under study, the temperature in Nuuk never dropped below -38.8 °C (the freezing point of mercury). This fact means that the freezing of mercury cannot have been a cause of measurement errors. We still cannot rule out the existence of minor errors that may have been committed by the person copying the original data from the source mentioned earlier, held at the archive in Copenhagen.

The MDAT values, which are available at https://doi.org/10.18150/IGYNGV (Przybylak et al., 2025), were used to calculate standard (monthly, seasonal and annual means) and less-typical climate statistics (indices) such as: 1) day-to-day temperature variability (DDTV); 2) frequency of occurrence of MDAT in 1-degree intervals, including the calculations of skewness ($\gamma 1$) and kurtosis ($\gamma 2$) of analyzed sets of air temperature using formulas recommended by von Storch and Zwiers (1999); 3) thermal seasons after Baranowski (1968) proposition for polar regions (for details, see Przybylak et al. 2024); 4) thermal roses of wind (relation between wind direction and temperature); and 5) annual air temperature range (ATR) and thermal climate continentality (K) using the following formula proposed by Ewert (1972):

$$K = [ATR - (3.81 \cdot \sin\varphi) + 0.1)] / (38.39 \cdot \sin\varphi + 7.47) \cdot 100\% \qquad (9)$$

where ATR is the annual air temperature range calculated as the difference between the mean temperatures of the warmest and coldest months, and φ is the geographical latitude.

This index considers the dependence of ATR not only on geographical latitude, but also on the percentage of land in a given latitudinal band. The K index changes worldwide from -1.5% for areas with extreme oceanic climate to more than 140% for the extremely continental part of Eastern Siberia (Ewert, 1997). For more details about the methods used to calculate the statistics mentioned above, see Przybylak et al. (2014, 2024).

The obtained results for the study period were compared against earlier temperature observations from the late 18th century (Przybylak et al., 2024) and with later records (Vinther et al., 2006), including modern observations from 1991–2020 (monthly data after Cappelen and Drost Jensen, 2021, and hourly data, based on which daily averages were calculated, after Drost

Jensen 2022). However, due to the lack of complete hourly data for the 4250 Nuuk (Fig. 1) station and the inability to calculate daily averages from 24 measurements for the whole period 1991-2020, the gaps in the daily averages were filled using an interpolation method (Nordli et al., 2020) based on data taken from the neighbouring 4254 Mittarfik Nuuk station (for more details see Przybylak et al., 2024, p. 1455).

Comparison of the same years 1807-13 was only possible with data taken from reanalyses: the NOAA/CIRES/DOE 20th Century Reanalysis (V3) (20CRv3) available for 1806–2015 (https://www.psl.noaa.gov/data/gridded/data.20thC_ReanV3.html, last access 20 August 2025) (see also Slivinski et al. 2019, 2021) and the Modern Era Reanalysis for 1421-2008 (ModE-RA; Valler et al., 2024) available via ClimeApp (Warren et al. 2024, https://mode-ra.unibe.ch/climeapp/, last access 21 August 2025).

3. Results

3.1. Monthly resolution

Due to the irregularity of meteorological observations between 1 November 1806 and 31 July 1807, we present here an analysis for the period of the regular and complete series of observations, i.e. August 1807 – July 1813 (6 full years). The average yearly temperature for this period, calculated from August to July next year, reached -4.3 °C. The mean yearly temperature in the coldest (1810/11) and warmest (1808/09) years reached -6.9 °C and -1.8 °C, respectively (Table 2, Fig. 4). In the warmest of the six years, temperatures were higher than the six-year average mainly from December to April, when mean monthly temperatures were even greater than the average temperature in the contemporary period 1991–2020. Similarly, in the coldest year, very low winter and spring temperatures also accounted for the significant decrease in the annual mean. On average, in the yearly cycle, the coldest mean monthly temperature occurred in February (-14.4 °C) and the warmest in July (5.3 °C) (Table 2, Fig. 4). In all analyzed years, the warmest month was always July (except for the first studied year, when it was August), whereas the coldest month occurred in a winter month or in March (Table 2). Mean year-to-year changes between ~~in~~ mean monthly values are clearly most significant in winter and spring months, oscillating from about 7 °C in January and February to almost 10 °C in March. Conversely, the smallest year-to-year variations (indicating the most stable months) occurred in October (0.5 °C) and September (1.1 °C), whereas these variations were slightly greater in the summer months, ranging from 1.4 °C in August to 2.7 °C in June (Table 2, Fig. 4).

Table 2. Mean monthly, seasonal and annual air temperature and variability (SD, DDTV) of MDAT in Nuuk in the historical (1807–13) and contemporary (1991–2020) periods

Period	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	DJF	MAM	JJA	SON	Aug-Jul
	Mean temperature (°C)																
1807/08	3.1	-2.8	-2.2	-4.0	-6.6	-19.4	-12.9	-10.7	-6.3	-2.2	0.6	1.5	-13.0	-6.4	1.7	-2.6	-5.0
1808/09	5.3	-1.3	-2.0	-4.7	-4.6	-3.4	-7.5	-4.1	-1.9	-2.0	-0.5	5.5	-5.2	-2.7	3.4	-2.7	-1.8
1809/10	4.1	1.2	-1.2	-2.5	-9.3	-8.3	-9.2	-5.6	-4.3	1.8	3.8	6.6	-8.9	-2.7	4.8	-0.8	-1.9
1810/11	*2.8*	*-0.9*	*-2.3*	*-3.2*	*-8.2*	*-15.3*	*-19.2*	*-25.0*	*-10.4*	*-5.6*	*0.8*	*3.7*	-14.2	-13.7	2.4	-2.1	*-6.9*
1811/12	4.9	-0.2	-2.2	-9.0	-10.4	-11.7	-25.3	-13.5	-4.6	-1.0	3.0	7.4	-15.8	-6.4	5.1	-3.8	-5.2
1812/13	4.6	-0.3	-2.0	-3.9	-4.8	-15.8	-11.9	-23.3	-9.6	-4.0	5.7	7.4	-10.8	-12.3	5.9	-2.1	-4.8
1807-13	**4.1**	**-0.7**	**-2.0**	**-4.5**	**-7.3**	**-12.3**	**-14.4**	**-13.7**	**-6.2**	**-2.2**	**2.2**	**5.3**	**-11.3**	**-7.4**	**3.9**	**-2.3**	**-4.3**
1991-2020	**6.8**	**3.9**	**0.2**	**-3.2**	**-5.4**	**-7.4**	**-8.5**	**-7.6**	**-3.1**	**0.9**	**4.7**	**7.2**	**-7.1**	**-3.3**	**6.2**	**0.3**	**-1.0**
1807-1813 – 1991-2020 (diff)	-2.7	-4.6	-2.2	-1.3	-1.9	-4.9	-5.9	-6.1	-3.1	-3.1	-2.5	-1.9	-4.2	-4.1	-2.3	-2.6	-3.3
	SD (°C)																
Period	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	DJF	MAM	JJA	SON	Aug-Jul
1807/08	3.5	2.6	3.2	2.8	3.3	7.1	8.4	5.7	7.2	3.3	3.2	3.0	6.2	5.4	3.3	2.9	4.4
1808/09	2.3	2.7	1.6	4.1	3.8	4.3	6.1	3.7	2.4	2.6	1.2	1.5	4.8	2.9	1.7	2.8	3.0
1809/10	1.5	2.1	2.2	3.9	3.4	5.1	6.6	6.2	4.4	2.9	2.2	2.5	5.0	4.5	2.1	2.7	3.6
1810/11	*1.4*	*1.5*	*2.3*	*3.0*	*5.0*	*5.9*	*5.7*	*4.1*	*4.2*	*4.5*	*2.0*	*3.3*	*5.5*	*4.3*	2.2	*2.3*	*3.6*
1811/12	2.9	2.2	2.5	2.8	5.0	4.8	8.7	9.1	5.0	2.4	3.1	2.5	6.2	5.5	2.8	2.5	4.2

1812/13	2.3	2.4	2.4	3.3	4.6	6.0	4.7	4.3	5.3	2.2	3.8	2.2	5.1	4.0	2.8	2.7	3.6
1807-13	**2.3**	**2.3**	**2.3**	**3.3**	**4.2**	**5.6**	**6.7**	**5.5**	**4.8**	**3.0**	**2.6**	**2.5**	**5.5**	**4.4**	**2.5**	**2.6**	**3.8**
1991-2020	**2.1**	**1.9**	**2.7**	**3.7**	**4.8**	**5.3**	**7.2**	**5.8**	**4.3**	**3.6**	**2.5**	**2.0**	**5.8**	**4.6**	**2.2**	**2.8**	**3.8**
1807-1813 – 1991-2020 (diff)	0.2	0.4	-0.4	-0.4	-0.6	0.3	-0.5	-0.3	0.5	-0.6	0.1	0.5	-0.3	-0.2	0.3	-0.2	0.0
	DDTV (°C)																
Period	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	DJF	MAM	JJA	SON	Aug-Jul
1807/08	1.9	2.0	2.1	1.4	2.4	2.8	3.6	2.8	2.0	1.5	1.8	1.3	2.9	2.1	1.7	1.6	2.1
1808/09	1.4	1.5	1.1	1.9	2.4	2.3	3.4	2.4	1.6	2.0	1.1	1.2	2.7	2.0	1.3	1.5	1.9
1809/10	1.3	1.5	1.5	2.0	2.3	2.8	3.5	1.9	2.4	1.9	1.5	1.5	2.9	2.1	1.4	1.6	2.0
1810/11	*1.3*	*1.0*	*1.6*	*2.4*	*2.9*	*3.2*	*2.5*	*2.3*	*2.5*	*2.0*	*1.5*	*1.9*	*2.9*	*2.3*	1.6	*1.6*	*2.1*
1811/12	1.4	1.5	1.3	1.9	3.1	3.5	3.4	3.9	2.6	1.4	1.6	2.3	3.3	2.6	1.8	1.6	2.3
1812/13	1.2	1.2	1.2	1.8	2.5	2.8	3.3	2.2	4.0	1.9	2.3	2.0	2.9	2.7	1.8	1.4	2.2
1807-13	**1.4**	**1.5**	**1.5**	**1.9**	**2.6**	**2.9**	**3.3**	**2.6**	**2.5**	**1.8**	**1.6**	**1.7**	**2.9**	**2.3**	**1.6**	**1.6**	**2.1**
1991-2020	**1.3**	**1.1**	**1.4**	**1.8**	**2.1**	**2.3**	**2.4**	**2.4**	**1.8**	**1.4**	**1.6**	**1.6**	**2.3**	**1.9**	**1.5**	**1.5**	**1.8**
1807-1813 – 1991-2020 (diff)	0.1	0.2	0.1	0.1	0.5	0.6	0.9	0.2	0.7	0.4	0.0	0.1	0.6	0.4	0.1	0.1	0.3

Key: SD – standard deviation, DDTV – day-to-day temperature variability, bold font – long-term average, underline – the warmest year, italic – the coldest year

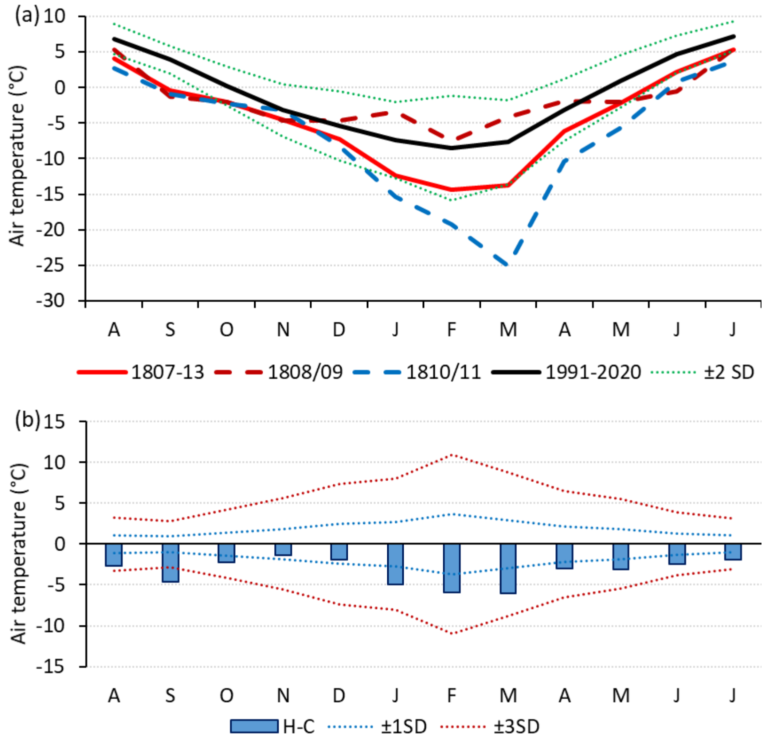

Fig. 4. a) Annual cycles of air temperature in Nuuk in the study historical period 1807–13, including the warmest (brown dashed line) and the coldest (blue dashed line) years, and in the contemporary period (1991–2020), b) differences between historical and contemporary mean monthly temperature values.

Key: SD values were calculated from the series of monthly mean temperatures from the contemporary period 1991–2020.

Reliable information about the thermal continentality of climate in the Arctic, calculated based on instrumental data, is unavailable for the period before 1840 because of the lack of long-term data series. For the first time, we have a six-year series of air temperature observations for Nuuk from the beginning of the 19th century. Based on data from Nuuk from 1991–2020, six-year moving averages of ATR and K were calculated. The calculation errors of these values compared to the 30-year period are small and amount to ±1.5 °C and ±3.5%, respectively. In the study period (1807–13), the mean ATR reached 24.0 °C, while K reached 49.2%. In the contemporary period, these values are 17.3 °C and 33.4%. This indicates that climate continentality in SW Greenland at the beginning of the 19th century was about 15% greater than at present. This difference is mainly accounted for by winter months having been significantly colder in the historical period than at present (see Fig. 4).

Statistics were also calculated for each observation time to roughly estimate the changes in air temperature during the day. In line with expectations, the average annual temperature was highest at midday (-2.1 °C) and lowest in the morning (-4.8 °C) (Table S1). At all times of the day, the warmest month was July, while the coldest was February (midday and morning) or March (evening). In the study period, the highest temperature (18.5 °C) was noted in midday on 16 July 1810, while the lowest (-36.5 °C) occurred in the morning and evening observation times on 21–24 February 1812. Thus, the absolute range of temperature reached as much as 55 °C. The temperature in the historical period in all months was lower than today, in particular in February and March, when the difference reached about 6 °C (Table 2, Fig. 4). On the other hand, this difference was the smallest in November (1.3 °C), as well as in December and July (1.9 °C in both). On average, according to annual averages, the historical period was 3.3 °C colder than today (1991–2020). The warmest (1808/09) and coldest (1810/11) years were also colder than today – by 0.8 °C and 6.9 °C, respectively (Table 2, Fig. 4).

Figure 5 shows the course of monthly average air temperatures in the study period to determine whether the strong eruption (the third largest since 1500) of an unidentified volcano at the end of 1808, and most likely at the beginning of 1809 (Vinther et al. 2006; Timmreck et al., 2021), influenced the air temperature in SW Greenland. A significant cooling in Nuuk occurred from the second winter after the eruption. This cooling occurred mainly in wintertime and persisted until the end of the series, but the greatest was in the expedition year 1810/11. Following the eruption, there was a notable increase in the frequency of calm days and winds from the north-east sector, accompanied by a decrease in the number of winds from other directions, particularly those from the south-east and south-west sectors (Fig. 6).

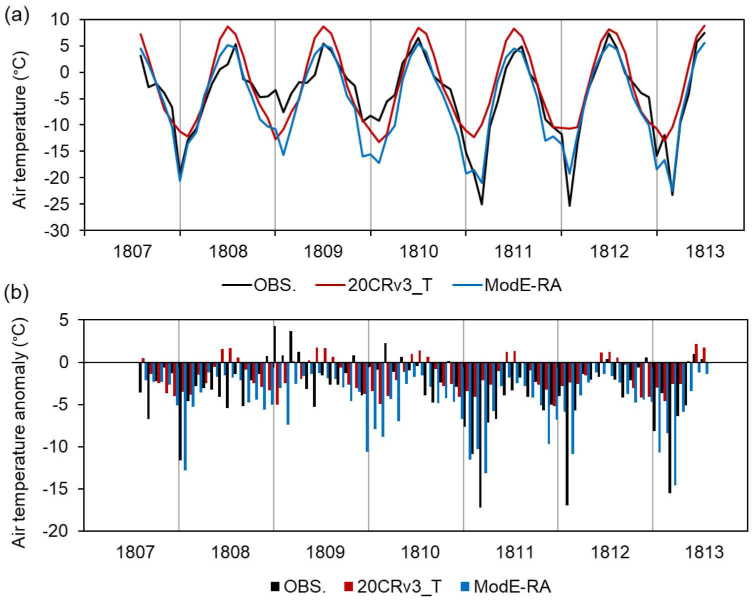

Fig. 5. (a) Time series of mean monthly air temperatures in Nuuk in the period 1807–13 according to different datasets, and (b) their anomalies in reference to the period 1991–2020. A large, unknown, volcanic eruption most likely occurred in early 1809.

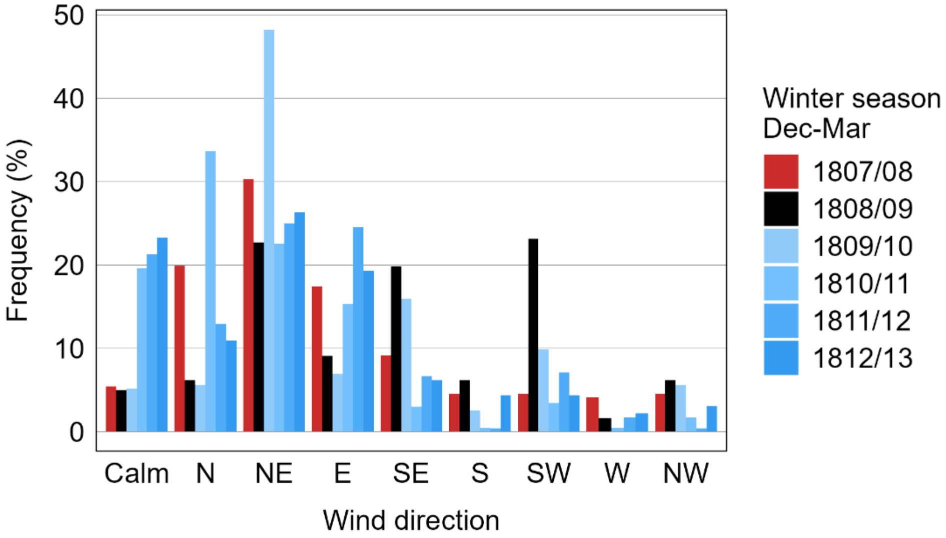

Fig. 6. Frequency of winds in Nuuk in the winter season (Dec – Mar) in particular years of the period 1807–13. In black, the year of the eruption of an unknown volcano

3.2. Daily resolution

3.2.1. Annual cycle

Most studies analyzing climate and its changes in various areas of the globe, including the polar regions (including the Arctic), most often use monthly, seasonal and annual data. For many purposes, these are overly generalized data that do not allow for a complete understanding of the wide range of climate features that characterize each area, particularly the extreme phenomena. Therefore, over the last 20 years, we have started using higher-resolution data, i.e. daily and sub-daily, for our analyses of weather and climate in the Arctic (e.g., Przybylak and Vizi 2005; Nordli et al. 2014, 2020; Przybylak et al. 2016, 2018, 2022, 2024; Przybylak & Wyszyński, 2017). That is why we also present here some statistics based on this kind of data, and, thanks to that, we present an in-depth analysis of the weather and climate in Nuuk during the study period.

Figure 7 presents the annual cycle of air temperature in Nuuk based on MDAT for each study year and the average for the six-year period 1807–13. On average, with few exceptions, MDATs were colder in the historical period than at present. The greatest differences occurred in winter months (Dec–Mar) and September, while the smallest occurred from mid-May to mid-August. For some of the historical years, the picture is different; specifically, some had a greater frequency of MDATs that were warmer than today than did other years. Nonetheless, these of course occurred more rarely than did days that were colder in the past than at present. The

MDATs that were most similar to present conditions were noted in the warmest year, i.e. 1808/09, while MDATs were least similar in the coldest year (1810/11) (Fig. 7). The year 1808/09 was the warmest due to the very high MDATs from mid-December to mid-April, which were significantly greater than present MDATs. Conversely, the year 1810/11 was the coldest due to a significant, prolonged period of very low MDATs from the beginning of January to the start of April. This means that MDAT values in winter and the first half of spring are mainly responsible for the mean annual air temperature values, which is a typical pattern for moderate latitudes, but particularly for polar regions (Przybylak, 2016). MDATs in the historical period usually do not exceed 2 SD from the contemporary long-term average MDAT (Fig. 7).

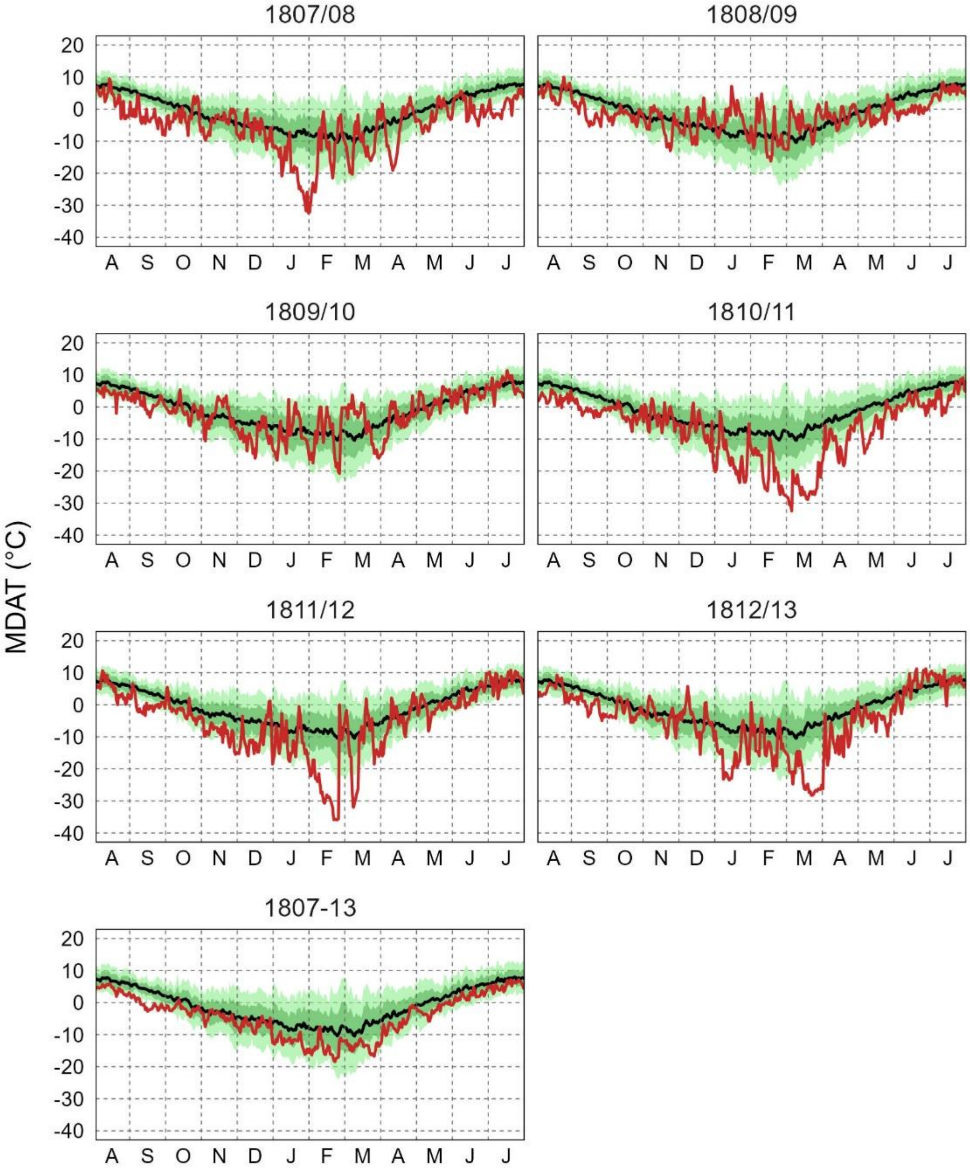

Fig. 7. Annual courses of MDAT in Nuuk in historical years (red lines) and 1991–2020 mean (black lines). Dark and light green surfaces indicate ±1 SD and ±2 SD, respectively, calculated using MDAT from the period 1991–2020 and added and subtracted from the 30-year mean.

More precise information about the character of MDAT changes between historical and present times is contained in Fig. 8, which shows relative seasonal frequencies of occurrence of specific MDAT values stratified into one-degree intervals. In all seasons, warmer MDAT values occur clearly more frequently in the contemporary period than in the historical period. The range of the highest-frequency MDAT values frequencies also shifted towards higher values for all seasons. For example, for winters, they shifted from being flatly distributed across a wide range (-16 °C to -5 °C) to a more narrowly spread range (-10 °C to -5 °C) comprising with higher frequencies of MDATs (Fig. 8). The shape of MDAT distributions in all seasons and in both historical and contemporary periods are close to normal because both skewness (γ1) and kurtosis (γ2) are not greater/smaller than ±1, except γ1 in spring in the historical period (-1.03 and -1.02). The left-skewed distribution of MDATs is a very characteristic feature of the climate in all seasons in Greenland, except for summer in the contemporary period. Leptokurtic distribution is also a very characteristic feature of MDAT distribution in all seasons (except summer) in the historical period, whereas, in modern times, weak platykurtic distribution (γ2>-0.2) is evident except in spring (Fig. 8).

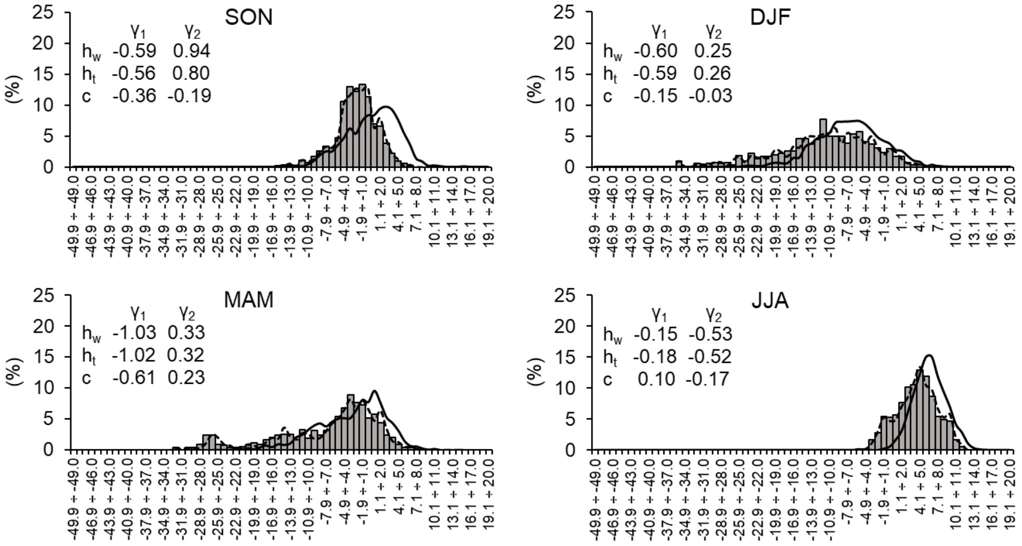

Fig. 8. Seasonal (SON, DJF, etc.) relative frequencies of occurrence (in %) of MDAT in historical (bars – weighted mean, dashed lines – simple arithmetic means from three measurement times) and modern (solid lines) sites located in Nuuk 1807–13 and 1991–2020. Values of skewness (γ1) and kurtosis (γ2) for historical weighted mean (h_w), simple arithmetical mean (h_t) and contemporary (c) times are also shown.

3.2.2. Day-to-day temperature variability (DDTV)

Annual courses of DDTV in Nuuk are shown for each of the six historical years for which complete or near-complete data are available for the entire year (Table 3, Fig. 9). Similarly to the climate of the present (Przybylak, 2002) and to the late 18th century (Przybylak et al., 2024), the DDTV in the study period was greatest in the cold half-year, but particularly in winter, and lowest usually from May to October, but especially in summer (Fig. 9). In summer, values of DDTV are approximately similar among all historical years, usually not exceeding 5.0 °C. Only on single days do values of DDTV oscillate between 6 and 8 °C. In winter, changes in DDTV are greater than in summer, and their values are also several times greater. In each year except the warmest year (1808/09), there are some spans in which DDTVs exceed 10 °C, but they are less than 15 °C, except one value at the end of February 1812 (see Fig. 9). The change in measured temperature from evening 25 February (orig. 36 °K) to morning of 26 February (orig. 1.5 °W) reached 37.5 °C (MDAT difference 35.6 °C). Under the table of data from February 1812, Giesecke wrote the following (see Fig. 3): “Hochste Kälte 21sten - 23sten, 24sten und 25sten [Februar] 36 ½ °. Wärmer den 26ten – 1 ½ °” [translation, first author: Extremely cold 21st – 23rd, 24th and 25th [February] -36.5 °C. Warmer the 26th − 1.5 °C.]. February 1812 was exceptionally cold according to the Giesecke measurements. The temperature between 5 and 25 February never rose above -20 °C, and between 19 and 25 February, it was constantly below -30 °C (see also Figs. 3 and 7). In the days mentioned by Giesecke in his written note (21–25 Feb), the temperature oscillated constantly between -34 °C and -36.5 °C (see Fig. 3). It seems to us that, although the entire series of temperatures from Nuuk (1873–2021; data from Meteorologiske Aarbøger 1874–1957 and Drost Jensen 2022) reveals that the maximum MDAT change from one day to the next was of 20.7 °C (from 7 to 8 March 1939), we cannot assume that the historical value of 35.6 °C is incorrect.

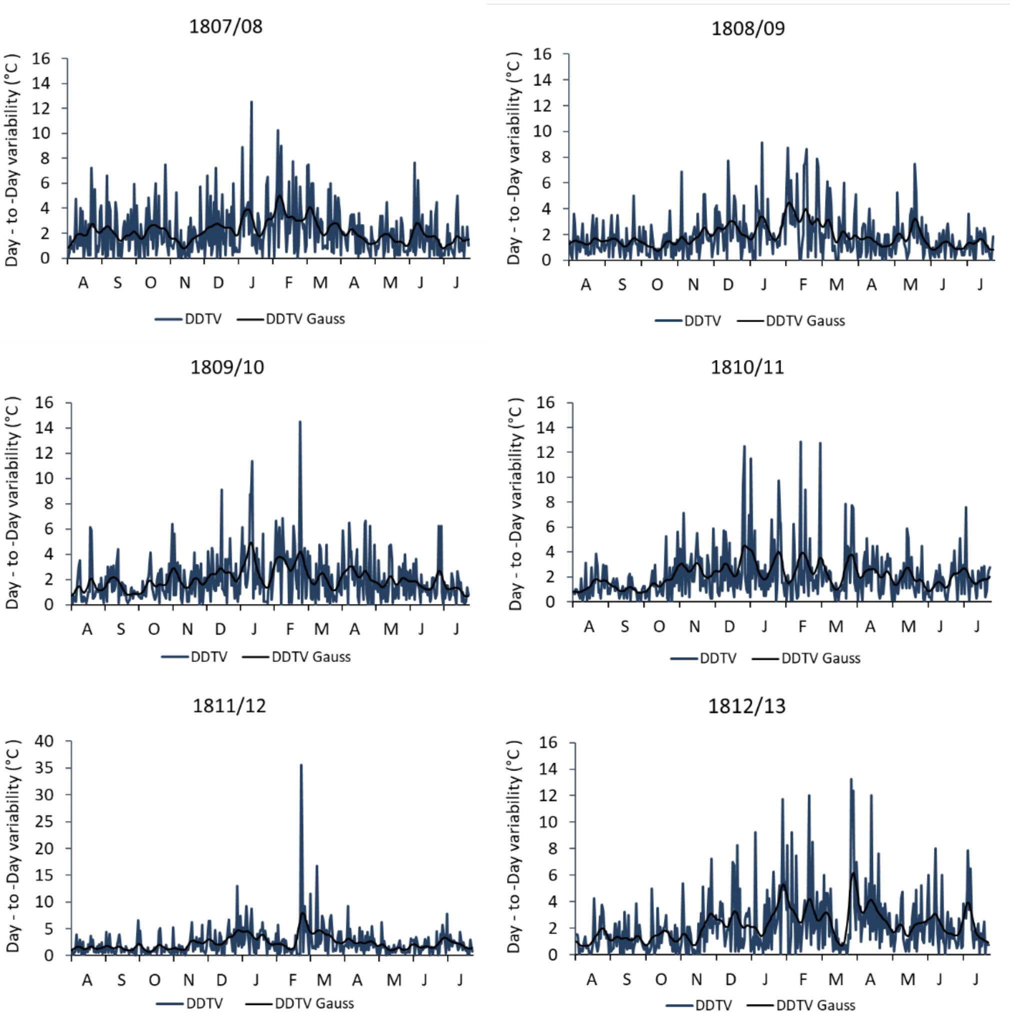

Fig. 9. Annual courses of DDTV in Nuuk in historical periods. Individual days (grey) are filtered by a Gaussian low-pass filter (black) with a standard deviation of 3 d in its distribution, corresponding to a rectangular filter of about 10 d.

*In February 1812 the shift from –35.6 °C to 0 °C produced an exceptional DDTV of 35.6 °C, requiring the vertical axis to extend to 40 °C to capture the full variability

The question arises: What could be the reason for such great heating from one day to the next? From the meteorological register, we know that, from the evening of 25 February to the morning of 26 February, the wind direction changed from NE to SE (see Fig. 3). From Fig. 11, it is evident that, in Nuuk in the historical period in winter, such a change of wind direction brought an average warming of about 14 °C. We can only speculate that, during the night, a very strong fohn may have occurred from the area of the Greenland ice sheet, significantly enhancing the effect associated with the mentioned change in direction of air mass inflow (Putnins, 1970).

To compare the DDTV shown in Fig. 9 against the analogous data from contemporary years, two thermally contrasted years from the period 1991–2020 were selected (i.e., the warmest [2018/19] and the coldest [1992/93]). The results presented in Fig. S1 show that the scale of differences between these two years and years taken from the historical period is similar. The average yearly differences in DDTV between years 2018/19 and 1992/93 reached only 0.3 °C, but the highest were in the first year. Therefore, a more detailed comparison of the DDTV in the historical period is shown only for the year 2018/19 (Fig. 10).

The averaged annual DDTVs in Nuuk, during the studied historical years, were usually slightly greater (by 0.1 to 0.5 °C) than in 2018/19. Looking at the annual cycle, it is evident that the greatest positive differences were usually noted between September and March, and the smallest occurred in the rest of the year (see Fig. 10). Such changes in DDTVs are in line with expectations, which are that, in a warmer climate, a decrease in high-frequency temperature variability should be observed (e.g., Karl et al. 1995; Zwiers & Kharin, 1998; Przybylak, 2002).

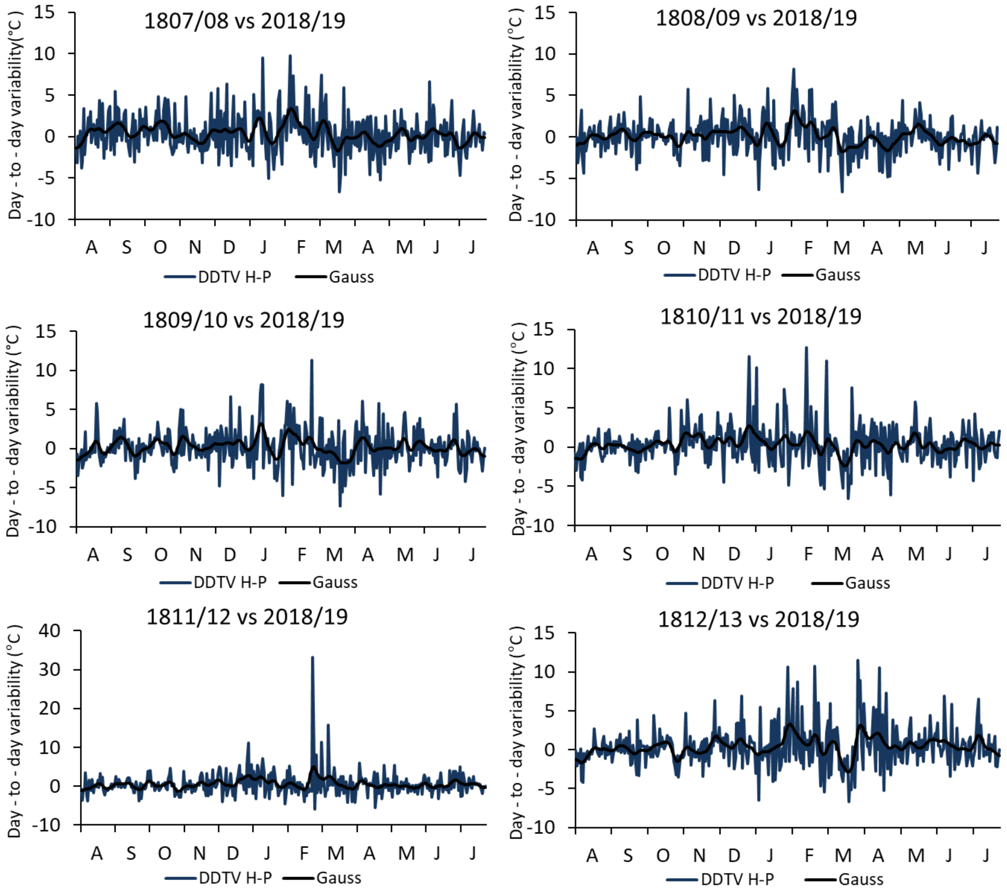

Fig. 10. Differences in DDTV in Nuuk between historical and contemporary (2018/19) periods. Individual daily differences (grey) are filtered by a Gaussian low-pass filter (black) with a standard deviation of 3 d in its distribution, corresponding to a rectangular filter of about 10 d.

*In February 1812 the shift from –35.6 °C to 0 °C produced an exceptional DDTV of 35.6 °C, requiring the vertical axis to extend to 40 °C to capture the full variability.

3.2.3. Temperature versus wind directions

The analyzed series of observations available for the years 1807–13 also contains observations of wind directions. Therefore, we decided to calculate how, on average, wind direction influenced the value of MDATs both in historical and contemporary periods. For this purpose, we use “thermal roses” consisting of eight wind directions. They were constructed for all seasons and for the year (Fig. 11). It is clear that, at present, wind direction influences air temperature in Nuuk significantly less than it did in historical times; the roses are more regular. In historical times, the deviation from circular symmetry of thermal roses is especially great in winter and spring. From historical to present times, the greatest thermal conditions in winter and spring changed for the winds coming from the sector N–NE and also E in winter and NW in spring (Fig. 11). The explanation of these changes remains an open question.~~unknown~~. One likely explanation is ~~However, it is possible that one reason is connected with~~ the recession, in the last 200 years, of the Greenland ice sheet and local icefields surrounding Nuuk to the ~~northern~~ north-east (Lea et al. 2014a, b). In all seasons, winds from all directions bring warmer air masses at present than in the historical period, except for winds from some southern directions in winter (Fig. 11).

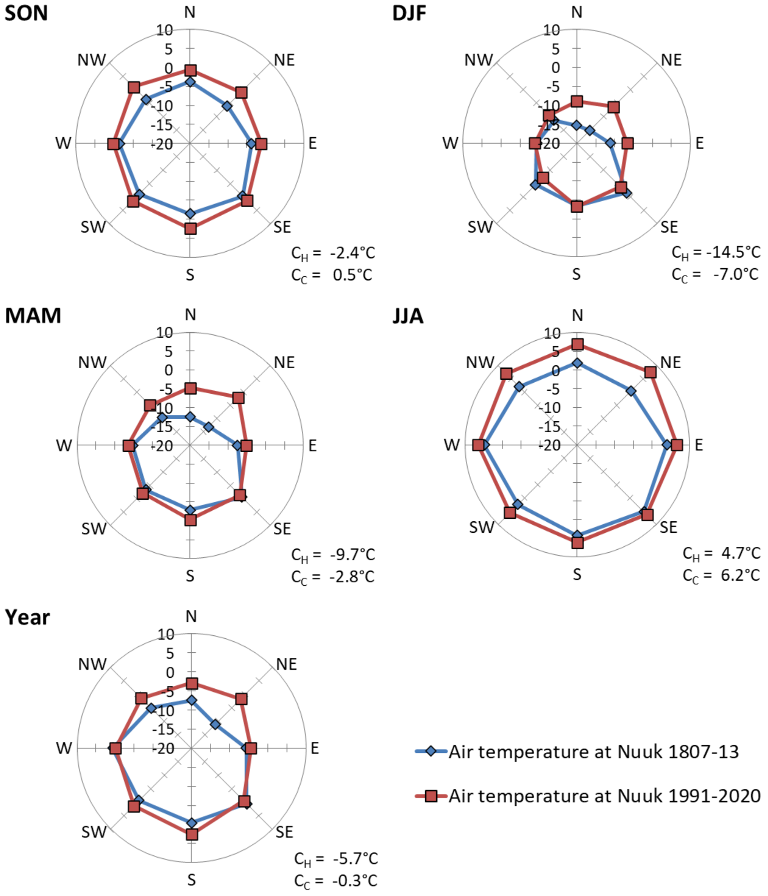

Fig. 11. Seasonal and yearly thermal roses of wind in Nuuk in the historical (1807–13) and contemporary (1991–2020) periods

3.2.4. Thermal seasons

At the moderate latitudes, to distinguish the thermal seasons (winter, spring, summer, and autumn), three thresholds are usually used, i.e. 0 °C, 5 °C, and 15 °C. For the Arctic, including Greenland, such thresholds are not appropriate because, as Przybylak et al. (2024) write, "the annual cycle is significantly flatter and less clear than at moderate latitudes and is dominated by the winter, which is much longer than the other seasons" (Przybylak 2016). For this reason, for the polar regions, Baranowski (1968) proposed other criteria to delimit the four standard seasons using the thresholds -2.5 °C, 0 °C and 2.5 °C (for details, see Przybylak et al. 2024). Using this division of the year into seasons has the additional advantage that, in addition to providing information about the value of the average temperature or other weather elements, it makes it possible to study changes in the durations of seasons, as well as their changes in dates of onset and ending. All this information is very important for people's everyday lives and also, for example, for agricultural, economic and tourist activities.

In the historical time, the longest season was winter, varying from 161 days in 1809/10 to 221 days (1810/11), and the shortest was spring (from 32 to 85 days) (Fig. 12). On average, winter lasted 191 days, i.e. more than half of the year. The durations of the other seasons were roughly equal to one another, at 50 days for spring to 64 days for summer. From historical to contemporary times, the duration of summer has increased markedly – on average, by 58 days (Fig. 12). The other seasons showed decreases in duration, ranging from 13 days for spring to 27 days for winter, i.e. each of less than half the scale of the increase in summer duration.

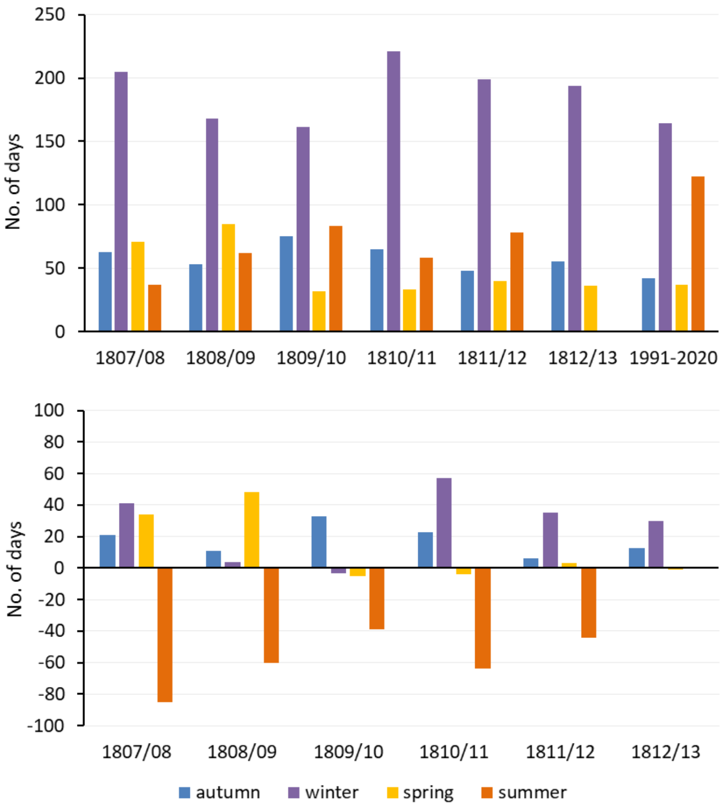

Fig. 12. Duration of thermal seasons in Nuuk in the historical (1807–13) and modern (1991–2020) periods (upper figure) and their differences (lower figure). Key: contemporary data were subtracted from historical data.

4. Discussion and conclusions

This newly discovered series of meteorological measurements in Nuuk (SW Greenland), encompassing a complete series of observations from August 1807 to July 1813, is very unique and therefore very valuable for the study of climate in this part of the Arctic. Analyses of the history of early instrumental meteorological observations, conducted by Przybylak et al. (2010) for the entire Arctic and by Vinther et al. (2006) for Greenland, lead to the conclusion that the newly discovered series is the longest which exists for the Arctic prior to the 1840s. Its usefulness, apart from providing detailed insight into the climatic conditions in SW Greenland at the beginning of the 19th century, is much broader. The data can be used for the calibration of, among others: (i) climate reconstructions based on various proxy data; (ii) climate reconstructions based on models; and (iii) climate reconstructions from the NOAA/CIRES/ DOE 20th Century Reanalysis (V3) (20CRv3) available for 1806–2015 (see also Slivinski et al. 2019, 2021). Slivinski et al. (2021) documented that the 20CRv3 is a good tool for reconstructing even extreme weather and climate events, and we therefore plan to use this reanalysis to study (in a separate paper) the reason for the described great warming from 25 to 26 February 1812.

Better knowledge about the climate in Greenland at the beginning of the 19th century can help explain the reasons for very cold spells that have occurred on this island in the past millennium. We documented in the Results section that the temperature in the study period was considerably lower than in the contemporary period (1991–2020). We also checked how this period compares thermally with other available instrumental data (the newest and the oldest). For this purpose, we calculated 30-year average temperatures (Aug 1870–Jul 1900, Aug 1900–Jul 1930, …, Aug 1990–Jul 2020), starting from the beginning of the available continuous series of meteorological measurements in Nuuk since 1866 (Przybylak, 2000; Vinther et al., 2006) (Fig. 13). Moreover, in order to have periods that are more comparable in length with the study period, we also chose, from the entire mentioned series (1870–2020), two six-year periods representing the periods that were the warmest (1926–32) and the coldest (1881–87) and simultaneously described the range of thermal changes in 1870–2020 (Fig. 14a). For Nuuk, for the period before 1870, a complete five-year series of temperature data (1816–20) is also available that was gathered by Vinther et al. (2006). It is worth adding that this series includes the year 1816 (called the “year without summer”), which was one of the coldest years in all the Northern Hemisphere (due to the Tambora eruption, see Raible et al. 2016). We used this 1816–20 series for comparison against the thermal state of the period 1807–1813. In addition, we also added a curve to Fig. 14a that represents the mean yearly cycle of temperature based on data available for the period 1784–92 (after Przybylak et al. 2024). How the available datasets from reanalyses (20CRv3 and ModE-RA) reconstruct the surface air temperature is shown in Figs. 5 and 14b. Figs. 13 and 14 clearly indicate that the period under study was extremely cold. It was significantly colder than: i) all 30-year periods; ii) the coldest six-year period in the series 1871–2020; iii) the late 18th century; and iv) reconstructed temperature for the period 1807-13 by 20CRv3. The period 1807–13 was also colder (but only slightly) than the five-year period 1816–20. Only the ModE-RA data are significantly colder than the measured data from October to February, while for the remaining months they are similar (Fig. 14b). Vinther et al. (2006) concluded that the decade 1810 was the coldest in the entire record available for Nuuk, i.e. since 1784. They have at their disposal data from the mentioned five-period as well as for the years 1811 and 1812. The data come, however, from another locality than the place of meteorological observations made by Giesecke. A comparison of data for the latter two years (1811 and 1812) presented by Vinther et al. (2006) and in this study is shown in Fig. S2. There is a good coherence between monthly means from June to December, but in the rest of the year, the differences are quite large. The reasons for these are difficult to explain, but they may be connected mainly with the localities of measurement places being different. Probably, the data presented by Vinther et al. (2006) comes from a site located near the coast, while Giesecke's site is assumed to have been located at some distance from the coast and probably also at a higher altitude. Brohan et al. (2010) studied Arctic marine data from the seas surrounding the south part of Greenland in the period 1810–25 and found that this period was also “significantly cooler than that of today”.

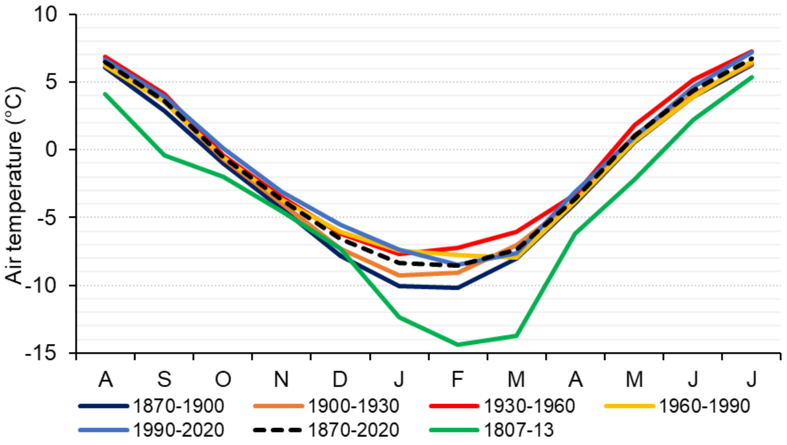

Fig. 13. Yearly cycle of mean air temperature in Nuuk in the period 1807–13 compared to the mean from the entire series (1870–2020) and means calculated from that series for 30-year periods (data taken from Vinther et al. 2006).

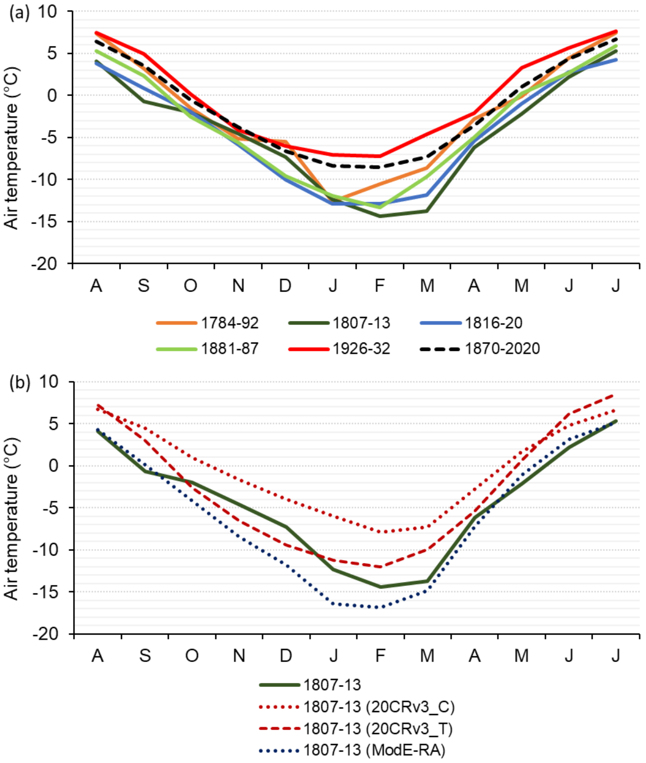

Fig. 14. Yearly cycle of mean air temperature in Nuuk in the period 1807–13 compared to: a) the mean for 1870–2020 and for various short-term series available since the late 18th century. Explanation: 1784–92 – data after Przybylak et al. (2024); 1816–20 – data after Vinther et al. (2006); Jan 1870–Jul 1990 – data after Vinther et al. (2006); Aug 1990 – 2020 data after Cappelen and Drost Jensen, 2021, and b) the mean for 1807-13 taken from reanalyses: 20CRv3 (C – coastal grid point, T – terrestrial grid point; Slivinski et al., 2019) and ModE-RA (Valler et al., 2024)

The question arises as to whether and to what extent this cold period in SW Greenland at the beginning of the 19th century is correctly reflected in air temperature reconstructions based on proxy data and computer climate simulations. Unfortunately, in the area of Nuuk, there does not exist any series of proxy data of value for the reconstruction of air temperature; the closest according to Kaufmann et al. (2009) and McKay and Kaufmann (2014) is located in Lake Braya Sø, lying about 313 km to the north (φ= 67° 00' N, λ= 50° 42' W). Lake sediments allow for reconstructing summer temperature only, according to Table 1 in McKay and Kaufman (2014), but the reconstruction is not shown. Further north in the Ilulissat region, there are other lakes for which proxy data are available, and it is possible to reconstruct July temperature based on chironomids present in sediments (Axford et al., 2013), which were not included in the paper written by McKay and Kaufman (2014). The temperature reconstructions presented in Axford et al. (2013) are not of sufficient resolution to be used for comparing short-term temperature changes in the last millennium. Most of the proxy data for Greenland (and the most well-known) come from the Greenland Ice Sheet. According to the information given in Table 1 (McKay & Kaufman, 2014), ten series of proxy data exist in a PAGES Arctic 2k database published in 2013 by PAGES 2k Consortium. Two more such data series can be found in the publication of Jones and Mann (2004), who used data from Fischer et al. (1996) and Vinther et al. (2003). All of them use ice-core data (δ^{18}O) and allow for the reconstruction of annual mean temperatures. Recently, two series of annual air temperatures for central (Kobashi et al., 2010) and central-northern (Hörhold et al., 2023) Greenland for the last millennium were reconstructed using ice-core data, i.e. isotope ratios of nitrogen (15N/14N) and argon (40Ar/36Ar) in air bubbles and δ^{18}O, respectively. According to Kobashi et al. (2010), the beginning of the 19th century saw one of the coldest temperatures in the last millennium; lower temperatures were noted only in two short periods in the 18th century and in the first half of the 17th century. The reconstruction presented in Fig. 1 of Hörhold et al. (2023) shows a picture for central-northern Greenland that differs only slightly. It shows four periods of similar size cooling in the last millennium, including one in the first half of the 19th century. It also shows that the mean annual air temperature at the beginning of the 19th century was about 3 °C colder than the present time and about 2 °C colder than medieval times. Using instrumental data from Nuuk from the periods 1807–13 and 1991–2020, we found a 3.3 °C increase in annual air temperature from historical to present times. This indicates a very good agreement between the measured and temperatures reconstructed using ice-core data. As we mentioned earlier, such a good correlation (r=0.67 and r=0.60 for the periods 1785–1872 and 1873–1970, respectively) between the extended SW Greenland temperature series and the ice-core was also found by Vinther et al. (2006). Hörhold et al. (2023) found that the Arctic 2k reconstruction after McKay and Kaufman (2014), which represents large parts of the higher Arctic circumpolar region, shows a low correlation over Greenland. Nevertheless, the greatest cooling in the last millennium, according to the Arctic 2k reconstruction, evidently occurred at the beginning of the 19th century. This is particularly clear for the revised PAGES 2k Arctic reconstruction (see Fig. 2 in McKay and Kaufman, 2014). According to that reconstruction, the mean annual Arctic air temperature at the beginning of the 19th century was about 2 °C colder than at present. Arctic-wide summer-weighted annual temperature reconstructed for the last 400 years by Overpeck et al. (1997, see their Fig. 3) also shows that a great cooling started at the beginning of the 19th century but peaked in the 1840s. The temperature at this time was about 1.5 °C colder than in the late 20th century. Also, the spatially resolved two-millennium summer (Jun–Aug) temperature reconstructed for the Arctic and sub-Arctic domain (north of 60°N) calculated by Miller et al. (2010) reveals a great cooling in the first half of the 19th century, being one of the three coolest episodes in the two millennia analyzed. In comparison to the present, the temperature in the first half of the 19th century was about 2 °C colder (see their Fig. 2). This reconstruction is very close to the reconstruction of mean annual air temperatures presented by McKay and Kaufman (2014); the latter, however, shows a cooling that was greater and occurred earlier than in the case of reconstructed summer temperatures (see Fig. 3 in Miller et al. 2018). A two-millennium summer (Jun–Aug) temperature reconstruction over the Arctic and sub-Arctic domain (north of 60°N) is also presented by Werner et al. (2018). They used a set of 44 annually dated temperature-sensitive proxy archives of various types from the PAGES 2k database, revised in 2017. Also, in this reconstruction, a cooling at the beginning of the 19th century is evident that is the greatest of the entire 2000 years. Werner et al. (2018) compared their reconstruction with the other six reconstructions published in recent years and found their reconstruction to be very close to that presented in the work of McKay and Kaufman (2014). The summer cooling, however, according to this reconstruction (see Fig. 3 in Werner et al. 2018), was about 0.5 °C smaller than McKay and Kaufman’s reconstruction. Other reconstructions presented by Werner et al. (2018) in their Fig. 3 (i.e., Kaufman et al., 2009; Shi et al., 2012; Hanhijärvi et al., 2013; Tingley & Huybers, 2013) also confirm the occurrence of significant cooling, except the last-cited paper. In conclusion, we can state that the cooling in the first half of the 19th century was common throughout the Arctic, including Greenland.

Let us now check how climate models reconstruct this period in Greenland and the Arctic. According to the annual mean surface temperature reconstructed for the Arctic using an ensemble of five simulations performed with a global three-dimensional, atmosphere–sea-ice–ocean model driven by both natural (solar and volcanic) and anthropogenic (increase in greenhouse gas concentrations and tropospheric aerosols) forcings, the last millennium featured four periods of great cooling. These were in the mid-11th century, the second halves of the 15th and the 17th centuries, and the beginning of the 19th century (see Fig. 1c in Goose and Renssen, 2003). The last two cooling periods simulated by the model occurred in the years 1670–1700 and 1800–30, when surface temperatures were about 0.5 °C colder than the mean in the Arctic from the period 1000–1850. Another modelling work, presented by Crespin et al. (2013), using the three-dimensional Earth system model of intermediate complexity LOVECLIM forced by changes in solar irradiance, volcanic activity, land use, greenhouse gas concentrations and orbital parameters, also shows a very cold period in the first half of the 19th century. This was the coldest period in the entire last millennium. The temperature difference in comparison to present times reached about 1.8 °C. Figure 1.4 in Crespin (2014) shows that simulations of annual mean Arctic temperature in five different GCM models (CCSM4 [USA], GISS-E2-R [USA], IPSL-CM5A-LR [France], MPIESM-P [Germany], and Bcc-csm1-1 [China]) confirm the existence of cold period in the first half of the 19th century, but this was not always found to be the coldest period in the past millennium.

According to investigations conducted by Crespin et al. (2013) and Crespin (2014), the reasons for this great cold period at the beginning of the 19th century were mainly intense volcanic activity, in particular in the period 1810–40, and a smaller-scale decrease in solar irradiance connected with the Dalton minimum occurring in 1790–1830 (most intensely in 1797–1827; Silverman & Hayakawa, 2021) as well as changes in land use. Volcanic eruptions were the main reason for the cooling that occurred in the 1810s (in particular, in 1811 and 1817–18), according to Vinther et al. (2006). They connected these two cold spans with eruptions of an unidentified volcano around 1809 and the very well-known eruption of the Tambora volcano in 1815, respectively. Our results, presented in Fig. 5, confirm the existing finding of Vinther et al. (2006), i.e. the existence of very cold temperatures in the first years of the 1810s. According to our data, a cooling occurred after 1809 that was initially small in winter 1809/10 and then significantly greater in the following three winters, 1810/11–1812/13. This cooling is also observed in data from palaeoreanalysis (ModE-RA), but not in the data from the 20th Century Reanalysis (20CRv3). In summer, some cooling is evident only in 1811. As a result, the coldest expedition year after a volcanic eruption in 1809 occurred in 1810/11. Data series presented in Fig. 5 (except 20CRv3) also confirm Schneider et al.'s (2017) finding that, after the 1809 event, temperatures remain low until the Mt. Tambora eruption of 1815. Changes in atmospheric circulation that occurred after this eruption, from a negative to a positive NAO indices in wintertime (see Luterbacher et al., 2002a, b), caused a change in wind directions in SW Greenland, (i.e., domination of winds from the northern sector, see Fig. 6). Positive phase of the NAO cause a significant decrease (3–6 °C) of winter 1810/11 air temperature in the western part of Greenland in contemporary series of data, particularly in its SW part (see Fig. 12 in Przybylak 2000). A similar finding was recently presented by Faust et al. (2025, submitted; see their Fig. 4) for south-west Greenland, based on temperature reconstruction using a high-resolution sedimentary record for the late Holocene. Box (2002), investigating air temperature variability in Greenland from 1873 to 2001, found that the greatest anomalies during this period were also linked to large volcanic eruptions, sea-ice extent, and the NAO. Brohan et al. (2010), analyzing marine data extracted from the reports of the noted whaling captain William Scoresby Jr (Greenland Sea) and from the records of a series of Royal Navy expeditions to the Arctic preserved in the UK National Archives, concluded that the cold early-19th-century climate was linked with low solar activity and followed a series of large volcanic eruptions.

Summarizing the obtained results, we can again underline that the first two decades of the 19th century in the study region, in all of Greenland and on average in the Arctic, were, according to reconstructions based on proxy data (Miller et al. 2010; Werner et al. 2018), one of the coldest periods in the past two millennia (and possibly the coldest). It is also probable that such a large scale of cooling and its durability are one of the main reasons that almost all available reconstructions of air temperatures using different proxy data or using climate models for this purpose are almost fully consistent with the available meteorological observations for this period. For example, such good correlations between instrumental temperature data and different reconstructions are not observed for analyses encompassing the earlier period (1784–92) for SW Greenland (for details, see Przybylak et al., 2024). The late 18th century in SW Greenland and many places in the Arctic was warm, but the warming in this time was not so spectacular as the cooling that occurred in the Arctic at the beginning of the 19th century. Also, a good agreement exists concerning the reasons for the cooling of the early 19th century in

Greenland and the Arctic. The two main reasons underlined by most authors studying this issue are mainly intense volcanic activity and, to a lesser degree, low solar activity connected with the Dalton minimum. In addition, land use changes in mid-latitudes are also mentioned by some researchers. Changes in atmospheric circulations described using the NAO must also be taken into account in the case of SW Greenland's climate.

There are many advantages of instrumental observations in comparison to the possible reconstruction of climate using proxy data and simulations by climate models. Reconstructions are less precise, have smaller resolution and are limited most often to i) only some parts of the year (mainly to summer) and ii) one main climate variable (air temperature). For this reason, searching for new meteorological data series in archives and libraries is extremely important and necessary. It seems that it should still be intensified despite the fact that, for the last approximately 30–40 years, this type of activity has been carried out intensely worldwide. The newly discovered unique series of meteorological observations for SW Greenland for the period 1807–13 that is presented in this article proves that new data of this type can still be found for various parts of the globe, including the Arctic, where they are many times more valuable than comparable data for moderate latitudes (for which the network of stations is significantly denser). Unfortunately, fewer scientists are involved in this type of data rescue activity for the Arctic at present than in previous times. ~~Most scientists are focused on climate reconstructions based on proxy data and climate model simulations, which is very good, but we should also motivate young scientists to be more interested in the history of the Arctic climate based on early instrumental observations and other documentary evidence.~~

Data availability. Datasets of surface air temperature for this research were derived from the following public domain resources:

1. Repository for Open Data (RepOD), Nicolaus Copernicus University Centre for Climate Change Research collection, https://doi.org/10.18150/IGYNGV, as cited in Przybylak et al. (2025),
2. Vinther et al. (2006) and Danish Meteorological Institute (DMI); https://www.dmi.dk/publikationer/, as cited in Cappelen and Drost Jensen (2021) and Drost Jensen (2022),
3. Repository for Open Data (RepOD), Nicolaus Copernicus University Centre for Climate Change Research collection, https://doi.org/10.18150/L1Y21Q as cited in Singh et al. (2023),
4. The NOAA/CIRES/DOE 20th Century Reanalysis (V3) (20CRv3), https://www.psl.noaa.gov/data/gridded/data.20thC_ReanV3.html (Slivinski et al. 2019)
5. The Modern Era Reanalysis (ModE-RA, Valler et al. 2024) via ClimeApp https://mode-ra.unibe.ch/climeapp/ (Warren et al. 2024)

Data available upon reasonable request from the Department of Meteorology and Climatology, Nicolaus Copernicus University:

1. Photos of Meteorologisk Aarbøger (Danish Meteorological Yearbooks), 1874–1957, Det Danske meteorologiske Institut, Kjøbenhavn

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