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Recovering nineteenth-century temperature and pressure measurements for Eurasian climate analysis

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Abstract. Historical instrumental observations are a valuable source of quantitative information on past climate variability, especially when printed records can be transformed into machine-readable datasets. This study uses meteorological observations published in the *Annalen des Physikalischen Centralobservatoriums* (Annals of the Central Physical Observatory) in St. Petersburg to assess their potential for Eurasian climate analysis. We digitized monthly temperature and pressure data from printed tables and converted them into a machine-readable dataset, addressing challenges related to station metadata, spatial coverage, multilingual headings, historical station names, decimal notation, missing entries, and optical character recognition errors. Using selected stations, we construct monthly surface air temperature and pressure anomaly maps for 1877 and 1879 relative to station-specific monthly reference means based on the other available years within 1874–1894. The year 1877 falls within the major 1877–1878 global climate anomaly, while 1879 provides a contrasting case. The station-based anomaly maps show coherent spatial structures across large parts of Eurasia. In 1877, late-year positive pressure anomalies over central and eastern Eurasia are accompanied in December by widespread cold anomalies. In 1879, the maps show stronger regional contrasts and a markedly different December pressure pattern. Our results demonstrate that the *Annalen* observations are valuable not only as historical records, but also as quantitative data for studying nineteenth-century atmospheric variability.

1 Introduction

In the nineteenth century, meteorological observing practices became increasingly organized into systematic programs. Measurements were made more routinely, instruments and procedures became more standardized, and observations from different sites became progressively more comparable and suitable for compilation into shared tables and serial publications (U.S. National Library of Medicine (Digital Collections), n.d.). Such publications were not only scientific outputs, but also practical media of standardization: by fixing station names, observing hours, instrument categories, tabular formats, and reduction procedures, they made it possible to compare observations across large territories and over many years. On a broader scale, these developments formed part of the rise of national meteorological institutes and observing services in the nineteenth century (Edwards, 2023). Modern inventories and global compilations of early instrumental records further demonstrate the scientific value of recovering dispersed observations and transforming them into analyzable datasets (Allan et al., 2011; Brönnimann et al., 2018, 2019; Lundstad et al., 2023).

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Across Europe, these developments were accompanied by the expansion of national meteorological networks and by growing exchange across political borders. They culminated in the Vienna Congress of 1873, which is commonly regarded as a key step in the emergence of the International Meteorological Organization (World Meteorological Organization (WMO), n.d.). The subsequent history of data rescue, homogenization, and regional synthesis is illustrated by products such as HISTALP, which show how heterogeneous historical series can be transformed into internally consistent datasets suitable for climate analysis (Auer et al., 2007). At the same time, detailed studies based on original observing journals demonstrate that historical measurements can be critically assessed and productively reused when their documentary context and metadata are sufficiently well preserved (Pliemon et al., 2022). More generally, the interpretation of long instrumental series depends not only on digitization, but also on careful metadata assessment, quality control, and homogenization (Venema et al., 2012). A further prerequisite is the practical assessment of the sources themselves: whether their printed tables, typography, station nomenclature, and numerical layout make them suitable for reliable digitization and subsequent quality control.

Within this wider international setting, a coordinated meteorological observing system developed across a large part of northern Eurasia during the nineteenth century. Its institutional center was the Central Physical Observatory in St. Petersburg, whose activity, as reported by A. T. Kupffer, began on 1 July 1849 (Kupffer, 1843, 1849). Kupffer, a Baltic-German physicist and metrologist, played a central role in organizing physical observation, including efforts to establish common standards of weights and measures. His concern with standardization also shaped the observatory's meteorological programme, which aimed to collect observations according to common instruments, procedures, and reporting practices. The resulting annals were intended to follow international standards of presentation and measurement, allowing observations from distant stations to be compared both with one another and with data from other countries. After Kupffer, the development of the Central Physical Observatory and its observing network was continued under Heinrich von Wild, who became director in 1868 and held the post until 1895 (Gorgé, 2014). Wild, a Swiss physicist and meteorologist, further expanded the station network and placed increasing emphasis on the regularity, comparability, and centralized publication of observations (ZDB – Zeitschriftendatenbank, n.d.; Deutsche Digitale Bibliothek, n.d.; HathiTrust Digital Library, n.d.). These centrally published station records provide a rare opportunity to examine a relatively standardized set of meteorological observations from a large part of northern Eurasia and to evaluate the practical recoverability of the source material itself.

The spatial extent of this network is important because the *Annalen* reported, among other variables, station-level barometric pressure and temperature. Together, these variables make the material relevant not only for local climatology, but also for the study of large-scale atmospheric variability. Pressure observations provide information on the spatial structure of circulation anomalies, while temperature observations show how these anomalies were expressed at the surface. This is especially relevant over Eurasia, where persistent pressure anomalies can influence temperature, snow conditions, and hydrological variability over very large regions, particularly during the cold season. When such anomalies are sufficiently persistent and spatially organized, they may be related to atmospheric blocking or blocking-like circulation regimes (Dole and Gordon, 1983; García-Herrera and Barriopedro, 2006; Woollings et al., 2018).

The circulation perspective is particularly relevant for the late nineteenth century, when the background climate state differed from that of the present day. Relative to 1850–1900, global surface temperature in 2001–2020 was approximately 0.99 °C

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higher (IPCC, 2023). This warming has been accompanied by substantial changes in Northern Hemisphere cryospheric conditions, including a decline in snow-cover extent (Mudryk et al., 2020). Such changes matter for Eurasia, where snow cover, persistent snow and soil conditions, and lower-atmospheric processes can modulate the surface response to circulation anomalies. Reconstruction-based and process-oriented studies indicate that cold-season anomalies over Eurasia may persist through snow-cover feedbacks even after the circulation anomaly that initiated them has weakened (Valler et al., 2022). The *Annalen* observations therefore offer a way to investigate how circulation anomalies and their surface impacts appeared under late nineteenth-century boundary conditions.

The material also contributes to broader historical data-rescue and reconstruction efforts. Early instrumental observations remain difficult to use quantitatively when they are preserved in printed or archival sources rather than in machine-readable form (Allan et al., 2011; Stickler et al., 2014; Brönnimann et al., 2018, 2019; Lundstad et al., 2023). Recent data-rescue studies have demonstrated the value of recovering temperature and pressure observations from original documentary sources, preserving raw values and metadata, and making the resulting series available for historical climate analysis and reanalysis applications (Brugnara et al., 2015; Ashcroft et al., 2018; Brugnara et al., 2020). Regional historical datasets show how rescued observations can support long-term climate analysis when accompanied by careful metadata work and homogenization (Auer et al., 2007; Trewin, 2010; Venema et al., 2012). Studies of historical atmospheric conditions further demonstrate that recovered observations and reconstructions can be used to investigate specific extreme periods, including cold Eurasian winters and their relation to circulation and snow-cover feedbacks (Valler et al., 2022). The *Annalen* of the Central Physical Observatory add a distinct contribution to this literature because they provide centrally compiled, spatially extensive, and relatively standardized station observations from a large part of northern Eurasia during the late nineteenth century.

We focus on 1877 and 1879 as two selected demonstration years. The year 1877 falls within the major 1877–1878 global climate anomaly, while 1879 provides a contrasting case for testing whether the digitized observations distinguish different circulation states and their surface-temperature expressions. This allows us to test whether the digitized *Annalen* data can support spatially coherent analyses of historical circulation variability, rather than serving only as a collection of isolated station records. The study therefore bridges data rescue and dynamical climate interpretation: it documents the source material, evaluates its digitization potential, and illustrates how nineteenth-century observations may contribute to the study of circulation anomalies over a large continental domain.

The study has three aims. First, we characterize the meteorological observations published in the *Annalen* as a historical dataset for climate and meteorological research. Second, we assess whether the published observations can be digitized in a systematic and reliable way, including the practical challenges posed by tabular structure, station metadata, typography, language, and numerical consistency. Third, we illustrate the analytical potential of the recovered data using monthly station-based maps of surface temperature and pressure anomalies for 1877 and 1879. The paper thereby contributes both to the recovery and documentation of historical meteorological data and to the use of nineteenth-century observations for studying large-scale atmospheric variability under climate conditions different from those of the present day (Brönnimann et al., 2019; Lundstad et al., 2023).

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2 Data

2.1 The *Annalen* and the observing network

The source material used in this study comes from the annual publications of the Central Physical Observatory in St. Petersburg. These publications were not handwritten station journals, but centrally compiled and typographically printed annual tables. The observations had therefore already passed through an institutional process of collection, organization, and standardization before publication. This gives the series a relatively uniform tabular structure and makes it particularly valuable for data rescue, while also meaning that the present dataset reflects the published version of the observations rather than the full original observing records.

Fig. 1 shows the spatial development of the measurement network between 1870 and 1890. It highlights both the marked densification of the network in European Russia and the eastward and southward expansion of observations across Siberia, Central Asia, and East Asia. By 1890, the network covered a large part of northern Eurasia and also included several sites beyond this core region, among them Beijing, Tehran, Seoul, and Urga (present-day Ulaanbaatar), where measurements were conducted at diplomatic sites. The series also includes observations from Sitka for 1860–1867, that is, from the years immediately preceding the transfer of Alaska to the United States in 1867. Taken together, these records provide a rare basis for studying late nineteenth-century surface meteorology through a geographically connected network rather than only through isolated station series.

The annals were issued in a parallel-language format. In the volumes up to 1869, the content was printed in both French and Russian, with the same information repeated in the two languages. From 1870 to 1894, this bilingual structure was retained, but German replaced French, so that the volumes were published in German and Russian. From 1895 onward, the series appeared in Russian, with part of the material also duplicated in French.

This changing language structure reflected both the administrative setting of the observing network and changes in the international languages of scientific communication. The early use of French alongside Russian was consistent with the role of French as an important language of scholarly and diplomatic communication in the nineteenth century and made the work of the observatory accessible to a wider European readership. The German-language phase, represented by the *Annalen des Physikalischen Centralobservatoriums*, coincided with the directorship of Heinrich von Wild and plausibly reflects both Wild's Swiss-German scientific background and the strong position of German in nineteenth-century physical, meteorological, and geophysical research. The renewed use of French after 1895 may be interpreted as a return to a broader international idiom, whereas the later transition to Russian-only publication in the twentieth century marks a further change in the intended readership and institutional setting of the series.

These language changes are also practically relevant for data rescue because titles, headings, station names, explanatory notes, and metadata may vary between publication phases. The geographical reference convention also changed. In the earlier French-language volumes, station longitudes were given relative to the Paris meridian, whereas in the later German–Russian volumes they were given relative to Greenwich. This distinction must be taken into account when station metadata are harmonized across the different editions.

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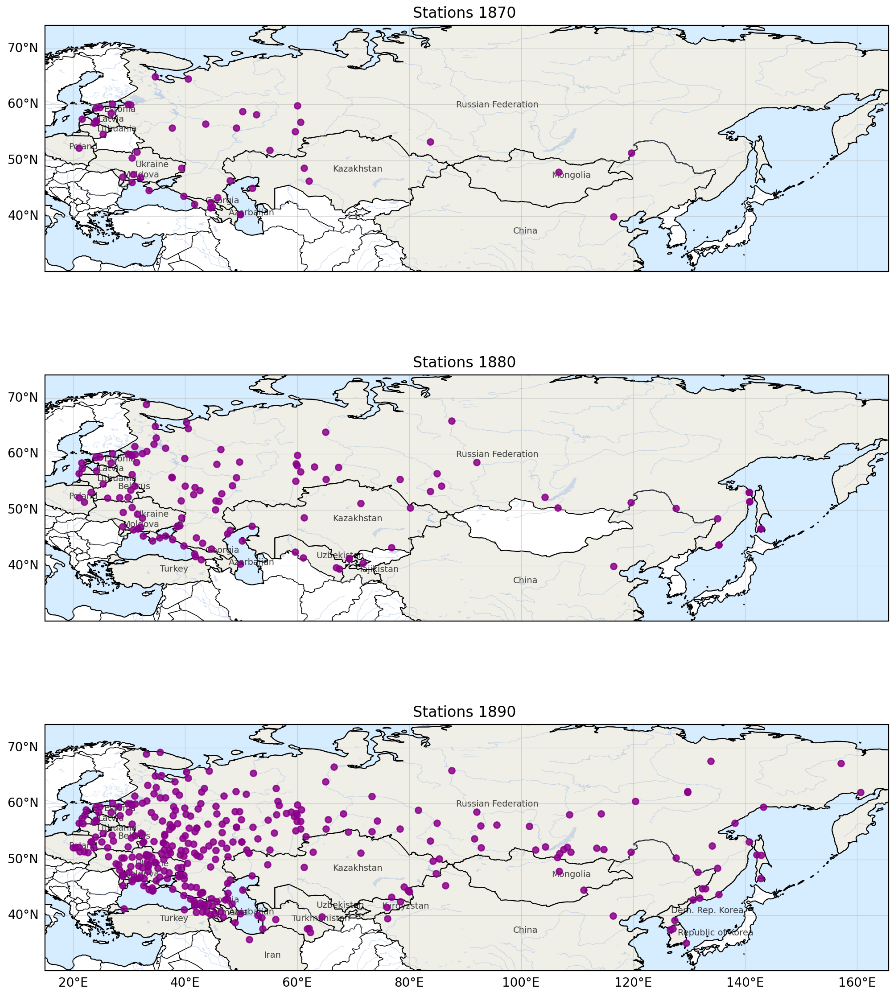

Figure 1. Development of the measuring network from 1870 to 1890. The upper, middle, and lower panels show station locations in 1870, 1880, and 1890, respectively. Purple points represent individual stations; grey shading highlights the present-day countries in which the stations were located.

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From 1878 onward, the annual volumes were issued in two parts. *Teil 1* was primarily devoted to magnetic observations and other specialized physical or geophysical measurements. These extended observations did not cover the full meteorological station network, but were restricted to a smaller number of observatories equipped for such measurements. Earlier geomagnetic material is known from observatories such as St. Petersburg, Ekaterinburg, Barnaul, Nerchinsk, and Peking/Beijing, while later specialized observatory publications also document magnetic observations at Tiflis/Tbilisi.

Teil 1 therefore documents the observatory's role not only as a meteorological institution, but also as a centre for broader geophysical monitoring, while reflecting more selective spatial coverage than the regular meteorological network. Some of the nineteenth-century geomagnetic material from this observatory network has already been digitized and analysed for the earlier period 1850–1862 (Nevanlinna and Häkkinen, 2010). *Teil 2*, in contrast, contained the meteorological observations from the wider station network, including the tabulated atmospheric variables used in the present study. The discussion below therefore concerns the meteorological material published in *Teil 2* of the annals.

2.2 Observing practices and published variables

Our study is based on records compiled and published for the period 1874–1894. By this time, measuring practices within the network had become highly systematized and the published material was particularly well suited to coherent network-based analysis. Measuring procedures were standardized across the stations, and at most sites atmospheric observations were made three times per day at the fixed observing hours of 7, 13, and 21.

Fig. 2 illustrates the resulting subdaily temperature and station-pressure observations for St. Petersburg in 1877. The close correspondence among the three observing times in the pressure series provides a useful illustration of the temporal consistency of the published daily observations.

The meteorological material in the *Annalen* is presented at two complementary levels. First, the volumes include daily station tables in which subdaily observations are reported for individual days and observing hours. Second, they include monthly summary tables that aggregate the observations into station-level monthly means, extrema, totals, or counts, depending on the variable.

Fig. 3 illustrates both forms of data presentation using the daily observations for St. Petersburg in January 1879 and the corresponding monthly summary tables for the same year. In the present study, we use the monthly values because they provide a consistent basis for comparing station anomalies across the network. The variables and headings appearing in the historical tables are summarized in Table 1.

The published temperature values are expressed in degrees Celsius. For temperature, humidity, and barometric pressure, the daily means were generally calculated as simple arithmetic means of the three fixed-term observations, and the monthly means were then derived from the available daily values. According to the introduction to the 1877 volume, days for which one of the three observations was missing were not assigned an interpolated daily mean.

The pressure values represent barometric pressure at the level of the instrument rather than pressure reduced to mean sea level. The barometer readings were corrected for documented instrumental effects and reduced to a standard mercury temperature of 0 °C; the height of the barometer above sea level was reported separately for each station. Because the present study

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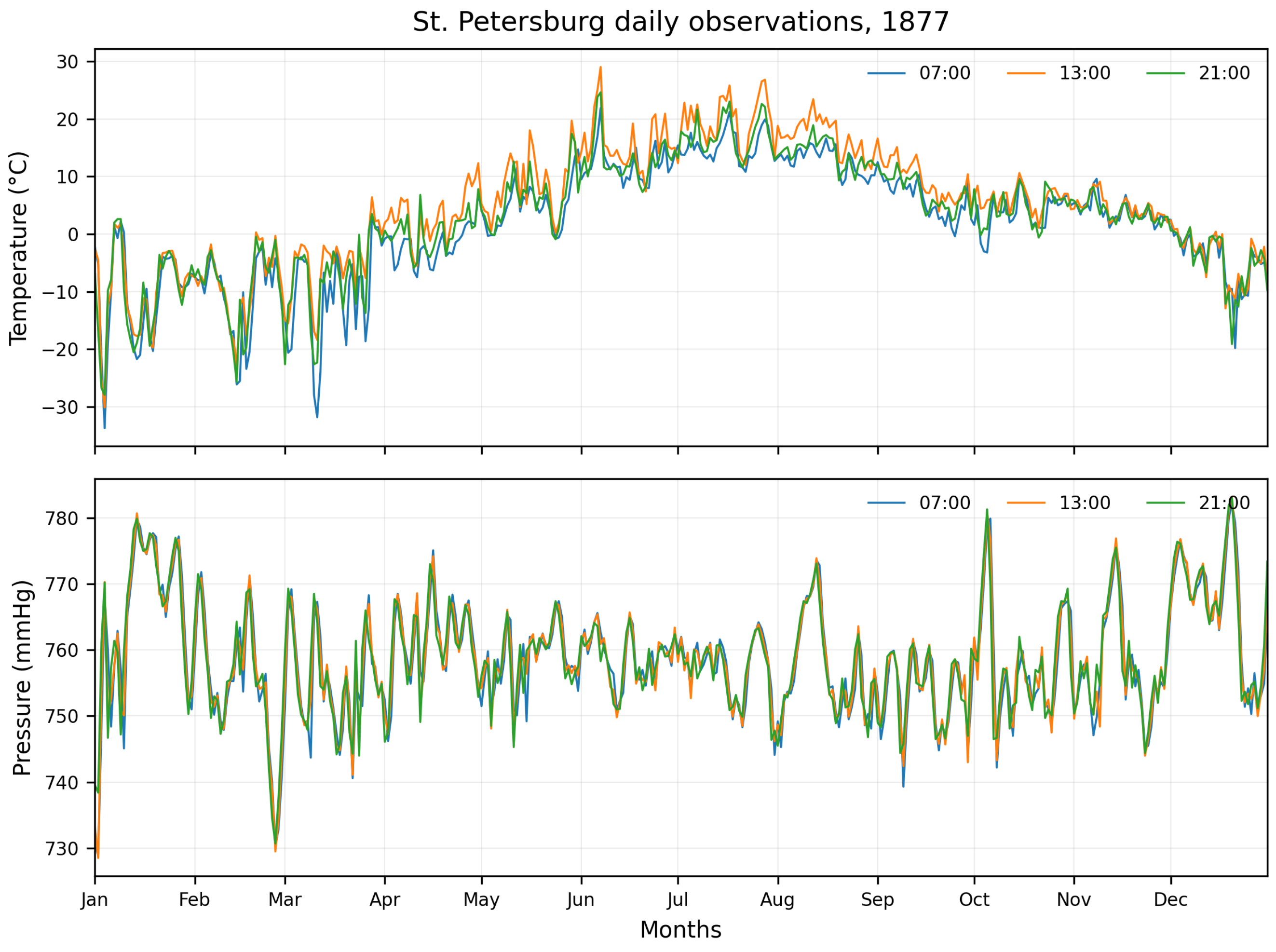

Figure 2. Daily temperature and station-pressure observations at St. Petersburg in 1877 at the three standard observing times of 07:00, 13:00, and 21:00. The upper panel shows air temperature in °C, and the lower panel shows barometric pressure in mmHg at the level of the instrument. The figure illustrates the subdaily temporal resolution of the observations published in the *Annalen*.

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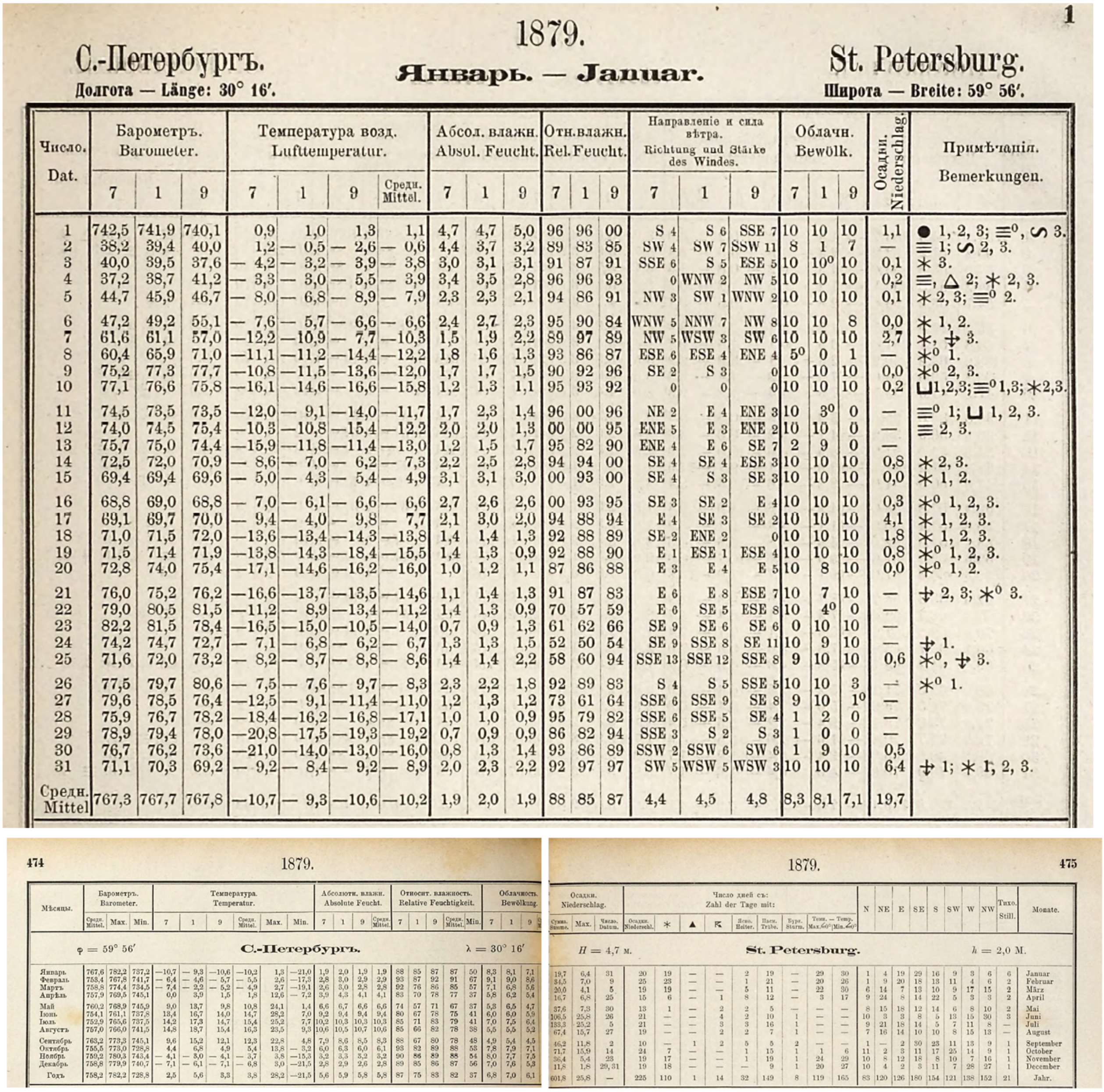

1879. 1

С.-Петербургъ. Январь. — Januar. St. Petersburg.

Долгота — Länge: 30° 16′. Широта — Breite: 59° 56′.

Число. Dat.	Барометръ. Barometer. 7	1	9	Температура возд. Lufttemperatur. 7	1	9	Средн. Mittel.	Абсол. влажн. Absol. Feucht. 7	1	9	Отн. влажн. Rel. Feucht. 7	1	9	Направленіе и сила вѣтра. Richtung und Stärke des Windes. 7	1	9	Облачн. Bewölk. 7	1	9	Осадки. Niederschlag.	Примѣчанія. Bemerkungen.
1	742,5	741,9	740,1	0,9	1,0	1,3	1,1	4,7	4,7	5,0	96	96	00	S 4	S 6	SSE 7	10	10	10	1,1	● 1, 2, 3; ≡⁰, ∽ 3.
2	38,2	39,4	40,0	— 1,2	— 0,5	— 2,6	— 0,6	4,4	3,7	3,2	89	83	85	SW 4	SW 7	SSW 11	8	1	7	—	≡ 1; ∽ 2, 3.
3	40,0	39,5	37,6	— 4,2	— 3,2	— 3,9	— 3,8	3,0	3,1	3,1	91	87	91	SSE 6	S 5	ESE 5	10	10⁰	10	0,1	✱ 3.
4	37,2	38,7	41,2	— 3,3	— 3,0	— 5,5	— 3,9	3,4	3,5	2,8	96	96	93	0	WNW 2	NW 5	10	10	10	0,2	≡, △ 2; ✱ 2, 3.
5	44,7	45,9	46,7	— 8,0	— 6,8	— 8,9	— 7,9	2,3	2,3	2,1	94	86	91	NW 3	SW 1	WNW 2	10	10	10	0,1	✱ 2, 3; ≡⁰ 2.
6	47,2	49,2	55,1	— 7,6	— 5,7	— 6,6	— 6,6	2,4	2,7	2,3	95	90	84	WNW 5	NNW 7	NW 8	10	10	8	0,0	✱ 1, 2.
7	61,6	61,1	57,0	—12,2	—10,9	— 7,7	—10,3	1,5	1,9	2,2	89	97	89	NW 5	WSW 3	SW 6	10	10	10	2,7	✱, ✢ 3.
8	60,4	65,9	71,0	—11,1	—11,2	—14,4	—12,2	1,8	1,6	1,3	93	86	87	ESE 6	ESE 4	ENE 4	5⁰	0	1	—	✱⁰ 1.
9	75,2	77,3	77,7	—10,8	—11,5	—13,6	—12,0	1,7	1,7	1,5	90	92	96	SE 2	S 3	0	10	10	10	0,0	✱⁰ 2, 3.
10	77,1	76,6	75,8	—16,1	—14,6	—16,6	—15,8	1,2	1,3	1,1	95	93	92	0	0	0	10	10	10	0,2	⊔ 1,2,3; ≡⁰ 1,3; ✱ 2,3.
11	74,5	73,5	73,5	—12,0	— 9,1	—14,0	—11,7	1,7	2,3	1,4	96	00	96	NE 2	E 4	ENE 3	10	3⁰	0	—	≡⁰ 1; ⊔ 1, 2, 3.
12	74,0	74,5	75,4	—10,3	—10,8	—15,4	—12,2	2,0	2,0	1,3	00	00	95	ENE 5	E 3	ENE 2	10	10	0	—	≡ 2, 3.
13	75,7	75,0	74,4	—15,9	—11,8	—11,4	—13,0	1,2	1,5	1,7	95	82	90	ENE 4	E 6	SE 7	2	9	0	—	
14	72,5	72,0	70,9	— 8,6	— 7,0	— 6,2	— 7,3	2,2	2,5	2,8	94	94	00	SE 4	SE 4	ESE 3	10	10	10	0,8	✱ 2, 3.
15	69,4	69,4	69,6	— 5,0	— 4,3	— 5,4	— 4,9	3,1	3,1	3,0	00	93	00	SE 4	S 3	SE 3	10	10	10	0,0	✱ 1, 2.
16	68,8	69,0	68,8	— 7,0	— 6,1	— 6,6	— 6,6	2,7	2,6	2,6	00	93	95	SE 3	SE 2	E 4	10	10	10	0,3	✱⁰ 1, 2, 3.
17	69,1	69,7	70,0	— 9,4	— 4,0	— 9,8	— 7,7	2,1	3,0	2,0	94	88	94	E 4	SE 3	SE 2	10	10	10	4,1	✱ 1, 2, 3.
18	71,0	71,5	72,0	—13,6	—13,4	—14,3	—13,8	1,4	1,4	1,3	92	88	89	SE 2	ENE 2	0	10	10	10	1,8	✱ 1, 2, 3.
19	71,5	71,4	71,9	—13,8	—14,3	—18,4	—15,5	1,4	1,3	0,9	92	88	90	E 1	ESE 1	ESE 4	10	10	10	0,8	✱⁰ 1, 2, 3.
20	72,8	74,0	75,4	—17,1	—14,6	—16,2	—16,0	1,0	1,2	1,1	87	86	88	E 3	E 4	E 5	10	8	10	0,0	✱⁰ 1, 2.
21	76,0	75,2	76,2	—16,6	—13,7	—13,5	—14,6	1,1	1,4	1,3	91	87	83	E 6	E 8	ESE 7	10	7	10	—	✢ 2, 3; ✱⁰ 3.
22	79,0	80,5	81,5	—11,2	— 8,9	—13,4	—11,2	1,4	1,3	0,9	70	57	59	E 6	SE 5	ESE 8	10	4⁰	0	—	
23	82,2	81,5	78,4	—16,5	—15,0	—10,5	—14,0	0,7	0,9	1,3	61	62	66	SE 9	SE 6	SE 6	0	10	10	—	
24	74,2	74,7	72,7	— 7,1	— 6,8	— 6,2	— 6,7	1,3	1,3	1,5	52	50	54	SE 9	SSE 8	SE 11	10	9	10	—	✢ 1.
25	71,6	72,0	73,2	— 8,2	— 8,7	— 8,8	— 8,6	1,4	1,4	2,2	58	60	94	SSE 13	SSE 12	SSE 8	9	10	10	0,6	✱⁰, ✢ 3.
26	77,5	79,7	80,6	— 7,5	— 7,6	— 9,7	— 8,3	2,3	2,2	1,8	92	89	83	S 4	S 5	SSE 5	10	10	3	—	✱⁰ 1.
27	79,6	78,5	76,4	—12,5	— 9,1	—11,4	—11,0	1,2	1,3	1,2	73	61	64	SSE 6	SSE 9	SE 8	9	10	1⁰	—	
28	75,9	76,7	78,2	—18,4	—16,2	—16,8	—17,1	1,0	1,0	0,9	95	79	82	SSE 6	SSE 5	SE 4	1	2	0	—	
29	78,9	79,4	78,0	—20,8	—17,5	—19,3	—19,2	0,7	0,9	0,9	86	82	94	SSE 3	S 2	S 3	1	0	0	—	
30	76,7	76,2	73,6	—21,0	—14,0	—13,0	—16,0	0,8	1,3	1,4	93	86	89	SSW 2	SSW 6	SW 6	1	9	10	0,5	
31	71,1	70,3	69,2	— 9,2	— 8,4	— 9,2	— 8,9	2,0	2,3	2,2	92	97	97	SW 5	WSW 5	WSW 3	10	10	10	6,4	✢ 1; ✱ 1, 2, 3.
Средн. Mittel	767,3	767,7	767,8	—10,7	— 9,3	—10,6	—10,2	1,9	2,0	1,9	88	85	87	4,4	4,5	4,8	8,3	8,1	7,1	19,7	

474 1879. — С.-Петербургъ. φ = 59° 56′ λ = 30° 16′ (Мѣсяцы; Барометръ. Barometer.; Температура. Temperatur.; Абсолютн. влажн. Absolute Feucht.; Относит. влажность. Relative Feuchtigkeit.; Облачность. Bewölkung.)

1879. 475 — St. Petersburg. H = 4,7 м. h = 2,0 M. (Осадки. Niederschlag.; Число дней съ: Zahl der Tage mit:; N NE E SE S SW W NW Тихо. Still.; Monate)

Figure 3. Example pages from the *Annalen* for St. Petersburg. The upper panel shows the daily observations for January 1879, while the two lower panels present the corresponding monthly summaries for 1879. The figure illustrates the printed structure from which the monthly temperature and station-pressure values were digitized.

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Table 1. Variable names and table headings appearing in the historical station tables, shown as printed in Russian and German, with English translations. The upper and lower parts refer to the daily and monthly tables, respectively.

Russian	**German**	**English**
Daily data (see upper panel of Fig. 3)		
Число	Dat.	Date / day number
Барометръ	Barometer	Barometer
Температура возд.	Lufttemperatur	Air temperature
Средн.	Mittel	Mean
Абсол. влажн.	Absol. Feucht.	Absolute humidity
Отн. влажн.	Rel. Feucht.	Relative humidity
Направленіе и сила вѣтра	Richtung und Stärke des Windes	Wind direction and force
Облачн.	Bewölk.	Cloudiness
Осадки	Niederschlag	Precipitation
Примѣчанія	Bemerkungen	Remarks
Monthly data (see lower panel of Fig. 3)		
Мѣсяцы	Monate	Months
Температура	Temperatur	Temperature
Абсолютн. влажн.	Absolute Feucht.	Absolute humidity
Относит. влажность	Relative Feuchtigkeit	Relative humidity
Облачность	Bewölkung	Cloudiness
Сумм.	Summe	Total
Число дней съ:	Zahl der Tage mit:	Number of days with
Ясно	Heiter	Clear/fair weather
Пасм.	Trübe	Overcast weather
Буря	Sturm	Storm
Тем.	Temp.	Temperature
Тихо	Still	Calm

is based on pressure anomalies rather than absolute pressure, no reduction of the historical station-pressure measurements to mean sea level was applied.

2.3 Digitization, quality control, and station selection

The data used in this study were obtained from scanned copies of the *Annalen* provided by the Digitalisierungszentrum of the Bayerische Staatsbibliothek in Munich. The selected records were converted into machine-readable form using optical character recognition (OCR) with ABBYY FineReader. This procedure was also supplemented by AI-assisted transcription using ChatGPT (OpenAI). ChatGPT was used to assist with the recognition, extraction, and restructuring of numerical entries

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from selected scanned tables, particularly in cases where conventional OCR did not preserve the historical tabular structure reliably. Values obtained through AI-assisted transcription were checked against the corresponding scanned source pages before being included in the dataset.

The tabular layout of the source material was generally suitable for OCR, but recognition quality varied between volumes. In particular, several later volumes, especially those from 1888–1894, used a typographic style that was more difficult to recognize reliably. These volumes therefore required more extensive manual checking and correction. After OCR, the extracted tables were inspected against the original scans, with particular attention to station names, dates, column alignment, decimal signs, missing entries, and physically implausible values.

For the present analysis, we selected stations with relatively good temporal coverage and a spatial distribution that provides broad coverage of the study domain, while avoiding excessive clustering in regions with a particularly dense station network. The selected stations do not represent the complete observing network. Rather, they were chosen to provide a balance between temporal continuity, spatial coverage, and practical digitization effort. Consequently, the analysis emphasizes large-scale monthly variability rather than local-scale extremes or the full density of the historical network. The locations of the selected stations are shown in Fig. 4 using present-day station names. Table 2 provides the corresponding historical names used in the *Annalen*, together with the present-day names, geographical coordinates, and temporal coverage.

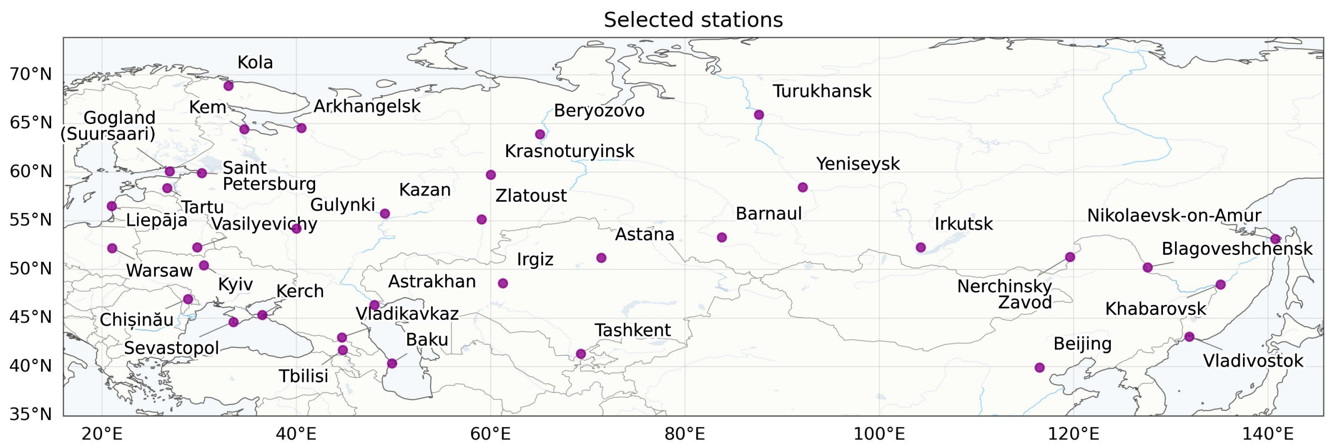

Figure 4. Spatial distribution of the selected stations, labelled with their present-day names.

2.4 Comparison with HCLIM series

Some observations from stations represented in the *Annalen* may also be present in modern climate archives. To examine possible overlap, the digitized monthly temperature and pressure series were compared with records in the Global Historical Climate Database (HCLIM) (Lundstad et al., 2023).

HCLIM records the modern digital collection from which each series was obtained, such as GHCN-Monthly, CRU, Berkeley Earth, PALAEO-RA, or a Russian meteorological archive. This source information identifies the collection through which the

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Table 2. Historical and present-day station names, geographical coordinates, and years covered by the digitized monthly observations. Years not listed were not available in the annual source files.

Historical name	Present-day name	Latitude (°N)	Longitude (°E)	Covered years
Akmolinsk	Astana	51.20	71.38	1874–1877, 1879–1885, 1890–1894
Archangelsk	Arkhangelsk	64.55	40.53	1874–1877, 1879–1894
Astrahan	Astrakhan	46.35	48.03	1874–1877, 1879–1894
Baku	Baku	40.37	49.83	1874–1877, 1879–1894
Barnaul	Barnaul	53.33	83.78	1874–1877, 1879–1894
Berezov	Beryozovo	63.93	65.07	1879–1894
Blagoveschensk	Blagoveshchensk	50.25	127.63	1877, 1879–1890, 1892–1894
Bogoslovsk	Krasnoturyinsk	59.75	60.02	1874–1877, 1879–1894
Chabarovka	Khabarovsk	48.47	135.12	1879–1881, 1890–1894
Derpt	Tartu	58.38	26.72	1874–1877, 1879–1891
Eniseisk	Yeniseysk	58.45	92.10	1874–1877, 1879–1894
Gulinki	Gulynki	54.23	40.00	1874–1877, 1879–1893
Hogland	Gogland (Suursaari)	60.10	26.98	1874–1877, 1879–1894
Irgis	Irgiz	48.62	61.27	1874–1877, 1879–1893
Irkutsk	Irkutsk	52.27	104.27	1874–1877, 1879–1894
Kazan	Kazan	55.78	49.13	1874–1877, 1879–1894
Kem	Kem	64.45	34.65	1874–1877, 1879–1893
Kertsch	Kerch	45.35	36.48	1874–1877, 1879–1893
Kiew	Kyiv	50.45	30.50	1874–1877, 1879–1893
Kischinew	Chişinău	46.98	28.85	1874–1877, 1879–1880, 1886–1893
Kola	Kola	68.88	33.02	1879–1894
Libava	Liepāja	56.52	21.02	1876–1877, 1879–1894
Nerchinksii zavod	Nerchinsky Zavod	51.32	119.62	1874–1877, 1879–1880, 1882–1894
Nikolaevsk-on-Amur	Nikolaevsk-on-Amur	53.13	140.75	1874–1877, 1879–1881, 1883–1894
Peking	Beijing	39.95	116.48	1874–1877, 1879–1884, 1886, 1889–1894
St.-Petersburg	Saint Petersburg	59.93	30.27	1874–1877, 1879–1893
Sevastopol	Sevastopol	44.62	33.52	1874–1877, 1879, 1882–1893
Taschkent	Tashkent	41.33	69.30	1874–1877, 1879–1887, 1892–1893
Tifliss	Tbilisi	41.72	44.78	1874–1877, 1879–1893
Turuhansk	Turukhansk	65.92	87.63	1877, 1879–1894
Warsaw	Warsaw	52.22	21.03	1874–1877, 1879–1881, 1883–1894
Wasilevichi	Vasilyevichy	52.27	29.80	1879–1894
Wladikawkas	Vladikavkaz	43.03	44.68	1874–1877, 1879–1893
Wladivostok	Vladivostok	43.12	131.90	1874–1877, 1879, 1881–1894
Zlatoust	Zlatoust	55.17	59.07	1874–1877, 1879–1894

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series entered HCLIM, but not necessarily the original nineteenth-century publication, manuscript, or archive from which the observations were first transcribed. There is therefore no evidence that the overlapping modern series were transcribed directly from the *Annalen*. Possible documentary pathways by which nineteenth-century observations may have entered modern digital collections are summarized schematically in Fig. A1 in Appendix A.

For several securely matched stations, the *Annalen* and HCLIM temperature series show similar variability, suggesting that they may ultimately contain observations from the same station network. However, the monthly values are not always identical. Even where the same underlying observations may be involved, the values may have been recalculated, corrected, rounded, homogenized, or otherwise processed at a later stage.

For pressure, only HCLIM series identified as station pressure were considered; mean sea-level pressure series were excluded. The *Annalen* pressure values likewise refer to the level of the barometer rather than to mean sea level. Nevertheless, nominally corresponding station-pressure records can show substantial systematic offsets, and the available HCLIM metadata do not consistently establish whether the compared series refer to equivalent station identities, station elevations, barometer elevations, instrumental corrections, historical reduction procedures, or subsequent processing.

These differences do not establish that either dataset is erroneous. Rather, they demonstrate the scientific value of direct documentary traceability. The present digitization provides a source-resolved link to the printed *Annalen* and preserves the published temperature and pressure values together with their historical station metadata and measurement context.

A detailed station-level comparison is provided in Appendix A. Table A1 summarizes the identified temperature-series matches, their coverage during 1874–1894, the mean diagnostic offset for overlapping monthly values, the number of overlapping months, and the digital source collection recorded in HCLIM. Table A2 provides the corresponding comparison for the identified station-pressure series. For both the *Annalen* and HCLIM, only pressure values referring to the station or instrument level were considered; mean sea-level pressure series were excluded. The reported offsets are descriptive comparison quantities rather than formal validation statistics. This distinction is particularly important for pressure because equivalence in station identity, station elevation, barometer elevation, instrumental correction, historical reduction procedure, and subsequent processing could not be established consistently from the available HCLIM metadata.

3 Large-scale temperature and pressure anomalies for 1877 and 1879

To demonstrate the analytical potential of the digitized *Annalen* observations, we calculated monthly anomalies of surface air temperature and station pressure and mapped them for 1877 and 1879. For each station and calendar month, the anomaly was calculated by subtracting a station-specific monthly reference mean from the value in the target year. The reference mean was calculated from all other available years within 1874–1894. The unavailable year 1878 and the target year itself were excluded. Additional missing station months were ignored, and no missing observations were interpolated.

For visualization, we use two complementary representations of the monthly station anomalies. Here, the 1877 anomalies are shown as spatially interpolated fields (Fig. 5), whereas the 1879 anomalies are shown directly at the observation sites using station-centred coloured circles (Fig. 6). For the interpolated representation, the available station coordinates and anomaly

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values were triangulated and linearly interpolated between neighbouring observations, with no extrapolation beyond the outer triangulation of the available stations. Because the station network is uneven, with much denser coverage in the western part of the domain than across Siberia and the Far East, interpolated features in sparsely observed regions are less tightly constrained. For each variable and target year, a common colour scale centred on zero was used across all 12 monthly panels. The Appendix provides the complementary representation for each year: the 1877 anomalies are shown directly at the stations in Fig. A2, while the 1879 anomalies are shown as interpolated fields in Fig. A3. Accordingly, the interpolated fields are interpreted as broad regional patterns rather than detailed local reconstructions, and the monthly resolution does not resolve individual synoptic events.

As a sensitivity check, the anomalies were recalculated after excluding 1883–1885 from the reference period, as this interval includes the aftermath of the 1883 Krakatau eruption and may therefore contain atypical large-scale climate conditions that could disproportionately influence the relatively short reference means. The principal spatial patterns and their qualitative interpretation remained unchanged, and all available reference years were therefore retained in the main analysis. Because the station-specific monthly reference samples are short and vary with data availability, the maps are used as descriptive evidence of spatial coherence rather than for station-by-station significance testing.

The years 1877 and 1879 were selected as an initial demonstration pair for both practical and scientific reasons. From a data perspective, the observations for this period are sufficiently standardized and spatially extensive to allow monthly station-based pressure and temperature anomaly maps to be constructed across much of the study domain. From a climate perspective, 1877 falls within the major 1877–1878 global climate anomaly, which has been associated with widespread droughts in Asia, Brazil, and Africa and with the Global Famine of 1876–1878 (Singh et al., 2018). The year 1879 provides a contrasting case after this episode, allowing us to examine whether the recovered observations distinguish different pressure–temperature configurations over Eurasia.

Surface pressure anomalies provide information about the monthly mean circulation, while temperature anomalies record the near-surface response to that circulation. In winter, positive pressure anomalies over continental Eurasia are often associated with anticyclonic conditions, weak winds, reduced cloudiness, and suppressed vertical mixing. Such conditions can favor strong longwave radiative cooling of the surface, particularly over snow-covered land, and can produce or maintain cold near-surface air masses. Negative pressure anomalies are more often associated with cyclonic activity, enhanced mixing, cloudiness, and advection, although the temperature response depends strongly on the direction of the anomalous flow. The same pressure anomaly can therefore have different thermal effects in different parts of the domain, depending on whether it promotes northerly, southerly, continental, or maritime air-mass transport.

Figure 5 combines the monthly temperature and station-pressure anomalies for 1877, with temperature shown in the upper 12 panels and pressure in the lower 12 panels. The temperature maps reveal pronounced month-to-month variability, but also coherent regional structures. The annual sequence includes repeated longitudinal contrasts between western or central Eurasia and eastern Siberia or the Far East, indicating that the anomalies reflected regional circulation differences rather than a uniform warm or cold departure across the domain. The strongest cold signal occurs in December, when central and eastern parts of the domain show pronounced negative temperature anomalies, while conditions farther west are weaker or locally positive.

Positive pressure anomalies dominate much of central Eurasia in January and become especially strong and extensive again in late autumn and early winter, particularly in December. By contrast, the period from February to May is characterized by lower pressure over the western part of the domain and higher or near-normal pressure farther east. During summer, the pressure anomalies are weaker but remain spatially organized. This seasonal behavior is physically plausible: in the warm season, surface temperature anomalies are less directly controlled by snow cover and persistent cold-air pooling than in winter, whereas in the cold season pressure anomalies can more strongly shape near-surface temperature through advection, radiative cooling, and boundary-layer stability.

The strong positive pressure anomaly over central and eastern Eurasia coincides with pronounced cold anomalies over much of the same region. This pattern is consistent with continental anticyclonic conditions, under which weak turbulent mixing, clear-sky radiative cooling, and possible snow-cover feedbacks can reinforce near-surface cold anomalies. In such a situation, pressure and temperature anomalies are not independent: the spatial pattern of station-pressure anomalies indicates the circulation regime, while the station-temperature anomalies show its near-surface expression. This interpretation is consistent with reconstruction-based and process-oriented studies showing that Eurasian cold-season anomalies can persist through snow-cover and land-surface feedbacks even after the initiating circulation anomaly has weakened (Valler et al., 2022). The spatial coherence of the pressure anomaly suggests that the recovered data can identify periods of persistent anticyclonic circulation that may be relevant for later blocking-oriented analysis.

Figure 6 shows the corresponding monthly temperature and station-pressure anomalies for 1879 directly at the observation sites. The mapped temperature anomalies differ markedly from those in 1877. In winter, the maps show a strong west–east contrast, with positive anomalies over western parts of the domain and colder conditions farther north and east. This dipole-like structure is dynamically informative because it suggests anomalous air-mass redistribution rather than a uniform thermal anomaly across the network. Warm anomalies in the west may reflect enhanced advection of milder air into European Russia, while colder anomalies farther east are consistent with the persistence or displacement of continental cold air. Later in the year, the anomalies remain regionally organized, with widespread warmth in October and a renewed regional contrast in December.

The lower pressure-anomaly panels in Fig. 6 help to interpret these temperature patterns. January is characterized by strong positive pressure anomalies over western and central Eurasia, but the temperature response is not spatially uniform. This illustrates why pressure and temperature anomalies need to be interpreted together rather than through a simple one-to-one relationship: anticyclonic conditions can support local cooling through radiative processes, but they can also be associated with warm anomalies on their flanks if the circulation promotes advection of milder air. In February, the station-pressure pattern changes substantially, with a marked negative pressure anomaly over the western part of the domain. This is consistent with a more active cyclonic circulation over western Eurasia and may help explain the longitudinal temperature contrast seen in the same month. In December, the pressure pattern contrasts sharply with December 1877, showing lower pressure over central and eastern Eurasia and a different distribution of temperature anomalies.

The comparison between 1877 and 1879 shows that the recovered data capture more than local station variability. The monthly maps reveal coherent pressure structures, regional temperature dipoles, and physically plausible pressure–temperature relationships across a very large continental domain. In 1877, the late-year circulation is characterized by strong positive

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pressure anomalies over central and eastern Eurasia, accompanied in December by pronounced cold conditions over much of the same region. In 1879, the winter and late-year patterns are different, with stronger regional contrasts and, in December, a pronounced negative pressure anomaly over central and eastern Eurasia. These differences show that the digitized *Annalen* observations can be used to compare contrasting circulation states and their surface impacts.

The historical station-derived anomaly fields can also be interpreted in relation to present-day Eurasian climate. The main difference is that the late nineteenth-century circulation anomalies acted on a colder background climate state, with more extensive and persistent snow and cryospheric conditions than today (IPCC, 2023; Mudryk et al., 2020). The surface response to pressure anomalies over Eurasia depends strongly on land-surface conditions. A winter anticyclone over snow-covered continental regions can promote strong radiative cooling, shallow boundary-layer stability, and persistence of cold near-surface air. Under present-day warmer conditions, reduced snow cover, later snow onset, earlier melt, and a warmer lower troposphere may modify the same circulation pattern's surface expression. Thus, the 1877 and 1879 station-anomaly patterns should not be viewed simply as analogues of modern circulation events, but as examples of how pressure anomalies were expressed at the surface under late nineteenth-century boundary conditions.

4 Conclusions

This study demonstrates that meteorological observations published in the *Annalen* can be recovered from printed historical tables and transformed into a scientifically useful dataset for large-scale climate analysis. The digitized monthly temperature and station-pressure observations reveal spatially coherent anomaly patterns across a large part of Eurasia, showing that the *Annalen* are not only an important documentary source for the history of meteorological observation, but also a quantitative source for investigating nineteenth-century atmospheric variability.

The examples from 1877 and 1879 illustrate the analytical value of the recovered observations. The monthly maps show coherent pressure structures, regional temperature contrasts, and physically plausible relationships between circulation and near-surface conditions. In December 1877, pronounced positive pressure anomalies over central and eastern Eurasia coincide with widespread cold anomalies in the same region, a pattern consistent with continental anticyclonic conditions, radiative cooling, stable boundary layers, and possible snow-cover feedbacks. The corresponding patterns in 1879 differ substantially, demonstrating that the digitized observations can distinguish contrasting pressure–temperature configurations rather than merely reproducing local station variability.

A particular strength of the *Annalen* is the availability of multiple meteorological variables, of which temperature and station pressure are considered here in combination. Pressure anomalies provide information on the monthly mean circulation, while temperature anomalies show how that circulation was expressed near the surface. This combination is especially valuable over Eurasia, where continentality, snow cover, boundary-layer stability, and air-mass advection strongly influence the development and persistence of cold-season anomalies. The recovered observations therefore provide a basis for studying circulation–surface coupling under late nineteenth-century boundary conditions and for placing present-day Eurasian circulation–temperature relationships into a longer historical context. Because the late nineteenth century represents a colder background climate state,

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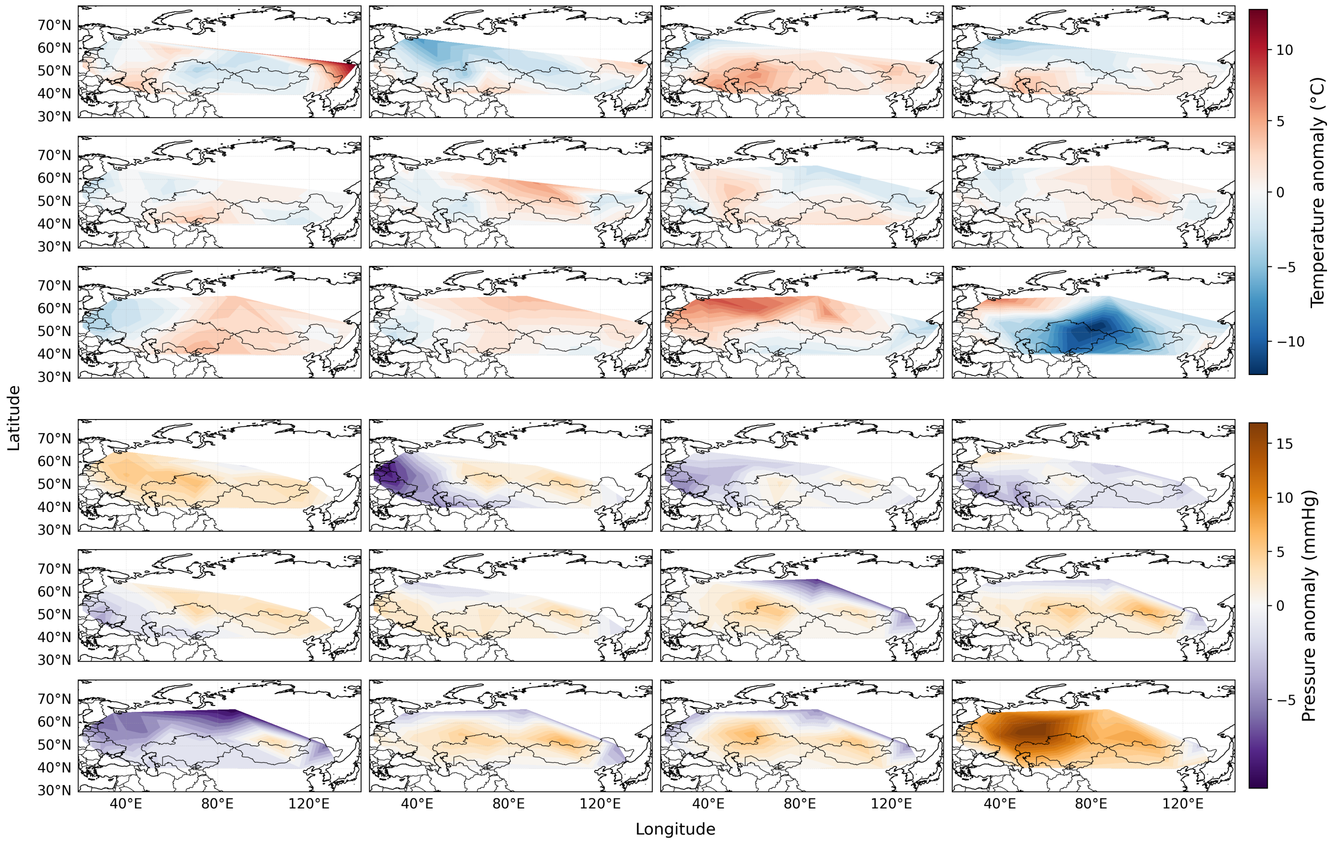

Figure 5. Monthly surface air temperature and station-pressure anomalies for 1877 relative to station-specific monthly reference means calculated from the other available years within 1874–1894. The upper 12 panels show temperature anomalies (°C), and the lower 12 panels show station-pressure anomalies (mmHg); within each block, months are arranged chronologically from January to December. Shading shows linearly interpolated fields between the available station observations within the triangulated station domain. The interpolation is intended to emphasize broad regional structure and should not be interpreted as a gridded reconstruction independent of station coverage.

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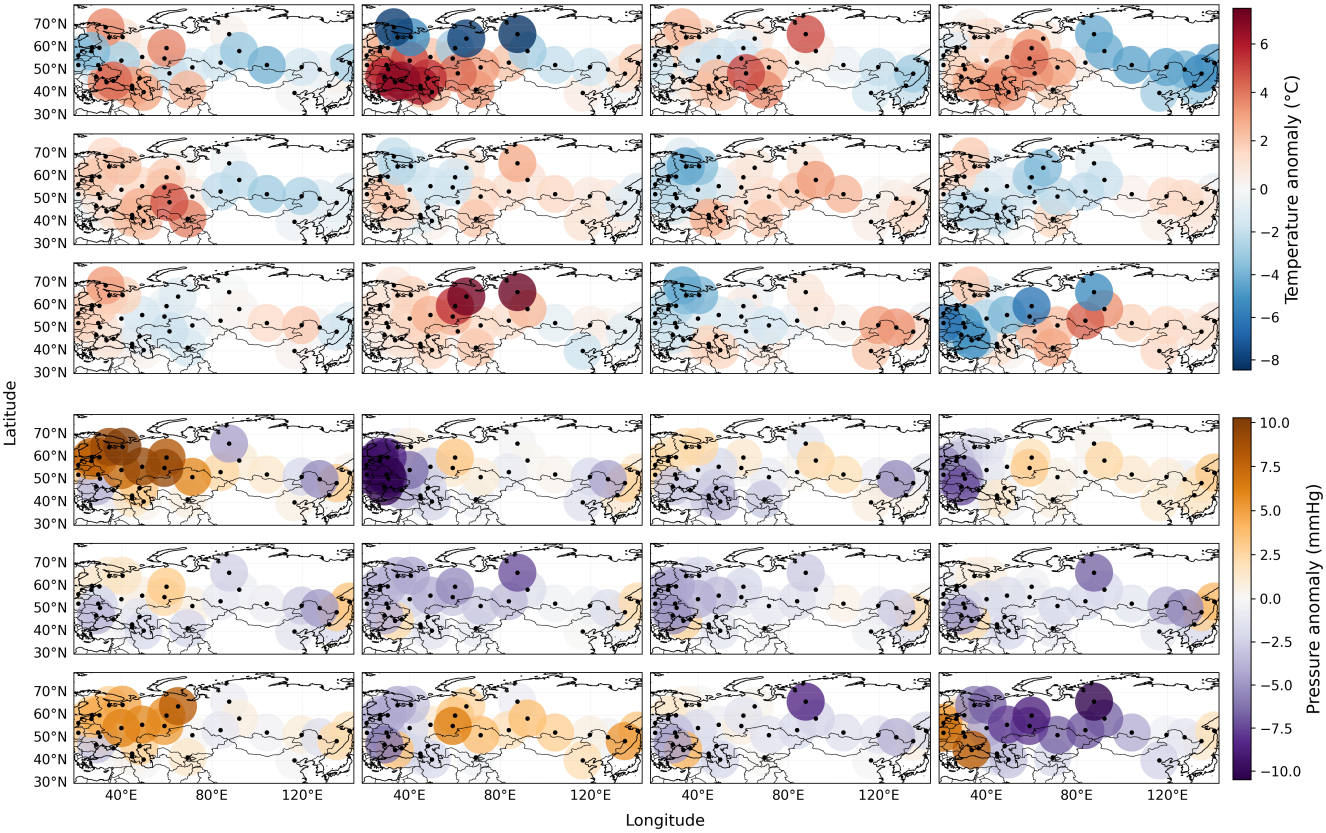

Figure 6. Monthly surface air temperature and station-pressure anomalies for 1879 shown directly at the observation sites. The upper 12 panels show temperature anomalies (°C), and the lower 12 panels show station-pressure anomalies (mmHg); within each block, months are arranged chronologically from January to December. Black points mark the station locations, and the surrounding coloured circles show the sign and magnitude of the anomalies. No spatial interpolation, smoothing, or extrapolation was applied between stations.

similar circulation anomalies may not have produced the same near-surface temperature responses as they do under modern conditions.

The study also highlights the importance of treating digitization as part of the scientific analysis rather than as a purely technical preprocessing step. The printed monthly summaries are well suited to network-based analysis, but their reliable use requires careful treatment of historical station names, changing language conventions, decimal notation, column alignment, missing values, typographic differences between volumes, and physically implausible entries. Preserving the documentary context of the observations is therefore essential for interpreting the recovered values and assessing their comparability with modern climate records.

Overlapping temperature and pressure series were identified in HCLIM, although pressure matches were fewer and more difficult to interpret because equivalence in station identity, barometer elevation, correction procedures, pressure reduction,

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and subsequent processing could not always be established. The numerical similarities indicate that some modern series may derive from the same underlying station observations as those published in the *Annalen*, but there is no evidence that they were transcribed directly from the *Annalen*, and their complete documentary and processing pathways remain uncertain. The principal added value of the present dataset is therefore its direct traceability to the original printed volumes and its preservation of temperature and pressure observations together with their historical metadata and measurement context.

Appendix A: Comparison with HCLIM series

Figure A1 summarizes possible documentary pathways by which nineteenth-century station observations may have entered modern digital collections. Tables A1 and A2 then provide parallel station-level comparisons of the digitized *Annalen* observations with overlapping nineteenth-century temperature and pressure series in HCLIM, respectively. Because of their length, each table is continued on a second landscape page but retains a single table number. The timelines are restricted to 1874–1894 and show the years represented in each dataset. Mean diagnostic offsets and overlap counts are calculated only from months for which both datasets contain values.

For temperature, diagnostic offsets are expressed in degrees Celsius and are defined as *Annalen* minus HCLIM. For pressure, the *Annalen* values were converted from mmHg to hPa before calculating the same diagnostic quantity. The pressure comparison highlights the importance of documentary provenance: the *Annalen* values are directly traceable to the original printed tables and their documented historical conventions, whereas the complete documentary pathway and processing history of the overlapping HCLIM series could not always be reconstructed from the available metadata. The pressure offsets therefore cannot be attributed uniquely to measurement or digitization error and may reflect differences in station identity, barometer elevation, instrumental correction, historical reduction procedure, aggregation, rounding, or later processing. The HCLIM source column identifies the immediate digital collection from which HCLIM obtained the series and does not necessarily identify the original nineteenth-century documentary source.

For completeness, the Appendix shows the complementary visualization for each year. Figure A2 presents the 1877 anomalies directly at the station locations using coloured circles and without spatial interpolation, whereas Fig. A3 presents the 1879 anomalies as linearly interpolated fields.

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Table A1. Documentary and numerical comparison of monthly temperature in the *Annalen* with HCLIM series. The timeline shows 1874–1894 only; filled black bars indicate years with coverage in the separate A and H rows; outlined boxes indicate years without coverage. Mean diagnostic offsets are *Annalen* minus HCLIM and are reported only for overlapping monthly values. The offsets are descriptive and should not be interpreted as formal validation statistics because the complete documentary provenance and processing history could not always be established from the available HCLIM metadata. BE–HC–CRU denotes the Berkeley Earth–Hadley Centre–CRU partial-data collection. The number of overlapping monthly values is reported as n.

Historical station	Present-day station	HCLIM station	HCLIM ID		Coverage 1874–1894	Mean offset A–H (°C)	Overlap (n)	HCLIM source
Akmolinsk	Astana	Astana	1537	A H		0.36	109	GHCN_v4_qcf
Archangelsk	Arkhangelsk	Arhangelsk	1649	A H		0.40	195	GHCN_v4_qcf
Astrahan	Astrakhan	Astrakan	1687	A H		0.02	233	GHCN_v4_qcf
Baku	Baku	Baku	1163	A H		0.23	24	GHCN_v4_qcf
Barnaul	Barnaul	Barnaul	3117	A H		0.34	177	PALAEO-RA
Berezov	Beryozovo	Berezovo	2418	A H		0.19	171	ISTI-CRU
Blagoveschensk	Blagoveshchensk	Blagovescensk	1679	A H		0.28	139	GHCN_v4_qcf
Bogoslovsk	Krasnoturyinsk	Bogoslowsk	3120	A H		0.41	72	PALAEO-RA
Chabarovka	Khabarovsk	Habarovsk	2443	A H		0.15	81	ISTI-CRU
Derpt	Tartu	Dorpat	3127	A H		–	–	PALAEO-RA
Eniseisk	Yeniseysk	Enisejsk	2437	A H		0.93	238	ISTI-CRU
Gulinki	Gulynki	No reliable same-station match	–	A H		–	–	–
Hogland	Gogland (Suursaari)	Gogland	2774	A H		0.16	191	meteo.ru
Irgis	Irgiz	Irgis	493	A H		0.29	60	BE–HC–CRU
Irkutsk	Irkutsk	Irkutsk	495	A H		0.34	212	BE–HC–CRU
Kazan	Kazan	Kazan	1669	A H		0.00	239	GHCN_v4_qcf
Kem	Kem	Kem Port	1648	A H		0.28	215	GHCN_v4_qcf
Kertsch	Kerch	Kerch	1792	A H		0.84	156	GHCN_v4_qcf

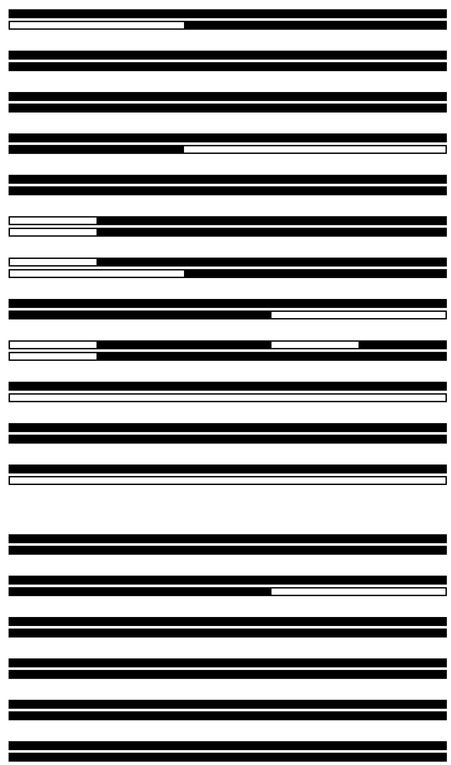

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Table A1. Documentary and numerical comparison of monthly temperature in the *Annalen* with HCLIM series (continued).

Historical station	Present-day station	HCLIM station	HCLIM ID	Coverage 1874–1894	Mean offset A–H (°C)	Overlap (n)	HCLIM source
Kiew	Kyiv	Kiev	1783	A H	0.10	215	GHCN_v4_qcf
Kischinew	Chişinău	Kisinev	1553	A H	0.38	146	GHCN_v4_qcf
Kola	Kola	Kola	2407	A H	0.14	146	ISTI-CRU
Libava	Liepāja	Liepaja	1545	A H	-0.01	91	GHCN_v4_qcf
Nerchinksii zavod	Nerchinsky Zavod	Nerchinskij_Zavod	2441	A H	0.30	224	ISTI-CRU
Nikolaevsk-on- Amur	Nikolaevsk-on-Amur	Nikolayevsk-na-Amure	496	A H	0.25	211	BE–HC–CRU
Peking	Beijing	Beijing	1354	A H	-0.31	176	GHCN_v4_qcf
Sevastopol	Sevastopol	Ssevastopol	1796	A H	0.32	24	GHCN_v4_qcf
St.-Petersburg	Saint Petersburg	St. Petersburg	1663	A H	-0.23	171	GHCN_v4_qcf
Taschkent	Tashkent	Tashkent	2183	A H	-0.18	118	GHCN_v4_qcf
Tifliss	Tbilisi	Tbilisi	408	A H	0.29	180	BE–HC–CRU
Turuhansk	Turukhansk	Turuhansk	2416	A H	0.26	198	ISTI-CRU
Warsaw	Warsaw	No comparable temperature series	–	A H	–	–	–
Wasilevichi	Vasilyevichy	Vasilevici	1241	A H	0.00	167	GHCN_v4_qcf
Wladikawkas	Vladikavkaz	Vladikavkaz	1690	A H	0.44	137	GHCN_v4_qcf
Wladivostok	Vladivostok	Vladivostok	490	A H	0.17	146	BE–HC–CRU
Zlatoust	Zlatoust	Zlatoust	2434	A H	0.54	168	ISTI-CRU

Notes: A and H denote the *Annalen* and HCLIM, respectively. The immediate source is the digital collection named in HCLIM and is not necessarily the original nineteenth-century documentary source. An en dash indicates that no diagnostic offset could be reported because overlap was insufficient or no reliable same-station series was identified.

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Table A2. Documentary and numerical comparison of monthly mean pressure in the *Annalen* with HCLIM station-pressure series. Only the HCLIM variable "Station pressure, monthly mean" (p) was considered; mean sea-level pressure was excluded. The timeline shows 1874–1894 only; filled black bars indicate years with coverage in the separate A and H rows; outlined boxes indicate years without coverage. The *Annalen* values were converted from mmHg to hPa using $1\,\mathrm{mmHg} = 1.33322387415\,\mathrm{hPa}$. Mean diagnostic offsets are *Annalen* minus HCLIM and are reported only for overlapping monthly values. They should not be interpreted as measurement errors or formal validation statistics because equivalence in station identity, barometer elevation, instrumental correction, reduction procedure, and subsequent processing could not be established consistently. The number of overlapping monthly values is reported as n.

Historical station	Present-day station	HCLIM station	HCLIM ID	Coverage 1874–1894	Mean offset A–H (hPa)	Overlap (n)	HCLIM source
Akmolinsk	Astana	No comparable station-pressure series	–	A H	–	–	–
Archangelsk	Arkhangelsk	Archangelsk	EKF400v1p_034	A H	-2.37	240	EKF400
Astrahan	Astrakhan	Astrahan	EKF400v1p_014	A H	1.88	233	EKF400
Baku	Baku	No comparable station-pressure series	–	A H	–	–	–
Barnaul	Barnaul	Barnaul	EKF400v1p_080	A H	-19.46	228	EKF400
Berezov	Beryozovo	No comparable station-pressure series	–	A H	–	–	–
Blagoveschensk	Blagoveshchensk	No comparable station-pressure series	–	A H	–	–	–
Bogoslovsk	Krasnoturyinsk	No comparable station-pressure series	–	A H	–	–	–
Chabarovka	Khabarovsk	No comparable station-pressure series	–	A H	–	–	–
Derpt	Tartu	No comparable station-pressure series	–	A H	–	–	–
Eniseisk	Yeniseysk	Enisejsk	EKF400v1p_081	A H	-9.79	238	EKF400
Gulinki	Gulynki	No comparable station-pressure series	–	A H	–	–	–
Hogland	Gogland (Suursaari)	No comparable station-pressure series	–	A H	–	–	–
Irgis	Irgiz	No comparable station-pressure series	–	A H	–	–	–
Irkutsk	Irkutsk	No comparable station-pressure series	–	A H	–	–	–
Kazan	Kazan	Kazan	WMO-27595	A H	-11.13	228	CRU
Kem	Kem	Kem	WMO-22522	A H	-2.52	33	CRU
Kertsch	Kerch	No comparable station-pressure series	–	A H	–	–	–

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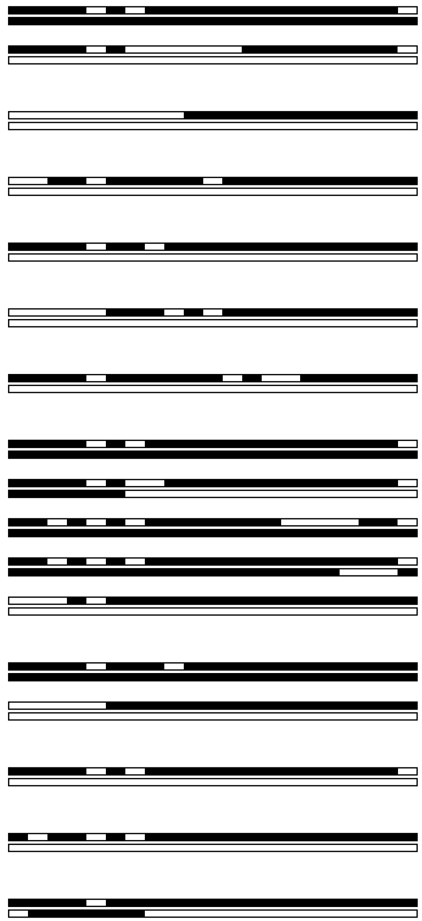
Table A2. Documentary and numerical comparison of monthly mean pressure in the *Annalen* with HCLIM station-pressure series (continued).

Historical station	Present-day station	HCLIM station	HCLIM ID		Coverage 1874–1894	Mean offset A–H (hPa)	Overlap (n)	HCLIM source
Kiew	Kyiv	Kiev	EKF400v1p_012	A H		-24.11	216	EKF400
Kischinew	Chişinău	No comparable station-pressure series	–	A H		–	–	–
Kola	Kola	No comparable station-pressure series	–	A H		–	–	–
Libava	Liepāja	No comparable station-pressure series	–	A H		–	–	–
Nerchinksii zavod	Nerchinsky Zavod	No comparable station-pressure series	–	A H		–	–	–
Nikolaevsk-on- Amur	Nikolaevsk-on-Amur	No comparable station-pressure series	–	A H		–	–	–
Peking	Beijing	No comparable station-pressure series	–	A H		–	–	–
St.-Petersburg	Saint Petersburg	St. Petersburg	EKF400v1p_043	A H		-2.25	216	EKF400
Sevastopol	Sevastopol	Sevastopol	WMO-20304	A H		-4.15	54	CRU
Taschkent	Tashkent	Tashkent	EKF400v1p_083	A H		-55.87	152	EKF400
Tifliss	Tbilisi	Tiflis	WMO-37549	A H		-47.19	168	CRU
Turuhansk	Turukhansk	No comparable station-pressure series	–	A H		–	–	–
Warsaw	Warsaw	Warsaw	EKF400v1p_041	A H		-16.01	228	EKF400
Wasilevichi	Vasilyevichy	No comparable station-pressure series	–	A H		–	–	–
Wladikawkas	Vladikavkaz	No comparable station-pressure series	–	A H		–	–	–
Wladivostok	Vladivostok	No comparable station-pressure series	–	A H		–	–	–
Zlatoust	Zlatoust	Zlatoost, Russia	001018_zlatoost	A H		2.25	52	ISPD



Notes: A and H denote the *Annalen* and HCLIM, respectively. The immediate source is the digital collection named in HCLIM and is not necessarily the original nineteenth-century documentary source. Because the *Annalen* pressure values refer to the level of the barometer, no reduction to mean sea level was applied. "No comparable series identified" indicates that no HCLIM record containing station pressure could be matched with sufficient confidence.

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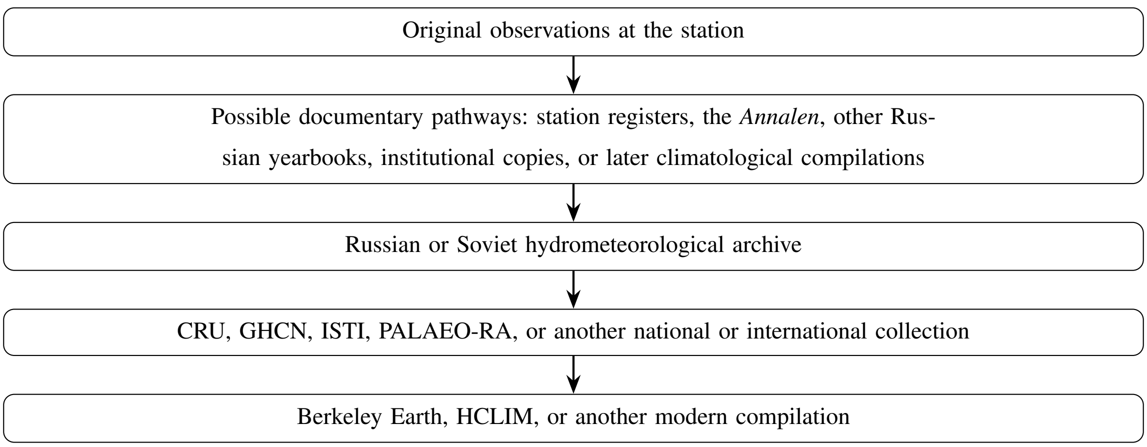

Figure A1. Schematic pathways by which nineteenth-century station observations may have entered modern climate databases. There is currently no evidence that overlapping modern series were transcribed directly from the *Annalen*, and individual records may have followed different routes.

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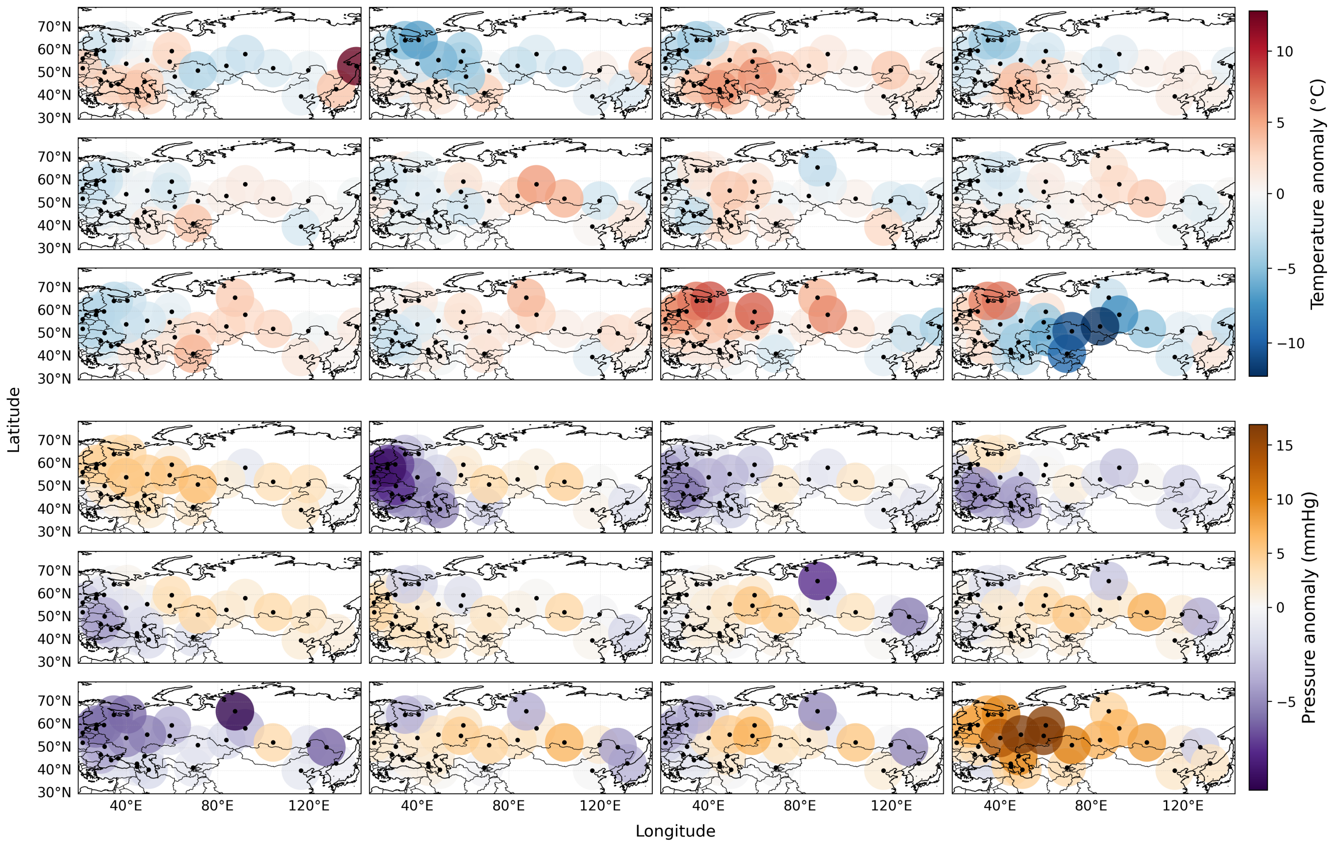

Figure A2. Monthly surface air temperature and station-pressure anomalies for 1877 shown directly at the observation sites. The upper 12 panels show temperature anomalies (°C), and the lower 12 panels show station-pressure anomalies (mmHg); within each block, months are arranged chronologically from January to December. Black points mark the station locations, and the surrounding coloured circles show the sign and magnitude of the anomalies. No spatial interpolation, smoothing, or extrapolation was applied between stations.

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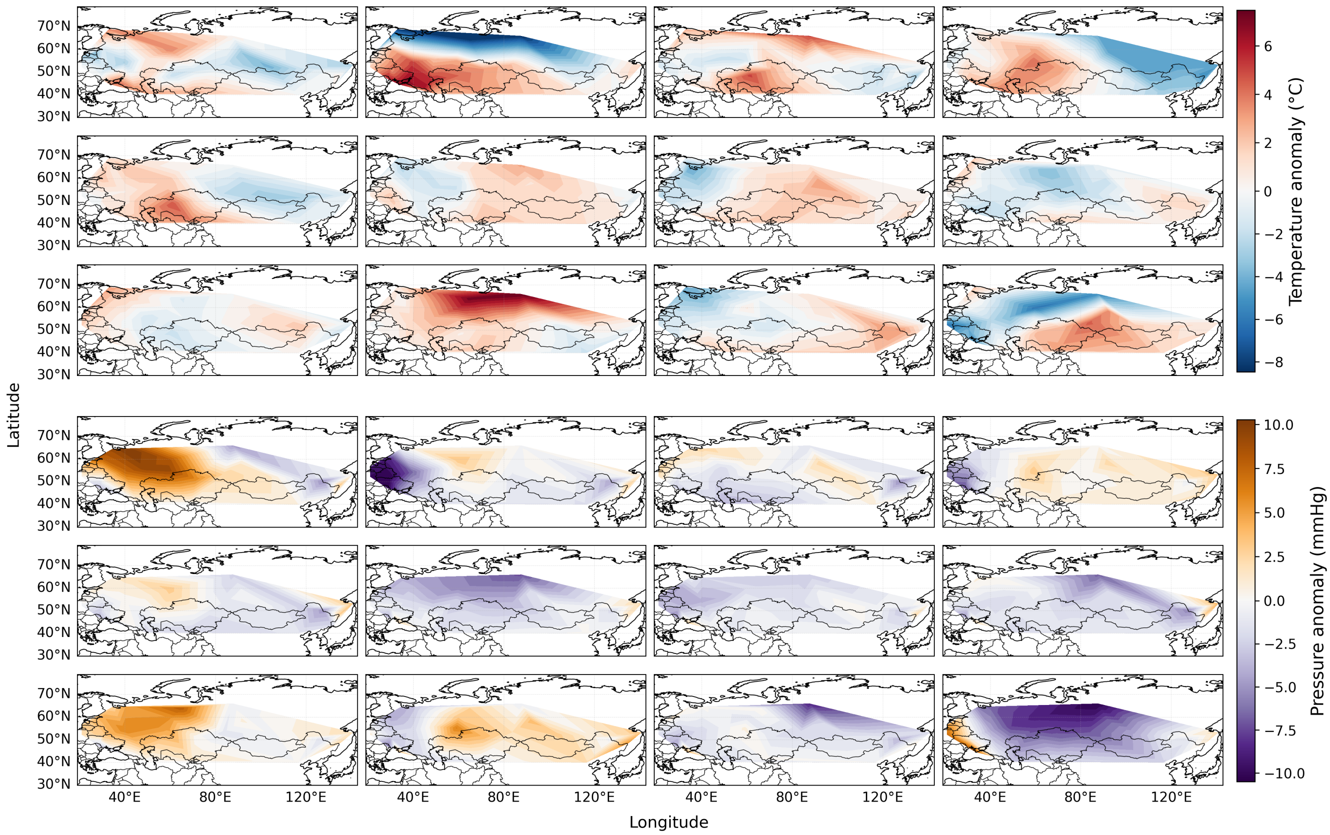

Figure A3. Monthly surface air temperature and station-pressure anomalies for 1879 relative to station-specific monthly reference means calculated from the other available years within 1874–1894. The upper 12 panels show temperature anomalies (°C), and the lower 12 panels show station-pressure anomalies (mmHg); within each block, months are arranged chronologically from January to December. Shading shows linearly interpolated fields between the available station observations within the triangulated station domain. The interpolation is intended to emphasize broad regional structure and should not be interpreted as a gridded reconstruction independent of station coverage.

Code availability. The scripts used for data processing, analysis, and visualization are available from the corresponding author upon reasonable request.

Data availability. The monthly temperature and station-pressure values used in this study, the subset of daily observations underlying Fig. 2, and the station coordinates and essential metadata required to interpret the records will be made publicly available at https://doi.org/10.5281/zenodo.22641658. The original scanned volumes are publicly available through the digital collections and catalogue of the Bayerische Staatsbibliothek, Munich: https://opacplus.bsb-muenchen.de/. The relevant volumes can be found by searching for *Annalen des Physikalischen Centralobservatoriums*. HCLIM data are available from the repository cited in the text.

Author contributions. AVS conceived and led the study, designed the research, digitized and processed the data, performed the analysis, and wrote the manuscript. UF supervised the work, provided scientific guidance and advice throughout the study, and contributed to the interpretation of the results.

Competing interests. The authors declare that they have no conflict of interest.

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