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ABSTRACT

Early instrumental weather observations document European climate before the era of standardized national networks, but no harmonized dataset has provided daily and sub-daily values across multiple variables for the early instrumental period. We present HIST-DAILY, a dataset of 1,798 daily and sub-daily series from 480 locations, spanning 1658 to the end of the 19th century. The dataset integrates temperature, pressure, precipitation, and wind direction records from published literature, online databases, collaborator contributions, and original digitizations at the University of Bern. All observations are converted to standard units and the Gregorian calendar, times are adjusted to UTC, and quality control is applied using the 'dataresqc' package. Each series is delivered in the Station Exchange Format, ensuring that the source, units, and any transformation applied to a value remain traceable. Technical validation through a comparison with the Twentieth Century Reanalysis version 3 confirms the dataset's suitability for capturing day-to-day weather variability and extreme events. The dataset is intended for use in historical weather reconstruction, extreme event studies, and improvement of pre-20th-century reanalyses.

Background & Summary

Early instrumental meteorological observations are a fundamental resource for understanding past climate variability. The pre-industrial period is a valuable test bed for studying natural forcing factors and the frequency and dynamics of extreme events, but only if weather data are available at the temporal resolution at which these phenomena operate. Successful reconstructions at the daily scale have already been achieved thanks to the recovery of early instrumental records. The Twentieth Century Reanalysis version 3 (20CRv3), which assimilates surface pressure observations back to 1806, reliably reproduces individual extreme events such as the Great Blizzard of 1888[1,2]. Newly digitized pressure observations have also improved the reanalysis of the severe windstorm of February 1903, better constraining its atmospheric circulation[3]. Further examples include the temperature and pressure reconstruction for the severe winter of 1788/89[4] and the evaluation of daily reconstructions for the European heatwave summer of 1807[5].

Two problems, however, limit wider progress. The first is accessibility: early meteorological records are scattered across national meteorological archives, university libraries, private collections, and published literature. The global inventory of Brönnimann et al. (2019) identified over 4,500 pre-1850 series from approximately 2,250 locations worldwide, yet roughly half remain undigitized[6]. Moreover, the lack of standard units of temperature, pressure, and precipitation until the mid-19th century

leaves most existing series incompatible with one another. The second problem is temporal resolution: the few compilations that go beyond individual stations or networks, such as HCLIM[7] or HISTALP[8], have focused on the monthly scale. Projects such as ISPD[9], ECA&D[10], and CHIMES[11] have made long daily series available, but each covers only a subset of available sources and focuses on a single variable, a specific region, or a shorter time period.

No harmonized dataset of daily and sub-daily European observations covering multiple variables and spanning the full early instrumental period, from the mid-17th century through the 19th century, currently exists. Here we present HIST-DAILY, a compilation of 1,798 daily and sub-daily historical European weather series from 480 locations spanning 1658 to the end of the 19th century. HIST-DAILY integrates temperature, pressure, precipitation, and wind direction records from published literature, online databases, collaborator contributions, and digitizations at the University of Bern. All series undergo consistent unit and date conversion and quality control (QC) and are delivered in the Station Exchange Format (SEF)[12], a format that is readily machine-readable and designed for assimilation into historical reanalyses.

The remainder of this paper describes the data sources, the pre-processing steps applied, the spatial and temporal characteristics of the dataset, and the data availability.

Methods

The procedures followed to compile, harmonize, and quality-control the dataset are summarized in Figure 1.

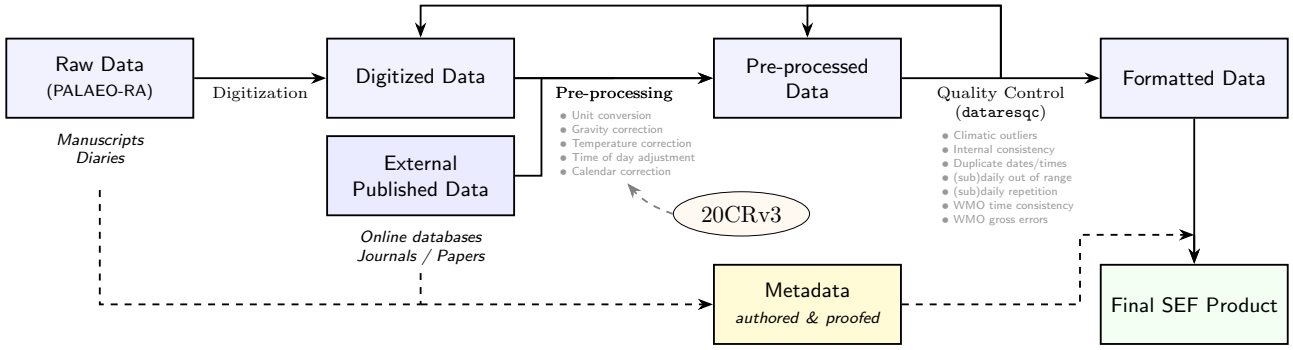


Figure 1. Schematic overview of the development and filtering process of the historical dataset.

Two input streams feed the workflow: manuscripts and diaries digitized as part of the PALAEO-RA (European Union, 787574) and WeaR projects (Swiss National Science Foundation, 188701), and external published data from online databases and journals. Both pass through a pre-processing step, where we convert the units to the International System of Units (SI), adjust for the time of day, and apply gravity, temperature, and calendar corrections. In cases of ambiguous original unit or calendar convention, we use 20CRv3 as a reference to resolve the ambiguity (see Units and Conversions and Calendar Handling below). Pre-processed data then pass through QC, which checks for climatic outliers, internal inconsistency, duplicate dates and times, out-of-range sub-daily values, sub-daily repetition, time consistency, and gross errors. Alongside the computational pipeline, we assemble metadata manually, documenting sources, observers, and station history. Dashed lines in Figure 1 mark this parallel track. Together, the formatted data and the authored metadata constitute the final SEF Product.

Data Sources

Data are assembled from two categories of sources. The first, of external origin, includes online databases, institutional repositories, individual series published in the research literature, and series contributed directly by co-authors. The second comprises series digitized from historical manuscripts at the University of Bern. Institutional and project-level sources, including national meteorological services we contacted directly, are listed in Supplementary Table 1. Individual contributed series are listed in Supplementary Table 2, with the associated publication for context in case they are not yet publicly available. Series digitized at the University of Bern are listed in Supplementary Table 3 and account for 23.4% of the total. A further 22 series from institutional sources and 26 individually contributed series are also made publicly available for the first time in this work, bringing to 26.0% the share of the dataset published here for the first time. All source tables are provided in the Supplementary Information.

Units and Conversions

Historical meteorological records use units of measure that have largely been replaced by the SI. Table 1 summarizes the variables included in this dataset, their standardized abbreviations, and the units to which we convert all observations. We list

the 18 series whose units have no clear conversion to SI in Supplementary Table 4.

Table 1. Variable abbreviations and number of series

	Abbreviation	Variable	Unit	N series
Core variables	ta	Temperature	°C	560
	p	Pressure	hPa	560
	dd	Wind Direction	degrees	113
	rr	Precipitation	mm	285
	Tx	Maximum Temperature	°C	105
	Tn	Minimum Temperature	°C	109
Others	rh	Relative Humidity	%	19
	w	Wind Speed	various	31
	rrt	Precipitation Type	rain/snow	6
	eee	Snow Depth	cm	8
	fs	Fresh Snow	cm	2

Temperature

Temperature observations in Europe were recorded on a variety of scales, most commonly Réaumur, Fahrenheit, and Celsius. The Réaumur scale was dominant in Continental Europe throughout much of the 18th and into the early 19th century[13]. The Fahrenheit scale was used predominantly in Britain and Ireland and the Netherlands, and persisted in some Scandinavian records into the second half of the 19th century. Celsius became the standard across most of Europe gradually from the mid-19th century onward[14]. A smaller number of series used regional scales, such as the Micheli du Crest scale and the related Brander scale, both used mainly in Swiss records[15]. These series were already converted to the reformed Réaumur scale by the original contributors, so we applied only the standard Réaumur-to-Celsius conversion described below. All temperature observations in this dataset are converted to degrees Celsius using:

$$^{\circ}\mathrm{C} = {}^{\circ}\mathrm{R} \cdot \frac{5}{4} \tag{1}$$

$$^{\circ}\mathrm{C} = (^{\circ}\mathrm{F} - 32) \cdot \frac{5}{9} \tag{2}$$

Early thermometer readings can carry a systematic warm bias arising from incorrect instrument placement. Réaumur's contemporary guidance recommended mounting thermometers on north-facing walls to avoid direct solar radiation[13,15], but non-compliant exposures were common, and direct sunlight can introduce errors of up to 5 °C[16]. Where known, we describe the placement of the instrument in the metadata. We do not apply corrections for this bias, though some resulting anomalies may be flagged by the QC procedure, and we leave further assessment to the data user.

Maximum and minimum daily temperatures (Tx and Tn) are obtained either from a maximum-minimum thermometer, which directly registers the extremes reached over a given period, or derived as the highest and lowest values among several fixed-hour readings taken during the day. In the latter case, the observing window used to define the daily extreme may differ from a standard 24-hour period. For example, in the Irish ILMMT dataset, daily extremes are obtained from fixed-hour readings rather than continuous observation[17]. This information is noted in the table's Meta column where known. The same unit conversion described above applies equally to Tx and Tn.

Pressure

Early barometric observations were typically recorded as the height of a mercury column measured in regional varieties of "inches" and "lines". The specific definition of an inch was highly dependent on the geographic origin of the instrument. Across much of Continental Europe, the Paris inch was standard until the mid-to-late 19th century. In Eastern Europe and parts of the German states, the Prussian inch prevailed[18]. The English inch was standard in Britain and Ireland, and the Viennese and Castilian inches were used in the Habsburg and Spanish domains, respectively[19,20]. Pressure observations from the modern territory of Ukraine were recorded in a mix of Russian semi-lines and Russian inches[21,22]. The Russian inch was defined equal to the English inch following a standardization decree of Peter the Great in the early 18th century[23]. Table 2 summarizes the conversion factors applied.

If the unit of measurement is not explicitly stated in the source documentation, we resolve the ambiguity by comparing the historical series against the nearest grid cell in 20CRv3. We convert the series under each candidate unit and select the one that

Table 2. Conversion factors for historical pressure units

Unit	mm Hg equivalent	Region of use
Paris inch	27.07	Continental Europe
Viennese inch	26.34	Habsburg domains
Prussian/Rhineland inch	26.15	Eastern Europe, German states
English/British/Russian inch	25.40	Britain and Ireland, Russia, Ukraine
Castilian inch	23.22	Spain
Russian semi line	1.27	Russia, Ukraine
1 hPa	0.7501	

yields the smallest mean absolute difference and an offset from the reanalysis that stays stable over time. If this method cannot resolve the unit, we record it as "unknown" in the header (see Supplementary Table 4).

Where the temperature of the mercury column is available from an attached thermometer, the observation is first reduced to 0 °C using:

$$L_0 = (1 - \gamma T) \cdot L_{mm} \tag{3}$$

where $\gamma = 1.82 \cdot 10^{-4} \mathrm{K}^{-1}$ is the thermal expansion coefficient of mercury at 0 °C, T is the temperature of the barometer in °C, L_{mm} is the original observation in millimeters of mercury, and L_0 is the temperature-corrected column height. We indicate in the header's Meta line as *PTC* (Pressure Temperature Correction) whether this correction was applied, and the value of T used for each observation, as *atb* (attached thermometer to barometer).

The corrected column height is then converted to hectopascals by accounting for the local gravitational acceleration, which depends on latitude φ and elevation h:

$$g_{\varphi,h} = 9.8062 \cdot \left(1 - 2.6442 \cdot 10^{-3} \cdot \cos(2\varphi) - 5.8 \cdot 10^{-6} \cdot \cos^2(2\varphi)\right) - 3.086 \cdot 10^{-6} \cdot h \tag{4}$$

$$P_n = \rho \, g_{\varphi,h} L_0 \cdot 10^{-5} \tag{5}$$

where $\rho = 1.35951 \cdot 10^4 \,\mathrm{kg\,m^{-3}}$ is the density of the mercury at 0 °C. If we cannot retrieve a station's exact elevation, we used the mean elevation of the corresponding populated locality instead. The gravity correction is recorded as *PGC* (Pressure Gravity Correction) in the header's Meta line, and the resulting P_n values represent station-level pressure. Some series are instead provided already reduced to mean sea level by the original data contributors, and flagged as *MSLP* (Mean Sea Level Pressure).

Precipitation

Observers recorded historical precipitation using rain gauges of varying designs, apertures, and mounting heights, making direct comparison of absolute values across sites and periods unreliable. Amounts were typically recorded in local inch variants, which we convert to millimetres using the same inch definitions applied to pressure (Table 2).

The dataset includes precipitation series from several sources, most notably the KNMI collection[24], GHCNd[25], and Weather Rescue Data[26]. For a number of KNMI series in particular, the original unit is not clearly documented, which limits the interpretability of absolute values. Users working with precipitation from this dataset should take this uncertainty into account, particularly when comparing absolute amounts across series or sites.

Wind Direction

Wind direction observations were recorded in a wide variety of notations depending on the language and convention of the observer, including compass abbreviations in Latin, German, French, Spanish, and full words in some Iberian records. All notations are translated to degrees, using a 16-point compass rose where 0 ° corresponds to north and 180 ° to south (Figure 2). When a single observation recorded multiple directions (e.g. "NNW–NW"), we generally retained only the first value. For the Warsaw series, the clean and consistent formatting of the source data made it straightforward to compute a circular mean of the corresponding angles instead by averaging their sine and cosine components to avoid the discontinuity that a direct average of degree values produces near due north.

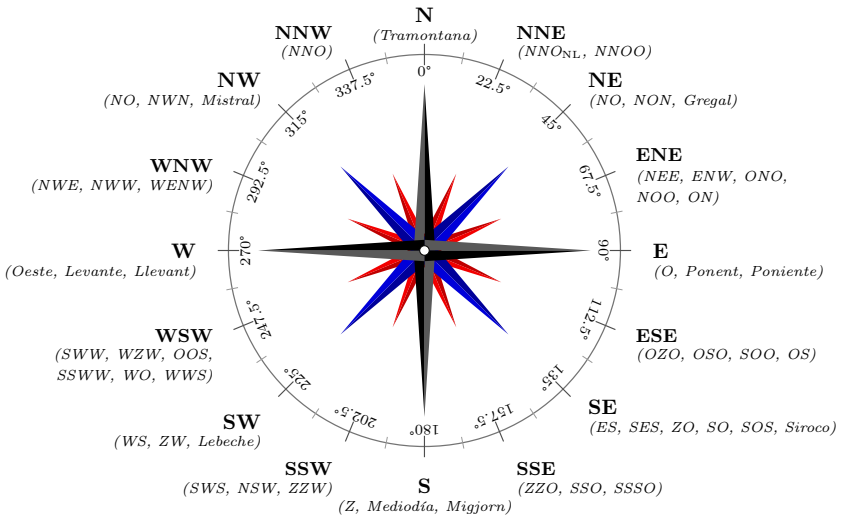


Figure 2. Wind direction notations used in the historical sources and their conversion to degrees.

Wind intensity was often recorded alongside direction. For the series from the PALAEO-RA project, intensity was digitized as integers on a 0–4 scale (0 = calm, 1 = light, 2 = moderate, 3 = strong, 4 = storm). Wind speed series contributed by external sources retain their original units. If intensity was described in qualitative terms (e.g. " calm", "strong", "stormy"), we preserve the original annotation in the table's Meta column of the corresponding wind direction entry (*dd*) rather than converting it to a numeric value. Given the heterogeneity of wind intensity records across sources, we treat the *w* variable as supplementary and list it under "Others".

Other Variables

The dataset includes relative humidity (*rh*), fresh snow (*fs*), precipitation type (*rrt*), wind speed (*w*), and snow depth (*eee*) whenever the original sources provided them. For the PALAEO-RA wind speed series, values are mapped to the 0–4 scale as described in the Wind Direction section above. For all other variables, we do not carry out additional unit harmonization beyond the original contributors' work. We retain them because discarding co-located observations would reduce the dataset's value for users interested in multi-variable analyses or physical consistency checks. Together, these variables account for 66 series, or 3.7% of the total, and we refer to them hereafter as "Others".

Calendar Handling

Correct date attribution is essential for any analysis conducted at the daily or sub-daily scale. A one-day error in the date of an observation is sufficient to eliminate its usefulness for data assimilation into reanalyses, reconstruction of synoptic weather situations, or attribution of observed extremes to specific atmospheric circulation patterns[27].

Historical meteorological observations in Europe were recorded under two different civil calendar systems during the period covered by this dataset. The Gregorian calendar was introduced in 1582 and gradually adopted across the continent over the following three and a half centuries. Traditionally Catholic countries in Western Europe had already introduced the Gregorian calendar by the late 16th or early 17th century. Britain and Ireland followed in 1752, and Sweden in 1753. Eastern Orthodox countries converted much later. Russia did not adopt the Gregorian calendar until 1918, and Greece until 1923. Within the territory of modern Ukraine, the Julian calendar remained in official use until 1918[21]. The offset between the Julian and Gregorian calendars grew with each century that passed without a switch, from 10 days in the 16th century to 11 days after February 1700, 12 days after February 1800, and 13 days after February 1900. We convert all Julian-calendar dates in this dataset to the Gregorian calendar by adding the appropriate number of days, and we document the calendar convention applied to each series in the metadata.

For most of Western and Central Europe, observations were recorded directly in the Gregorian calendar and no conversion is necessary. For the stations of the ClimUAsd-Stn dataset, stations originally recorded dates in the Julian calendar[21,22]. To detect the exact period during which the Julian convention was in use at each station, we compare daily temperature series against the nearest grid cell of 20CRv3 by computing Pearson correlations at lags ranging from -14 to $+14$ days. For stations such as Kherson, the correlation analysis reveals a systematic lag consistent with the expected Julian–Gregorian offset of 12

days for the 19th century. For Kyiv, we detect no significant lag, consistent with the station metadata indicating that its records were likely already transcribed or copied into tables at a later date, possibly already in New Style.

If neither the metadata nor the lag-correlation analysis could determine the calendar system, we assume the Julian calendar for Eastern Orthodox territories and the Gregorian calendar elsewhere, following the convention adopted in ClimUAsd-Stn[21].

Time of Observation

Official standard times did not exist in most of Europe before the second half of the 19th century, and clocks used for meteorological purposes were generally adjusted to apparent solar time even once mechanical timekeeping became available[28]. For series digitized from manuscripts, we assume that the recorded times corresponds to local solar time[20], and convert them to Coordinated Universal Time (UTC) using the longitude of the station.

$$t_{\mathrm{UTC}} = t_{\mathrm{loc}} - \lambda \cdot \frac{24}{360} \tag{6}$$

where λ is the longitude of the station in degrees (positive East). When a specific clock time was recorded, the conversion to UTC applies directly. Series delivered to us already in standard time by national services or other contributors were left unchanged. If the time of observation was instead described qualitatively in the corresponding language, we apply the following fixed conversions:

Qualitative entry	Assigned local time
Morning	07:00
Midday	12:00
Afternoon	15:00
Evening	19:00
Night	21:00

These assignments are approximations. The meaning of terms like “morning” or “evening” is not uniform across Europe, and individual observers sometimes specified their conventions only at the beginning of a manuscript. When this information is available, we rely on it in preference to the default conversions above.

We convert observation times recorded as “sunrise” or “sunset” to local time:

$$H_{\mathrm{sun}} = \arccos\left(-\tan\varphi \cdot \tan\delta\right) \cdot \frac{24}{2\pi} \tag{7}$$

where H_{sun} is the half-day length in hours, φ is the latitude of the station, and δ is the solar declination computed following J. Meeus’s astronomical algorithms[29]. Local sunrise (sunset) is then $0.5\,H_{\mathrm{sun}}$ before (after) local noon.

Quality Control

We used the `dataresqc` R package (`https://CRAN.R-project.org/package=dataresqc`[30]), developed specifically for the Copernicus Data Rescue Service, for QC. The package detects erroneous and suspicious values in historical climate records at daily and sub-daily resolution. The following tests are applied to all variables where applicable:

- `daily_out_of_range`; `subdaily_out_of_range`: detects temperature, precipitation, wind direction, and fresh snow values exceeding $[-35, 40]$, $[0, 100]$, $[0, 360]$, $[0, 100]$, respectively.
- `daily_repetition`; `subdaily_repetition`: reports occurrences of identical consecutive values in daily or sub-daily data.
- `duplicate_columns`: detects values that may have been digitized twice by mistake.
- `duplicate_dates`; `duplicate_times`: flags dates (times) that appear more than once in daily (sub-daily) data.
- `climatic_outliers`: detects values falling outside the range $[P_{25} - n \cdot \mathrm{IQR},\ P_{75} + n \cdot \mathrm{IQR}]$, where P_{25} and P_{75} are the 25th and 75th percentiles, IQR is the interquartile range, and $n = 3$ for temperature, 4 for pressure, and 5 for precipitation. This test is applied only where at least 5 years of non-zero daily values are available and 3 years for sub-daily data.
- `wmo_gross_errors`: flags observations exceeding the limits recommended by World Meteorological Organization (WMO) guidelines[31].

- `wmo_time_consistency`: flags records where the change between consecutive observations exceeds the WMO-recommended tolerances as a function of the time interval between measurements[31].

The QC procedure is applied iteratively. After each iteration, we check WMO gross errors and impossible dates against the original manuscript photocopies or the digitized files, correct digitization errors directly in the primary data file, and repeat the QC procedure. All remaining flags are retained as-is in the Meta column of the corresponding SEF file, so no values are removed from the dataset. Per-observation QC flags inherited from the original data contributors are likewise preserved in the data Meta column. When `QC=Y` appears in the file header's Meta field, the series was quality-controlled by its original contributors, and users should consult the cited source directly for more detailed information. Files without the `qc` label lack the temporal coverage required to compute a climatological mean for comparison. We encourage users to identify and, if necessary, filter flagged observations.

Data Records

The dataset covers 480 locations and 1,798 series, split between 773 daily and 1,025 sub-daily records[32].

Definition of Series

We define a series as a sequence of observations of the same variable, recorded at one station with a consistent instrument and recording method. A series may span changes in observer or minor relocations of the station, which we note in the metadata header. We keep series from different contributors or repositories separate when their pre-processing steps are unclear. The various versions may differ in the quality-control procedures or unit conversions applied by the original data providers.

Station Exchange Format

All timeseries are provided in tab-separated SEF files, a standardized format developed by the Copernicus Climate Change Service[12]. Each SEF file begins with a 12-line metadata header followed by a tab-separated table of observations. The header contains station coordinates, source details, and a link to the original publication where available. The final entry of the header may contain additional descriptive information, such as the name of the observer, the instrument type, known station relocations, or changes in observational practices or units. The observation table includes date, time, period, value, and an optional metadata field used to record the original units, pre-processing notes, and quality-control flags. Together, the header and metadata column ensure full traceability from each observation back to its original source, units, and any transformations applied. Both the original digitized files and the pre-processed, quality-controlled versions are available. Figure 3 contains an example of a SEF file.

```
SEF     1.0.0
ID      Bern_Trechsel
Name    Bern
Lat     46.94694
Lon     7.450515
Alt     548
Source  GCOS
Link    https://doi.pangaea.de/10.1594/PANGAEA.948258
Vbl     p
Stat    point
Units   hPa
Meta    Observer=Trechsel | PGC=Y | PTC=Y | Coords=(46.94694,7.450515,548m,18440101-18461231);
(46.948056,542m,7.451607,18480101-18490930) | QC software=dataresqc v1.1.0
Year    Month   Day     Hour    Minute  Period  Value   Meta
1826    4       1       8       30      0       963.1   orig.time=09:00 | orig=26.8.78Pin | atb=7.5R
1826    4       1       11      30      0       962.8   orig.time=12:00 | orig=26.8.74Pin | atb=8.3R
1826    4       1       14      30      0       962.1   orig.time=15:00 | orig=26.8.53Pin | atb=8.4R
1826    4       1       21      30      0       962.8   orig.time=22:00 | orig=26.8.50Pin | atb=5R
1826    4       2       8       30      0       963.3   orig.time=09:00 | orig=26.8.79Pin | atb=6.8R
1826    4       2       11      30      0       962.6   orig.time=12:00 | orig=26.8.80Pin | atb=9.8R
```

Figure 3. An example SEF file showing the 12-line metadata header and the tab-separated observation table.

Naming Convention

Files are organized in directories named after the observing location, using the current standard English place name. Each directory typically corresponds to a city, village, or named geographical feature such as a lighthouse. Alternative names, historical variants, and local-language equivalents are recorded in the accompanying `metadata_summary` file. Where multiple independent series exist for the same location, they are stored in the same directory and distinguished by the filename. Each filename follows the convention:

`Source_Station_Observer_startdate-enddate_variable_freq_qc.tsv`

`Source` identifies the project, repository, or author that contributed the series. `Station` matches the directory name. `Observer` is included only where multiple overlapping series for the same location must be distinguished from one another, and is otherwise omitted. Dates are given in `yyyymmdd` format. `variable` follows the abbreviations in Table 1. `freq` is either `subdaily`, when the time of each individual observation is known, or `daily`, when only a daily aggregate is available. The `qc` suffix is appended only to series that were quality-controlled as part of this work.

In the dataset, a series is classified as *subdaily* if the time of each individual observation is recorded or can be reliably inferred, even if there is only one observation per day. A series is classified as *daily* if only a daily aggregate is available. This can be a mean derived from sub-daily readings by the original source (e.g. $(T_x + T_n)/2$) or a value for which no specific observation time could be determined.

Temporal and Spatial Coverage

Figure 4 shows how the network of available series in HIST-DAILY grew between the 17th and the 20th century. The peak in the 1780s reflects the activity of the Palatine Society, a coordinated European network that used standardized instruments across its member stations.

The collapse of the Palatine Society in 1795 and the disruption of scientific activity across Europe during the Napoleonic Wars account for the more limited coverage during the first half of the 19th century[33,34]. The network then grows steadily from the middle of the century onward as national meteorological services started to be established across Europe. The two apparent spikes around 1861–63 and 1872–75 reflect the temporal envelope of the digitized UK Met Office Daily Weather Reports[35]. The earlier spike is further reinforced by a cluster of Swiss private-observer series that were still active in 1861 and end around 1863[11]. The abrupt decline after 1875 simply marks the end of the time window covered by the transcribed Daily Weather Reports, not a real contraction of the underlying observational network.

The inset in Figure 4 breaks down the 1,798 series by variable. Temperature and pressure series dominate the collection, with 560 and 560 series respectively. Precipitation, wind direction, and the maximum and minimum temperature series make up the rest. Most of these only entered the network from the 19th century onward.

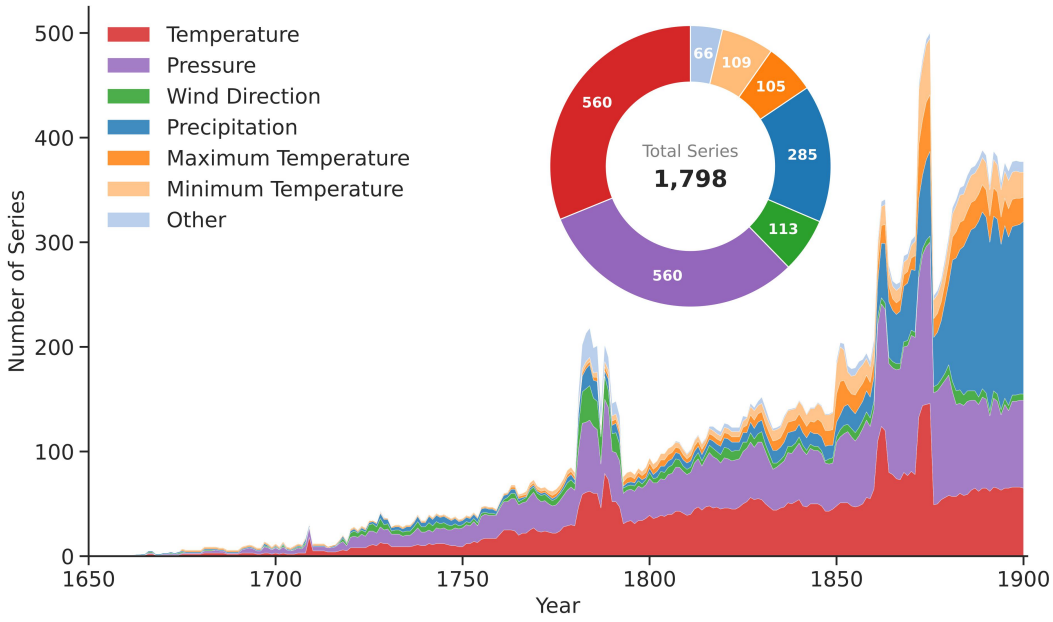


Figure 4. Temporal evolution of the HIST-DAILY observing network. The stacked area chart shows the number of active series per year from 1658 to 1900, broken down by meteorological variable. The inset donut chart shows the total composition of the 1,798 series in the dataset by variable.

Figure 5 maps the spatial extent of HIST-DAILY and the year each station began recording. The dataset covers Europe and the Mediterranean basin. Beyond this region, HIST-DAILY includes stations in northern Africa, the Middle East, central Asia, and the eastern Atlantic (the Azores, Iceland, Greenland, and Newfoundland), all drawn from broader digitized collections. Temperature and pressure series offer the broadest geographic coverage before 1850, with stations dating back to the early 18th

century spread from the Iberian Peninsula through Scandinavia. Precipitation series also extend widely across the domain, including into eastern Europe and Russia, but this eastern coverage derives almost entirely from GHCNd stations beginning in the 1860s; before that decade, precipitation records are concentrated mainly in Britain and Ireland and the Alpine region. Wind direction series concentrate in central Europe. Coverage is thinner across southeastern Europe and much of Scandinavia, where most series begin only in the second half of the 19th century. Before roughly 1750, only a small number of stations were active simultaneously.

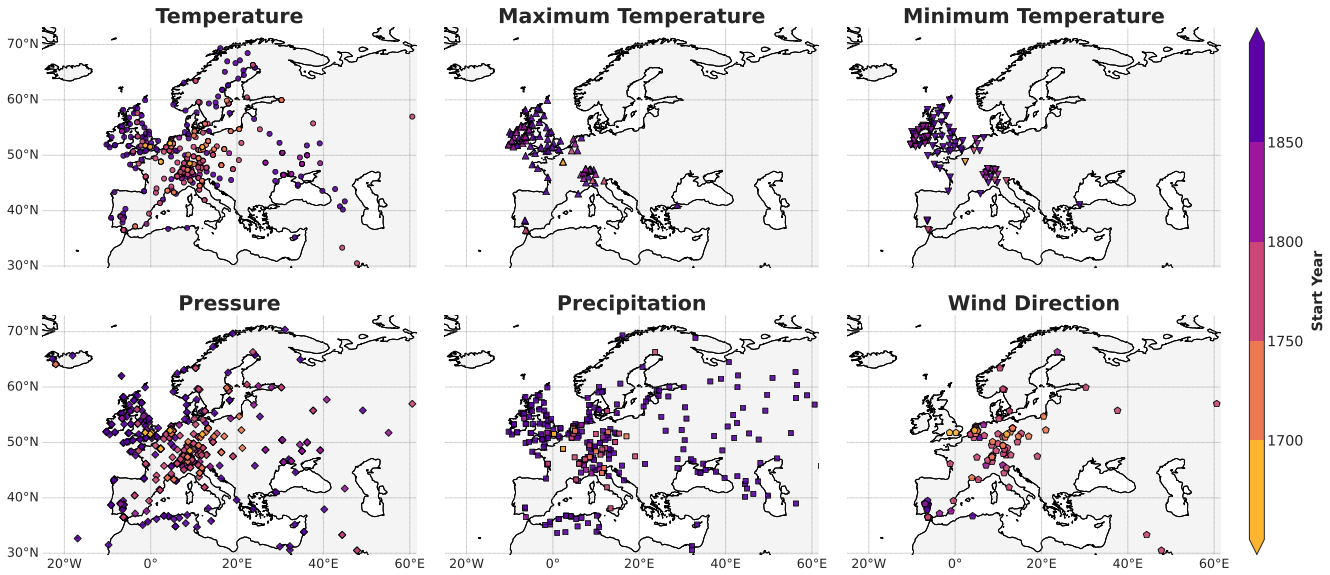


Figure 5. Spatial distribution of historical stations across the domain, color-coded by the starting year of the observational record for the primary meteorological variables.

Table 3 lists the earliest known start date in the network for each meteorological variable. The earliest temperature series begins in Paris on 25 May 1658, with observations made by Ismaël Boulliau and later continued by a long succession of observers and institutions through to the modern Montsouris observatory[36,37]. This start date is already well established in the literature[7,38]. The contribution of HIST-DAILY for this series is to make it available at daily rather than monthly resolution. Daily pressure and wind direction observations from Oxford, digitized under the PALAEO-RA project, begin on 4 July 1666, four years before the Paris pressure series usually given as Europe's earliest, which starts in 1670[39]. The earliest precipitation record in the dataset also comes from Paris and begins on 1 February 1665, more than two decades before the gauge-based Paris precipitation series of 1688[40]. It is reconstructed from Louis Morin's narrative observations of rain intensity and duration[41], and it extends the Paris precipitation record back by 23 years, although the absence of direct gauge measurements means this entry carries higher uncertainty than later gauge-based series. An even earlier temperature record exists for Florence, part of the Medici Network active from 1654 to 1670[42]. No data repository or file accompanies the publication, so we could not include this series in HIST-DAILY.

Table 3. Oldest series per variable

Variable	Station	Start Date	Source
ta	Paris	1658-5-25	Rousseau[37]
p	Oxford	1666-7-4	PALAEO-RA
dd	Oxford	1666-7-4	PALAEO-RA
rr	Paris	1665-2-1	Pliemon[41]
Tn	Paris	1675-12-1	Rousseau[37]
Tx	Paris	1675-12-1	Rousseau[37]

Technical Validation

Quality Control Summary

The dataset contains 28,426,779 non-NA values across 1,798 series, 88,815 of which carry at least one QC flag (0.31%). Series obtained from external databases such as ECA&D and ISPD are already screened by their providers, so any flag our pipeline assigns to these series represents a residual finding on top of prior QC. Our digitized series account for 6.07% of all non-NA values but contribute to 13.32% of all flagged values. This disproportion is justified, as these series had received no prior screening.

Flag instances total 114,107 across the dataset, a count larger than 88,815 because a single observation can carry more than one flag. The majority of flags (84%) describe structural features of the source record. The four most common structural flag types are `duplicate_columns` (40,322 instances), `subdaily_repetition` (36,408), `duplicate_times` (10,091), and `daily_repetition` (8,896), all arising from records in which the same observation appears more than once across rows, columns, or time steps. Most of the remainder (15%) covers failed plausibility checks, with `wmo_time_consistency` as the most frequent (11,980 instances), followed by `climatic_outliers` (3,760) and `wmo_gross_errors` (1,234). The remaining checks (around 1%) cover a long tail of rarer flag types not individually detailed here.

Table 4 reports flag counts for the six core variables. Wind direction (*dd*) shows the highest rate at 3.20%. This elevated rate reflects the manual transcription step required to convert language-specific compass abbreviations to degrees. Automated repetition and consistency checks are particularly sensitive to entries that were ambiguous or that mapped to the same degree value. Temperature, pressure, and precipitation percentage of flagged values remain below 0.35%.

Table 4. QC flag counts by variable

Variable	Total values	Flagged	%
ta	7,403,947	21,222	0.29
p	8,970,052	17,481	0.19
rr	7,836,657	2,552	0.03
dd	1,191,400	38,149	3.20
Tn	1,097,007	2,615	0.24
Tx	1,074,126	3,440	0.32
Others	853,590	3,356	0.39
Total	28,426,779	88,815	0.31

Case Study: The Winter of 1829/30

The winter of 1829/30 was among the most severe in the European record, second only to 1740[43]. A long documentary severity classification places it in the highest category[44]. We examined the season through five northern Italian stations with continuous daily temperature: Padua, Milan, Bologna, Turin, and Rovereto. We compared the winter months with the ensemble mean of 20CRv3 at the closest grid cell of each station.

Figure 6 sets the five records against the reanalysis. 20CRv3 follows the day-to-day variability of the stations closely. It misses the depth of the cold minimum on 11 January 1830 and runs too warm at the end of February. The stations themselves agree remarkably well with each other, and together they trace the cold extreme that the reanalysis only partly resolves. The stations share no common data source, so their mutual agreement confirms a real climate signal rather than a processing artifact. We computed these values as anomalies from each station's mean over the winter window, so the comparison cannot reveal systematic biases in the absolute temperature level. Panel (b) makes the same point through the distribution, where the bulk aligns with 20CRv3 but the cold tail falls below it. Agreement between the stations and 20CRv3 is consistent across the network, with per-station correlations ranging from $r = 0.78$ (Turin) to $r = 0.84$ (Padua) and RMSE from 2.5°C (Padua) to 3.2°C (Turin). Panel (c) shows that correlations among the stations reflect the regional geography, strongest within the Po Plain and weaker for the more distant and topographically isolated stations. HIST-DAILY can therefore capture extremes that current reanalyses underestimate, and it provides the kind of information needed to improve them.

We additionally estimated the random observation error in the temperature series independently of the reanalysis comparison, using the approach of Wartenburger et al. (2013)[45]. The regression of the variance of pairwise monthly anomaly differences against squared station distance across the ten station pairs gives $\sigma_e \approx 0.63\,^{\circ}\mathrm{C}$, well below the 2.9 °C RMSE relative to 20CRv3 reported above. This result suggests that disagreement among the stations in the case study network mainly reflects real spatial variability and limitations in the reanalysis representativity rather than random error in the digitized observations. The small number of station pairs limits this estimate, and the intercept is not significant at the 95% confidence level.

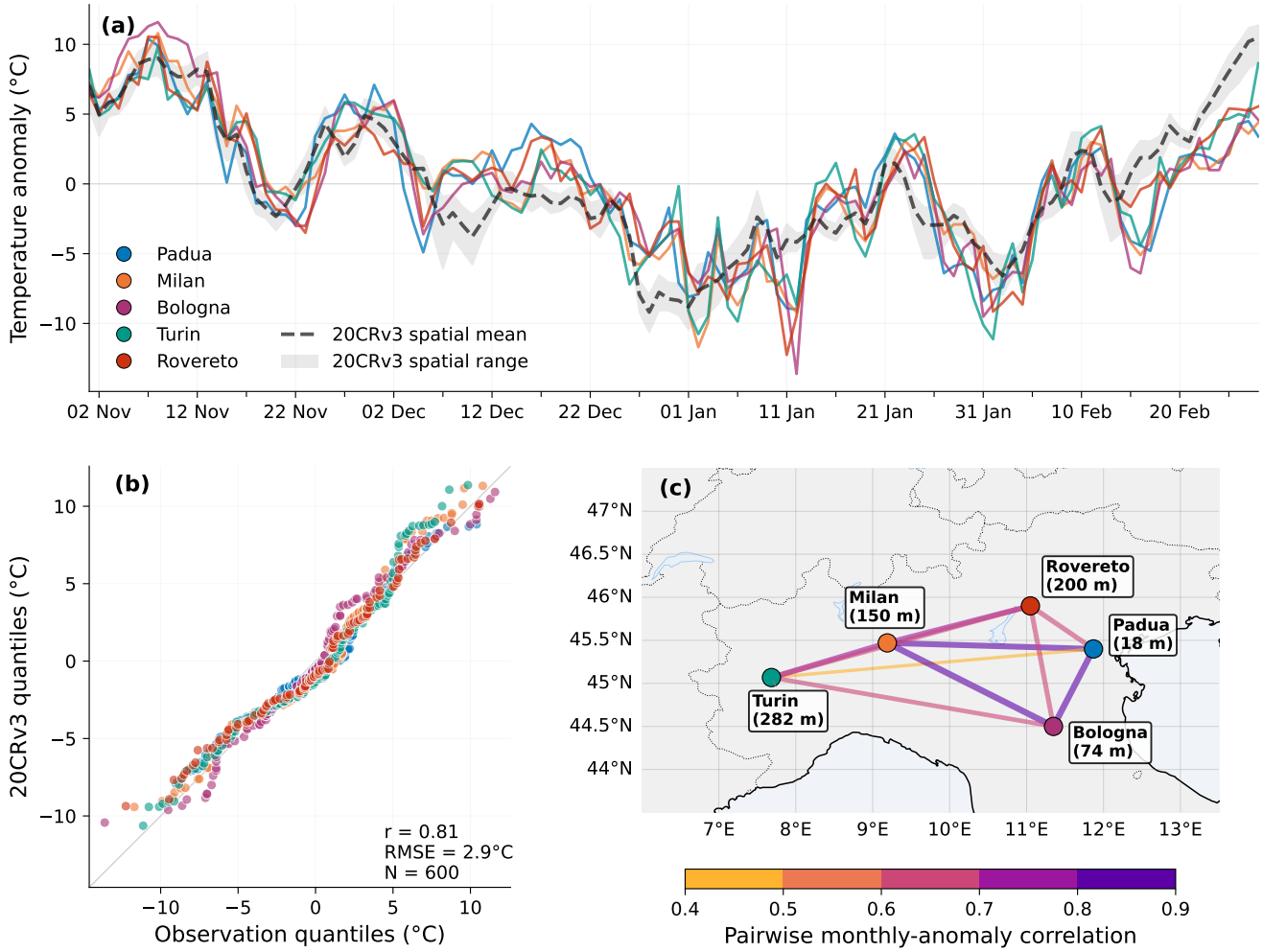


Figure 6. Technical validation of HIST-DAILY over northern Italy during the winter of 1829/30. **(a)** Daily temperature anomalies from 1 November 1829 to 28 February 1830 for five stations: Padua, Milan, Bologna, Turin, and Rovereto. Station anomalies were computed by subtracting each station's mean over the November 1829 to February 1830 window. The 20CRv3 ensemble mean was extracted at the nearest grid cell to each station, converted to anomalies by subtracting its own mean over the same window, and then averaged across the five grid cells to produce the reference line shown. The shaded envelope shows the range across those five grid cells. **(b)** Quantile-quantile plot comparing the empirical distribution of daily anomalies from the five stations against the corresponding 20CRv3 anomalies over the same period. Quantiles were computed independently for each station and its nearest grid cell, then pooled. Pooled statistics across all five stations are shown in the lower right. **(c)** Station network map showing the locations of the five stations with elevation in metres above sea level. Edges connect each station pair and are coloured and weighted by the Pearson correlation of monthly temperature anomalies, computed over the full overlapping period of each pair from their respective daily records (minimum 24 common months required). Monthly anomalies were derived by subtracting the long-term monthly climatology of each station from its full daily record resampled to monthly means. Correlations range from $r = 0.45$ (Padua-Turin, 330km) to $r = 0.86$ (Milan-Bologna, 201km), computed over overlapping periods ranging from 308 months (Bologna-Rovereto) to 2182 months (Padua-Bologna).

Known Limitations

Early instrumental observations lack the standardization of modern measurements, and a number of situations across the dataset call for particular care in interpretation. In all cases we retain the affected data and document the relevant issues in the Meta fields of the corresponding SEF files.

For Paris and London, Cornes et al. assembled continuous daily pressure records spanning 1670 to 2007 and 1692 to 2007 respectively by combining observations from successive observers[39,46]. We include these alongside the individual observer segments from which they were built. Both long-term series are provided in non-homogenized form, and homogenized versions

are available through the original publications and flagged in the header's Meta line of the corresponding SEF files.

Precipitation records from the KNMI historical archive show anomalously low values. For the Utrecht series, a discrepancy between the conversion factor in the digitized files and the scale description in the original manuscript suggests that the applied conversion is approximately 2.5 times too small[47]. At other stations, instruments placed on rooftops caused systematic underestimation of precipitation totals[47,48]. Pre-1900 records from this archive are generally considered unreliable due to the absence of standardized measuring practices[48]. We advise users to treat these records with caution.

Supplementary Table 4 lists 18 cases for which the original measurement scale is unknown or insufficiently documented, and no reliable conversion to standard units could be established. These observations are included as originally digitized, with the original unit label preserved in the header's Meta line.

Usage Notes

This dataset provides, for the first time, sub-daily and daily documentary weather data from multiple European sources in a unified, quality-controlled format. Its purpose is to facilitate historical weather reconstruction and data assimilation efforts, but individual time series may also be used for case studies and validation exercises. Additional processing of wind direction data, for example through weather-typing approaches that combine wind with pressure and other variables to classify synoptic situations, could support reconstructions of past extreme events[49].

An initial quality-control procedure has been applied to all series. This first-pass screening is intentionally simple and attempts to flag the most evident outliers and internal inconsistencies. However, users should remain aware of the limitations of early meteorological instruments and observing practices. Systematic biases, calibration issues, and instrument misreadings may still be present in some records. Digitization errors have been extensively checked and corrected wherever detected, but it cannot be fully excluded that a small number of issues may have escaped attention. Where multiple series from different sources cover the same station and period, systematic offsets may arise from differences in quality-control procedures or unit conversions applied by the original contributors. In such cases, computing anomalies from each series independently, rather than working with absolute values, can help reduce the influence of these offsets when comparing or combining records.

Substantial effort has been invested in converting units and adjusting calendar conventions. However, particular caution is advised. Standardized measurement units only became common internationally in the 20th century, but local and national units persisted much longer[15]. Similarly, calendar systems were not uniformly aligned across Europe. The transition to the Gregorian calendar was completed only by 1923, but individual regions implemented date adjustments in different ways –incrementally over several years or by shifting several days at once. These historical differences can introduce discontinuities or offsets in the raw observations, and users are encouraged to verify the temporal and unit conventions relevant to their analyses. The dataset is designed primarily to support weather reconstructions, analyses of extreme events, and targeted case studies. We do not recommend its use for deriving long-term climatic trends, as remaining inhomogeneities and gaps in documentary records may obscure or distort multidecadal signals.

Data Availability

The HIST-DAILY dataset is available in Zenodo at `https://doi.org/10.5281/zenodo.22895829`[32]. The deposit contains the processed files (`SEF/`), the original source files (`original/`), and a flat-file index (`inventory.csv`). The dataset is released under a CC BY-NC 4.0 licence, reflecting the non-commercial licence terms of a constituent source[50].

Code Availability

Quality control was performed using the publicly available `dataresqc` R package (v1.1.1; `https://CRAN.R-project.org/package=dataresqc`). Unit conversion and data formatting followed the procedures described in the Methods section. These were implemented as source-specific scripts tailored to each station's original format rather than as a generalizable pipeline, and are therefore not released as standalone software.

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