UNLOCKING PRE-1850 INSTRUMENTAL METEOROLOGICAL RECORDS

A Global Inventory

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A global inventory of early instrumental meteorological measurements is compiled that comprises thousands of mostly nondigitized series, pointing to the potential of weather data rescue.

As Enlightenment scientists initiated regular meteorological measurements in the seventeenth and eighteenth centuries (Wolf 1962), scientists today have access to a wealth of early weather and climate information from across Europe (Jones 2001), and also other parts of the world. Very long series such as central England temperatures (start date 1659; Manley 1974; Parker et al. 1992) or Paris temperatures (1658; Rousseau 2015) are widely used as a baseline for current temperature changes and to study past climatic variations at regional scale. The same holds for long rainfall series such as those for Paris (1688; Slonosky 2002), Ireland (1716; Murphy et al. 2018), and Seoul (1770; Arakawa 1956). A considerable number of other long, mostly European, instrumental records have been published (e.g., Wheeler 1995; Moberg and Bergström 1997; Jones and Lister 2002; Moberg et al. 2002; Bergström and Moberg 2002; Maugeri et al. 2002a,b; Camuffo et al. 2006; Bryś and Bryś 2010a,b; Cornes et al. 2012a,b, 2012; Brázdil et al. 2012). While these records shed light on past climatic variations, they constitute only a subset of all measurements taken. Here we aim at providing an inventory (see online supplemental material; https://doi.org/10.1175/BAMS-D-19-0040.2), still far from comprehensive, of where, when, and by whom meteorological measurements were made prior to circa 1850.

Numerous efforts by individuals, weather services, international projects, and efforts coordinated by the Atmospheric Circulation Reconstructions over the Earth Initiative (ACRE; Allan et al. 2011) form the basis of our inventory. A selection of long European daily records (from Italy, Spain, Sweden, Belgium, Russia) of air temperature and air pressure, some reaching far back into the eighteenth century, were compiled within Project Improved Understanding of Past Climatic Variability from Early Daily European Instrumental Sources (IMPROVE) (Camuffo and Jones 2002). The Austrian-led dataset Historical Instrumental Climatological Surface Time Series of the Greater Alpine Region (HISTALP; Auer et al. 2007) collected and processed long instrumental series for temperature, pressure, precipitation, cloudiness, sunshine duration, water vapor pressure, and relative humidity back to 1760. Project Annual to decadal variability in Climate in Europe (ADVICE) compiled monthly mean air pressure data for several sites in

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Europe back to 1780 (Jones et al. 1999). Early instrumental series were compiled for Portugal and its colonies (Alcoforado et al. 2012), Spain (Barriendos et al. 2002; Domínguez-Castro et al. 2014; Prohom et al. 2016; Sanchez-Rodrigo 2019), Italy and the western Mediterranean (Cantù and Narducci 1967; Brunetti et al. 2001, 2006; Camuffo and Bertolin 2012; Camuffo et al. 2013, 2017), the Mediterranean North Africa and the Middle East (Brunet et al. 2014b; Ashcroft et al. 2018), the Czech Republic (Brázdil et al. 2005, 2012), and Poland (Przybylak and Pospieszyńska 2010; Przybylak et al. 2014). Canadian data were published by Slonosky (2003, 2014) and long series compiled in the United States by Burnette et al. (2010). Historical U.S. daily weather data were archived and imaged by NOAA under the Climate Data Modernization Program, with more than 15,000 station months (more than 140 stations) digitized for the period prior to 1850 (Dupigny-Giroux et al. 2007; Westcott et al. 2011). Domínguez-Castro et al. (2017) compiled early instrumental series for Latin America, while Ashcroft et al. (2014, 2016) and Gergis and Ashcroft (2013) provide data for southeastern Australia and Williamson et al. (2018) for southeastern Asia. For an overview of data in Africa see Nash and Adamson (2014). A global inventory of these records, however, does not exist yet.

Interest in such historical weather data are not new. Scientists in the early eighteenth century compiled meteorological data in their efforts to study and understand weather and climate in different parts of the world (Maraldi 1709; Derham 1735; Hadley 1741, 1744; Wargentin 1758; Kirwan 1787). In the nineteenth and early twentieth centuries, numerous inventories were compiled (e.g., Schouw 1839; Dove 1839, 1841a,b, 1844, 1847, 1852; Blodget 1857; Schott 1876a,b, 1881; Angot 1897; Hellmann 1883, 1901a,b, 1927; Supan 1898; Eredia 1912, 1919). Data were used for regional climate descriptions (e.g., Kreil 1865; de Strzelecki 1845) or for the construction of isothermal maps (Humboldt 1817; Berghaus 2004; Dove 1852). Although attempts were made again in the 1970s through 2000s to systematically compile eighteenth century records (Kington 1988), most historical inventories are nowadays largely forgotten, mainly because the metadata from these inventories have never been digitized.

Dove's articles did not just include summaries of the data and source details, but monthly averages for over a thousand series. These were used in Northern Hemisphere temperature estimates produced in the early 1980s (Bradley et al. 1985; Jones et al. 1985, 1986). Almost 100 years earlier, these same Dove sources, together with data published in European meteorological journals were used by Köppen (1873, 1881)

Table 1. Global (italics) and national repositories searched (see also Table 3), number of pre-1850 records *N*, and reference.

Repository	Abbreviation	*N*	References
Global Historical Climatology Network	GHCN	596	Lawrimore et al. (2011), Menne et al. (2012)
International Surface Temperature Initiative	ISTI	710	Rennie et al. (2014)
Climatic Research Unit Temperature	CRUTEM3/4	476	Jones et al. (2012)
Berkeley Earth	BEST	358	Rohde et al. (2013)
International Surface Pressure Databank	ISPD	193	Cram et al. (2015)
Historical Instrumental Climate Series of the Greater Alpine Region	HISTALP	85	Auer et al. (2007)
Canada (including the Hudson Bay Company)	—	369	Slonosky (2014), V. C. Slonosky (2019, personal communication)
U.S. Army Signal Service and other nineteenth-century Voluntary Observations	CDMP Forts	142	Dupigny-Giroux et al. (2007), Westcott et al. (2011)
Météo-France	Météo-France	236	Brunet et al. (2014a)
French National Archives	FNA	53	Brunet et al. (2014a)
Swiss Metadata Inventory	CHIMES	200	Pfister et al. (2019)
German Weather Service	DWD	138	—
Austria	ZAMG	66	—
Sweden	Moberg	~100	Moberg (1998)
National Library of Iceland	ICELAND	65	—
Cambiamenti climatici e agricoltura	CLIMAGRI	28	Maugeri et al. (2006)
Early meteorological records from Latin America and the Caribbean	EMERLAC	33	Domínguez-Castro et al. (2017)
Russia	RIHMI	28	Gazina and Klimenko (2008)

to produce the first estimate of average temperatures in the Northern Hemisphere.

Large fractions of the data listed in these inventories, particularly the shorter series, have not been digitized. The value of such shorter series is well recognized today. Historical reanalyses such as the "Twentieth Century Reanalysis" (20CR; Compo et al. 2011) are able to generate useful weather reconstructions from records of only a few years, as demonstrated for the "Year without a Summer" of 1816 (Brugnara et al. 2015; Brohan et al. 2016), though long-term homogeneity of such short records is problematic. A backward extension not just of climate data, but also weather data contributes toward a better understanding of extreme, and thus rare, events. It allows important climate processes to be addressed such as the transit of the climate system out of Little Ice Age climate, the impacts of volcanic eruptions or natural, interannual to decadal variability [e.g., Trigo et al. 2009; Domínguez-Castro et al. 2013; Fragoso et al. 2015; Brönnimann et al. 2019; important early studies include Lenke (1964) and Manley (1975)]. However, this requires rescuing additional historical weather data (Brönnimann et al. 2018a). Together with other sources, they also allow climate data to be connected with climatic impacts and associated societal responses (e.g., resilience, adaptation).

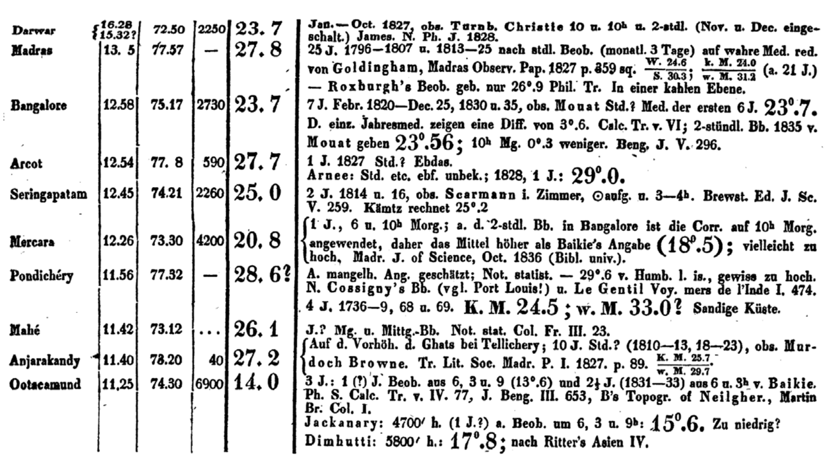
Here we provide an initial, systematic global compilation of information on early instrumental data. The paper documents efforts within ACRE, the International Surface Temperature Initiative (Thorne et al. 2011) as well as results from a workshop held in Bern, Switzerland, 18–21 June 2018. Experts from all parts of the world are involved in this initiative (the authors of this paper represent 26 different countries) and have contributed to making the inventory as comprehensive as possible.

The focus is on instrumental series with regular (daily or more frequent) measurements over at least one year prior to 1850, even if some of the data have so far not been found. The inventory contains the relevant meta information when and where available (station name, coordinates, altitude, observer, source) as well as information on availability or state of data rescue. Though far from complete, our inventory, along with data rescue services (Brönnimann et al. 2018b), aims to support future data rescue efforts. It should also help to counteract the danger of losing data. Climate data are societal products (Brönnimann and Wintzer 2019) and form part of our cultural heritage. The inventoried information may also interest historians and experts of related disciplines.

The paper is organized as follows. The second section describes the generation of the inventory. The third section provides an overview of the stations inventoried, starting with a global overview and then focusing on World Meteorological Organization (WMO) regions. Conclusions follow in the fourth section.

METHODS.

Criteria for data collection. Before inventorying the data, we defined criteria for collection. We defined 1850 as a cutoff year because this approximately reflects the start of national weather services (e.g., Prussian Meteorological Institute: 1847; Smithsonian Institution network: 1849; weather service of the Austrian empire: 1851; French meteorological service at the Observatoire de Paris: 1855); this makes 1850 also broadly the beginning of international standards. For the same reason, many global datasets reach back to around that time. For instance, Climatic Research Unit Temperature dataset, version 4 (CRUTEM4) (Jones et al. 2012), and 20CRv2c go back to 1850 and 1851, respectively.



Darwar	16.28 / 15.32?	72.50	2250	23. 7	Jan.—Oct. 1827, obs. Turnb. Christie 10 u. 10h u. 2-stdl. (Nov. u. Dec. eingeschalt.) James. N. Ph. J. 1828.
Madras	13. 5	77.57	—	27. 8	25 J. 1796—1807 u. 1813—25 nach stdl. Beob. (monatl. 3 Tage) auf wahre Med. red. von Goldingham, Madras Observ. Pap. 1827 p. 359 sq. W. 24.6 / S. 30.3; k. M. 24.0 / w. M. 31.2 (a. 21 J.) — Roxburgh's Beob. geb. nur 26°.9 Phil. Tr. In einer kahlen Ebene.
Bangalore	12.58	75.17	2730	23. 7	7 J. Febr. 1820—Dec. 25, 1830 u. 35, obs. Mouat Std.? Med. der ersten 6 J. 23°.7. D. einz. Jahresmed. zeigen eine Diff. von 3°.6. Calc. Tr. v. VI; 2-stündl. Bb. 1835 v. Mouat geben 23°.56; 10h Mg. 0°.3 weniger. Beng. J. V. 296.
Arcot	12.54	77. 8	590	27. 7	1 J. 1827 Std.? Ebdas. Arnee: Std. etc. ebf. unbek.; 1828, 1 J.: 29°.0.
Seringapatam	12.45	74.21	2260	25. 0	2 J. 1814 u. 16, obs. Scarmann i. Zimmer, ⊙aufg. u. 3—4h. Brewst. Ed. J. Sc. V. 259. Kämtz rechnet 25°.2
Mercara	12.26	73.30	4200	20. 8	1 J., 6 u. 10h Morg.; a. d. 2-stdl. Bb. in Bangalore ist die Corr. auf 10h Morg. angewendet, daher das Mittel höher als Baikie's Angabe (18°.5); vielleicht zu hoch, Madr. J. of Science, Oct. 1836 (Bibl. univ.).
Pondichéry	11.56	77.32	—	28. 6?	A. mangelh. Ang. geschätzt; Not. statist. — 29°.6 v. Humb. l. is., gewiss zu hoch. N. Cossigny's Bb. (vgl. Port Louis!) u. Le Gentil Voy. mers de l'Inde I. 474. 4 J. 1736—9, 68 u. 69. K. M. 24.5; w. M. 33.0? Sandige Küste.
Mahé	11.42	73.12	...	26. 1	J.? Mg. u. Mittg.-Bb. Not. stat. Col. Fr. III. 23.
Anjarakandy	11.40	73.20	40	27. 2	Auf d. Vorhöh. d. Ghats bei Tellichery; 10 J. Std.? (1810—13, 18—23), obs. Murdoch Browne. Tr. Lit. Soc. Madr. P. I. 1827. p. 89. K. M. 25.7 / w. M. 29.7.
Ootacamund	11,25	74.30	6900	14. 0	3 J.: 1 (?) J. Beob. aus 6, 3 u. 9 (13°.6) und 2½ J. (1831—33) aus 6 u. 3h v. Baikie. Ph. S. Calc. Tr. v. IV. 77, J. Beng. III. 653, B's Topogr. of Neilgher., Martin Br. Col. I. Jackanary: 4700′ h. (1 J.?) a. Beob. um 6, 3 u. 9h: 15°.6. Zu niedrig? Dimhutti: 5800′ h.: 17°.8; nach Ritter's Asien IV.

Fig. 1. Excerpt from the inventory of Dove (1841b). It contains a lot of useful information in condensed form.

However, for some regions the 1850 cutoff is too early. Africa has almost no measurements prior to 1850, while much data from the second half of the century also have never been systematically compiled. The same is true for the Arctic (Przybylak et al. 2010). For these regions, we therefore set a later cutoff at 1890. Series that are listed in inventories published prior to 1850, but for which measurement years were not given,

Table 2. Historical inventories (italic) and collections considered, number of pre-1850 records *N*, and reference.				
Inventory/ collection	**Title/source**	**Region**	***N***	**References**
Berghaus	Physikalischer Atlas	Global	304	Berghaus (2004)
Dove	Repertorium/Isotherme Linien	Global	1,246	Dove (1841b, 1852)
Hellmann_Germany	Repertorium	Germany	457	Hellmann (1883)
Hellmann_global	—	Global	197	Hellmann (1901, 1927)
Schott	Tables, distribution and variations of the atmospheric temperatures in the United States and adjacent parts of America	North America	586	Schott (1876)
Schouw	Tableau du climat et de la végétation de l'Italie	Italy	49	Schouw (1839)
Angot	Premier catalogue des observationes météorologiques faites avant 1850	France	—	Angot (1897)
Raulin	Observations pluviométriques faites en France et dans les colonies françaises	France/ colonies	100	Raulin (1875a,b, 1876, 1881)
Havens	An annotated bibliography of meteorological observations in the United States	United States	89	Havens (1958)
Kanold	Kanold Collection	Europe	30	Brázdil et al. (2008), Lüdecke (2010)
Jurin	Royal Society	Europe North America Asia	28 1 1	Jurin (1723), Derham (1735), Hadley (1741, 1744)
Cotte	Mémoires sur la météorologie/Bibliothèque de l'Académie nationale de médecine	Europe	75	Cotte (1788)
Palatina	Ephemerides	Europe, North America	37	Kington (1974, 1988)

are also included (in the figures they are attributed to the years immediately before the metadata source was published).

A second criterion is that only metadata on instrumental measurements was searched. We did not consider records with only wind observations (but we kept wind measurements or wind information of unknown origin) or the number of rainy days, even though these are quantitative data that may be of high quality. This information could be compiled at a later stage in an inventory for noninstrumental observations. The same holds for inches of rain and snow in China (Yu-xue-feng-cun; Pei et al. 2018). Unlike the measurement of depth in a snow/rainfall gauge, these numbers refer to the depth of soil seeped through by rainwater for example (Ge et al. 2005; Wang and Zhang 1988). Although widely analyzed for climate reconstructions (Hao et al. 2012; Ding et al. 2014) we do not consider such data in the present inventory.

A third criterion concerned a minimum length. As a rule of thumb, we compiled only data series with a length of at least one year, although this lower limit was sometimes disregarded for very early data or shorter records from remote regions. If the length of the record was not known, the information was collected nevertheless (in the figures they appear as one year long).

Marine data are not considered in this inventory, except for the "stationary ships" of the European powers moored in the harbors of their various colonies around the world. To date, most of the ships identified are British vessels, serving as regional command posts, hospitals, coaling stations, guard ships, convict ships, receiving ships, store ships/depots, mooring ships, and hulks. Other European powers are highly likely to have had similar vessels stationed in their major colonial ports.

Sources used. Our procedure consisted of 1) searching existing digital data repositories, 2) searching readily available national inventories, 3) compiling community knowledge through ACRE, through the Bern workshop, and through further involvement with the community, 4) compiling early (nondigital) inventories, and 5) compiling early collections and networks:

1) We searched five global repositories (Table 1). These contained the series as well as some metadata (here we only compile the metadata). Many of the series were found in several of the

Table 3. Publicly accessible data repositories (italics) and with pre-1850 measurements as well as larger data collections published in data journals.

Repository	Abbreviation	URL
CRU Temperature	CRUTEM	https://crudata.uea.ac.uk/cru/data/temperature/crutem4/station-data.htm
Global Historical Climatology Network	GHCN	www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn
International Surface Pressure Database	ISPD	https://reanalyses.org/observations/international-surface-pressure-databank
International Surface Temperature Initiative	ISTI	ftp://ftp.ncdc.noaa.gov/pub/data/globaldatabank/monthly/stage3/
Berkeley Earth Surface Temperature	BEST	http://berkeleyearth.org/source-files/
Royal Dutch Weather Service	KNMI	http://projects.knmi.nl/klimatologie/daggegevens/antieke_wrn/index.html
German Weather Service	DWD	ftp://ftp-cdc.dwd.de/pub/CDC/observations_germany/climate/daily/kl/historical/ ftp://ftp-cdc.dwd.de/pub/CDC/observations_germany/climate/monthly/kl/historical/
German Weather Service, overseas data	DWD	www.dwd.de/DE/leistungen/ueberseestationen/ueberseestationen.html
Russian Hydrometeorological Service	RIHMI	http://meteo.ru/english/climate/cl_data.php
Norwegian Weather Services	MetNo	http://eklima.met.no
Japanese Data	JCDP	https://jcdp.jp/instrumental-meteorological-data/
Historical Arctic Database	HARD	www.hardv2.prac.umk.pl/
Mediterranean Data Rescue Project	MEDARE	http://app.omm.urv.cat/urv/accessdata/
Climate Database Modernization Programme	CDMP	www.ncdc.noaa.gov/IPS/ and https://mrcc.illinois.edu/data_serv/cdmp/cdmp.jsp
Early (pre-1900) rainfall records for Africa	NIC131	www1.ncdc.noaa.gov/pub/data/paleo/historical/africa/africa2001precip.txt
Early meteorological records from Latin America and the Caribbean during the eighteenth and nineteenth centuries	EMERLAC	Domínguez-Castro et al. (2017), https://doi.org/10.1038/sdata.2017.169
Southeastern Australian rescued observational climate network, 1788–1859	SEARCH	Ashcroft et al. (2014), https://doi.org/10.5281/zenodo.7598
A historical surface climate dataset from station observations in the Mediterranean, North Africa, and Middle East areas	EURO4M	Brunet et al. (2014b), https://doi.org/10.5281/zenodo.7531

repositories. In total, 741 unique records were found.

2) We next searched regional and national data repositories or metadata inventories (Table 1). These comprised around 1,500 records, but with a large overlap with step 1.
3) The community knowledge compiled was particularly important for those regions for which no repositories exist, and for time periods before the foundation of national agencies. The inventory for Europe and North America was greatly extended by the authors of this paper.
4) A number of early inventories were consulted where known and recoverable, some covering the globe, some covering certain regions or countries. Typically, these inventories contain only metadata, often in condensed form (Fig. 1). Note that the inventories may not be free of errors or ambiguities, and many errors were corrected by the authors.
5) From the earliest days of meteorology, scientists collected and published data (Table 2); some of which, such as the Societas Meteorologica Palatina (SMP) Network, can be considered coordinated networks.

Metadata compiled. The inventory should be able to store comprehensive meta information, but should also collect sparse information (e.g., a reference pointing to the existence of a measurement series, even without measurement years, observers, or exact location). The following information was compiled:

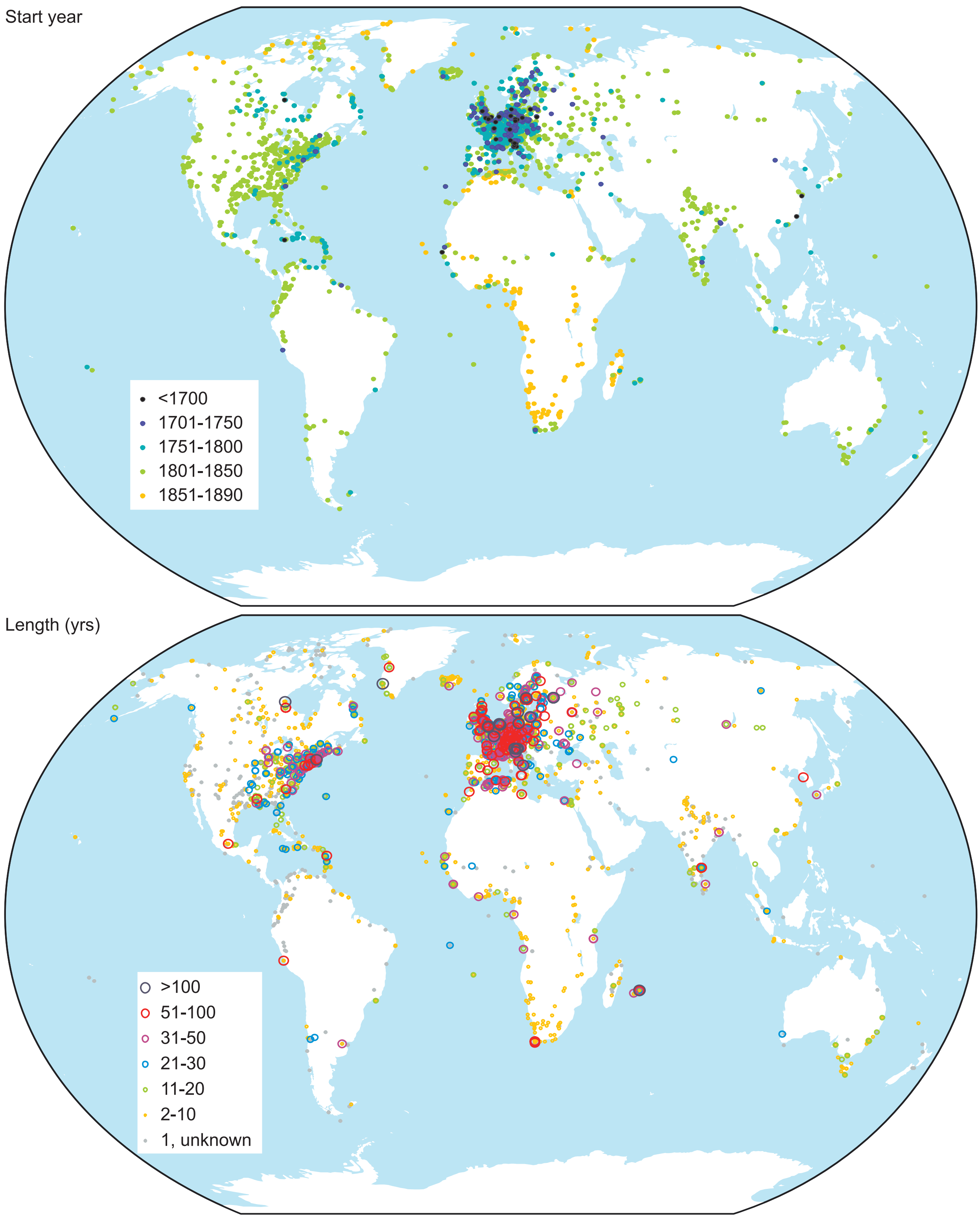


FIG. 2. Coverage of entries in the inventory as a function of (top) start years and (bottom) record length, i.e., the number of years prior to 1850 (1890 for Africa and Arctic).

1) existing station identifications (WMO, national, or other repositories);
2) the station location: WMO region, modern country, location, other names, location details, coordinates, station elevation;
3) observer name and context (e.g., profession of observer, missionary or military contexts), variables, measurement frequency;
4) inventory in which it is contained, source of metadata and data (see also Table 3);
5) start and end year and availability in present repositories;
6) status on digitizing and availability; and
7) comments.

Comments are used, for instance, to mark data that have already been investigated and discovered to be unusable, or data that have been irretrievably lost.

Quality control of metadata. After compiling the metadata, a quality control of the metadata was performed. Coordinates were tested against station names, countries, and a land–sea mask. Errors found in this procedure were corrected. Duplicates were identified, suspicious series were checked in the original sources (and sometimes identified as noninstrumental) and series starting after 1850 (or 1890 for Africa and the Arctic) were flagged. During this procedure, no information was removed. In case of duplicates, the unique information was combined into one record and the duplicates were flagged, with a cross-reference to the primary record.

Duplicate removal proved difficult. Often duplication was only partial; both entries were then left in. Some series were made up of multiple stations if within a certain distance, and some have overlapping periods. Some series have unique entries per variable (which may have different start and end dates), some have a unique entry per observer, or per source. We did not attempt to unify this. "Entry" in the following may therefore means one long multivariable record of a station, or only a segment, or just one variable.

We provide two versions of the inventory. Version "history" has all entries, including the flagged ones. Note that some of the flagged entries contain errors (corrections were only done on nonflagged entries). In version "clean," all flagged entries are removed.

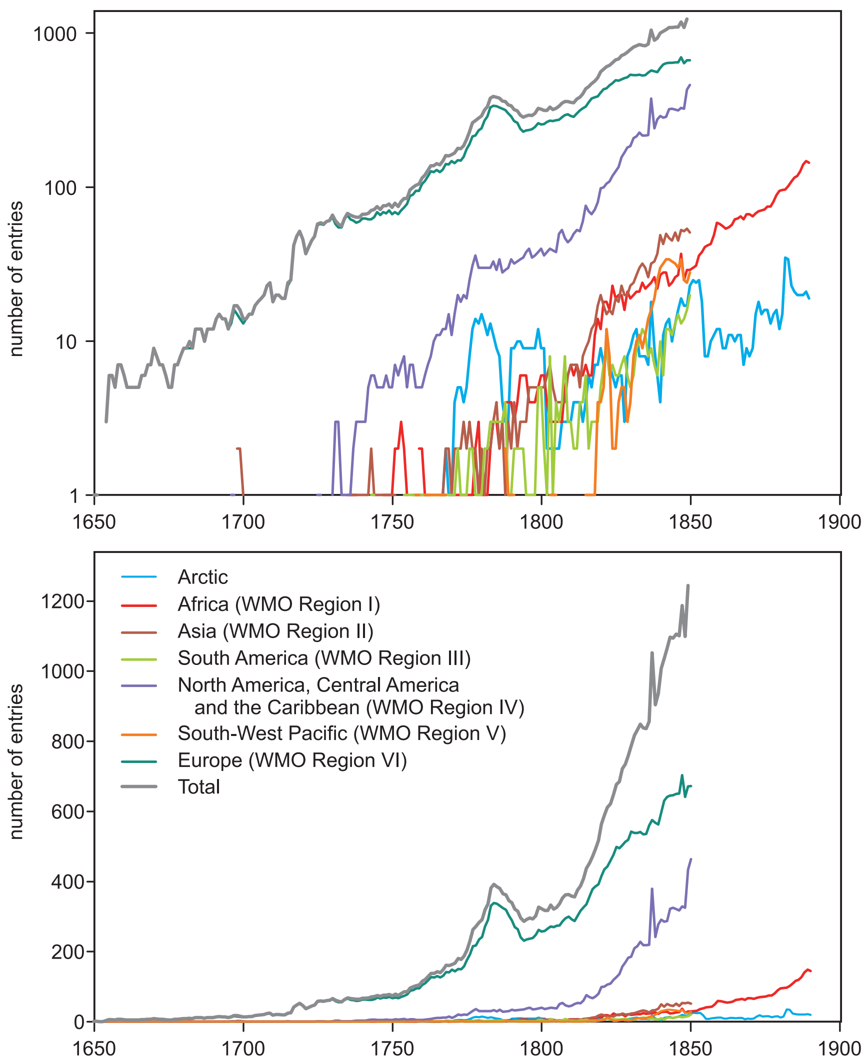


Fig. 3. Number of entries as a function of time and region (note the logarithmic scaling of the y axis in the top panel). The spikes in the nineteenth century are due to records with unknown observation periods, which for this figure were assumed to have ended in the year before the publication of the corresponding metadata collection (with an assumed length of 1 year unless the length was known).

RESULTS. *Global overview.* The inventory currently has 10,349 entries, the majority of which is flagged as duplicates, post-1850 (post-1890), or noninstrumental. The remaining 4,583 entries are from circa 2,250 locations. There are still numerous partial duplicates. Plotted as a map (Fig. 2), duplicates lie on top of each other and do not distort the result. Almost all early and long series are from Europe. Long records, though reaching less far back, also exist for New England and Canada. Early records from other WMO regions are sporadic and short. These data are mostly from expeditions and colonial endeavors. A close to global (though sparse) coverage, with continuous series in all WMO regions except Africa, is reached only after 1800. For Africa and the Arctic, good coverage emerges only in the period 1851–90. No entry exists for Antarctica (first measurements were taken during the S.Y. *Belgica* expedition 1897–99; Arctowski 1904; see also Jones 1990).

The first series start in the 1650s (Fig. 3). From the 1680s onward at least 10 records are inventoried in any year (but some are known to be lost). The number increases to approximately 50 in 1720, reaching the hundreds by 1800. The increases in the early eighteenth century as well as the peak in the late eighteenth century indicate coordinated activities, such as those of Johann Kanold and James Jurin in the 1710s and 1720s, and the SMP network in the 1780s (Table 2). The 30% drop in the late eighteenth century corresponds to the politically unstable Napoleonic period in Europe (and the subsequent period of "restauration" in continental Europe). The inventory lists the status (e.g., imaged, transcribed), although not systematically. A brief analysis shows that circa 25% of entry years are fully transcribed, another 25% partly so (e.g., as monthly means). Only around 20% of entry years are available from global repositories (Table 1), indicating that a considerable fraction of the transcribed data have not yet made it into these repositories. Table 3 provides URLs of important data collections. In the following, results are discussed by WMO regions (plus Arctic).

WMO region 1: Africa. For Africa, the start of instrumental meteorological measurements varies greatly by country. Rainfall records generally go back further than temperature records. The inventory map (Fig. 4) shows that the starting year is mostly after 1800. A good fraction of the series has already been digitized but due to the sparse coverage, additional series are particularly valuable. Africa's oldest instrumental records come from South Africa. Although Robert Jacob Gordon refers to barometric pressure records going back to at least 1737 in Cape Town, the original records have yet to be found. Four short records are known from Cape Town in the following decades (1751–52 by explorer Nicolas-Louis de Lacaille, 1766–68 by Paulus Henricus Eksteen, 1779 by the Bataviaasch Genootschap and 1789–92 by R. J. Gordon). The first regional network was set up by colonial district offices and covers the period 1818–27. However, there are large data gaps for several of these stations. In 1829, the Cape Town Port Office began meteorological measurements. Daily records the Royal Astronomical Observatory in Cape Town began in 1834 and continue to this day (stationary ships recorded weather at Cape of Good Hope, 1834–1912).

Outside of South Africa, instrumental records concern mostly rainfall, which relates to the importance of the amount of rain in the rainy seasons on all aspects of life, an emphasis that continues to this day. Most measurements were taken by colonial administrations. In some cases, regular measurements were made by missionaries, such as in Malawi, 1876–80 (Nash et al. 2018), or by individuals, such as the Urquiola sisters in equatorial Guinea in 1875 (Gallego et al. 2011). In some cases, lengthy series of measurements were made during scientific expeditions, such as the Loango expedition of 1873–76 (von Danckelman 1878, 1884). In general, the longest records are available for stations near the coast, with the far inland being nearly devoid of measurements until the twentieth century.

In Algeria, the first two rain gauges were installed in 1837 in Algiers by the Administration of Drying and in Constantine in the military and colonial hospital. Before 1890, measurements were made by engineers from the National Road and Bridge Administration, by military doctors at the colonial hospitals, and by military engineers. In 1865, 34 meteorological stations had been created in the main military hospitals. Rainfall data for Algeria were compiled by Raulin (1875b).

In Senegal, records begin in the 1830s [all available pre-1900 measurements have been compiled by Nicholson et al. (2012a)]. Meteorological measurements, made by military pharmacists at the military colonial hospitals, started before 1860 in Bakel, Podor, Saint-Louis, and Gorée (Raulin 1875a).

In Madagascar, measurements were taken at the military and colonial hospitals on Nosy Be (Nossi Be) Island in 1855 and on Nosy Bohara (Sainte-Marie) Island in 1863. Colin (1890) compiled the measurements in Antananarivo starting with Laborde, the first French consul in Madagascar, 1872–78, and followed by the fathers of the Catholic mission, 1879–89 (a short record from 1829 is known).

Less extensive records are available for Egypt, Morocco, Tunisia, and Namibia, with numerous

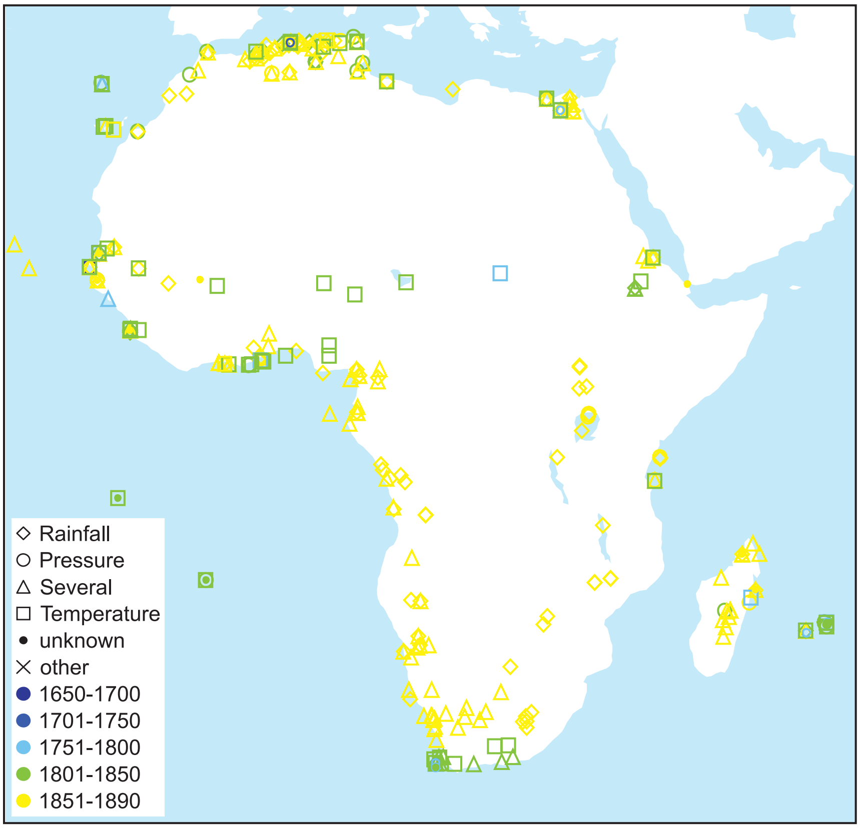


Fig. 4. Series inventoried for Africa.

stations in these countries starting in the 1870s or 1880s (in Egypt in the 1860s). In the same period, stations were established by the Germans in Togo, Tanzania, and Cameroon; by the British in Sudan, Ghana, Uganda, Kenya, Zimbabwe, Lesotho, and Malawi; and by the Spanish in the Canary Islands. Isolated measurements from this time were also made in the Portuguese colonies of Angola, Mozambique and the Cape Verde Islands, and in the Italian colonies of Eritrea and Libya. Rainfall records from these and other sites are described in Nicholson (2001) and Nicholson et al. (2012a,b). Several earlier records are also noteworthy. Rainfall was recorded at the Danish fort at Christianborg (today Accra, Ghana), 1829–34 and 1839–42. Records exist for Freetown, Sierra Leone, 1793–95 (rainfall, temperature, pressure), 1819, 1828, and 1847–51 (rainfall only) and since 1849 (temperature, plus measurements onboard stationary ships 1832–41 and 1861–67). Short records are available for Zanzibar since 1850, with continuous data since 1874. Measurements started in Luanda, Angola, in 1858. Sporadic records in the late 1850s and early 1860s exist for Bukoba, Uganda; Natete, Mozambique; Libreville and Sibange Farm, Gabon; Bathurst, Gambia; Grand Bassam, Ivory Coast; and Lagos, Nigeria.

For the Congo basin, the frequency of measurements follows colonial history. Shortly after King Leopold II of Belgium declared the Congo Free State his personal territory, a publication was issued containing meteorological measurements for the coastal village of Banana (Etienne 1892). More commonly, however, early measurements remained unpublished, and mostly in personal archives of explorers. Often measurements are merely sporadic, such as those by Cyriaque Gillian and Francis Dhanis noted in their travel diaries for 1889 and 1890–91, respectively.

The earliest measurements for Mauritius were made by French colonial residents and administrators, Jean-Nicolas Céré, Director of the Botanical Gardens at Pamplemousses (1770–90), the astronomer, botanist, and cartographer Jean-Baptiste Lislet-Geoffroy at Port Louis (1784–1834) and Mr. Labutte at Yemen (1812–47). A mix of French and English colonials followed, such as Lt.-Col. John Augustus Lloyd, Surveyor General of Mauritius (1831–49) at the "Government Observatory" at Port Louis, and Julien Desjardins, the first Secretary of the Natural History Society of Mauritius, at Flacq (1836–38). Most of these measurements are lost or only survive in summary form. For Réunion, various sources suggested that Jean Nicolas Céré took, or compiled, instrumental records from the late eighteenth century (but these have never been found). Stationary ships provide measurements for Ascension Island (1844–71) and Saint Helena (1819–31).

WMO region 2: Asia. The first measurements in Asia date back to the late seventeenth century, when Scottish surgeon and naturalist James Cunningham made meteorological measurements on his journey to China. Early records are also available for India (Fig. 5, left). The longest continuous series are rainfall in Seoul as well as temperature, pressure, and rainfall in Chennai, both reaching back to the eighteenth century. Unlike Africa, Asian records concern not only rainfall, but also pressure and temperature. Most records start after 1800. Various data rescue activities are underway. However, many records, including many shorter fragments, have not yet been digitized.

China holds a wealth of documentary climate data [compilation digitized in the Reconstructed East Asian Climate Historical Encoded Series (REACHES) dataset; Wang et al. 2018], but measurements are scarce. The earliest known measurements were made by Cunningham at Xiamen (Amoy) from October 1698 to January 1699. Between 1700 and 1702, a continuous record was also made by Cunningham at Zhousan, Zhejiang Province. Beijing temperatures were measured by P. Antoine Gaubil in 1743. Missionary Joseph Amiot recorded temperature, pressure, and rainfall in Beijing, 1757–62. The Russian observatory network also made measurements at their Consulate in Beijing from 1841.

Guangzhou (Canton) has records for 1771–74, 1785, 1789, 1804, 1829–31, 1830–39, 1836–38, and then periods in the 1840s. Some of these data can be found in old newspapers such as the *Canton Register*, including measurements made in Hong Kong (Tsukahara 2013). An early dataset was recovered for Macau in 1780. Measurements were also made in 1787 by the French orientalist Joseph de Guignes. For the period 1830–37 temperature, pressure and rainfall measurements exist in printed journals for Hong Kong and Macao. A couple of years for daily measurements of temperature and pressure at Macao (1840–41) were also published in the *Canton Register*.

Japan holds exceptionally early instrumental datasets (Zaiki et al. 2006). Early measurements were made by foreigners such as Carl Peter Thunberg in 1775/76 and 1779 (Demarée et al. 2013), J. Cock Blomhoff, 1819–23, and von Siebold, 1825–28, all in Nagasaki (Können et al. 2003). Other station records include Osaka, 1828–71, and Tokyo, 1825–75 (all digitized; Table 3). In the Asiatic part of Russia, the longest series, Irkutsk and Jakutsk, reach back to the 1820s (digitized; Table 3).

The earliest measurements made on the Indian subcontinent were by European missionaries in Puducherry and Chandannagar in the 1730s and 1740s. More regular measurements were later carried out at Chennai and Calcutta by British colonial officers. At Fort Saint George in Chennai, daily meteorological measurements were recorded in 1776–78, by, respectively, the assistant surgeon Dr. William Roxburgh and Colonel James Capper. The next instrumental record from Chennai is from William Petrie in 1787 (India Meteorological Department 1976) and from missionaries in 1789–91 (Walsh et al. 1999). From 1791 onward rainfall, temperature and pressure were measured at an observatory set up by the East India Company. The records from John Goldingham in 1793 (India Meteorological Department 1976) and successive astronomers until 1843 (Goldingham 1826; Goldingham and Taylor 1844) are gradually being digitized under ACRE. Monthly mean air pressures taken at the Chennai Observatory from 1796 to 2000 were recovered (Allan et al. 2002).

In Calcutta (Kolkata), the earliest known measurements are those made by British colonial officers, such as Henry Traill, treasurer of the Asiatic Society of Bengal, 1784/85 (Traill 1790) and Colonel Thomas Dean Pearce, 1785/86 (Pearce 1788). Temperature data from 1816 onward (Hardwicke 1830) are now in global repositories.

Pressure time series prior to 1850 have been recovered and digitized for Benares/Varanasi (1823–27) (Prinsep 1829a,b), Bangalore (1830–35) (Kingsford 1843), and others (see also Adamson and Nash 2014) as well as for locations in Nepal (including Kathmandu) in 1802/03 (Hamilton 1819). Long runs of such data tend to begin from the 1840s onward, such as for Hoshungabad (from 1849). Data from stationary ships exist from Trincomalee (Sri Lanka) (1819–64) and Hong Kong (1842–1920).

WMO region 3: South America. The longest instrumental record from South America is temperature from Lima, Peru, which reaches back to 1754 but is only available as annual minimum and maximum temperatures. Another noteworthy record is from Rio de Janeiro, 1781–88 (Farrona et al. 2012). Almost all other records inventoried start after 1800 (Fig. 5, right). Fewer records are available than for Asia, mostly less than 10 records at any time. Most records include at least temperature. No systematic inventories are currently available and data collected prior to the foundation of the national meteorological services is dispersed among a variety of archives. The most important effort to collect measurements prior to 1900 was made recently by Domínguez-Castro et al. (2017), who retrieved more than 300,000 meteorological measurements from 20 countries in South and Central America (Table 3).

This effort allowed the identification of some of the most relevant sources for the region. A large number of the measurements made during the colonial period were recorded with the objective of characterizing the climate of the region to evaluate possibilities to improve agricultural production as well as the influence of climate on health. The main

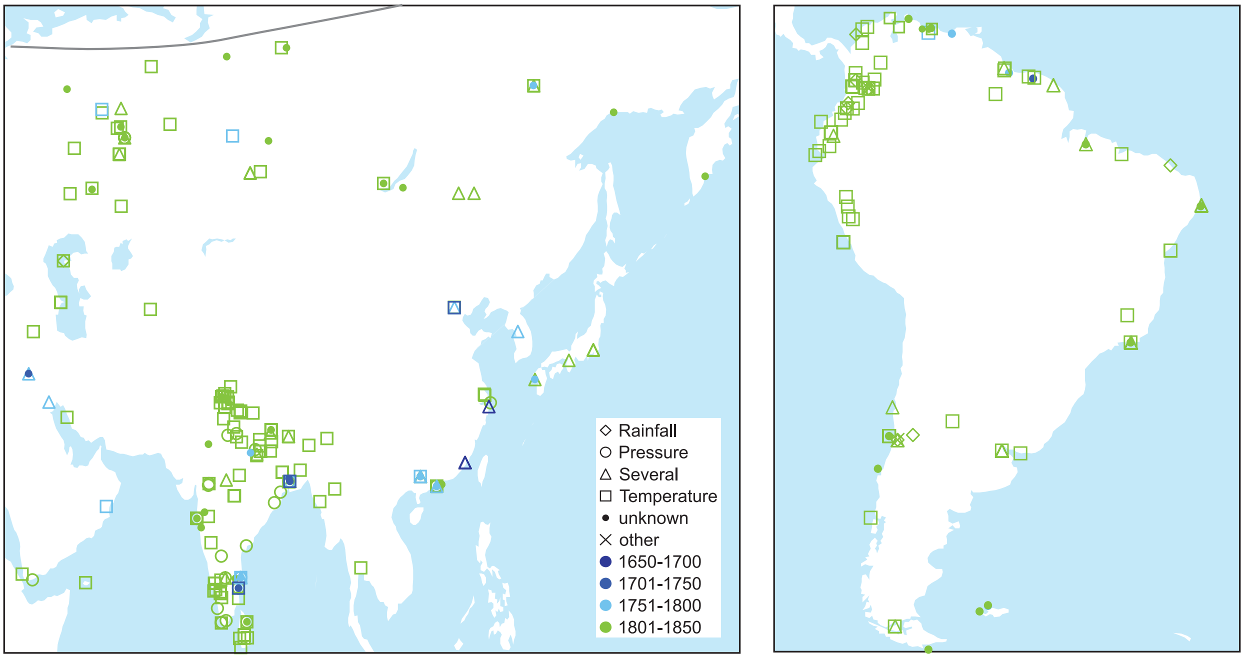


Fig. 5. Series inventoried for (left) Asia and (right) South America. The thick gray line denotes the Arctic region.

observers in the region were scientists, explorers and military personnel.

Explorers recorded meteorological data, but their series are short because they changed their observation locations frequently. They used portable instruments, sometimes with poor calibration processes. Measurements by explorers are usually recorded in printed books that describe the explored territories. Unfortunately, as the meteorological tables took up many pages, the measurements were usually summarized as monthly means (e.g., Boussingault 1849). A compilation of Spanish explorers in the region is given in Lucerna Giraldo (2009).

The longest series were recorded by researchers with the intention of starting a national observatory (generally astronomical and meteorological) or involved in academic initiatives, as José Celestino Mutis and José de Caldas in Colombia or Francisco Aguilar in Ecuador. The continuity of the series depends on the support they could obtain. Generally, these measurements were performed at subdaily scale but the manuscripts of the measurements were frequently lost or remain undiscovered.

During the early nineteenth century most of the countries suffered from wars of independence. Most of the series have gaps during this period and it is likely that some original records were lost during the wars because many observatories were used for military proposes. Stationary ship data are listed in the inventory for Rio de Janeiro (1840–75) and Valparaiso (1843–79).

WMO region 4: North America, Central America, and the Caribbean. Sporadic instrumental measurements from North America reach back to 1697. The first actual series started in the 1730s and 1740s in Charleston and in various places in Massachusetts, Quebec, and Philadelphia (Fig. 6). Havens (1958) inventories the early instrumental data [see also van der Schrier and Jones (2008) for an example of use of long early U.S. records]. Many of the early (prior to ca. 1820) series listed in our inventory have not yet been digitized, so there is potential for data rescue activities in North America. One of the most important collections of historical climatic data for North America originates from the efforts of the Smithsonian Institute, led by Joseph Henry, to collect meteorological measurements from across North America to compile statistics on the climate for agricultural purposes, and later to issue storm warnings (beginning in the 1840s). Although the active exchange of contemporary meteorological records by the Smithsonian started in the 1850s, the Smithsonian also became a repository for older climatic records. These records were compiled and analyzed in several publications over the course of the nineteenth century, including publications by Blodget (1857), Hough (1872), and Schott (1876a,b). The "Forts" dataset, with information from military and other early measurements sites across the United States, has 142 stations beginning before 1850 (Dupigny-Giroux et al. 2007; Westcott et al. 2011).

Among the earliest systematic measurements taken in North America are those kept by the medical establishment, including the Médécins du Roi under the French colonial regime, the U.S. Army Medical Department in the War of 1812, and monthly and quarterly reports sent to the U.S. Army Surgeon General, 1820–59. Other military units that kept systematic records include the Royal Artillery. Observers at colleges and universities made measurements for the purposes of agricultural planning, and individual volunteers also made important contributions. Only few Russian observations exist, most notably for Sitka, Alaska (Dall 1879; Parker 1984), and Fort Ross, California (Russian ship-based measurements from the northeast Pacific are listed in the "history" version of the inventory, flagged as marine data).

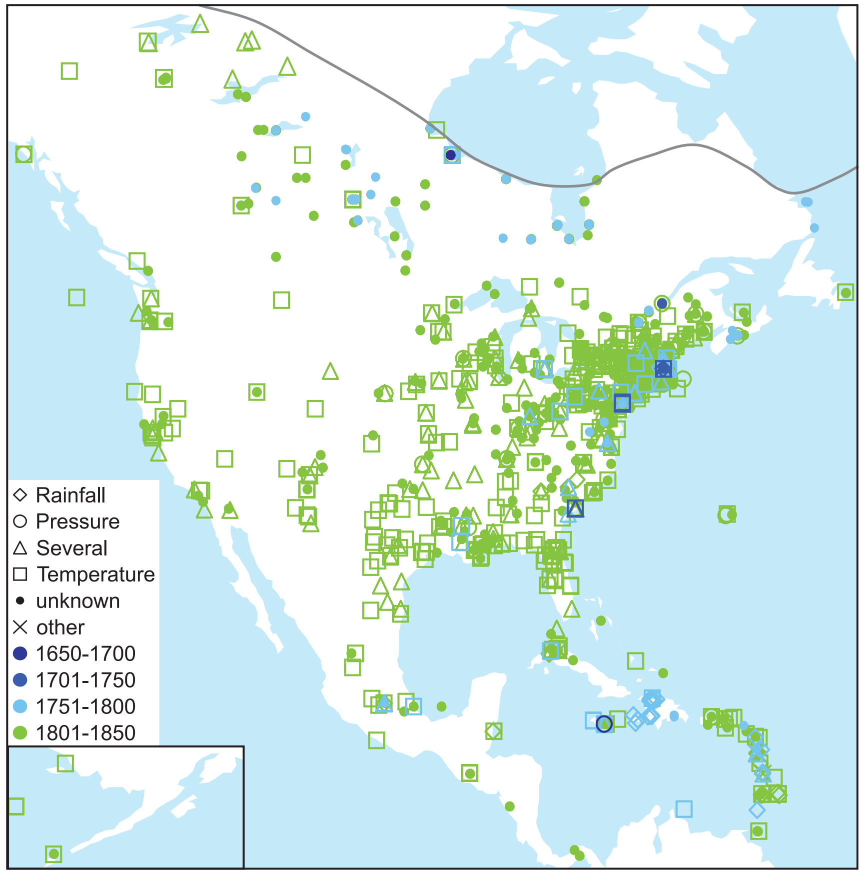


Fig. 6. Series inventoried for North and Central America and the Caribbean. The thick gray line denotes the Arctic region.

Many early records from eastern Canada have been digitized with the help of citizen science efforts. A nearly continuous daily temperature series has been developed for the Saint Lawrence valley region back to 1798, and more sporadically to 1742 (Slonosky 2015). Missionaries, explorers and Hudson's Bay Company (HBC) factors provided important measurements from the north and northwestern interior regions of the continent. Over 40 station records were found in the HBC and Royal Society archives for northern Canada, 1771–1840, in pioneering work by climatologist Cynthia Wilson in the 1980s.

The earliest instrumental series in Mexico were recorded by Jose Antonio Alzate in Mexico City in 1769. In the early nineteenth century some short series have been recorded mainly in the central region. The digital archives of the Spanish National Library contain records included in the Mexican newspapers *Gazeta del Gobierno de Mexico* and *Diario del Gobierno de la Republica Mexicana*. They include around four years of monthly data (1827–30) from Orizaba, one year (1831) from Veracruz and daily data from Mexico City for some period of 1833 and 1842–43.

In Central America and the Caribbean, some records reach back to the eighteenth century. Records exceeding 10 years are listed for Savanna-la-Mar, Jamaica (1760–86), Saint-Domingue (1772–84), Saint Barthélemy (1786–96), and Havana, Cuba (starting in 1791). In Guadeloupe measurements started in the 1780s; from the 1820s they were taken in the military hospitals by pharmacists or doctors. Charles Saint-Claire Deville, geologist and meteorologist, cofounder of the Société Météorologique de France and founder of the Paris-Montsouris observatory compiled several short temperature and pressure series measured in West Indies, 1840–50. Stationary ships are a source of meteorological measurements for Bermuda (1824–1904), Havana (1837–45), and Jamaica (1823–1903).

WMO region 5: Southwest Pacific. In Malaysia, measurements were made at Prince of Wales Island in Penang/George Town between 1815–16 and 1820–23 and at Malacca in 1809. The Royal Society in London holds a set of subdaily pressure, temperature and rainfall measurements kept at Penang, 1843–45. At Singapore, measurements were made from at least 1820 virtually continuously through until 1845, at which point there is currently a data gap until 1861. No datasets longer than one year are available for Indonesia (Dutch East Indies) pre-1850 except for West Java at Buitenzorg (Bogor), 1841–55, and for Padang, 1850–53 (both digitized by KNMI). Only scattered expedition data are available for Hawaii.

Pre-1850s land-based measurements for Australia date back to European settlement on the continent in 1788 (Fig. 7). They were taken primarily at the main colonial centers of population in southern Australia such as Sydney, Hobart, Melbourne, Adelaide, and Perth. However, other locations such as Albany (Frederick Town), the oldest colonial settlement in Western Australia, Launceston, Port Arthur (then a major penal settlement), and various properties of the Van Diemen's Land Company (such as in the Hampshire Hills) in Tasmania also kept records starting in the 1830–40s. Records should also exist for Brisbane, taken at the General Hospital, 1825–44 (Bartkey 2008; Ashcroft et al. 2016). Consequently, the spatial and temporal coverage of the pre-1850 data map (Fig. 7) closely relates to the expansion of English settlements, with early records from coastal regions and penal colonies in the southeast, before moving inland and westward with explorers and farming communities.

The earliest land-based measurement of temperature and pressure were recorded by Lieutenant William Dawes, 1788–91, from his observatory in Sydney Cove (Gergis et al. 2009). A detailed collection of 39 pre-1860 instrumental data sources for southeastern Australia is provided by Ashcroft et al. (2014). They show that only sporadic measurements have so far been uncovered for the 1790–1820 period, with an increase in the number of records available from the mid-1820s.

Measurements have also been found in newspapers, explorers' journals, colonial diaries, convict settlement documents, official observatory and government publications, doctors' records and private letters. A short-lived network of stations existed at penal colonies along the New South Wales and Tasmanian coast in 1822. More continuous records start later, such as temperature measurements for Sydney, 1826–48, and measurements made in Melbourne, Sydney, and Port Macquarie, 1840–51, under government order. Instrumental measurements were made on various expeditions, for example, by John Oxley to Bathurst, New South Wales, in 1823, or by Sir Thomas Livingstone Mitchell in southeastern Australia during 1831–32, 1835, 1836, and 1845–46 (Mitchell 1838), and are being digitized under ACRE Australia.

Recent efforts are currently underway to develop near-continuous daily records dating back to the early 1830s for the cities of Adelaide and Perth. The former consists of measurements made by Dr. William Wyatt in Adelaide from 1838 to 1843 (Ashcroft et al. 2014), newly imaged data from 1843–56 held by the National Archives of Australia, and available data from the Adelaide Observatory from 1856. Measurements of temperature and pressure from the Swan River settlement area of Perth, 1830–74, have recently been digitized. These records, in addition to the extensive data available for Sydney (Ashcroft et al. 2014), improve the possibility of developing long instrumental records back to 1830 for the underrepresented Southern Hemisphere. In Hobart, a stationary ship provided measurements for 1844–51. Additional pre-1850 instrumental data and supporting metadata around the scientific practices used in colonial Australia continue to be recovered around the country, many through citizen science activities (Ashcroft et al. 2016).

Limited land-based instrumental climate data are available before 1850 for New Zealand. The earliest

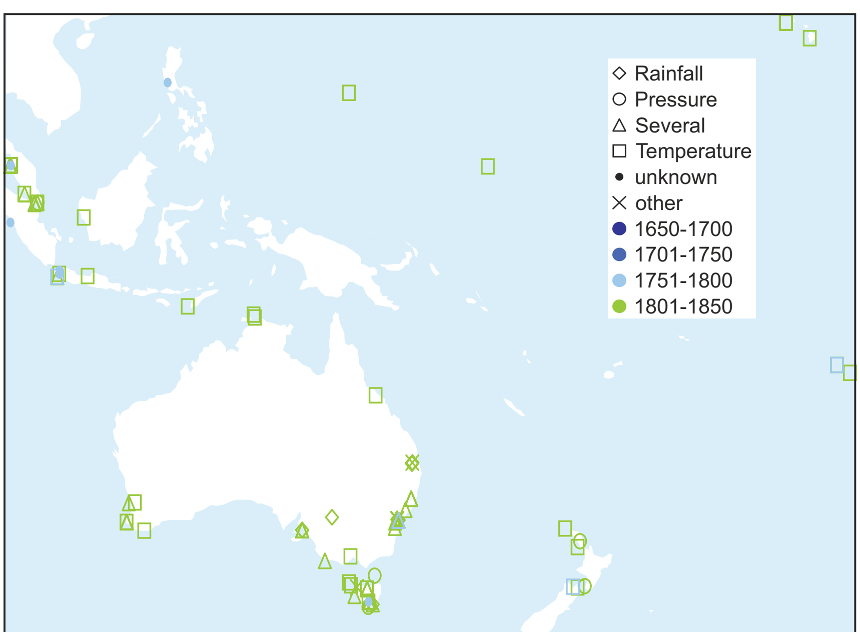


Fig. 7. Series inventoried for the southwest Pacific.

known multiyear measurement record is the diary of Reverend Richard Davis, an English missionary stationed at Waimate North and Kaikohe, Northland, in the 1830s to 1850s. Davis's weather diary covers nine years within the 1839–51 time span (Lorrey and Chappell 2016). In addition, pre-1839 instrumental measurements are provided by Davis from 1836 onward in his personal diary, but these are sporadic.

Old newspapers also contain printed measurements. Barometric pressure and temperature have been found for 1840–43 in the *New Zealand Gazette* and *Wellington Spectator* for Wellington. Similar data for 1842–43 have been found in the *Nelson Examiner* and *New Zealand Chronicle*; however, no metadata have been found about the location of these measurements.

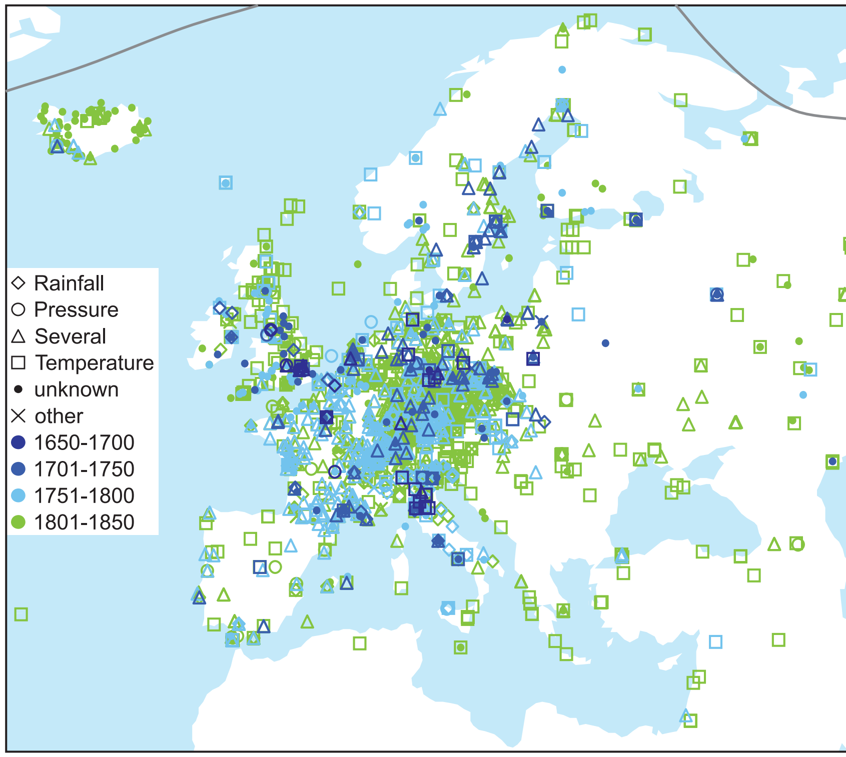


Fig. 8. Series inventoried for Europe. The thick gray line denotes the Arctic region.

WMO region 6: Europe. The first European measurements reach back to the seventeenth century. A good coverage of central Europe is reached by the first half of the eighteenth century (Fig. 8). The records usually comprise temperature and pressure, and less often precipitation. A particularly dense coverage is reached in the 1780s, when many networks were active (Table 2). Although many of these series have been digitized, an even greater coverage could be reached for this period and for the first half of the eighteenth century.

Italy was home to the "Medici network," the first international network of meteorological measurements established within the sphere of the Accademia del Cimento in Tuscany by the Grand Duke Ferdinand II de' Medici and his brother Prince Leopold (Camuffo and Bertolin 2012). The scientists of the Accademia del Cimento invented instruments and performed well-coordinated measurements with identical instruments. Observational activities were extended beyond the borders of Florence, with stations in Vallombrosa, Pisa, Cutigliano, Bologna, Parma, Milan, Paris, Innsbruck, Osnabrück, and Warsaw. The data were digitized and found to be of useable quality (Camuffo and Bertolin 2012). Italy also has several other long records (Brunetti et al. 2006).

In mainland France, instrumental measurements were carried out by astronomers, doctors, and Jesuits during the late seventeenth and the eighteenth centuries. Paris holds the longest temperature (back to 1658), pressure (1670), and precipitation records (1688), and several other stations started in the first half of the eighteenth century. An early collection was compiled by Louis Cotte (Table 2). Monthly weather reports, stored in the library of the Académie de Médecine in Paris, were sent to him by 173 doctors during the period 1776–93, until the French revolution put an end to this network. Météo-France's inventory shows the gap during the period 1795–1805 with only 14 French stations, including the two astronomical observatories Paris and Marseille. For the southeast of the country, the history of instrumental measurements was compiled by Pichard (1988).

Northern Europe is relatively well covered. For Iceland our inventory lists 49 series prior to 1850. The earliest available measurements from Sweden (see Moberg 1998) are from 1719 to 1723, though from an unknown site. Measurements in Uppsala started in 1722, arranged by astronomers at the Society of Science in the city and apparently in connection with Jurin's invitation (Jurin 1723). This became the start of what is now the longest instrumental record in Sweden, as measurements are still made in Uppsala. Two other Swedish cities with long continuous meteorological records are Lund and Stockholm, starting in 1740 and 1754, respectively. An effort to establish a national meteorological network was made by the Royal Academy of Sciences in 1786. At some sites, this led to continuous measurements being made for several decades, but none of their records stretch longer than to the 1840s.

Long instrumental records in present-day Finland encompass Turku (starting in 1748) and Oulu (1776). Data from Copenhagen (Denmark) reach back to 1786. In Norway, Trondheim has the longest record (1762) followed by a continuous record from Oslo (1816) (Hestmark and Nordli 2016). Long records reaching back to the eighteenth century are also available for Vilnius (Lithuania, 1777) and Riga (Latvia, 1795). The series from Tallinn (Estonia) starts in 1806.

First measurements were taken in Germany in the seventeenth century. The longest temperature record is that of Berlin, reaching back to 1701, but many other series start prior to 1750. The SMP network based in Mannheim comprised 14 stations in Germany, among them the mountain station Hohenpeissenberg. Another important record is that of Karlsruhe, reaching back to the 1770s. Hellmann's inventory (Table 2) of German instrumental series lists more than 450 stations prior to 1850, many have not been digitized.

Long records are also available for the Netherlands. A composite series for De Bilt back to 1706 has been composed, but there are also other long series (Table 3). A central Belgium daily temperature series was compiled from different records back to 1769 (Demarée et al. 2002).

The United Kingdom has some of the earliest meteorological measurement series. The central England temperature record, which is not an individual series but a composite, reaches back to 1659. Early pressure records are available from Oxford and later London (Cornes et al. 2012a). The Royal Society and its journal, particularly through the invitation of Jurin (1723), played an important role in the collection and dissemination of data. A composite precipitation record has been constructed for Ireland back to 1716 (Murphy et al. 2018).

Spain hosts several long instrumental measurement series such as Barcelona (back to 1780), Cadiz and Madrid (1786), and Valencia (1790); earlier short records from Madrid and Granada date back to the 1720s and 1730s (Rodrigo 2019). The first meteorological measurements in the Iberian Peninsula were taken in Portugal between 1 November 1724 and 11 January 1725 (Domínguez-Castro et al. 2013). The series for Lisbon reaches back to 1781. The Balkan Peninsula has only poor coverage prior to 1850. Our inventory lists two series from the 1780s to 1800s (Piran, Slovenia, and Timişoara, Romania). Data from Corfu (Greece) reach back to the early nineteenth century, but there are only few other records and they only reach back to the 1830s (Hvar, Croatia; Cluj and Stansilav, Romania; Athens, Greece).

Instrumental measurements in Poland began in the seventeenth century. Apart from Warsaw (in the Medici network), measurements took place in Gdansk and Wroclaw, for the latter including the series by David von Grebner (1710–21), Johann Kanold (1717–26), and Elias Büchner (1727–30). Although not all data have been found, Warsaw, Gdansk, Wroclaw, and Cracow all have long records (Przybylak 2010). At Gdansk, observations were conducted during 1655–1701 and 1721–86 (Filipiak et al. 2019) and from 1739 onward. In the Czech Republic, the series from Prague Klementinum reaches back to the 1770s, but other long series (e.g., Brno) exist. The Budapest series in Hungary reaches back to 1780. The first instrumental measurement in Austria date back to the early eighteenth century, continuous records started around 1770 (Kremsmünster, Vienna, Innsbruck). The longest Swiss records are those from Basel and Geneva, both reaching back to the mid-eighteenth century, but a recent inventory (Pfister et al. 2019) found data from several other stations for which continuous series back to the eighteenth century can be produced.

The earliest measurements in today's Ukraine date back to 1738 (Kharkiv) and 1770 (Kyiv); however, they were probably lost. Currently, the archive of the Ukrainian weather service contains eight pre-1850 stations; the earliest measurements date to 1808 (Kherson).

Measurements in Russia started in 1724 in Saint Petersburg. Only monthly minimum and maximum pressure were published during the first 20 years; from the 1740s onward, temperature data are available from global repositories. The Moscow series reaches back to the 1770s; other series then followed in the 1810s (e.g., Old Archangel) and particularly in the 1830s from the "Annuaire magnétique et météorologique du corps des ingénieurs des mines de Russie" (1837–46), the "Annales de l'observatoire physique central de Russie" (1847–61), and "Observations météorologiques faites à Nijné-Taguilsk et Vicimo-Outkinsk (Monts Oural), Gouvernement de Perm" (1839/40–1865/66) (Weselowksij 1857; Wild 1881, 1877; Leyst 1887; Bergman 1892).

Arctic. The first instrumental observations in the Arctic (Fig. 9; defined after Atlas Arktiki; see Przybylak 2016), at least of duration of three months or longer, were initiated by the "Moravian brethren" in 1767 in Neu-Herrnhut near Godthåb (present-day Nuuk), Greenland, and four years later Nain (Labrador) (Demarée and Ogilvie 2008). Demarée and Ogilvie (2008) proposed to distinguish four distinct periods in the time frame of the measurements in Labrador, from which three cover the period of interest in the present paper: 1771–90, 1801–83, and 1883–1900. Early instrumental meteorological data for Greenland are available from 1873 onward for the four regular stations run by the Danish Meteorological Institute and published in yearbooks until 1960: Ilulissat (Jakobshavn), Upernavik, Nuuk (Godthåb), and Iviituut (Ivigtut) (Cappelen 2018). However, measurements began much earlier, that is, in 1807 for Ilulissat and 1784 for Nuuk. All available series [see Table 1 and Fig. 2 in Vinther et al. (2006)], however, contain many gaps.

Another region covered by early measurements is the Canadian Arctic. Meteorological observations began here in 1819 when the Royal Navy sent the first expedition in search of the Northwest Passage. Later expeditions included those looking for the lost expedition of Sir John Franklin in 1848–59. A large number of those data (monthly and annual means for fixed hours) are available in the publications of Strachan (1879, 1880, 1882, 1885, 1888), while all source data with subdaily resolution (1 hourly, 2 hourly, 4 hourly, or 6 hourly) are in ship logbooks (Przybylak and Vizi 2005).

A third region of the Arctic with important sets of early meteorological measurements is Novaya Zemlya. Seven series with subdaily resolution are available, usually of 1-yr duration, from periods of 1832–39 and 1872–83 (Przybylak and Wyszyński 2017). The best coverage for the entire Arctic exists for the first International Polar Year, 1882/83, when nine stations were operating in the high Arctic, of which two (Sagastyr and Lady Franklin Bay) continued until 1884 (Przybylak et al. 2010; Wyszyński and Przybylak 2014).

CONCLUSIONS. This article describes a global inventory of terrestrial meteorological measurements prior to 1850 (1890 for Africa and the Arctic) that will support data compilation and data rescue efforts. It should provide the necessary information to prioritize data rescue efforts. The inventory comprises 4,583 (partly) unique entries from circa 2,250 locations. This is more than anticipated and suggests that climate or weather reconstruction (e.g., by means of reanalyses) based on instrumental data might be extended back well into the eighteenth century. Such datasets would allow new insights into the transition of the climate system from the Little Ice Age climate into the present climate, longer samples to learn from past extreme events, and new opportunities to analyze the climate–society interface.

However, the data are not readily available. Roughly half of the series (in terms of entry years) have not yet been transcribed, and of those that have been partly or fully transcribed, only half is represented in global inventories. Extending the data series backward thus

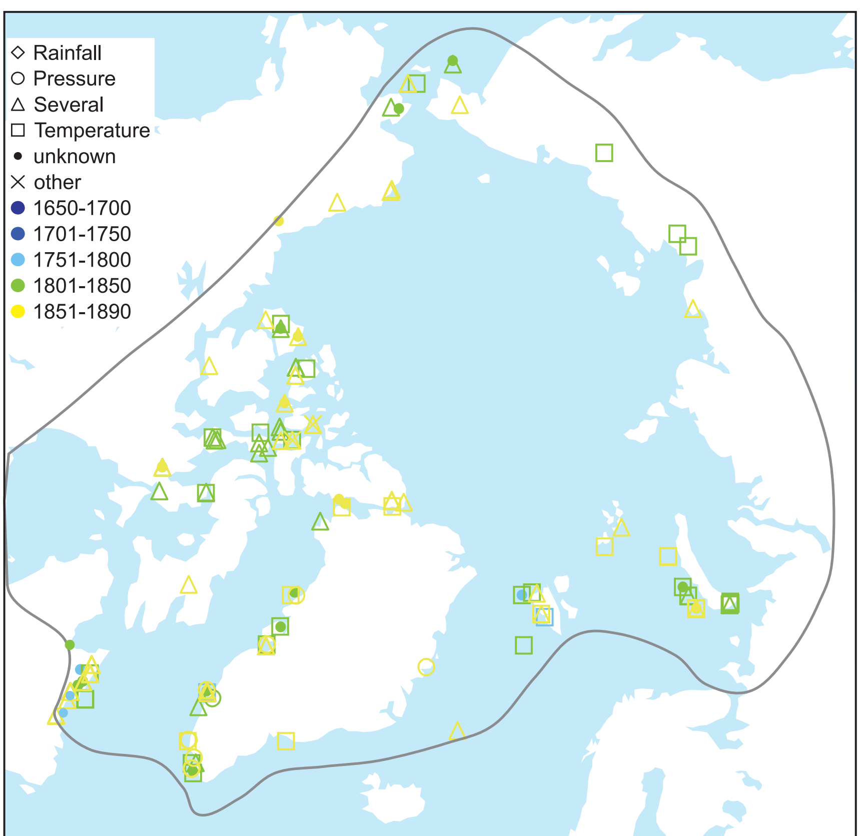


Fig. 9. Series inventoried for the Arctic (defined by the thick gray line).

requires further efforts on various aspects, including metadata cataloguing, current data holdings inventorying and updating, maintaining and expanding data compilations and enforcing data standards (see Thorne et al. 2017). The next steps for the community are therefore 1) to image and transcribe further early instrumental data and preserve them for posteriority [perhaps even an internationally coordinated effort between national meteorological services and other institutions such as Copernicus Climate Change Service (C3S)] and 2) to compile the digitally available data in a common repository. Activities currently undertaken within C3S (Brönnimann et al. 2018b) can support this process with broader contributions from the communities. The inventory will be maintained as a living document at the C3S website; additions to the inventory are welcome.

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