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A preliminary global inventory of historical documentary evidence related to climate since the 14th century

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The first global inventory of documentary evidence related to climate extending back to the Late Medieval Period lays the foundation for incorporating historical documentary evidence into climate reconstructions on a global scale, complementing early instrumental measurements as well as natural climate proxies.

Climatic variations have impacted societies since the very beginning of human history. To track these changes over time, humans have thus often closely monitored the weather as well as natural phenomena influencing everyday life. Resulting documentary evidence from archives of society gives invaluable insights into the past climate beyond the timescale of instrumental and early instrumental measurements. This information complements other proxies from the archives of nature (such as tree rings) in climate reconstructions, as documentary evidence often also covers seasons and regions that are not well represented with natural proxies. Tree-ring proxies, for example, are restricted to annual signals of temperature or precipitation during the growing season. Documentary evidence relating to ice freeze-up and break-up dates can provide complementary temperature signals for winter and spring.

While a mature body of research on detecting climate signals from historical documents exists, the large majority of studies are confined to a local or regional scale and thus lack a global perspective. Here, I attempt to compile the first systematic global inventory of documentary evidence related to climate extending back to the Late Medieval Period. It combines information on past climate from all around the world, retrieved from many studies of historical documentary sources.

Existing documentary evidence related to climate

Sources containing historical documentary evidence related to climate range from chronicles, administrative/clerical documents, personal diaries, and travel reports, to ship logbooks, scientific writings, and newspaper articles.

Documentary evidence can be divided into direct observations and indirect (proxy) data. Direct observations include narrative reports on daily weather, climate anomalies, weather-induced hazards, and non-weather-related events such as famines and epidemics. Indirect data are principally organic (plant phenology, information related to crop harvest) or non-organic (ice-snow phenology, information on water levels) in nature, but this category also includes cultural evidence (rogation ceremonies; Pfister et al. 1999). When using historical data, it is important to note that direct observations are not necessarily more accurate than indirect proxy data: a record of someone noting a "cold winter" can be much more vague than, for example, records of late flowering of cherry blossoms or delayed dates of ice break-up in a harbor. About half the documentary evidence included in this inventory is based on direct observations, 20% on indirect proxy data, and 15% on a combination thereof. A small number of series are multi-proxy reconstructions, combining documentary evidence with instrumental measurements and natural proxies.

While some documentary series extend further into the past beyond the Late Medieval Period, the focus here is on more recent evidence. About a third of all data series included in the inventory are available for the 15th century, 54% for the 16th century, 65% for the 17th century, 90% for the 18th century, and 100% after 1800.

Documentary evidence is unevenly distributed in space. While many series are available for Europe (43%) and Asia (31%), much less evidence stems from other continents: 10% from Africa, 8% from North America, 6% from South America, and only 2% from Australia (Fig. 1). For Europe and Asia, especially China, documentary series exist for both temperature and precipitation. For Africa and South America, on the other hand, all the available data provide information on precipitation but not temperature. The majority of data series in the inventory are proxies for precipitation (50%) and temperature (36%); very few data are available for other proxies such as wind and cryosphere parameters (e.g. data on glacier movements) (14%).

Case-study: Temperature anomalies after volcanic eruptions

To point out the value of documentary evidence for climate reconstructions, temperature anomalies after the strong volcanic eruption of Mount Serua (Indonesia) in 1693 (Arfeuille et al. 2014) and a further unknown eruption in 1695 (Sigl et al. 2015) are analyzed. These two eruptions resulted in a noteworthy cooling over the Northern Hemisphere (NH), especially in the summer months of the following years (Sigl et al. 2015). If this cooling is captured by natural proxies such as ice cores, one can assume that it must also have been documented in archives of society. Especially relevant in this context are records related to harvest, which would have been impacted by cooling during the growing season.

To investigate a potential cooling signal in the NH following the 1693 and 1695 volcanic eruptions, temperature signals from 22 available documentary series covering this timespan are analyzed. The temperature

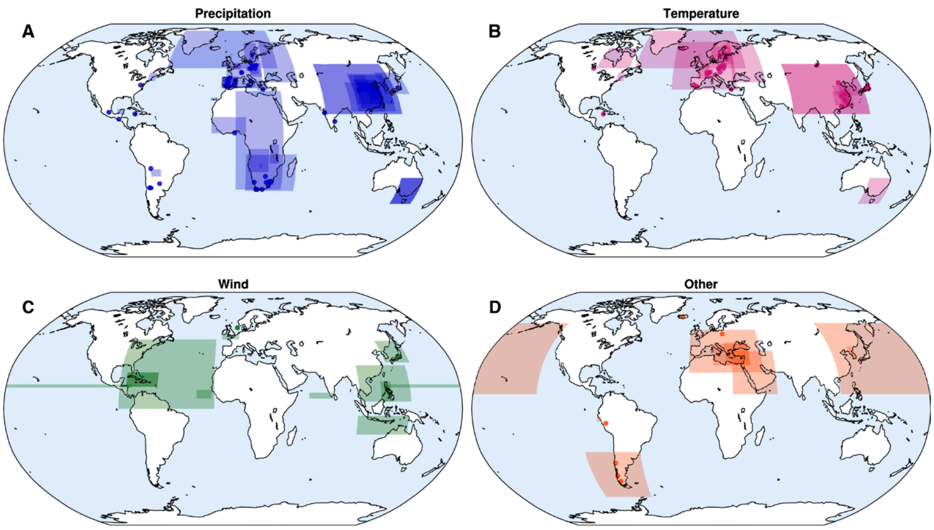

Figure 1: Spatial distribution of available documentary series on climate from the global inventory for **(A)** precipitation, **(B)** temperature, **(C)** wind, and **(D)** other. Circles indicate evidence assigned to a specific location; rectangles mark relevant areas for which climate information is found by a source.

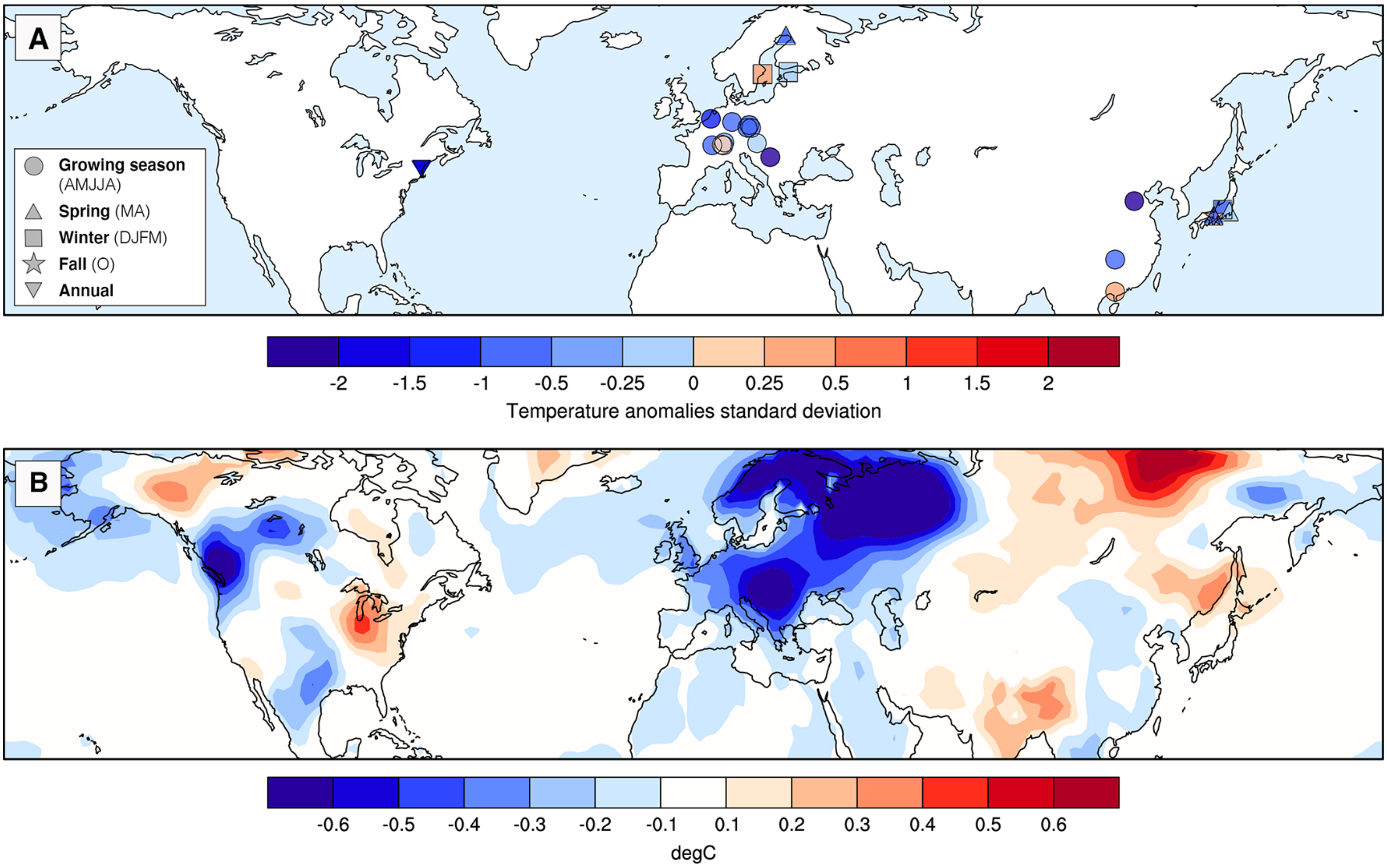

Figure 2: (A) Temperature composites from documentary series for the 1693 and 1695 volcanic eruptions. Proxy series are categorized into seasonal groups. **(B)** Composites of surface air temperature during the growing season (April–August) from the EKF400v2.0 reconstruction.

during the anomalous period 1693–1697 (five years) was expressed relative to the combined average of the 10 years prior (1683–1692) and 10 years after (1698–1707). Each documentary series represents a temperature signal for a particular season or month. To compare these temperature composites, they are grouped into signals for spring (March–April), growing season (April–August), fall (October), winter (December–March), as well as an annual signal.

As shown in Figure 2a, 16 of the 22 documentary series show negative temperature anomalies for the years after the volcanic eruptions in 1693 and 1695. The signal is especially homogenous over Europe where the growing season during 1693–1697 was notably cooler than during the reference period. All but one of the European growing season proxies exhibit negative anomalies. They consist of temperature proxies based on various phenological parameters, e.g. grape and grain harvest dates, freezing of water bodies, duration of snow cover, as well as direct observations of the weather such as reports on temperature-related features such as extreme frost periods. The most prominent anomaly can be seen over the Carpathian Basin, a proxy based on documentary evidence from Hungarian sources (Bartholy et al. 2004). Also, spring proxies in Europe (ice break-up on the Torne River; Loader et al. 2011) and Japan (dates of the cherry blossom; Aono and Kazui 2008; Aono 2014) indicate cooler-than-normal conditions. For winter and fall, less evidence is available, and no clear signal emerges.

The sole source for North America shows a strong negative anomaly based on the annual proxy in New England (Baron 1995). This potentially indicates that colder-than-average temperatures following the volcanic eruptions might not be restricted to the warm seasons but were rather a multi-annual event. The historical evidence relating to summer temperatures for China is based on the REACHES Climate Database (Wang et al. 2018) and contains regional variations.

These findings based on documentary evidence correspond with the temperature composite from the EKF400v2.0 reconstruction (Franke et al. 2017) for the growing season (April–August; Fig. 2b). The global reconstruction shows very strong negative anomalies over Europe and indicates that the post-volcanic cooling after the 1693 and 1695 eruptions was especially strong over Europe. The temperature signal over Asia and North America is more ambiguous. This is in good agreement with the signal shown in the documentary evidence (Fig. 2a).

Outlook

As demonstrated in the example of the volcanic eruptions of 1693 and 1695, documentary evidence has great potential to aid in accurately reconstructing past temperature. Although there is relatively little documentary evidence available compared to natural proxies or instrumental measurements, the historical information is of high precision and thus of great value. In addition to temperature proxies, there are many sources available that may help reconstruct precipitation through dry-wet indices. These sources might be particularly relevant in arid subtropical regions in the Mediterranean, China, and Africa, for example, where other sources of information are sparse.

This global documentary inventory on climate compiles a set of essential documentary evidence and thus lays the foundation for incorporating historical documentary evidence into climate reconstructions on a global scale. These sources are invaluable in complementing early instrumental measurements as well as natural climate proxies to realistically reconstruct the past climate.

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