1 **The weather diary of Georg Christoph Eimmart for Nuremberg, 1695-1704**

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8 **Abstract**

9 Data from weather diaries have long been used to reconstruct past climate. However, they could also
10 be used to reconstruct past weather. Weather reconstructions could help to better understand the
11 mechanisms behind, and impacts of, climatic changes. However, reconstructing the day-to-day
12 weather requires many diaries from different regions covering the same period, ideally combined with
13 instrumental measurements. In this paper, I describe the weather diary of Georg Christoph Eimmart
14 from Nuremberg, covering the period 1695 to 1704, which was particularly cold in Europe. The diary
15 was imaged from the Russian National Library in St. Petersburg and then digitized. It contains twice
16 daily weather conditions in symbolic form, wind direction, and information on precipitation and
17 temperature in text form. Symbols changed during the first two years, after which a much reduced
18 (and stable) set of symbols was used. Re-coding all days according to the later set of symbols, I find
19 no signs of inconsistency over time in symbols, wind direction, and precipitation information extracted
20 from the text. Comparisons with other sources confirm the day-to-day weather information in the
21 diary. For instance, the wind direction in Nuremberg agrees with the daily pressure gradient between
22 Jena and Paris. Three case studies further confirm the meteorological reliability of the information.
23 This is shown on behalf of an eight-day sequence of stormy weather in 1702, a study of the severe
24 winter of 1697/8, and of the summer of 1695, which was cold and wet, possibly related to tropical
25 volcanic eruptions. The examples underline the consistency of the weather diary with other
26 information and suggest that weather reconstructions as far back as the late 17th century might become
27 possible. However, the spatial information is limited, and any approach arguably needs to make good
28 use of the temporal sequence of information.

29 **1. Introduction**

30 For decades, historians have used data from weather diaries to reconstruct past climate, i.e., to
31 generate monthly or seasonal index series (e.g., Pfister, 1999, see overview in Nash et al., 2021).
32 However, they could also be used to reconstruct past weather day by day. In fact, Manley (1975)
33 described the daily weather during the cold winter 1683/4 based on instrumental data and data from
34 weather diaries. Kington (1988) and Lamb (1991) reconstructed daily weather types and drew daily
35 weather charts for periods in the 18th, 17th, and even 16th century. They combined sparse observations
36 with expert interpretation in a reproducible way (Kington 1988).

37 As weather extremes and changes in weather have come into focus of climate science, reconstructing
38 daily weather is again considered an important goal. García-Herrera at al. (2007), Wheeler et al.
39 (2009) and numerous others have demonstrated the value of carefully reconstructing past extreme
40 weather events. However, the subjective nature of these reconstructions is not without problems (e.g.,
41 Jones et al., 2014, and references therein). Furthermore, to produce complete daily data series,
42 automated and objective methods are used rather than time consuming expert interpretations. Daily

weather types (Schwander et al., 2017) and gridded daily weather reconstructions (Imfeld et al., 2022) have been performed for Switzerland back to 1763 and for Europe for the 1780s (Pappert et al., 2022). Other daily indices such as the wind direction over the English Channel reach further back, to the late 17th century (Wheeler et al., 2010). Cornes et al. (2012a,b) used daily data of sea-level pressure (SLP) from London and Paris to analyse atmospheric circulation and storminess. There are many more examples for analyses of daily weather 300 years back (e.g., Brázdil et al., 2008, Filipiak et al., 2019), a review of approaches is given in Brönnimann (2022). In addition to traditional statistical and numerical methods, new approaches such as machine learning (Brohan, 2022) could possibly replace the expert approach pioneered by Manley, Kington, and Lamb.

The success of any weather reconstruction approach ultimately depends on the available weather data. From the turn of the 17th to the 18th century, several weather diaries are available. The diary from Johann Heinrich Fries in Zurich covering 1684-1718 (Pfister, 1977) can be downloaded from EURO-CLIMHIST (Pfister et al. 2017). The diary of the Kirch family in Leipzig (and Guben) and later Berlin, covers 1677-1774 (Herbst, 2022) and was imaged by the author. Further diaries such as that of David Grebner in Wroclaw covering 1692-1710 (Przybylak and Pospieszyńska, 2010) and Joseph Dietrich in Einsiedeln covering 1670-1704 (Rohr and Schwarz-Zanetti, 2022) are under digitization (not considered here). There are also a number of instrumental records from the late 17th and early 18th century (see Brönnimann et al., 2019a, Lundstad et al., 2022), many of which also have weather descriptions. Combining all these data sets, reconstructing daily weather over Europe back to the late 17th century could become possible.

Here I add another weather diary, namely that of Georg Christoph Eimmart, founder of the first Nuremberg (Nürnberg) astronomical observatory. His weather diary covers the years 1695-1704. This paper describes the diary, its digitisation and (as the diary is mostly kept in symbolic form) categorization. I then compare Eimmart's observations with other sources of daily weather information.

The turn of the 17th to the 18th century is not only interesting as a test case as to how far back daily weather reconstruction can reach, but it is also climatically interesting. It fell into the so-called "Late Maunder Minimum" (Luterbacher et al., 2001), with particularly low temperatures in Europe coinciding with low solar activity. At the same time, several volcanic eruptions (Hekla and Serua in 1693, Komagatake in 1694) might have affected climate (see Burgdorf, 2022).

The paper is organised as follows. Section 2 provides background about the observer and the diary. Section 3 then describes the digitization and the data used for comparison. Results are presented in Section 4. A brief discussion then follows in Section 5 and conclusions are drawn in Section 6.

2. Georg Christoph Eimmart and his weather diary

Georg Christoph Eimmart (1638-1705) is known as the founder of the first Nuremberg astronomical observatory (the following text is based on Gaab, 2005, 2022). Eimmart attended the "Gymnasio poetico" at Regensburg and enrolled in 1655 at the University of Jena, where he studied mathematics. In 1658 he returned to Regensburg. After the death of his father, he moved to Nuremberg (following his sister) around 1660. He worked as an engraver and got involved in the management of the Academy of Painting founded in 1662, and from 1699 until shortly before his death he was director of this institution.

Using the money earned with his artistic activity, Eimmart set up an observatory at Vestnertor, north of Nuremberg Castle (Fig. 1) in 1678. At the end of the 17th century this observatory was the most well-known in Germany (Gaab, 2005). During special celestial events, the observatory was opened to

87 the public. In 1699, Eimmart was admitted to the Parisian Academy of Sciences, and at Leibniz's
88 suggestion two years later, he was also admitted as an external member of the Prussian Academy of
89 Sciences.

90 The written legacy of Georg Christoph Eimmart can be found today in the Russian National Library in
91 St. Petersburg. Vol. 40 of that legacy is the "Diarium tempestatum" (see also Gaab, 2022). It covers
92 the period 1 January 1695 to 25 November 1704 on 120 pages. The first three months are written in
93 ink, the remaining pages in pencil. The diary is structured in tables and contains only observations, no
94 measurements (although a sketch of an instrument is found on a verso page, Fig. 2; all other verso
95 pages are empty). The table is structured in columns, which on the first page are labelled as "Dies;
96 Qualitas Aeris; Temperam: cal: et frig:; Ventus". There is an apparent gap from 19-28 February 1700
97 („Incipit Dies 1. Martiy"), which is due to the change from the Julian to the Gregorian calendar.
98 Another (real) gap of four weeks occurs in January/February 1703.

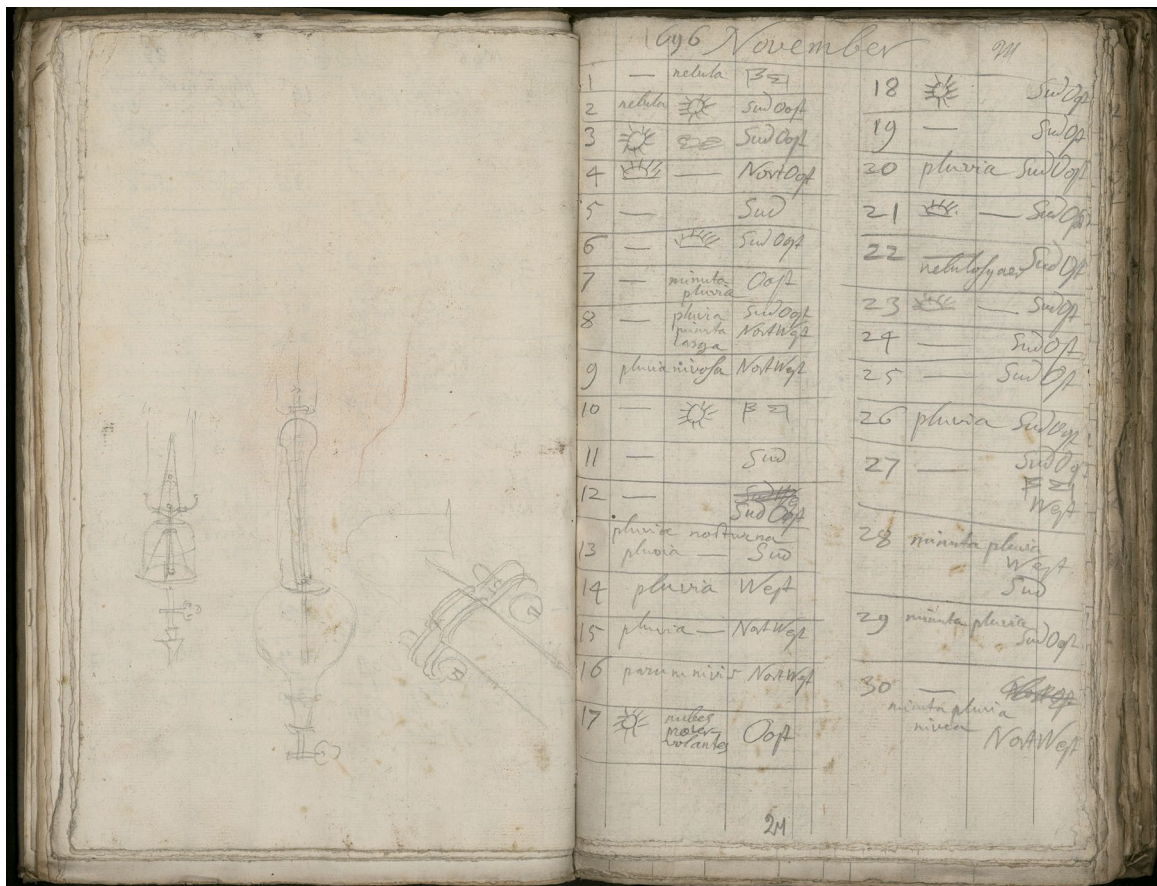
100 **Fig. 1.** (left) Map of Nuremberg, 1642 (engraving by Matthäus Merian from Germaniae, Edition Topographia
101 Franconiae, 1642; Wikimedia Commons, public domain) with the location of the observatory. (right) Location of
102 other weather observation series used in this study (dark green: instrumental measurements, light green:
103 observations).

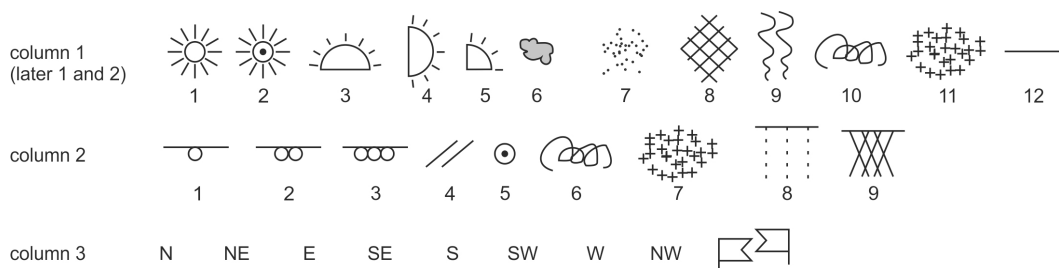
104 An interesting aspect of the diary is that it is in its majority symbolic. This means that the entry is
105 mostly given as symbol, sometimes in words, sometimes both. In the first two years, each column (one
106 month, August 1695, has four columns, all others have three) has a distinct set of symbols that is used
107 (see Fig. 3). Particularly in the first two years, there are often several symbols in the same cell. After
108 2-3 years, however, the distinction between columns 1 and 2 gets lost, while the wind column remains
109 unchanged until the end of the diary. Some of the symbols, particularly those used in the second
110 column (on temperature), vanish and those used in the first column also appear in the second. A much-
111 reduced set of symbols is used in both columns after ca. 1697. There are mostly just three symbols:
112 full sun, upper half of sun, and long dash.

113 Wind is given in cardinal/intercardinal direction, plus a symbol probably referring to changing winds.
114 Sometimes several wind directions are mentioned in the same cell (see example in Fig. 2), which
115 might indicate several observations per day.

116 In addition to symbols and wind direction, there are also occasional latin expressions such as „nebula",
117 "pluvial per intervalla", or "nix". They describe phenomena related to precipitation (rain snow,
118 thunderstorm, lightning, rainbows), wind speed, and temperature. Occasionally other aspects are

119 mentioned (changeable weather, clarity of the sky). Words are sometimes written across both columns
120 (sometimes even also across the wind column), which leads to the hypothesis that, from ca. 1697
121 onward (after the same symbols are used in both columns), Eimmart wrote twice daily observations,
122 where the first column refers to morning and the second to afternoon. This is supported by the fact that
123 "tonitru" (thunders) appears only 6 times in the first, but 33 times in the second column. Likewise,
124 "aestus" (heat) appears 23 times in the first and 47 times in the second columns. However, there is no
125 text to prove this hypothesis.

126 The text entries are not independent of the symbols. In about half of the cases, text entries replace
127 symbolic entries, i.e., these fields then do not have a symbol on the sky conditions. For the other half
128 of cases with text entries these complement existing symbols. Sometimes the text refers specifically to
129 precipitation that has fallen during the night. At few instances, an additional row is even added
130 between two rows noting nocturnal rain or nocturnal storms, or this is made clear by subdividing cells.
131 Overall, there are slightly more text entries in the second column than in the first. Text entries in the
132 third column are rare.

133

134 **Fig. 2.** Eimmart's diary for November 1696 from the National Library of Russia, St. Petersburg. The left page
135 shows sketches of scientific instruments (© National Library of Russia, St. Petersburg).

136

137 **Fig. 3.** Symbols used in the weather diary.

3. Digitising and formatting the diary and comparison to other data sources

139 Before digitizing, an inventory of all symbols appearing in the diary was compiled (Fig. 3), and a code
140 was assigned to each symbol. Then symbols were digitized as codes. For the text I use an additional
141 column. I transcribed the latin words as good as possible, some illegible words are marked with "$".
142 Eimmart abrreviated some words with a symbol resembling "y", which I transcribed as "y" (e.g.,
143 "frigy"). Words written over two fields are assigned to both fields with a corresponding bracket (e.g.,
144 „pluvius[„ and]pluvius"; for the special case of August 1695, with 4 columns, I kept the three column
145 structure but assigned words across several columns only to one, with a note "[2 columns]"). A pipe
146 symbol "|" is used to indicate line breaks within a cell. In case of nocturnal weather, when the diary
147 makes it clear to which night this refers, I add it to the following day (the weather diary also mostly
148 does it this way) with a note "[previous night: ….]". Within the text, Eimmart sometimes uses a
149 symbol for the Sun, which I transcribed as "[solaris]".

150 From this raw transcription I generated several derived variables. First, I categorized the text entries
151 related to precipitation into snow ("nix", "nivigit" or similar), rain ("pluvia"), or rain and snow. In the
152 category rain I also included expressions such as "tonitru" (thunder) or "nebula pluviosa" (rainy fog),
153 but not "tempestas" (storm). To these I also added symbols 7 to 9 (rain) and 11 (snow) of Fig. 3,
154 column 1, as well as symbols 7 (snow), 8 and 9 (rain) of Fig. 3, column 2. Note that these almost
155 exclusively appear in the first 9 months. This variable is called precipitation.

156 Second, I formed a unified code based on the three main symbols used after 1697, namely "sunny"
157 (full sun), "partly sunny" (half sun), and "cloudy" (horizontal line). For this, I grouped symbols 1, 2
158 (column 1) and 5 (column 2) to the category "sunny", symbols 3 to 5 (column 1) as well as any
159 combination of a symbol 1-5 (column 1) with another symbol as category "partly sunny", and
160 categories 6 and 12 (column 1) to category "cloudy". All days for which the diary indicates a weather
161 symbol (76% in column 1, 60% in column 2) are thus assigned one of the three categories. This
162 variable is called "WeatherSymb".

163 Third, for most of the days with missing symbols, there is a text entry. In a further step, I also
164 generated a code for these entries. The terms "serenum" (clear) and "sunidy" (sunny) were coded as
165 "sunny", "coelum varium" (changeable), "pluvia per intervalla" (occasional rain), "pluvia minuta"
166 (little rain), "tonitru" (thunder), and symbol 8 (column 2) were coded as "partly sunny", and the terms
167 "pluvia", "pluvia tota dia", and "nebula" as well as symbol 9 (column 2) were coded as cloudy. In this
168 way, 97% (80%) of the days in columns 1 and 2, respectively, could be coded. The smaller amount in
169 column 2 is due to the fact that many of the text entries refer to temperature and winds. This variable
170 is called "WeatherSymbText".

171 Eimmart's diary entries were then compared with daily weather information from other sources (see
172 Fig. 1 for locations). This includes a weather diary from Zurich, pressure measurements from London
173 (Cornes, 2012a), Paris (Cornes, 2012b), Leiden, Halle, and Jena (Lundstad et al., 2022; see
174 Supplementary Material), temperature measurements from Paris (Rousseau, 2009, Pliemon et al.,
175 2022), Berlin, Halle, and Kaliningrad (Lundstad et al., 2022; see Supplementary Material), as well as
176 wind direction from ships on the Channel (Wheeler et al., 2010, Barriopedro et al., 2014). Note that,
177 first, many of the series only overlap partly with the Eimmart diary, thus limiting comparisons, and,
178 second, their quality is mostly unknown. For instance, the Halle records of both temperature and
179 pressure did not seem to be usable in their present form and were discarded. The following
180 comparisons address the internal temporal consistency, the temporal agreement of the diary with other

181 time series, the spatial consistency across Europe, and the consistency of daily wind direction with a
182 large-scale pressure gradient.

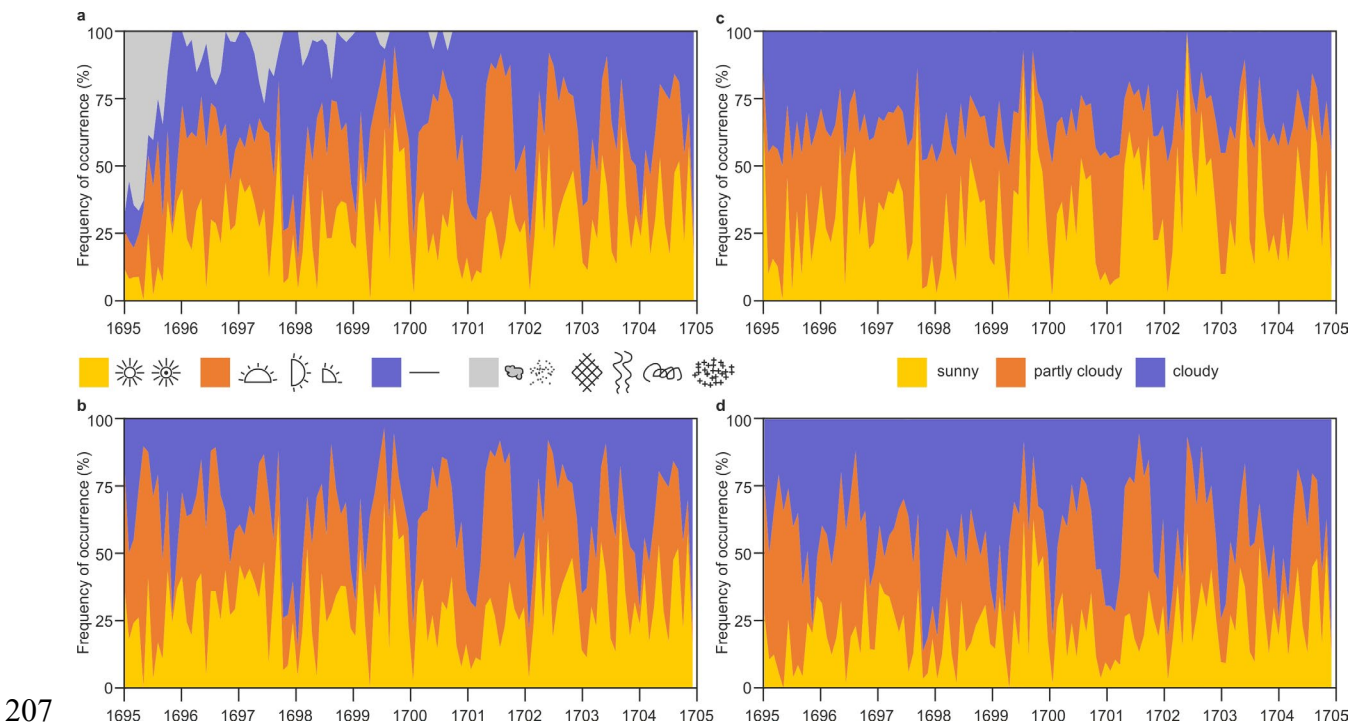
183 More comparability options would exist on a monthly scale by comparing with monthly
184 reconstructions. However, it is not straight forward to aggregate the daily weather information to a
185 monthly level, and the focus of this paper is on the daily scale. However, I compared the weather diary
186 with other documentary series (Burgdorf et al., 2022) and with monthly climate reconstructions for
187 two specific cases, namely the summer of 1695 and the winter of 1697/98. For these case studies I
188 used the ensemble mean of the reconstruction EKF400v2, which is a global, 3-dimensional climate
189 reconstruction based on data assimilation (Valler et al., 2022).

190 **4. Results**

191 *4.1. Time consistency of symbols, wind direction, and text*

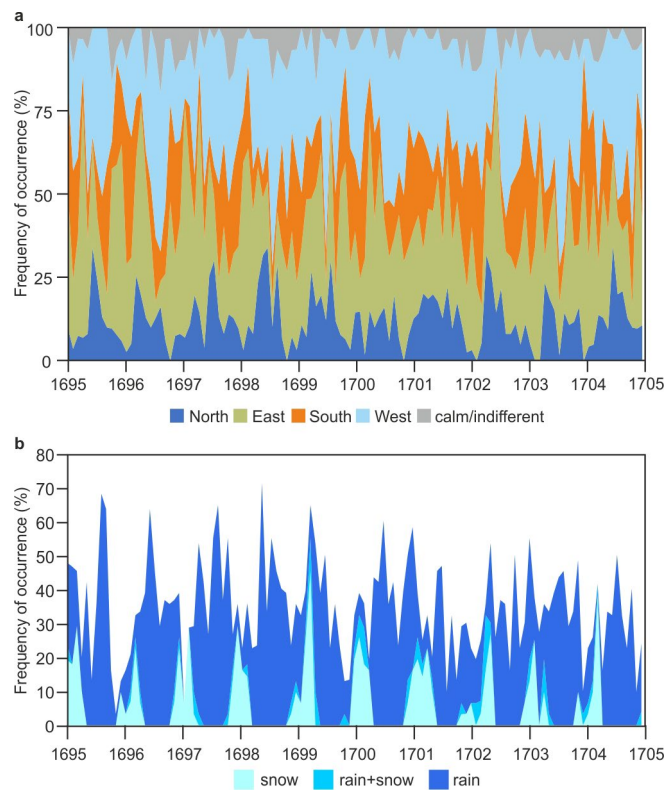
192 In first step I analysed the frequency of each symbol per month, over both columns. Due to the large
193 number of symbols used, especially at the beginning, I ignored the temperature related symbols
194 (symbols 1-4, column 2), which only appear in the first 4 months, and grouped the symbols remaining
195 related to the general weather characteristics and the sky into four main categories (see Fig. 4). I then
196 counted each use of a symbol and divided it by the total number of symbols in that month. There
197 might be several symbols per day, or just one. Note also that text is ignored here.

198 The results (Fig. 4a) show what was already observed during the digitization, namely that in the
199 beginning, many different symbols appeared while later basically three symbols were used. The grey
200 category of symbols vanishes almost completely and from around 1698 onward, the use of the
201 symbols is rather consistent. Figure 4b shows the results obtained when simply ignoring they grey
202 category of symbols. Their frequency over time changes less, but many days have no category. The
203 corresponding figure for variable "WeatherSymb" (Fig. 4c) shows slightly different behaviour in the
204 first years compare to later. When also text entries are categorized (variable "WeatherSymbText" Fig.
205 4d), no obvious inhomogeneity is seen anymore. The figure resembles Fig. 4b, but now almost all days
206 have a category. Note that cloudy conditions are more frequent because most text entries concern rain.

207

208 **Fig. 4.** Frequency of occurrence of weather symbols per month relative to all symbols in that month. **a** all
209 symbols (grouped into four categories), **b** only the first three categories, **c** variable "WeatherSymb", **d** variable
210 "WeatherSymbText".

211 Similar as for the weather symbols, I also analysed the wind direction. I counted the letters for the
212 cardinal directions (N, E, S, W as well as one letter for mixed), divided the counts by the number of
213 letters per day, and then averaged the number per month. Note that in this procedure NW counts as
214 two letters (each weighted half), N as one. This allows a first, albeit simple visualization (Fig. 5a).
215 Results show variations in occurrence, but no obvious inhomogeneity is seen in this plot.

216 The same was also done for the variable precipitation with its categories "snow", "rain and snow", and
217 "rain" (Fig. 5b). Variability in precipitation is high, but once again there is no evidence for an
218 inhomogeneity. The figure indicates a decrease of rain days over the 10 years. However, this might be
219 a true climatic signal. The large spike in the beginning of the series, in summer 1695, will be analysed
220 later and is arguably real.

221

222 **Fig. 5.** Frequency of occurrence of **a** cardinal wind directions per month and **b** days with snow, rain and snow, or
223 rain.

224 *4.2. Analysis of the wind direction*

225 As a next step I compared the daily wind direction at Nuremberg with the daily SLP gradient between
226 Jena and Paris in the year 1702 (the only year for which data from Jena are available). A positive
227 gradient is expected to correlate with winds from the South or East, whereas a negative gradient is
228 expected to correlate with winds from the North or West. I therefore grouped the winds accordingly
229 (S, SE, E, SW vs. W, NW, N, NE). Most of the days had only one wind direction. If more than one
230 was noted, I excluded days that would fall into both categories.

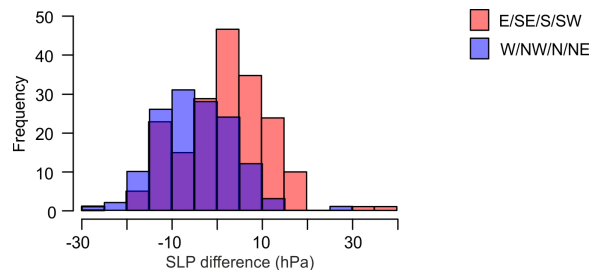
231 To calculate the pressure gradient between Jena and Paris, I reduced the Jena data to sea level. As no
232 temperature information was available, I assumed a sinusoidal seasonal cycle of temperature varying
233 between -4 °C (in January) and 20 °C (in July). As the thus obtained SLP data were clearly too low in

234 Jena, I added the mean difference between Jena and Paris such that both series have the same mean. I
235 analysed the data using a contingency table and by stratifying the SLP difference according to the
236 wind direction.

237 The contingency table (Table 1) clearly shows a very strong association between pressure gradient and
238 wind direction in the expected sense. A statistical test (Fisher's exact t) confirms the high significance
239 of the results. However, while there are more cases with a negative than with a positive SLP difference
240 (note that the average difference is zero), there are clearly more cases with an easterly-to-south-
241 westerly wind than a westerly-to-north-easterly wind. The histogram of SLP difference (Fig. 6) also
242 clearly shows a difference in the SLP gradient depending on the wind direction. Note that deviations
243 are expected. Apart from the measurement errors and errors in the reduction to SLP, it should be noted
244 that the SLP gradient may not be the best proxy for wind. Furthermore, Paris is relatively far away,
245 and the wind over land is not geostrophic. Thermotopographic winds or topographically channelled
246 winds may overlay the large-scale flow. Wind is a variable with a high variability, and observations
247 provide only a snapshot. Note also that the time of day of observations is not known. In light of these
248 uncertainties, the clear presence of a signal is therefore encouraging.

249 **Table 1.** Contingency table of wind observations in Nuremberg and SLP differences between Jena and Paris. The p-value
250 refers to Fisher's exact t.

	E/SE/S/SW	W/NW/N/NE	Sum
ΔSLP>0	118	40	158
ΔSLP<0	72	98	170
Sum	190	138	$p<0.0001$

251

252

253 **Fig. 6.** Histograms of SLP difference between Jena and Paris stratified by the wind direction in Eimmart's diary.

254 *4.3. Case studies*

255 4.3.1. Weather maps for October/November 1702

256 Next I analysed the entries in Eimmart's diary together with all other available information for an 8-
257 day sequence in 1702. The sequence was chosen as a strong storm was noted in this period in the
258 observations from Kaliningrad in the night from 31 October to 1 November (Anonymous, 1703). Note
259 that the year 1702 is arguably the year with the best data coverage within the 1695-1704 period.
260 Instrumental data are available from Jena, Paris, London, Berlin and Kaliningrad, weather
261 observations from Jena, Kaliningrad, Zürich, Nuremberg, and the English Channel. For display
262 purposes, I deseasonalised (by fitting the first two harmonics of the seasonal cycle) and standardized
263 the instrumental data with respect to the year 1702 and expressed the anomalies in standard deviations.
264 For Berlin where the observation hours change rapidly, I only used the 8 days displayed, chose the
265 observation closest to 8 in the morning and standardized the temperatures.

266 The sequence of maps (Fig. 7) starts with mild temperatures, sunny or changeable weather and
267 moderately low pressure across Europe. The next day pressure increased in Paris and Jena, it remained
268 rather warm. Pressure remained low over Kaliningrad. The next three days saw a clear pressure

269 increase over London, Paris, and Jena, with westerly flow. Temperatures were high especially on 30
270 October. Pressure and temperature then both decreased on the day of the storm. Pressure increased
271 right after the passing of the storm, accompanied by a marked temperature decrease and mostly sunny
272 weather.

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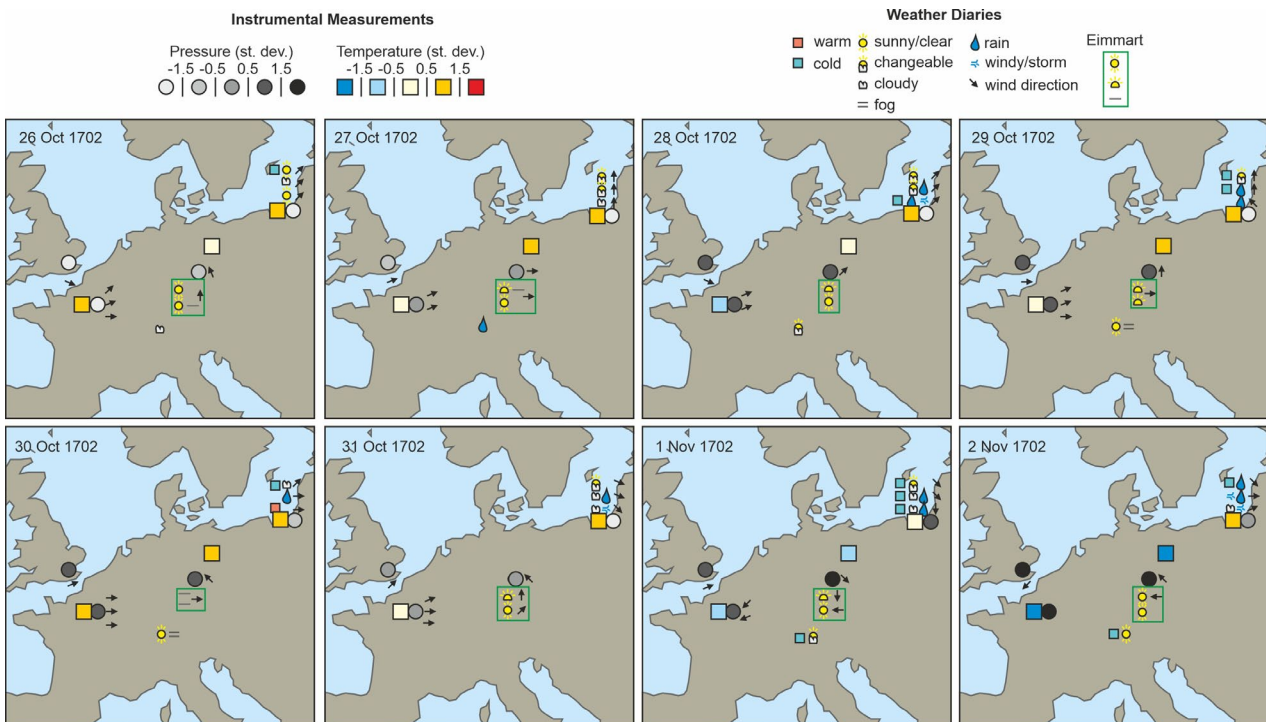


Fig. 7. Maps of pressure, wind, and temperature for an eight-day sequence in 1702. A vertical sequence of
symbols at the same location indicates sub-daily data (progressing from top to bottom).

276 While this sequence is plausible, the spatial information is insufficient to draw weather maps. There
277 could have been a quick succession of passing depressions over Northern Europe, that may have gone
278 unnoticed. However, the maps depict the high-pressure system to the south. Also, the passage of a cold
279 front on 1 Nov is clearly seen.

280 4.3.2. The harsh winter of 1687/8.

281 The second case study relates to the harsh winter of 1697/8. This winter is particularly well known in
282 England (Kington, 1999), where it was the coldest among six very cold winters in the 1690s.
283 However, the winter was also cold over Central Europe (Pfister and Wanner, 2021). A number of
284 European weather series exist on a daily scale for this winter, including pressure in London, Paris, and
285 Leiden, temperature in Paris, wind over the English Channel, cloud motion and cloud cover from
286 Paris, and weather observations from Zurich and Nuremberg. All observations are shown as time
287 series in Fig. 8.

288 Temperature measurements in Paris as well as notes on temperature in the Zurich series point to a
289 sequence of many cold spells during the entire winter and spring. For Nuremberg, notes on
290 temperature are sparser, but they also agree with the two other series. According to Kington (1999),
291 the first snow in London fell on 24 November. In Nuremberg and Zurich snowfall is reported on 22
292 November. We also see periods of higher temperature and thawing weather (or rainfall), such as in
293 early December. A snowy and cold period follows at all sites in mid-December. January then was
294 particularly cold in Paris, London, and Zurich. A notable pressure drop occurred in Paris on 1 February
295 1698, arguably associated with a warm front (Kington, 1999). Temperatures increased everywhere,

296 and precipitation fell as rain in Nuremberg (note that the temperature increase here occurred ca. two
297 days later than in Paris). The first half of March was again cold at all sites. Cold spells again occurred
298 in late April and early May. In fact, May 1698 still is the coldest May on record in the Central England
299 temperature series. This brief analysis shows that the daily series are consistent with each other. Even
300 wind directions agree well for locations close to each other (e.g., English Channel and Paris).

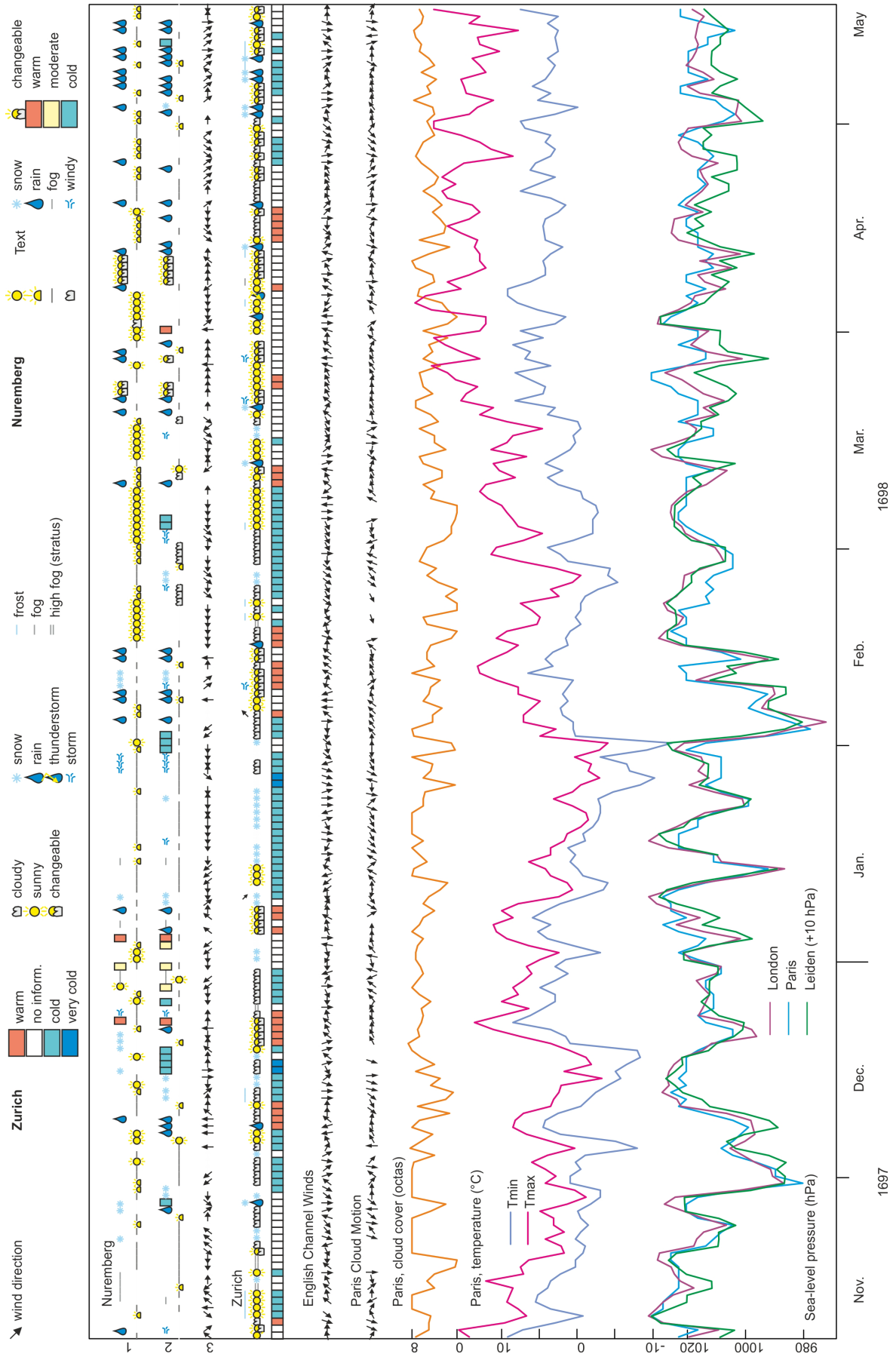



Fig. 8. Daily weather in the winter 1697/8. For Nuremberg, 1 to 3 marks the columns, subdivided into text entries that were transformed into symbols (upper line) and symbolic entries (lower line).

As a further opportunity for comparison, I considered the chronicle by Johann Laurentz Bünti (Bünti, 1973) from central Switzerland, which points to snow fall on 3 and 8 May and again on 21 May («Hierauff folget den 3. May ein Schnee [...] Den 8.ten May hat man wiederum im ganzen Boden Schnee.»). Bünti writes that precipitation was very high and that it fell as snow in the mountains, such that there was more snow in the mountains in May 1698 than in many winters.

To further investigate this winter, I analysed temperature and pressure anomalies in the monthly reconstruction EKF400v2 (Fig. 9). The fields are expressed as anomalies from the subsequent 30-yr period. The Dec.-Feb. patterns in sea-level pressure resembles the positive easterly index in Mellado-Cano et al. (2020), and in fact easterly wind components are soon in the English Channel winds, Paris cloud motion, and in Eimmart's observations at Nuremberg . The same figure also shows hand-drawn pressure maps by Wanner et al. (1995). These fields have no scale (and are here compared with anomalies). However, analysing the position of highs and lows (or positive and negative anomalies), I find a mostly good agreement, indicating that the data assimilation approach and an expert approach give consistent results. Into these we can now embed the weather diaries. The fields show that January and February were actually even colder in Central Europe than in Western Europe. In January, Eimmart notes mostly easterly winds and a horizontal line, arguably denoting a persistent stratus. These features stand out over the 10 year period and are also clearly seen in Fig. 4 (increased blue area) and Fig. 5 (increased green area denoting easterly winds). This is very well in line with the monthly charts shown in Fig. 9. The cold spells in May seemed to have had more pronounced effects in Zurich than in nearby Nuremberg, consistent in the reconstructed fields, the hand-drawn fields, and the diary entries.

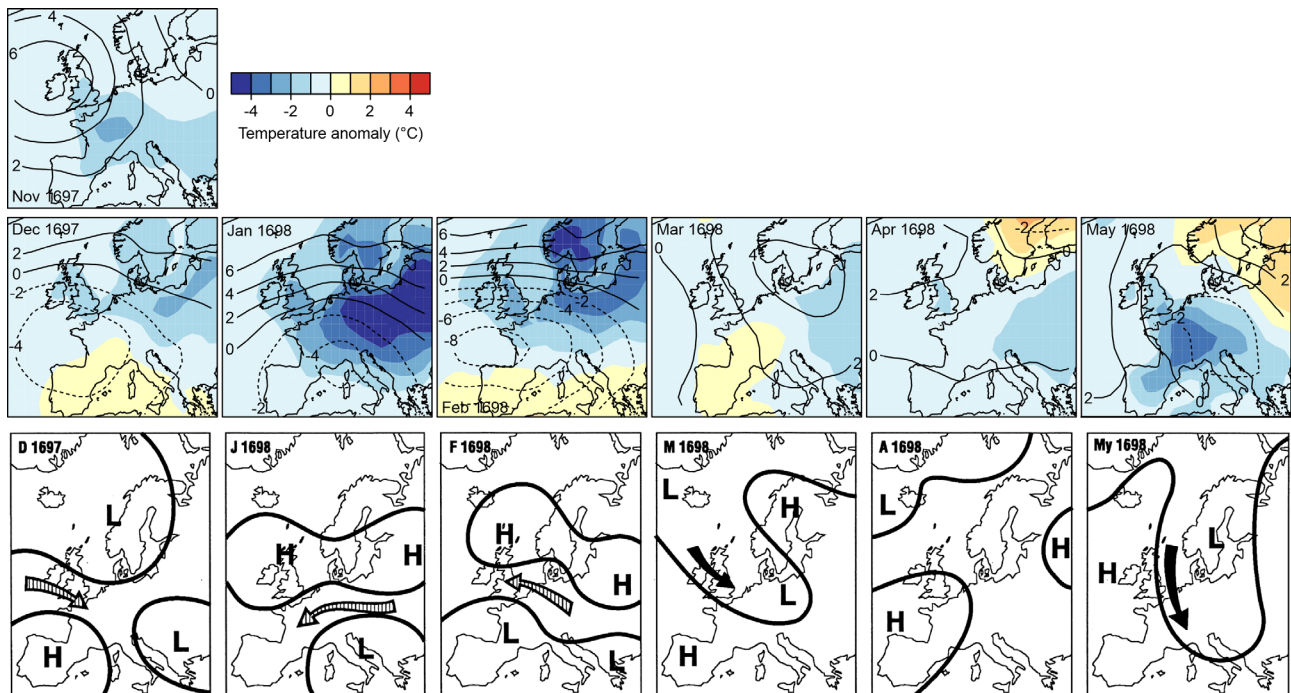



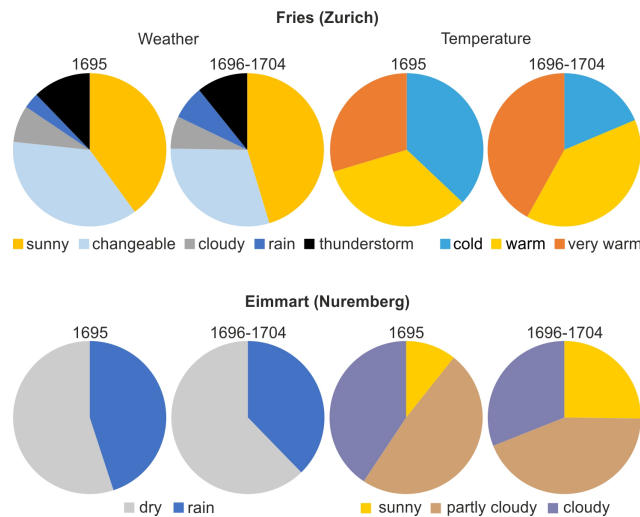
Fig. 9. Monthly temperature (colours) and pressure anomalies (contour, in hPa) relative to the period 1698/9 to 1727/28 from EKF400v2 (top) and an expert reconstruction of the pressure distribution and main flow for the same months form Wanner et al. (1995).

4.3.3. The summer of 1695

Finally, I also analysed the summer of 1695, which is known as a very cold summer (July 1695 was the second coldest July in the Central England temperature series behind 1816). The summer was also

332 cold in Switzerland. Bünti (1973) writes that 1695 was a late and wet year, with frequent summer
333 snowfall events in the Alps («Sonsten ist dissess 1695. Jahr ein spätes und nasses Jahr gesein; im
334 Summer [wurden] offt die Alpen überschnyt»).

335 For this case, I analysed the variables "Precipitation" and "WeatherSymbText" from Eimmart's diary
336 as well as temperature and weather conditions and in Zurich in June to August. I compared the
337 frequencies in 1695 to those obtained in 1696-1704 (Fig. 10). I also compared the result to
338 documentary climate data for that summer and to EKF400v2. For comparison, I standardized both
339 based on the 1696-1704 period (EKF400v2 is also shown as anomalies without standardizing).
340 Although this is a small sample, it is the longest statistical analysis the Eimmart diary allows.

341 The summer of 1695 was clearly less sunny in Eimmart's diary, while cloudy conditions were more
342 frequent. Also, there were more days with precipitation in Jun-Aug 1695 than in the average of all
343 other summers. A very similar behaviour is found in Zurich, where sunny conditions were less
344 frequent and "changeable" more frequent. A clear signal is also found in the temperature notes of
345 Zurich. Cold days were about twice as frequent in 1695 as in the reference period, mostly at the
346 expense of very warm days. For Nuremberg, there are too few temperature notes for an analysis.

347

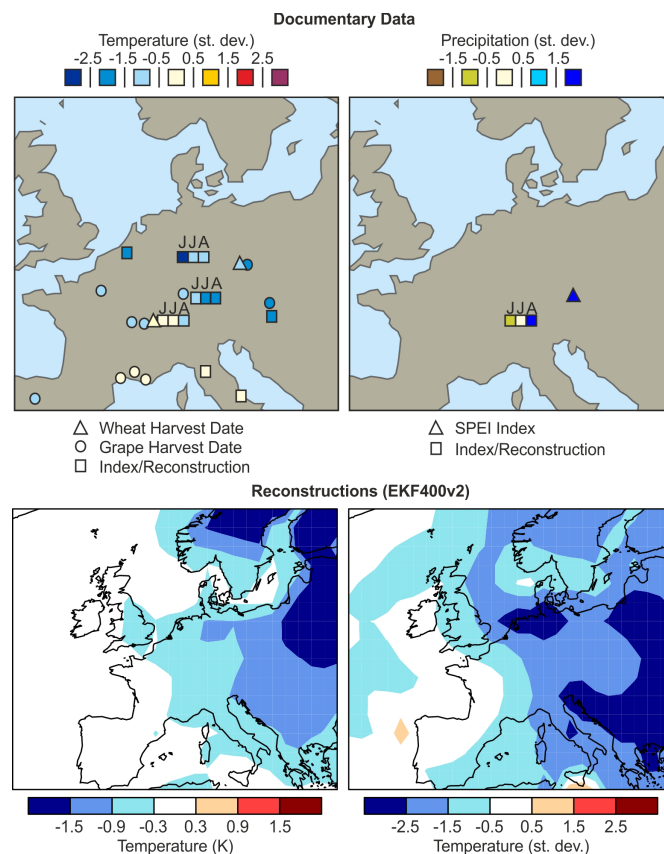
348 **Fig. 10.** Frequency of weather descriptions in the diaries of Eimmart (Nuremberg) and Fries (Zurich) for the
349 summer (Jun-Aug) of 1995 as well as for the remaining 9 summers of Eimmart's observation period.

350 The two diaries can now be compared to two further sources on that summer: documentary data (Fig.
351 11, top, Supplementary Material) and reconstructions (Fig. 11, bottom). Both sources show that it was
352 cold particularly in the northeast of the domain, less so in Western France and Spain. The
353 documentary data indicate no specifically cold period in Italy, whereas the reconstruction suggest
354 somewhat lower temperatures (note that the documentary data and reconstructions are largely
355 independent, only the monthly index series indicated in Fig. 11, top, with "JJA" were assimilated into
356 EKF400v2). Zurich and Nuremberg were both in a region that was affected by the adverse weather,
357 although not in the core region of this climatic anomaly.

358 **5. Discussion**

359 The weather diary by Georg Christoph Eimmart from Nuremberg, covering the period 1695 to 1704,
360 might be a useful addition to the compilations of existing weather diaries. The diary stands out in that
361 it is mostly symbolic for sky conditions, complemented with wind direction and text for precipitation
362 and temperature. Although there are quite large changes in the use of symbols and of text in the first 1-
363 2 years, derived variables that group sky conditions and precipitation each into 3 categories according

364   to both symbols and text show now sign of inhomogeneity. The same result is found for wind
365   direction. Observations seem to have been performed in a consistent manner over 10 years.

366   The diary compares well with other sources of information, such as the diary from Fries in Zurich. It
367   also compares well with instrumental data, as demonstrated by comparing wind direction with a large-
368   scale SLP gradient. This confirms that the diary not only has useful information on climate, but also
369   on the daily weather. Combining this diary with other available observation series shows that there is
370   spatial information in the combination of all weather data. Some features, such as the passing of a cold
371   front, can be clearly seen, but it is still difficult to draw detailed weather maps directly from this
372   information. Several more series will be available in the near future and might further help towards
373   that aim. However, there is also information in the time sequence of weather at each of these sites.
374   Given the sparse information in space, it is essential to also exploit the information in the time
375   sequence. Novel approaches such as deep learning algorithms might potentially be used for weather
376   reconstruction but arguably would have to make use of time sequences in order to be successful. Such
377   methods first need to be tested extensively in long data sets generated from recent products using tools
378   such as synthetic weather diaries (Brönnimann, 2021).

379

380   **Fig. 11.** Top: Standardised anomalies (relative to 1696-1704) of documentary data from Burgdorf et al. (2022)
381   for temperature and precipitation. Bottom: Anomaly (left) and standardized anomaly (right, both relative to
382   1696-1704) of temperature in EKF400v2. Note that EKF400v2 includes the four monthly series shown in the top
383   row (three temperature indices and one precipitation index), but not the other series.

384   Finally, the diary, together with other sources of information, provides some insights into the climate
385   processes in the 1690s, a period that was characterized by cold winters in Europe and also cold and
386   rainy summers. The winters such as 1697/98 were likely characterized by frequent blocking and a
387   meridionalisation of circulation. This is also seen in Eimmart's diary. The pressure difference between
388   Paris and London (Cornes et al., 2012a,b) exhibits its lowest values (winter average) in the 1690s (the

winters 1695, 1694, 1692, and 1698 occupy ranks 1, 2, 4, and 11). The North Atlantic Oscillation index calculated from EKF400v2 also shows low values in these years (see Brönnimann, 2022).

These winters fell into the so-called Late Maunder Minimum (Luterbacher et al., 2001), when sunspot activity was very low. In fact, these cold winters have often been attributed to low solar activity. A more meridional circulation with more frequent blocking events due to low solar activity would be in line with statistical analyses of later data (Woollings et al., 2010). In addition to solar forcing, also volcanic eruptions cold have played a role. Eruptions occurred in 1693 (Hekla, Serua) and 1694 (Komagatake), and although winters following volcanic eruptions sometimes show a winter warming in north-eastern Europe, this dynamical effect does not always appear and cold seasons following volcanic eruptions may also be cold. The summer case (1695) shows the cooling expected following a volcanic eruption (Raible et al., 2015); documentary data confirm this also on a hemispheric scale (Burgdorf, 2022). Whether cold winters and cold summers in the 1690s are related remains to be studied. There are several possible memory effects that might help to maintain the cooling from the summer to the next winter and spring, including the oceans (Raible et al. 2015) and Eurasian snow cover (Reichen et al., 2022). All factors together may have generated a decade of cold weather similar to the early 19th century (Brönnimann et al., 2019b), when both summers and winters were cold particularly over Eurasia. Historical weather diaries could help to further shed light on climate mechanisms operating on a decadal scale related to volcanic eruptions and a solar minimum. However, more weather and climate data are needed for this.

The first instrumental series in Nuremberg covers 1718-1730 (observer: Rost, 3-4x daily), another series (observer: Doppelmayr, daily) covers 1732-1743 (see Brönnimann et al., 2019a). Both were digitised and are included in the electronic supplement. Both also contain wind direction, such that a 1695-1743 record of sub-daily wind could be generated. However, homogeneity needs to be assessed.

6. Conclusions

This paper describes the digitization of the weather diary of Georg Christoph Eimmart. The diary contains information on sky conditions (in symbolic form), precipitation, temperature, and wind in Nuremberg, 1695-1704. It is relevant as the 1690s were a particularly cold decade in Europe. At the same time, this approximately marks the period back to which daily reconstructions of weather might be possible. The newly digitized diary might contribute towards this aim.

The diary structure changes during the first ca. two years, but afterwards (for wind throughout the period), the diary is consistent. Comparisons with other series from Europe show that the diary provides useful and usable information on the daily weather. For instance, the local daily wind direction in Nuremberg agrees with the large-scale pressure gradient. The usefulness is further demonstrated on behalf of several case studies, covering a storm passage in October/November 1702, the cold winter of 1697/8, and the cold summer of 1695. These cases also show that the spatial information at the daily level is inevitably sparse in the late 17th century. Any approach to reconstruct the daily weather during this time arguably needs to make use of the temporal as well as the spatial information contained in all available data sources.

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433 Supercomputer Centre (CSCS).

434 **Supplement:** Supplementary files include the diary in xls, the data files for Jena, Kaliningrad, Leiden, and
435 Nuremberg (instrumental data) in the SEF format and xls, an ASCII file with the documentary data (Fig. 10), R-
436 Code and a readme file.

437 **Code Availability:** R-code to produce Figures 9 and 11 is given in the Supplement.

438 **Data availability statement:** The diary is in the Supplementary Material, EKF400v2 is available from
439 DKRZ/WDCC (doi:10.26050/WDCC/EKF400_v2.0), the Fries diary is available from EURO-CLIMHIST
440 (www.euroclimhist.unibe.ch), pressure data from Paris and London are available from the Climatic Research
441 Unit (https://crudata.uea.ac.uk/cru/data/parislondon/), cloud cover and direction as well as temperature from
442 Paris is available from Climate of the Past (Pliemon et al., 2022). Documentary data are available from
443 https://boris-portal.unibe.ch/handle/20.500.12422/207 (Burgdorf et al., 2022).

444 **Conflict of interest statement:** The author declares no conflict of interests.

445 **Author contributions:** SB digitized the diary together with a student, performed all analyses and wrote the
446 paper.

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