Supplemental material for

The influence of temperature on the seasonality of historical plague outbreaks

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Table S1. Search strategies for the systematic search of literature containing plague mortality data

Source	Search terms / Restrictions
Jstor	((plague OR Pest OR peste) AND (epidemi* OR mortalit*) AND (histori*) NOT (India OR Indien OR Madagas*ar OR China OR Mongolia OR Kazakhstan OR United States OR Ameri*a OR Bra*il* OR Argentin* OR Afri*a OR Australi* OR Iran OR Hongkong OR Persi*)) Subjects: Agriculture, Anthropology, Aquatic Sciences, Archaeology, Bibliography, Biological Sciences, Botany & Plant Sciences, British Studies, Classical Studies, Cultural Studies, Development Studies, Ecology & Evolutionary Biology, Economics, Environmental Studies, Environmental Science, European Studies, General Science, Geography, Health Policy, Health Sciences, History, History of Science & Technology, Mathematics, Middle East Studies, Museum Studies, Population Studies, Public Health, Public Policy & Administration, Science & Technology Studies, Statistics, Technology, Urban Studies, Zoology Type: research-article
Pubmed	(plague OR Pest OR peste) AND (epidemi* OR mortalit*) AND (histori*) NOT (India OR Indien OR Madagas*ar OR China OR Mongolia OR Kazakhstan OR United States OR Ameri*a OR Bra*il* OR Argentin* OR Afri*a OR Australi* OR Iran OR Hongkong OR Persi*)
Internet Archive	-title:(India) AND -title:(Indien) AND -title:(Bombay) AND -title:(Ameri*a) AND -title:(Madagas*ar) AND -title:(Persi*) AND -title:(Hongkong) AND -title:(Hong Kong) AND -title:(China) AND -title:(Mesopotamie*) AND -collection:(jstor_publhealrepo1896) AND mediatype:(texts) AND -collection:(inlibrary) AND -collection:(dticarchive) AND ((plague OR Pest OR peste) AND (epidemi* OR mortalit*))

Table S2. Number of publications retrieved, screened and included from different databases and sources.

Database	N retrieved	N included after title/abstract	N included after full text
Pubmed	473	117	6
Jstor	1611	81	1
Archive.org	366	48	2
Opportunistic search	36	36	36
Total	2486	282	45

Table S3. Metadata of all included datasets. Mortality indicates whether the data are plague specific deaths or all-cause burials or deaths. Interval denotes the time step of the data collection. Source type indicates whether the data were digitized from a graph or a table/list. Values denotes whether the data are counts (deaths) or proportions/percentages. In the latter case, the data were only used for the assessment of the epidemic peak. Data ref gives the literature reference for the mortality data (and the population size if from a different source)

id	country	place	start year	end year	mortality	interval	calendar	source type	values	data ref
1	Syria	Aleppo	1761	1762	all-cause	weekly	julian	table	counts	[1]
2	Egypt	Alexandria[1]	1834	1835	plague	daily	gregorian	table	counts	[2]
3	Egypt	Alexandria	1836	1837	plague	monthly	gregorian	table	counts	[2]
4	Egypt	Alexandria	1838		plague	monthly	gregorian	table	counts	[2]
5	Egypt	Alexandria	1840		plague	monthly	gregorian	table	counts	[3]
6	Egypt	Alexandria	1840	1841	plague	monthly	gregorian	table	counts	[3]
7	Egypt	Alexandria	1842	1843	plague	monthly	gregorian	table	counts	[3]
8	Egypt	Alexandria	1842		plague	monthly	gregorian	table	counts	[3]
9	Algeria	Algiers	1817	1819	plague	daily	gregorian	table	counts	[4] ([5])
10	Algeria	Algiers	1821		plague	daily	gregorian	table	counts	[4] ([5])
11	Algeria	Algiers	1822		plague	daily	gregorian	table	counts	[4] ([5])
12	Italy	Arezzo	1390		all-cause	monthly	julian	graph	counts	[6]
13	Denmark	Asminderød	1711		all-cause	weekly	gregorian	graph	counts	[7]
14	Russia	Balga[2]	1710		plague	weekly	gregorian	table	counts	[8]
15	Spain	Barcelona	1457		plague	daily	julian	table	counts	[9], ([10])
16	Spain	Barcelona	1475	1476	plague	daily	julian	table	counts	[9], ([10])
17	Spain	Barcelona	1483		plague	daily	julian	table	counts	[9], ([10])
18	Spain	Barcelona	1489	1490	plague	daily	julian	table	counts	[9], ([10])
19	Spain	Barcelona	1494		plague	daily	julian	table	counts	[9], ([10])
20	Spain	Barcelona	1501		plague	daily	julian	table	counts	[9], ([10])
21	Spain	Barcelona	1515		plague	daily	julian	table	counts	[9], ([10])
22	Spain	Barcelona	1520		plague	daily	julian	table	counts	[9], ([10])
23	Spain	Barcelona	1530		plague	daily	julian	table	counts	[9], ([10])
24	Spain	Barcelona	1558		plague	daily	julian	table	counts	[9], ([10])
25	Spain	Barcelona[3]	1589		plague	daily	gregorian	table	counts	[9], ([10])
26	Denmark	Birkerød	1711		all-cause	weekly	gregorian	graph	counts	[7]
27	UK	Bishops Castle	1593		plague	monthly	julian	graph	counts	[11]
28	Germany	Bremen	1713		plague	monthly	gregorian	graph	counts	[7]
29	Denmark	Brønshøj	1711		all-cause	weekly	gregorian	graph	counts	[7]
30	Czech Republic	Broumov	1632	1635	plague	monthly	gregorian	table	counts	[12]
31	Egypt	Cairo	1801		all-cause	daily	gregorian	table	counts	[13]
32	Egypt	Cairo	1835		plague	daily	gregorian	table	counts	[14]
33	UK	Chester[2]	1604	1604	plague	monthly	gregorian	graph	counts	[15]
34	UK	Chesterfield	1586	1587	all-cause	monthly	julian	graph	counts	[11]
35	UK	Colchester[3]	1665	1666	plague	weekly	julian	graph	counts	[11]
36	France	Condé-sur-Noireau	1626	1627	plague	monthly	gregorian	table	counts	[16]
37	Denmark	Copenhagen	1711		all-cause	weekly	gregorian	graph	counts	[7]
38	Hungary	Debrecen	1739	1740	plague	daily	gregorian	table	counts	[17]
39	Denmark	Ejby	1711		all-cause	weekly	gregorian	graph	counts	[7]
40	Denmark	Esbønderup	1711		all-cause	weekly	gregorian	graph	counts	[7]
41	UK	Eyam	1665	1666	plague	daily	julian	table	counts	[18]

42	Italy	Florence	1400		all-cause	daily	julian	graph	counts	[19]
43	Italy	Florence	1424[4]		plague	daily	julian	graph	proportion	[19]
44	Italy	Florence	1430[4]		plague	daily	julian	graph	proportion	[19]
45	Italy	Florence	1450[4]		plague	daily	julian	graph	proportion	[19]
46	Italy	Florence	1456[4]	1457	plague	daily	julian	graph	proportion	[19]
47	Germany	Freiberg	1613	1614	plague	biweekly	gregorian	graph	counts	[20]
48	Poland	Gdansk	1709		all-cause	weekly	gregorian	graph	counts	[7]
49	France	Givry	1348		all-cause	daily	julian	table	counts	[21]
50	Germany	Halberstadt	1681	1682	all-cause	monthly	gregorian	table	counts	[22]
51	Germany	Halle	1682		all-cause	monthly	gregorian	table	counts	[22]
52	Denmark	Helsingør	1711		all-cause	weekly	gregorian	graph	counts	[7]
53	Denmark	Herfølge	1711		all-cause	weekly	gregorian	graph	counts	[7]
54	UK	Ipswich	1665	1666	plague	monthly	julian	graph	counts	[11]
55	Russia	Kaliningrad	1620		all-cause	weekly	gregorian	table	counts	[8]
56	Russia	Kaliningrad	1709	1710	all-cause	weekly	gregorian	table	counts	[8]
57	Denmark	Kildebrønde	1711		all-cause	weekly	gregorian	graph	counts	[7]
58	Lithuania	Klaipeda[2,3]	1710		plague	weekly	gregorian	table	counts	[8]
59	Denmark	Køge	1711		all-cause	weekly	gregorian	graph	counts	[7]
60	France	Le Tourneur	1635		plague	monthly	gregorian	table	counts	[16]
61	Denmark	Ledøje	1711		all-cause	weekly	gregorian	graph	counts	[7]
62	UK	Leeds[3]	1645		plague	weekly	julian	table	counts	[23]
63	Netherlands	Leiden	1624	1625	all-cause	daily	gregorian	table	counts	[24]
64	Netherlands	Leiden	1635		all-cause	daily	gregorian	table	counts	[24]
65	Netherlands	Leiden	1655		all-cause	daily	gregorian	table	counts	[24]
66	Netherlands	Leiden	1664		all-cause	daily	gregorian	table	counts	[24]
67	Portugal	Lisbon	1569		plague	monthly	gregorian	graph	proportion	[25]
68	Portugal	Lisbon	1579	1580	plague	monthly	gregorian	graph	proportion	[25]
69	UK	London	1563	1564	plague	weekly	julian	table	counts	[26], ([27])
70	UK	London	1578	1582	plague	weekly	julian	table	counts	[26], ([27])
71	UK	London	1593		plague	weekly	julian	table	counts	[28], ([27])
72	UK	London	1603		plague	weekly	julian	table	counts	[26], ([27])
73	UK	London	1605	1610	plague	weekly	julian	table	counts	[28], ([27])
74	UK	London	1625	1626	plague	weekly	julian	table	counts	[28], ([27])
75	UK	London	1630		plague	weekly	julian	table	counts	[28], ([27])
76	UK	London	1636	1637	plague	weekly	julian	table	counts	[28], ([27])
77	UK	London	1639	1647	plague	weekly	julian	table	counts	[28], ([27])
78	UK	London	1665		plague	weekly	julian	table	counts	[28], ([27])
79	UK	Ludlow	1609		plague	monthly	julian	graph	counts	[11]
80	Spain	Madrid	1599		plague	weekly	gregorian	graph	counts	[29]
81	Germany	Magdeburg	1681		all-cause	monthly	gregorian	table	counts	[22]
82	Malta	Malta	1813		plague	daily	gregorian	table	counts	[30]
83	Switzerland	Malters	1628	1630	all-cause	monthly	gregorian	graph	counts	[31]
84	UK	Manchester	1605		all-cause	daily	julian	table	counts	[32]
85	UK	Manchester	1645		all-cause	monthly	julian	graph	counts	[33]
86	Russia	Moscow	1771		all-cause	daily	julian	graph	counts	[34]
87	Germany	Mühlhausen	1683		all-cause	monthly	gregorian	table	counts	[22]
88	Denmark	Nakskov	1619	1620	all-cause	monthly	julian	graph	counts	[35]
89	UK	Newcastle	1636		plague	weekly	julian	table	counts	[36]

90	Estonia	Noarootsi	1710	1711	all-cause	weekly	gregorian	graph	counts	[7]
91	Italy	Nonantola	1630		all-cause	weekly	gregorian	graph	counts	[37]
92	Germany	Nordhausen	1682	1683	all-cause	monthly	gregorian	table	counts	[22]
93	UK	Norwich	1603	1604	plague	monthly	gregorian	graph	counts	[38]
94	UK	Norwich	1666		plague	weekly	julian	table	counts	[39]
95	Ukraine	Odessa	1812		plague	monthly	julian	table	counts	[40]
96	UK	Oswestry	1559	1560	plague	monthly	julian	graph	counts	[11]
97	Italy	Parma	1630		all-cause	monthly	gregorian	table	counts	[41]
98	UK	Penrith	1597	1598	plague	monthly	gregorian	graph	counts	[15]
99	Poland	Pisz[2]	1710		plague	weekly	gregorian	table	counts	[8]
100	Czech Republic	Prague[3]	1680	1681	plague	weekly	gregorian	table	counts	[42]
101	Czech Republic	Prague[3]	1713	1714	plague	daily	gregorian	table	counts	[43]
102	UK	Preston	1630	1631	all-cause	monthly	julian	graph	counts	[11]
103	Estonia	Reval	1710		all-cause	monthly	gregorian	graph	counts	[7]
104	Denmark	Roskilde	1711		all-cause	weekly	gregorian	graph	counts	[7]
105	France	Rouen	1668		plague	monthly	gregorian	table	counts	[16]
106	UK	Ruthin	1349		plague	monthly	julian	graph	counts	[11]
107	UK	Shrewsbury	1650	1651	plague	monthly	julian	graph	counts	[11]
108	Germany	Stade	1712		plague	weekly	gregorian	graph	counts	[7]
109	Sweden	Stockholm	1710	1711	all-cause	weekly	gregorian	graph	counts	[7]
110	Denmark	Store Magleby	1711		all-cause	weekly	gregorian	graph	counts	[7]
111	Denmark	Stralsund	1710	1711	all-cause	monthly	gregorian	graph	counts	[7]
112	UK	Stratford-upon-Avon	1564	1565	all-cause	monthly	gregorian	graph	counts	[15]
113	Denmark	Tårnby	1711		all-cause	weekly	gregorian	graph	counts	[7]
114	Denmark	Tikøb	1711		all-cause	weekly	gregorian	graph	counts	[7]
115	Lithuania	Tilsit[3]	1710		plague	weekly	gregorian	table	counts	[8]
116	UK	Totnes	1570		plague	monthly	julian	graph	counts	[11]
117	UK	Totnes	1590		plague	monthly	julian	table	counts	[26]
118	Germany	Uelzen	1566		all-cause	weekly	julian	graph	counts	[44]
119	Germany	Uelzen	1597		all-cause	weekly	gregorian	graph	counts	[44]
120	Germany	Uelzen	1626		all-cause	weekly	gregorian	graph	counts	[44]
121	Germany	Uelzen	1627		all-cause	weekly	gregorian	graph	counts	[44]
122	Spain	Valladolid[3]	1599		plague	weekly	gregorian	graph	counts	[29]
123	Russia	Vetlyanka	1878	1879	plague	daily	julian	graph	counts	[45]
124	Spain	Vic	1361	1362	all-cause	monthly	julian	table	counts	[46]
125	Spain	Vic	1371		all-cause	monthly	julian	table	counts	[46]
126	Austria	Vienna	1653	1656	plague	monthly	gregorian	table	counts	[47], ([48])
127	Austria	Vienna	1679		all-cause	monthly	gregorian	table	counts	[49], ([48])
128	Poland	Warsaw	1708		all-cause	weekly	gregorian	graph	counts	[7]
129	UK	Whitchurch	1650	1651	plague	monthly	julian	graph	counts	[11]
130	Poland	Zalewo[2]	1710		plague	monthly	gregorian	table	counts	[8]

1 some days in April 1835 in the original data seem to lack the 100 digit, which has been added in our data set

2 the number for the population size was approximated as the number of hearths/households given in the reference times six persons per household

3 incomplete epidemiological curve (beginning and/or end missing)

4 The y-axis of the original graph indicates number of daily deaths, but the occurrence of numbers smaller than one suggest that the data were interpolated. We therefore converted the curve to proportions

Fig. S1. Epidemiological curves from plague mortality data (red bars) and all-cause mortality data (blue bars).

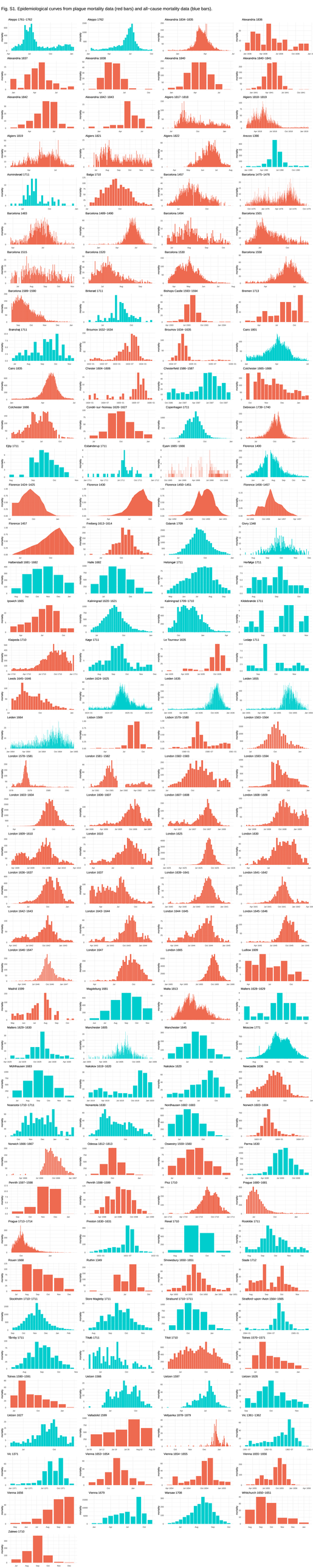


Fig. S2. Time series of normalized weekly plague deaths ordered by latitude (y-axis). The graph shows that the epidemic activity is shifted towards the end of the year for increasing latitude and that the seasonal pattern within the same location is quite constant (see for example London, Florence or Barcelona).

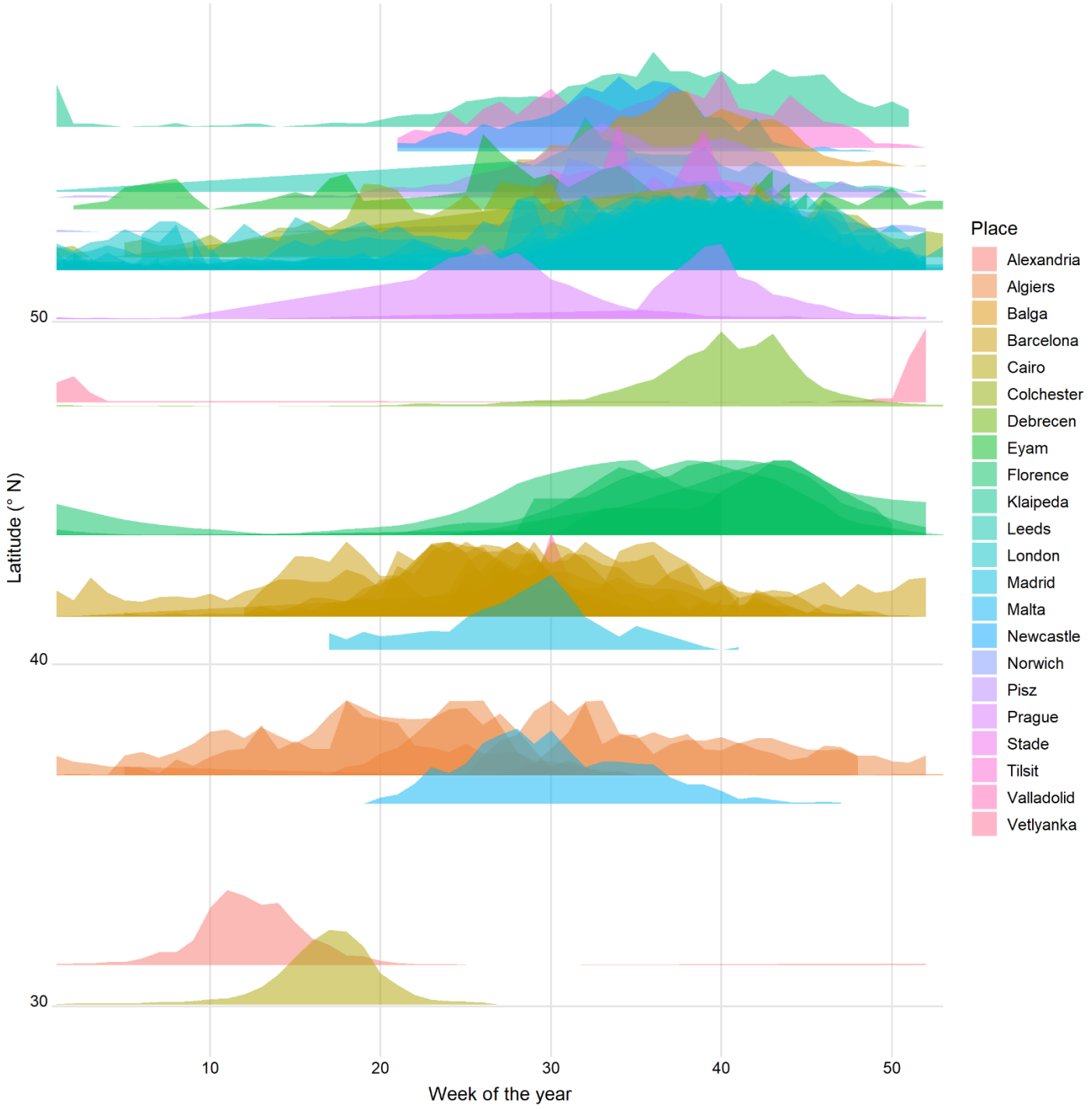


Fig. S3. Results of the sensitivity analysis on the association between annual mean temperature and epidemic peak timing using different datasets: A monthly plague data, B weekly plague and all-cause mortality data during plague outbreaks, C monthly plague and all-cause mortality data during plague outbreaks and D weekly plague deaths from outbreaks with at least 100 deaths at peak. The line and the shaded areas represent the fit and 95% CI.

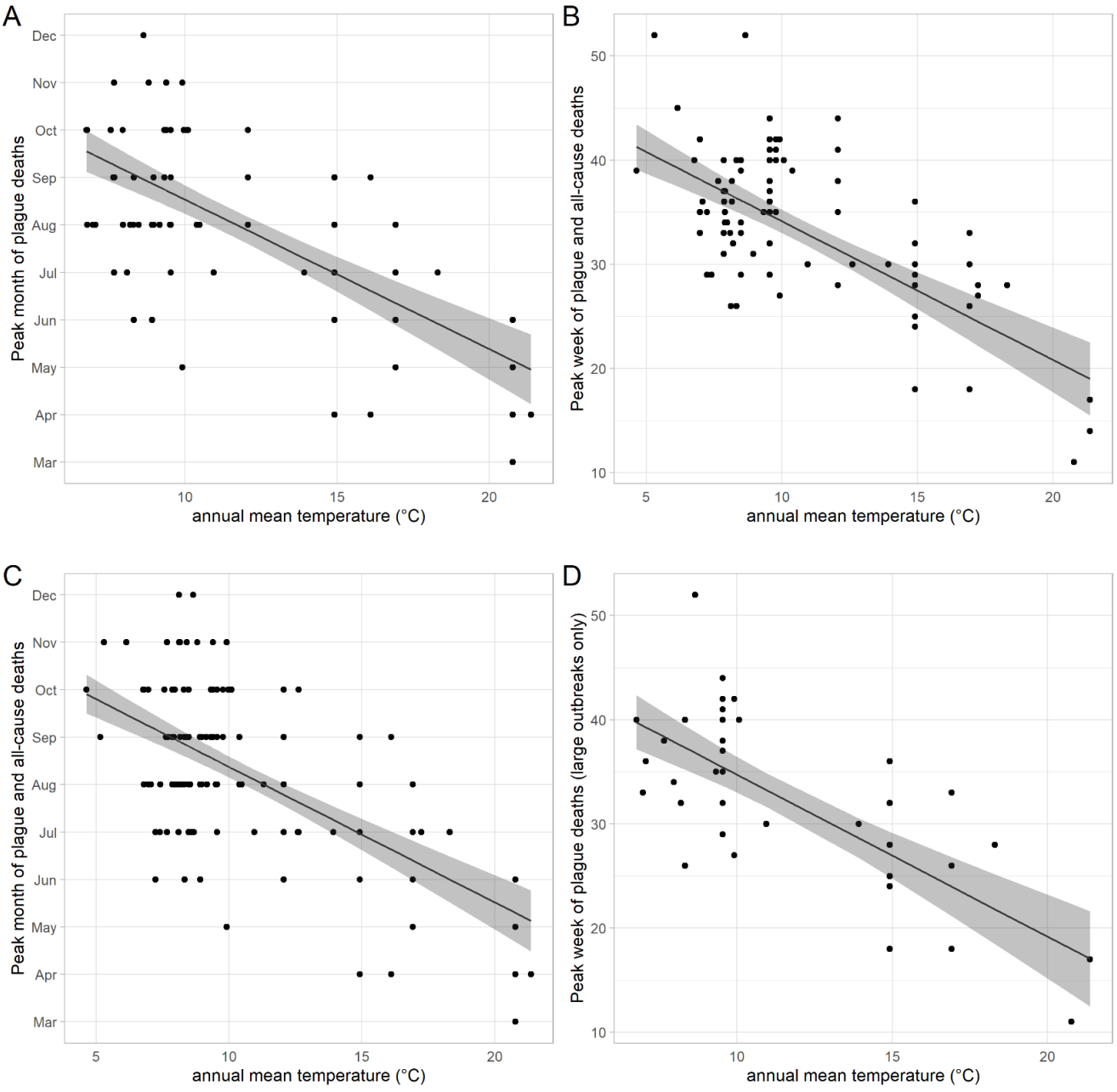


Fig. S4. Epidemiological curves and the corresponding time−varying growth rates. The dark grey bars represent the incident plague mortality, the light grey bars represent the incident plague cases calculated from the mortality data. The red line and pink ribbon are the mean estimate and 95% CI for the time−varying epidemic growth rate calculate based on the incident case data (right y−axis). Values below 0 indicate no growth (i.e. a decline of the epidemic). The values on the right y−axis represent the daily growth rate.

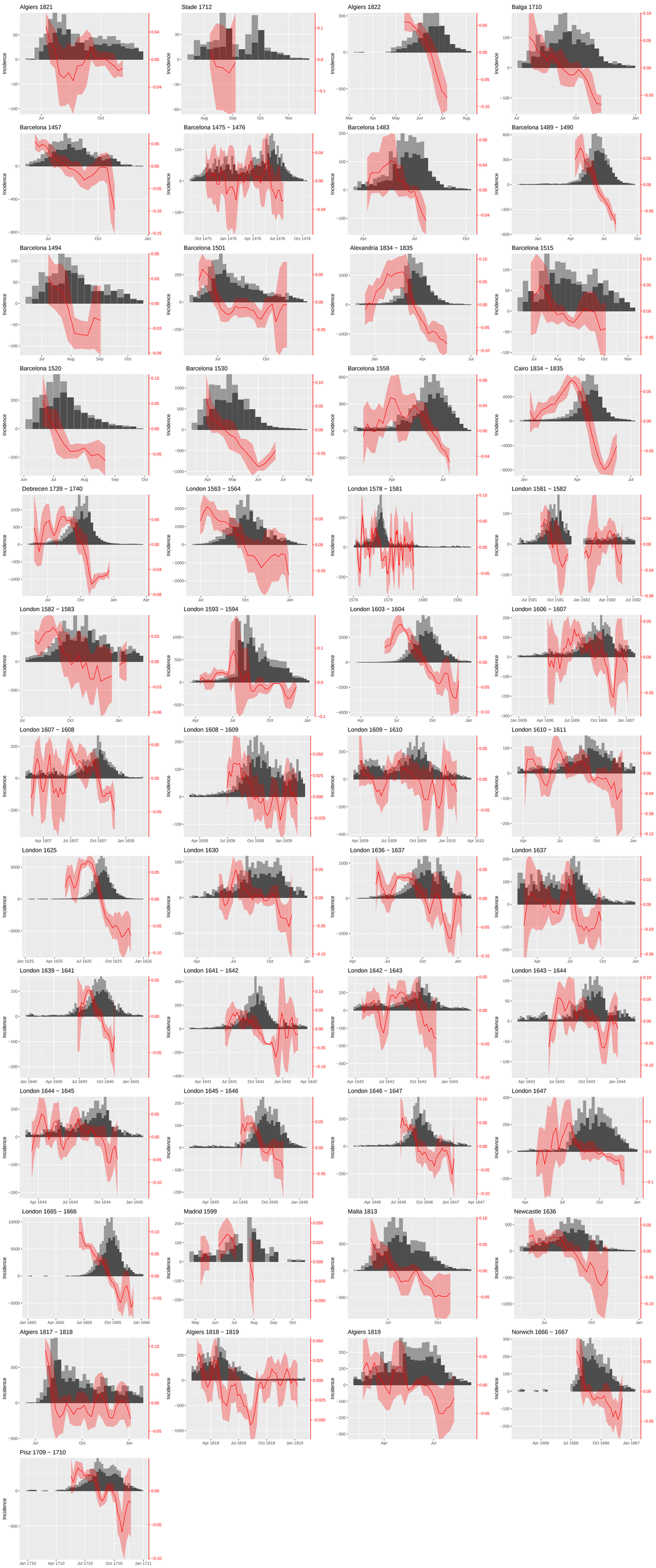


Fig. S5. Additional results for the GAM models of the time-varying growth rates as a function of meteorological factors. The red line and pink ribbon is the mean and 95% CI of the model prediction. A) The association of growth rates with temperature based on weekly plague data but excluding data from London was less strong than with the full dataset, but a unimodal relationship is still observable. B) The association of growth rates with precipitation based on the full data set suggested a weak non-linear relationship between precipitation and growth. C) When we fit the model without the data points from London, we observed a very weak association with a small increase in transmission at around 60 mm precipitation, but the proportion of variance explained was very low (0.05).

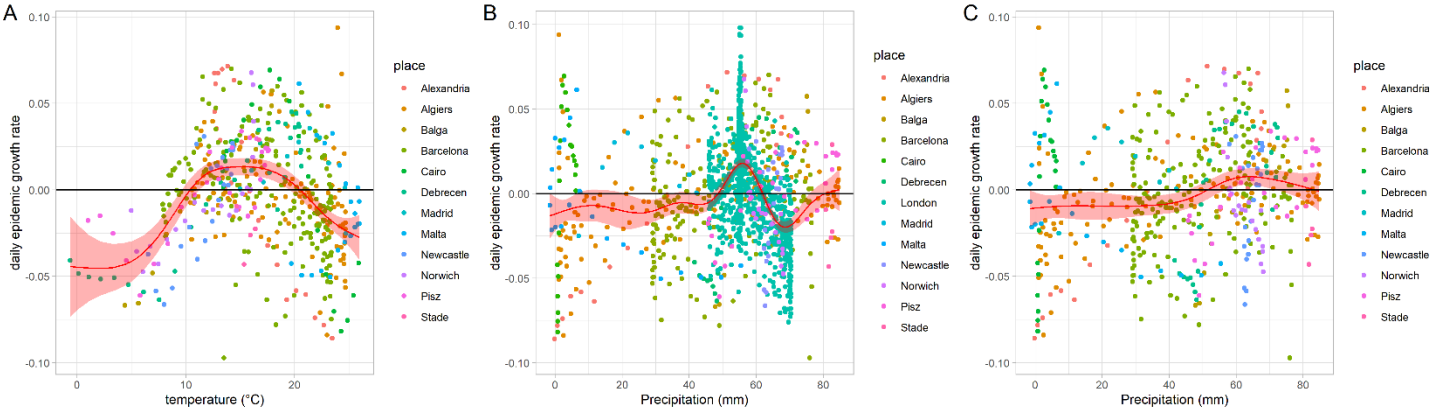


Fig. S6: Distribution of lead and lag times between the time point of the epidemic peaks and the end of the phase with predicted, positive growth. The majority of the peaks occurred towards the end of the positive growth phase suggesting that some outbreaks stopped because the climatic conditions became unfavourable for transmission. The black line is the kernel density estimation.

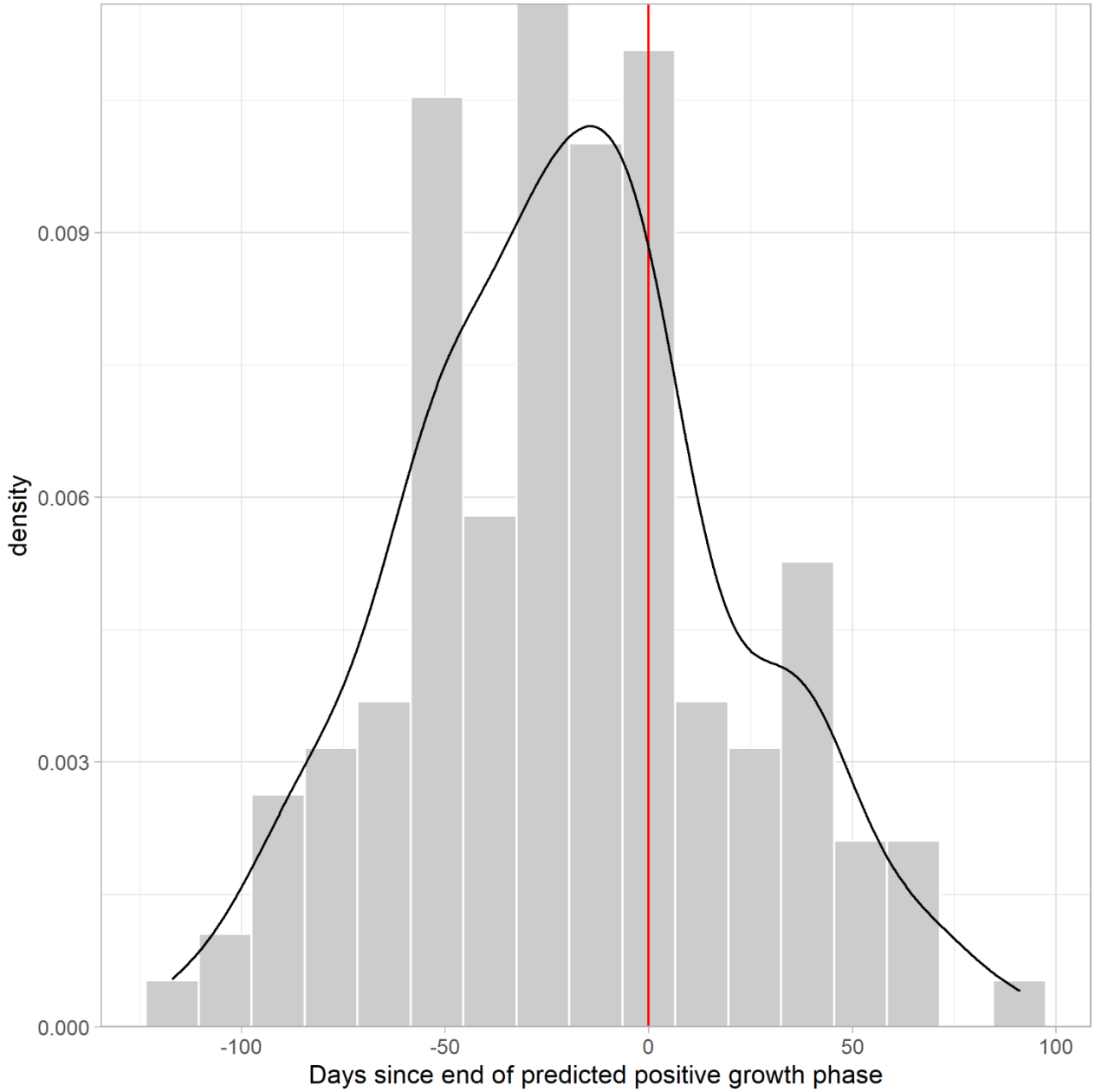
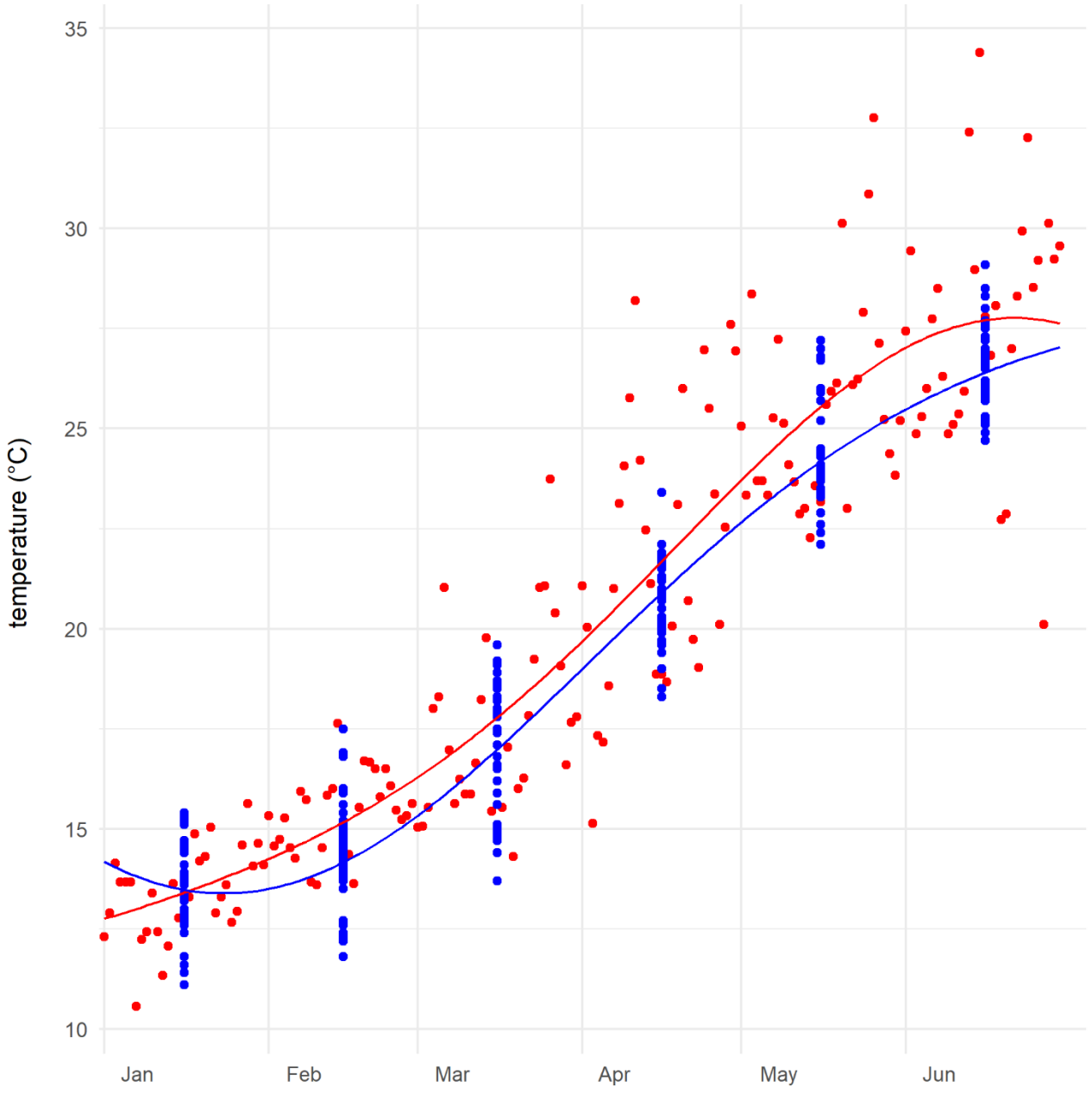


Fig. S7: Difference between daily averaged historical temperature (red dots) and the corresponding fit (red line) recorded during the plague outbreak in 1835 and the monthly averaged temperature measurements (blue dots) and the corresponding fit (blue) for the CRU time series data (1901-1939).



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