DAILY WEATHER MAPPING FROM 1781:

*A Detailed Synoptic Examination of Weather and Climate during the Decade leading up to the French Revolution**

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> Sure there is need of social intercourse,
> Benevolence and peace and mutual aid
> Between the nations, in a world that seems
> To toll the death-bell of its own decease,
> And by the voice of all its elements
> To preach the gen'ral doom. When were the winds
> Let slip with such a warrant to destroy,
> When did the waves so haughtily o'erleap
> Their ancient barriers, deluging the dry?
> Fires from beneath, and meteors from above
> Portentous, unexampled, unexplained,
> Have kindled beacons in the skies and th' old
> And crazy earth has had her shaking fits
> More frequent, and forgone her usual rest.
> Is it a time to wrangle, when the props
> And pillars of our planet seem to fail,
> And Nature with a dim and sickly eye
> To wait the close of all?
>
> William Cowper *The Time-Piece,* Book II, *The Task.*
>
> Written in 1783 and 1784 at Olney, Buckinghamshire (Spiller, 1968).

Abstract. An account is given of the preparation of daily weather maps within the historical-instrumental period, with details concerning the detection and location of source material and its subsequent examination, collection and reduction to provide a workable synoptic network of comparable meteorological observations over the eastern North Atlantic-European sector.

The application of the Lamb British Isles weather types and *Grosswetterlagen* for the statistical analysis of circulation patterns derived from these charts is discussed.

An objective test was devised whereby the frequency of monthly extremes of nine variables was examined with the following important conclusions:

i. the synoptic charts of the 1780s show no evidence of systematic errors when compared with rainfall figures,

ii. the early 1780s was a period of unusually high climatic variability on the

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*The text of this article is based on a paper presented at the International Conference on Climate and History held at the University of East Anglia, Norwich, England 8–14 July 1979.

Climatic Change 3 (1980) 7–36. 0165–0009/80/0031–0007$03.00.

month-to-month time-scale, especially in the frequencies of cyclonic and of anticyclonic days.

An account is given of the impact of climate on the affairs of man in the 1780s, highlighting some specific historical case studies and discussing agriculture and industry in general.

1. Introduction

What are the main differences between the construction of a present-day weather map and one for the latter part of the 18th century?

The answer to this question lies in the manner of the collection and analysis of the data. Today, the meteorologist receives his information almost immediately from a network of observation stations by radio and telegraphic links. In the 18th century, meteorological observations were being made, but the means to transmit the information quickly to a collecting centre and then to analyse the data in a meaningful way were lacking. These two developments were to come later following the invention of the electromagnetic telegraph and the introduction of isobaric analysis relating wind flow to the pressure pattern. Working with hindsight from the 20th century, the full potential of the meteorological observations that were being made in the latter part of the 18th century can now be realised.

This period lies between that of the modern era with meteorological analysis and climatological study based on standardised instrumental observations, and the era of historical and prehistoric climatology in which the reconstruction of past climate patterns has to be based on the interpretation of many different types of field and documentary evidence (Ingram *et al.*, 1979). Situated at such a significant juncture in the history of meteorology and climatology the project presents the opportunity to put into operation a two-way approach of ideas, methods and objectives which are common to the study of both eras.

The daily synoptic charts described in this paper are the earliest such charts available which are based on quantitative instrumental data and which are directly comparable with modern charts. Earlier maps of daily *circulation patterns* have been prepared for the summer of 1588 in a study of weather conditions during the voyage of the Spanish Armada (Douglas *et al.*, 1978 and 1979): but these maps are not based on instrumental data and so form a distinctly different genre of weather reconstructions.

2. Daily Weather Mapping in the Historical-Instrumental Period

The historical-instrumental period falls between two important advances in the history of meteorology: the invention of the thermometer and barometer in the late 16th and early 17th centuries and the establishment of telegraphic weather networks in the 1850s. The first of these breakthroughs allowed the two basic meteorological elements, temperature and pressure, to be observed and quantified, and the second made it possible to communicate data from a network of stations to a central office quickly enough to prepare

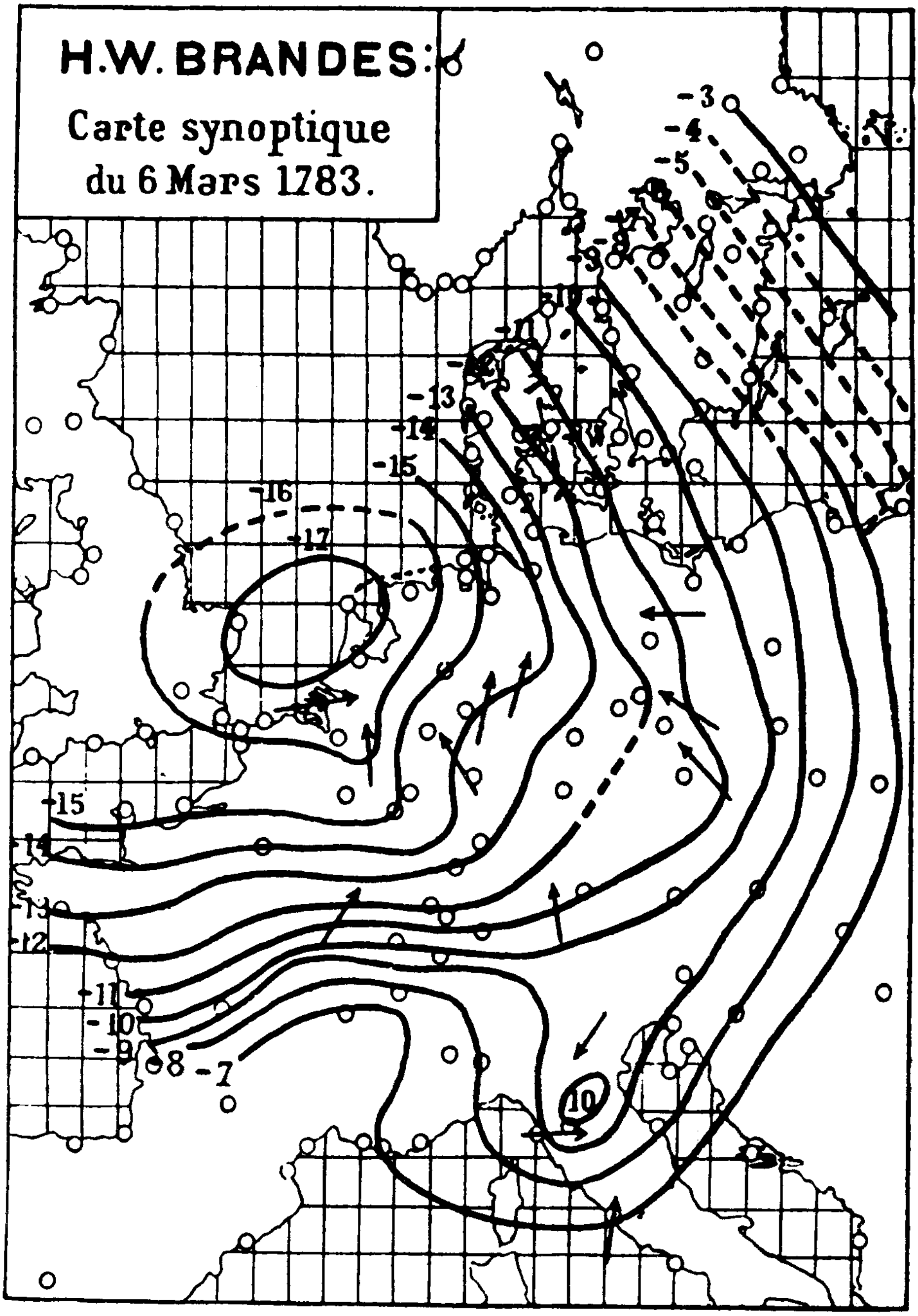


Fig. 1. Synoptic weather map for 6 March 1783 by H. W. Brandes, reconstructed by H. Hildebrandsson. Surface wind direction is shown by arrows and the distribution of pressure by isopleths of equal departure of pressure from normal (e.g. –17, –16, –15 etc.); by overcoming the uncertainty about the height at which the barometer readings were made, the observations were successfully combined to allow the equivalent of isobars to be drawn at a constant level (from Ludlam, 1966).

'current' weather charts for forecast purposes, which was the beginning of modern synoptic meteorology.

The development of instruments and their exposure, so as to obtain representative readings, was actively pursued during the second half of the 17th century and early 18th century, together with attempts to establish networks of meteorological observing stations, so that by the end of the 18th century, both instruments and station networks were sufficiently developed to provide a scientific basis for reconstruction and analysis of the weather situation.

It is known that in 1820 the German meteorologist, H. W. Brandes, had attempted to construct weather maps using observations made in the 1780s and, although his charts have not survived, sample reconstructions were made by the Swedish meteorologist, H. Hildebrandsson, towards the end of the 19th century (see Figure 1).

Following signs in the 1950s that weather and climatic patterns were beginning to behave differently from those of earlier decades in the 20th century, it is not surprising that, in the mid-1960s, the idea of constructing a series of daily historical weather maps to extend investigations of circulation patterns back beyond 100 years should have been reconsidered. It was decided to commence this historical series of charts with the 1780s, not only from the practical consideration that reasonably adequate sources of meteorological data were known to exist from that time onwards, but also because evidence derived from previous investigations appeared to indicate that the climate of the latter part of the 18th century had been notable for some interesting anomalies.

3. Sources of Historical Weather Data

In the 1780s many people in the British Isles, Europe and North America were keeping diaries and journals. The desire to observe and record the experience of daily life seems to have been universal amongst eighteenth-century gentlefolk. Events from many fields of interest were being recorded and the entries often contain information about the weather, ranging from an occasional comment concerning a particularly dramatic atmospheric phenomenon to fully detailed and carefully kept daily records maintained by serious observers of the atmosphere.

The search to find order and regularity in the workings of the natural environment was a characteristic feature of the intellectual climate of the age. It had begun earlier with the pioneering efforts of John Ray (1627–1705) and Carl von Linné (1707–1778) to classify flora and fauna. However, it was during the latter part of the 18th century that natural history became more intensively and widely studied by an increasing number of enthusiasts. Although the vagaries of the weather had been watched from earliest times by country folk and mariners, they were now being more methodically observed and studied in the new light of natural history. Great enthusiasm and conscientiousness were being shown in keeping meteorological registers; daily readings of pressure, temperature, wind and rain as well as descriptive comments about the state of the sky and significant weather were being made at a large number of locations during the second half of the 18th century. On the European Continent observational networks were being organised by scientific

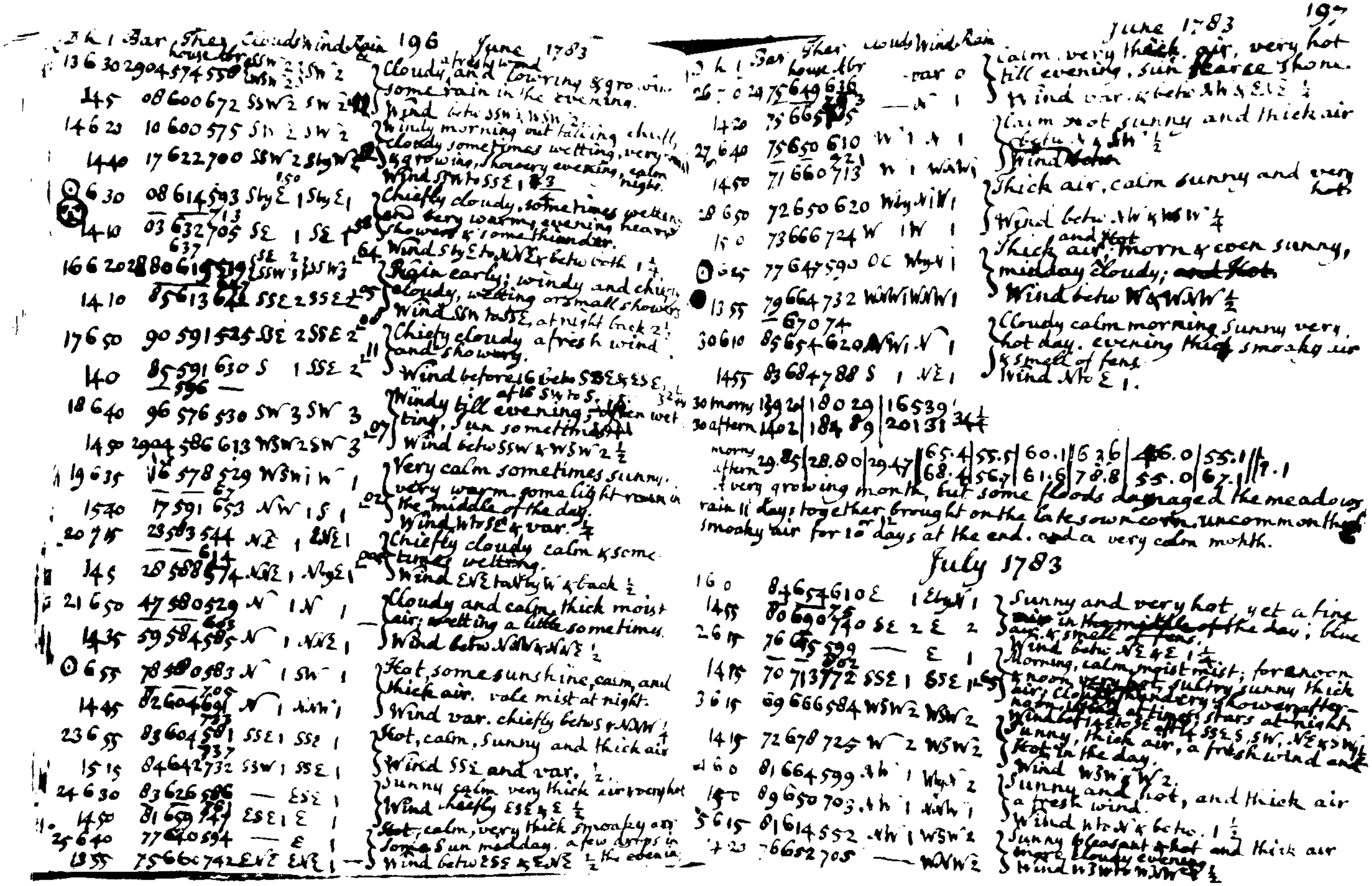


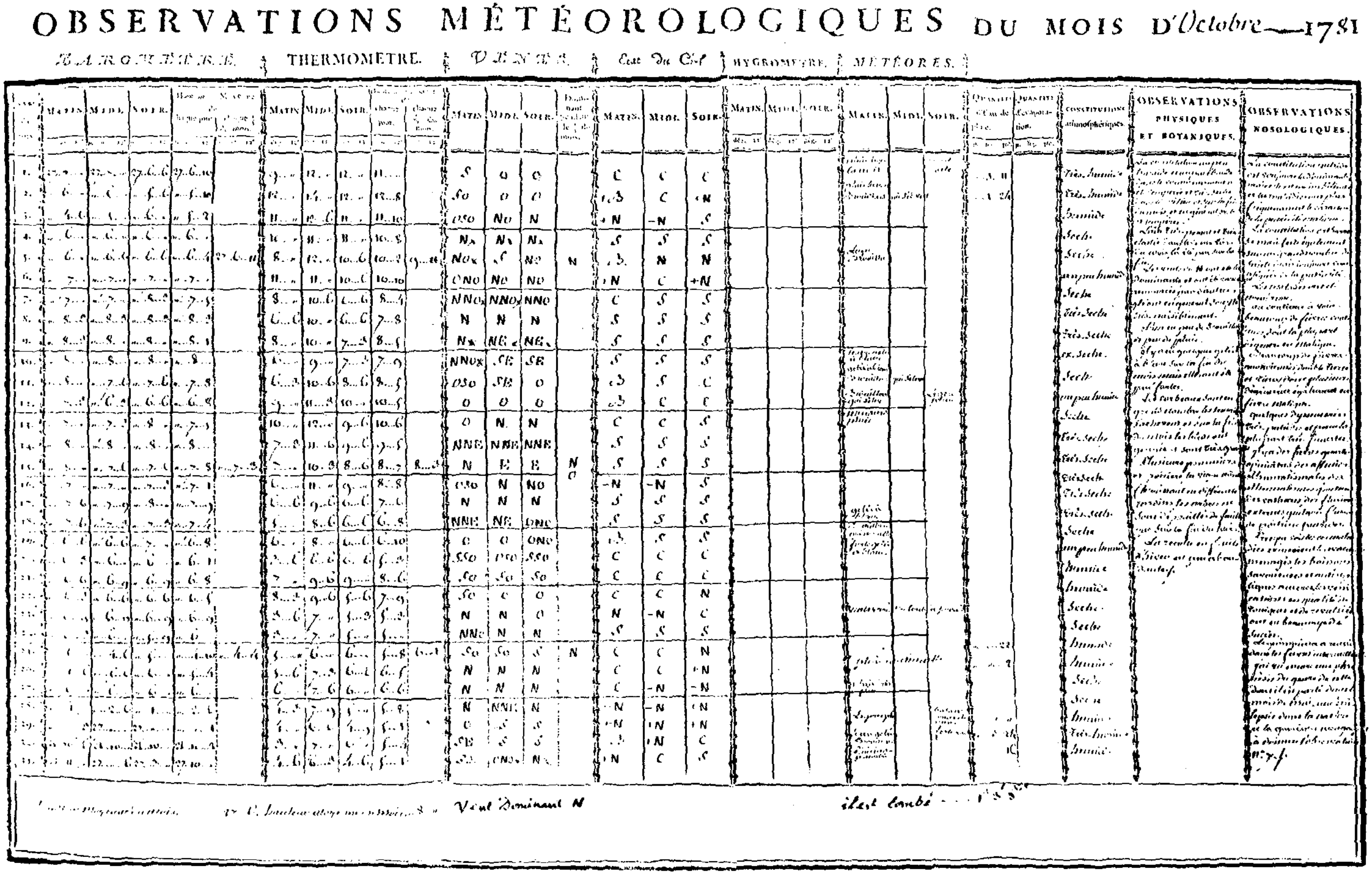
Fig. 2. Extract from the meteorological register kept at Lyndon Hall, Rutland by Thomas Barker for June and July 1783. The two pages illustrated from this manuscript record show daily observations made at about 0700h and 1400h of pressure in English inches and hundredths, temperatures in degrees Fahrenheit (interior and exterior thermometers), cloud velocity, wind velocity, rain, state of sky and significant weather.

societies that became established in France, Germany and Scandinavia and will be discussed in more detail later. In Britain, more individualistic efforts were being made by a dedicated group of amateurs mostly comprising physicians, parsons and country squires. These people sometimes corresponded with one another about their interests in meteorology and natural history, the Royal Society, London providing a centre for the more formal discussion and exchange of ideas. In fact, the efforts of Dr. James Jurin, Secretary of the Royal Society, to establish a network of meteorological stations in the 1720s had probably not been forgotten, and by the 1780s comparable methods of recording standard weather elements at specific times every day were being followed at several places in the British Isles. One of the best of these amateur eighteenth-century weather observers was Thomas Barker, a country squire of Lyndon Hall in Rutland, who began over sixty years of daily observations in 1733 (see Figure 2). Barker married one of the sisters of the famous naturalist Gilbert White, of Selborne, Hampshire, who himself kept a detailed meteorological register in his later years.

Logbooks kept on board British naval vessels and East Indiamen provide another useful source of daily weather observations around the coasts of the British Isles and over the Atlantic Ocean (Oliver and Kington, 1970).

Returning to the European Continent, concerted efforts in making and collecting meteorological observations were being made on an increasingly ambitious scale in the latter part of the 18th century. Following the lead of the Dutch physician Hermann Boerhaave (1668–1738), the medical profession throughout the 18th century became interested in the possibility of a relationship between weather and diseases. In 1778 the *Société Royale de Médecine* was set up in France under the patronage of Louis XVI to maintain detailed and regular correspondence on medical and meteorological matters with doctors throughout the kingdom. Vicq d'Azyr was appointed secretary-general and the French meteorologist Louis Cotte (1740–1815) was actively involved with establishing and maintaining an extensive network of observing stations for the Society. Detailed instructions were issued on instrumental operation and exposure and observational procedure, with the request that standardised observations of pressure, temperature, wind, humidity, rainfall, evaporation, state of sky and significant weather should be made three times a day at specified times. The correspondents of the Society were also issued with specially printed forms for recording the daily observations during each month (see Figure 3); these forms were sent at regular intervals to Paris for perusal and analysis. By 1784 the network comprised over 70 stations and had been extended beyond France to include correspondents in Holland, Germany, Austria, New York and Baghdad (Kington, 1970).

Mannheim, the capital of the Palatinate of the Rhine, developed into an influential centre of the arts and sciences during the 18th century under its Elector Karl Theodor. In 1780 he founded the *Societas Meteorologica Palatina* with Johann Hemmer as its director. Standardised instruments were supplied to correspondents of the Society with instructions on instrumental operation and observational procedure. Like the *Société Royale de Médicine*, correspondents were requested to make full meteorological observations thrice daily, preferably at 0700h, 1400h and 2100h. Observational records were



OBSERVATIONS MÉTÉOROLOGIQUES DU MOIS D'Octobre—1781

BAROMETRE. THERMOMETRE. VENTS. Etat du Ciel HYGROMETRE. METÉORES.

OBSERVATIONS PHYSIQUES ET BOTANIQUES. OBSERVATIONS NOSOLOGIQUES.

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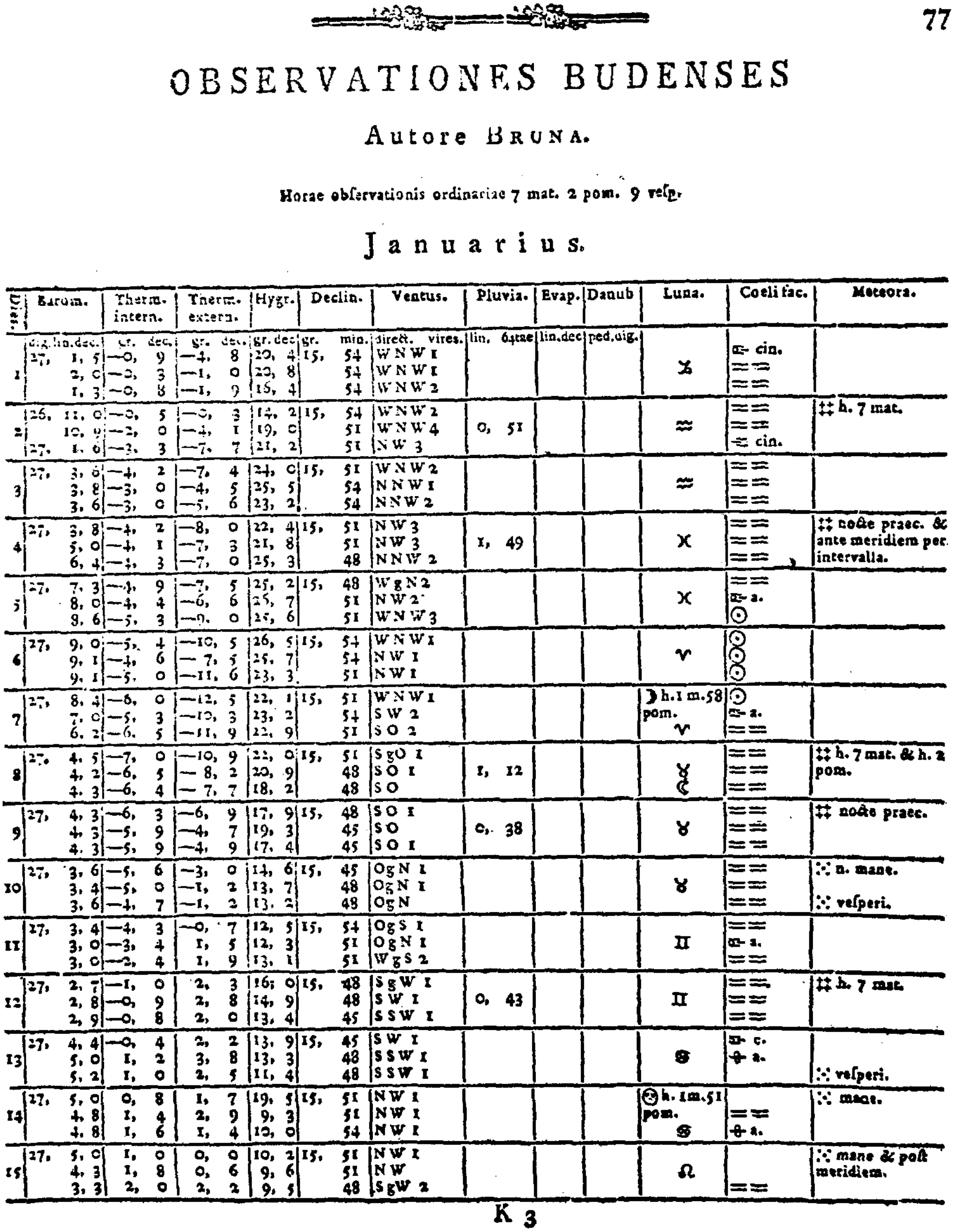
Fig. 3. Register of daily observations for October 1781 kept at Dijon, Burgundy by Dr. Maret for the *Société Royale de Médecine*. Thrice-daily readings are given of barometer (Paris inches, lines and twelfths), thermometer (degrees Réaumur), wind direction, state of sky and significant weather. Monthly summaries relating to the atmosphere, botany and diseases are also given.



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OBSERVATIONES BUDENSES

Autore BRUNA.

Horae obſervationis ordinariae 7 mat. 2 pom. 9 veſp.

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Dies.	Barom.	Therm. intern.	Therm. extern.	Hygr.	Declin.	Ventus.	Pluvia.	Evap.	Danub	Luna.	Coeli fac.	Meteora.
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Fig. 4. Extract from the Ephemerides of the *Societas Meteorologica Palatina*, showing daily observations made at Buda, Hungary by Francisca Bruna from 1 to 15 January 1786. The columns contain thrice-daily readings (0700h, 1400h and 2100h) of barometer (Paris inches, lines and tenths), interior and exterior thermometers (degrees Réaumur), hygrometer, magnetic declination, wind velocity, state of sky and significant weather. Rainfall and phases of the moon were also regularly recorded.

dispatched to Mannheim for collation and publication in the annual *Ephemerides* of the Society (see Figure 4). From the entries in these publications it can be seen that the Mannheim Meteorological Society was using a system of weather symbols which owed something of its origin to earlier schemes devised by Pieter van Musschenbroek (1692–1761) and Johann Heinrich Lambert (1728–1777); traces of it still survive in the present international synoptic weather code. From a nucleus of about a dozen stations, mostly located in central Europe at the beginning of 1781, the network spread extensively during the next five years to include over 50 observatories from Russia across Europe to Greenland and North America (Kington, 1974).

In Scandinavia and Iceland, instrumental meteorological observations had already been established from the earlier part of the 18th century. The observers in Scandinavia were mostly astronomers and mathematicians including Rømer, Celsius and Wargentin (Kington, 1972). By the 1780s, regular and standardised meteorological observations were being made at Stockholm, Copenhagen, Trondheim and Lambhús, near Reykjavik (see Figure 5).

4. Production of a Synoptic Network

The collection of data for these daily historical weather maps has involved searches and correspondence with libraries, archives, institutions and private individuals throughout the British Isles and Europe (Kington, 1975). The size of the task of processing the large volume of assorted data that this research has uncovered will be appreciated when it is realised that not only does one have to deal with material in several different languages, usually in handwritten form, but also with a variety of formats and units, all of which have to be reduced to present standards. Meteorological observations in the 18th century were not made according to agreed international standards as they are today. At stations in the British Isles, pressure was recorded in English inches and temperature in degrees Fahrenheit. On the Continent pressure was usually recorded in Paris inches and temperature in degrees Réaumur. There were however a few exceptions, for example: pressure in millimetres and temperature in degrees Celcius at Basel; pressure in Swedish decimal inches and temperature in degrees Celcius up to December 1782 at Stockholm and pressure in Viennese inches and temperature in degrees Celsius at Vienna. The results of this data collection and reduction have given a synoptic coverage for the area of the British Isles, western Europe and the eastern North Atlantic.

5. Statistical Analysis of Circulation Patterns – Synoptic and Historical Climatology

To date, six complete years of charts are available covering the years 1781–1786, together with some short sequences of specially prepared charts for separate case studies of events both before and after these years. How can these daily weather maps, amounting at present to over 2000 charts, best be used for statistical analysis and comparative studies with other climatic periods?

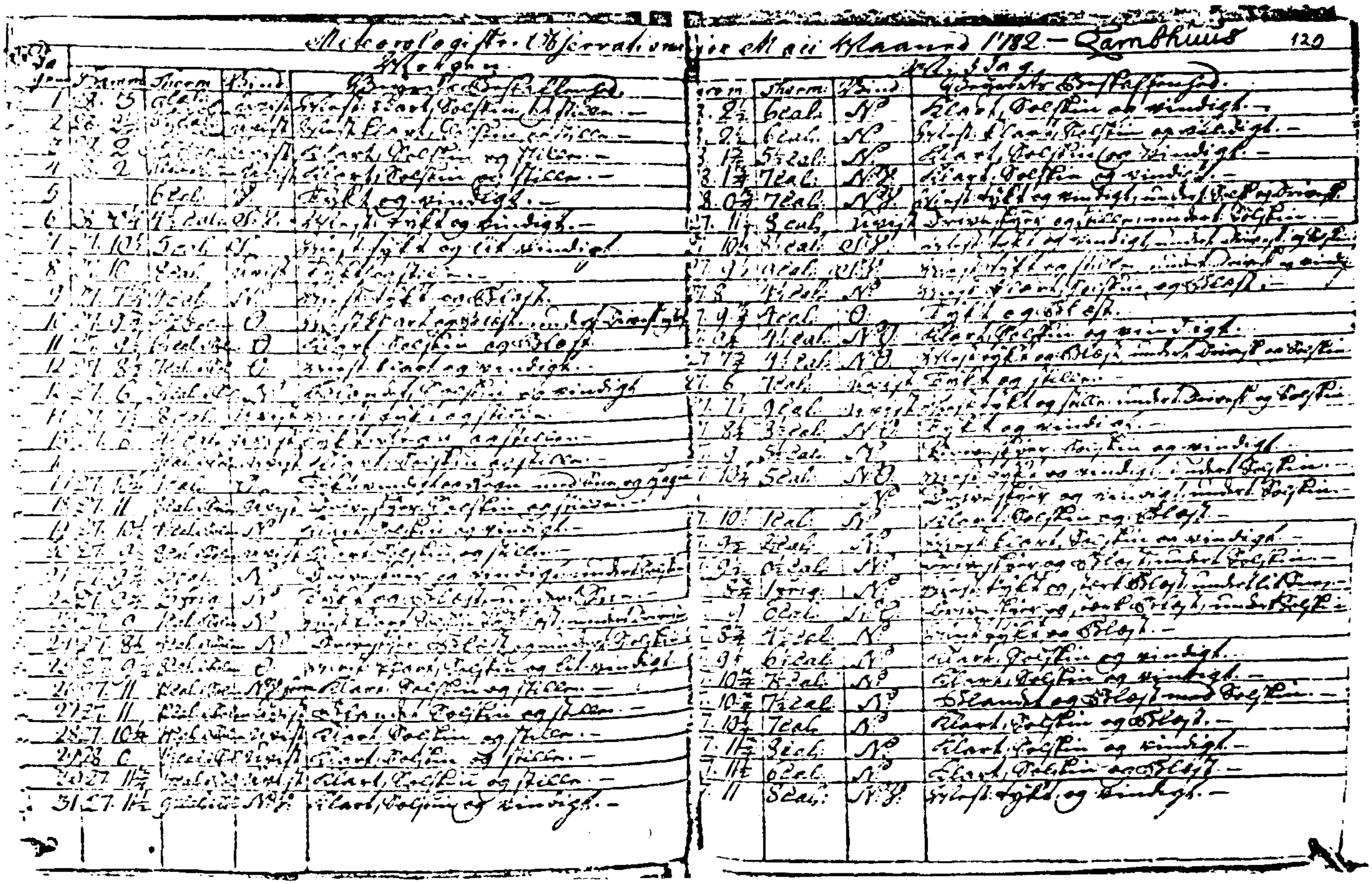

Fig. 5. Extract from the meterological register kept at Lambhús, Iceland by Rasmús Lievog in May 1782. The two pages illustrated from the manuscript record are of observations made in the morning (0600h) and at midday (1300h). The columns contain readings of barometer (Paris inches, lines and quarters or sixths), exterior thermometer (degrees Réaumur), wind direction, state of sky and significant weather. This last column also contains standard terms used by Danish observers to describe wind strength. (From Kington, 1972).

It is convenient to reduce the information in a weather-map series into a less unwieldy form by classifying the daily synoptic situations depicted on the charts according to the pressure and circulation patterns. For the area covered by the charts in question two methods of classification have been applied, namely, the Lamb British Isles weather types (Lamb, 1972) and the *Grosswetterlagen* (Baur, 1947; Hess and Brezowsky, 1969). The charts from 1781 have been classified according to both systems. The main difference in approach between these two methods is one of how the development and movement of weather patterns are regarded in both time and space. Both classifications are useful in providing information about the circulation patterns from different aspects for comparison and discussion.

From an examination of the frequencies of the Lamb British Isles weather types in 1781–1785 (see Table I), it has been found that the mean value of the westerly type, the type most closely linked to the well-known mild character of the climate of the British Isles, was 66 days per year, with only 45 days in 1785. This indicates a remarkably diminished frequency regime of this type when compared with the long-period average value of 93 days per year (1861–1969). During the period 1900–1950 the average value was about 100 days per year. However, since 1955 the frequency of the westerly type has again fallen; averaging 80 days per year in the 1960s and only 68 days per year in the five-year period 1968–1972. Apart from 1974, when it was 96 days, recent yearly values have continued at this diminished level up to and including 1979.

The classification of weather types and circulation patterns allows further synoptic-climatological studies to be made. For example, for some purposes it is desirable to have a ready indication of the general character of a month, season, year or period of years.

TABLE I: Lamb British Isles daily weather types: yearly and average frequencies 1781 – 1785; long-period averages and extremes, 1861–1978

	W	NW	N	E	S	A	C
			Number of days per year				
1781–1785							
1781	74.8*	28.0	19.2	37.7	29.8	91.0	77.5
1782	75.8	27.0	31.3	43.0	24.0	63.2	90.7
1783	75.5	13.0	21.5	24.5	35.5	98.8	84.2
1784	59.7	27.5	46.2	42.3	20.3	106.5	56.5
1785	45.0	32.5	35.5	30.2	30.2	97.7	80.0
Average	66.2	25.6	30.7	35.5	28.0	91.4	77.8
1861–1978							
Average	91.6	18.2	27.5	28.1	31.0	91.2	63.9
Highest value	128.7 (1923)	42.5 (1973)	48.8 (1919)	57.8 (1963)	54.2 (1924)	129.2 (1971)	100.0 (1872)
Lowest value	56.3 (1969)	5.0 (1911, 1960)	10.2 (1920)	9.7 (1967)	15.5 (1896)	38.2 (1872)	41.7 (1921)

*Decimal values arise because of allocating hybrids of two or three types to the seven basic weather types: Westerly (W), North-westerly (NW), Northerly (N), Easterly (E), Southerly (S), Anticyclonic (A) and Cyclonic (C).

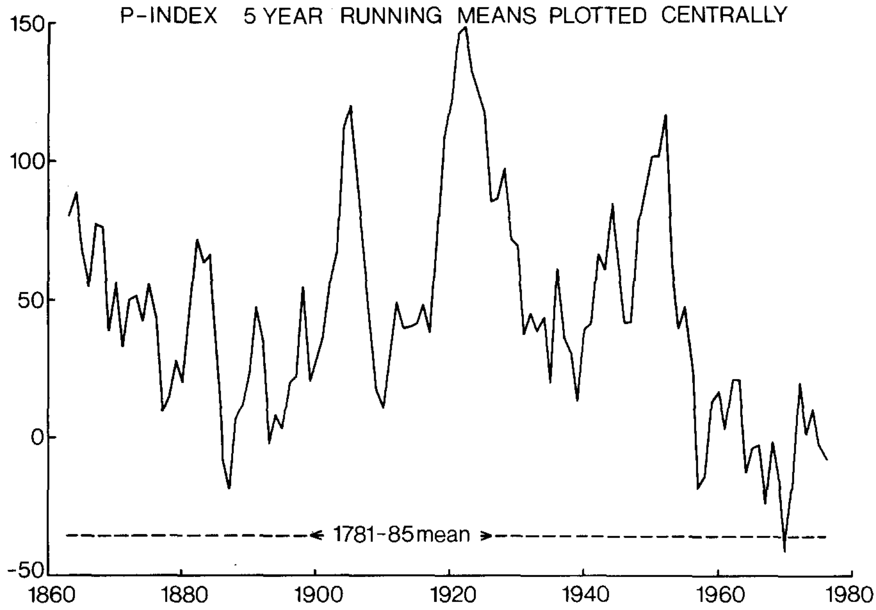

Fig. 6. *P* index: graph of 5-year running means (1861–1978).

The indices of progression, meridionality and cyclonicity or *PSCM* indices (Murray and Lewis, 1966), based on the Lamb British Isles weather types, fulfil this function.

The *P* index is a measure of the frequency difference between days of progressive (that is westerly) and blocked (that is easterly or meridional) circulation types, with *P* being positive when progressive types predominate over blocked types. The *S* index is a measure of the frequency difference between days of southerly and northerly types, with *S* being positive when the bias is towards southerliness. The *M* index is a measure of *total* meridionality, that is, the total frequency of both southerly and northerly types; and the *C* index is a measure of the frequency difference between days of cyclonic and anticyclonic types, with *C* being positive when the bias is towards cyclonicity.

The *P* index curve of 5-year running means in Figure 6 shows a decrease of progression from 1861 to the late 1880s, then a rise to the overall maximum of progressiveness in the early 1920s, followed by a decrease, apart from a temporary increase around the early 1950s, to the low values of recent years. The period mean value of 1781–1785 of –36 (the dashed line) is the second lowest on record, the overall extreme being –41 in 1968–1972. This indicates a very pronounced dominance of blocked or non-progressive weather types during this five-year period.

Although generally depressed in magnitude the *P* index curve (broken line) in Figure 7, showing seasonal variations of progression for 1781–1785, suggests that even during a period of reduced westerly type a fundamental pattern continues to exert control over much of the year. However, there are several interesting points which stand out when this

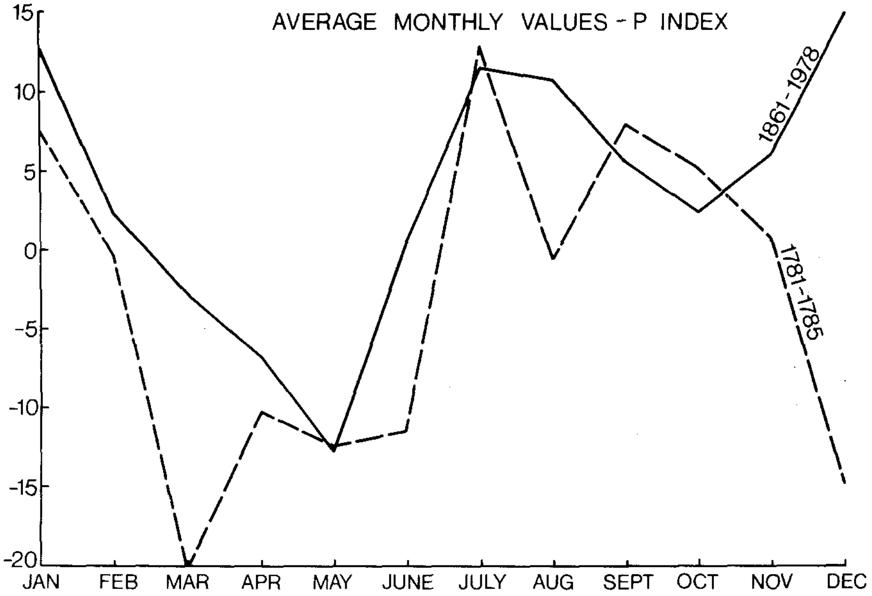

Fig. 7. *P* index: graphs of the seasonal pattern of progression for the periods 1861–1978 and 1781–1785.

curve is compared with the recent long-period mean curve. For example:

(i) maximum of blocking occurring in *early* rather than late spring;

(ii) a sharp increase in progression occurring in early summer, with the July value for 1781–1785 comparable to the long-period mean value, indicating that the timing and magnitude of the onset of the so-called 'European monsoon' was similar to average in 1781–1785;

(iii) a marked departure from the mean curve in December, showing that there was a pronounced secondary maximum of blocking during the early winter period, indicating an early start to cold-season continental conditions in 1781–1785.*

6. Climatic Variability in the 1780s

A superficial look at the period 1781 to 1785 gives the impression that the climate was extremely variable, with year-to-year variations being much more marked than in the twentieth century. Since it has been suggested that future climatic conditions may be more variable than those of today, the 1780s may give us valuable insight into the question of variability. However, recent work by Ratcliffe *et al.* (1978), Van Loon and Williams (1978) and Chico and Sellers (1979) has shown that changes in variability cannot be

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* This is an interesting and certainly genuine characteristic of the Little Ice Age period. Another, noted by Pfister (1975, 1978) is that March was the month which in terms of temperature differed most (colder) compared with recent times.

judged by a superficial analysis and that subjective impressions can be misleading. We therefore devised an objective test.

We decided to examine the frequency of monthly extremes of the following variables: temperature and precipitation, the three most common Lamb types (Westerly, Anticyclonic and Cyclonic – these types together account for 68% of all cases), and the Murray and Lewis *PSCM* index values. A month was defined as 'extreme' if the value of a particular variable was either first, second or third highest or first, second or third lowest in the 123-year composite period 1781–85, 1861–1978. For any one variable there were thus 72 extremes in a sample of 1476 monthly values. The number of extremes was summed for five-year groups (with appropriate weighting in the case of ties) and the results are shown in Table II.

The average number of extremes in a five-year period is 2.93. If the occurrence of extremes were random the distribution of the number of extreme months should be determined by a Poisson distribution. This indicates that both two and three extreme months in a five-year period are almost equally likely; and that the probability of no extremes is 0.0534 and of more than five extremes is 0.0301. For a given five-year period zero or more than five extreme months must be counted as statistically unlikely events and their occurrence would indicate either a significantly low number of extreme months (or low variability), or a significantly large number of extreme months (or high variability).

Table II shows a number of anomalous five-year periods of both low and high variability. Is the period 1781–85 one of an unusually high frequency of extremes? Of the *PSCM* indices the number of extremes of the *C* index is highly significant, and is not approached by any other five-year period. This result is parallelled by the large number of extremes in the frequency of cyclonic and anticyclonic days (note that the Murray and Lewis *C* index is the difference between these two). No other five-year period has as many extremes in cyclonic or anticyclonic days, and the results for the period 1781–85 are highly significant. For extremes in temperature, the period is much less unusual and three other periods (1891–95, 1921–25 and 1936–40) had a marginally greater number of extreme months. For precipitation the number of extreme months is near-average.

It is possible that the high frequencies of months with an extreme number of cyclonic days, an extreme number of anticyclonic days and an extreme value of the *C* index are the result of changes in the mean values of these parameters. It is essential, therefore, that we examine the means for the periods 1781–85 and 1861–1978. For the period 1861–1978 the mean number of cyclonic days per year was 63.9 (with standard deviation of 12.0 days/yr.), while for the period 1781–85 the mean was 77.8 days/yr. (with standard deviation of 12.9). This difference in the means is statistically significant at the 5% level, but not at the 1% level. At least part of the high frequency of extremes of this parameter may be attributed to a different mean; but, nevertheless, the period 1781–85 had extremes of both high and low values pointing to a real increase in variability (note that Table II only gives the sum of the number of extremes of both types). For the number of anticyclonic days per year the corresponding results are: 1861–1978, mean = 91.2 days/yr., standard deviation = 17.6 days/yr.; 1781–85, mean = 91.4 days/yr.,

TABLE II: Simple test of variability: based on 1476 monthly values (for 1781–1785 and 1861–1978) of the Murray and Lewis *PSCM* indices; Lamb Westerly, Anticyclonic and Cyclonic weather types; Manley Central England temperature series and England and Wales rainfall series

Number of extreme months in 5-year periods (with appropriate weighting in the case of ties)

Period / Variable	1781–85	1861–65	1866–70	1871–75	1876–80	1881–85	1886–90	1891–95	1896–1900	1901–05	1906–10	1911–15
P-index	4.3	4.0	5.0	1.0	1.0	2.0	1.0	2.0	1.5	3.5	1.0	2.3
S-index	3.5	1.0	4.2	2.0	4.0	4.0	3.2	3.3	2.3	5.0	3.0	2.5
C-index	9.0	3.0	3.0	2.0	4.5	1.0	3.0	2.0	3.0	1.0	5.0	4.0
M-index	1.0	2.2	1.0	2.0	4.7	2.5	3.6	0	2.0	3.8	3.7	3.9
Westerly days	4.3	4.6	3.4	1.0	1.0	1.7	1.3	3.9	1.5	4.1	2.2	3.0
Anticyclonic days	7.5	4.3	4.0	0	3.0	2.0	2.0	2.5	3.0	1.0	4.0	5.0
Cyclonic days	7.9	2.3	2.0	2.6	1.0	0.6	4.3	1.1	3.3	1.0	6.0	4.3
Temperature	4.7	2.5	1.7	1.0	4.4	4.3	2.4	4.8	2.5	2.4	1.5	4.0
Precipitation	3.0	3.5	2.0	1.0	9.0	0	0	5.0	2.5	1.0	0	5.0

	1916–20	1921–25	1926–30	1931–35	1936–40	1941–45	1946–50	1951–55	1956–60	1961–65	1966–70	1971–75	1974–78
P-index	2.5	5.0	3.7	3.5	1.7	3.5	5.3	2.7	3.0	2.0	3.0	4.7	6.7
S-index	4.7	5.0	0.5	3.0	1.0	2.0	1.5	3.0	5.3	2.0	3.0	2.0	2.0
C-index	2.0	2.0	1.0	4.0	4.0	1.0	2.5	6.0	1.5	3.5	1.5	0	2.5
M-index	6.5	5.6	3.5	2.5	1.7	2.0	2.3	2.6	1.0	1.5	6.7	4.1	3.7
Westerly days	2.4	4.5	3.4	2.3	1.0	4.0	3.8	4.0	3.0	2.9	2.0	2.6	5.6
Anticyclonic days	5.3	2.5	2.0	5.7	3.0	2.0	2.0	3.7	1.0	2.0	2.0	0.5	2.0
Cyclonic days	1.6	3.0	1.2	1.7	5.7	2.8	1.0	2.3	6.3	3.3	4.0	1.6	1.6
Temperature	4.1	5.3	0	1.0	5.0	2.0	4.7	1.0	3.5	2.0	2.0	3.5	4.0
Precipitation	2.0	4.0	2.5	2.0	4.0	4.0	3.0	1.0	6.0	1.0	3.0	3.5	3.0

standard deviation = 16.7 days/yr. The difference in means is negligible. Furthermore, as for the number of cyclonic days, both the number of anticyclonic days and the *C* index had extremes of both high and low values. For anticyclonic days and for the *C* index we can conclude, therefore, that the greater numbers of extremes for the period 1781–85 are not artifacts of a change in the means.

Although these results confirm our suspicions about the variability of the 1780s, it is possible that they might reflect a systematic error in constructing the maps. The significantly larger mean value for the number of cyclonic days in the period 1781–85 may be due to a bias in drawing closed isobars around low pressure regions. This possibility can be tested by using the known relationship between the Murray and Lewis *C* index and precipitation. For five-year averages the correlation coefficients between the *C* index and Kew precipitation range from 0.38 (May) to 0.84 (April). These correlation coefficients are all significant at the 5% level or better, with the exception of May which just fails to be significant at this level. For the *C* index and England and Wales precipi-

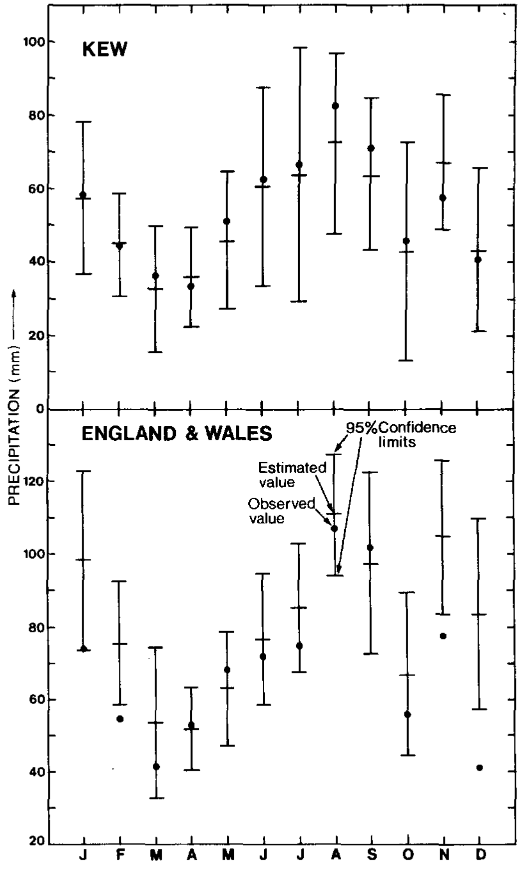

Fig. 8. Comparison of observed monthly precipitation data for Kew and England and Wales in 1781–1785 and predicted values derived from *C*-index data for the same period.

tation the correlation coefficients range between 0.60 (March) to 0.88 (April) for the period 1861–1975. All of these correlation coefficients are significant at the 1% level or better. The England and Wales rainfall series is a composite series derived from data from a number of stations (fewer stations in earlier years), originally compiled by Nicholas and Glasspoole (1932) and subsequently updated by the U.K. Meteorological Office.

To use these relationships we developed regression equations relating monthly *C* index values averaged over five-year periods to both Kew precipitation (from Wales-Smith, 1971) and England and Wales precipitation. These regression equations, 24 in all, were calculated using the 23 five-year periods from 1861–65 to 1971–75. Monthly *C* index data for 1781–85 were then used to estimate both Kew and England and Wales precipitation for this period. Figure 8 compares the predicted results with the observed data.

For Kew, the comparison between predicted and observed is excellent, with all observations falling within the 95% confidence limits of the predictions. For England and Wales, however, the results are not as good, and the months November, December and February show statistically significant errors. The reason for this, however, does not lie with the *C* index data. This is indicated by the results for Kew, but is also confirmed on *a priori* grounds. The England and Wales rainfall series is, unfortunately, not a homogeneous one. For the early (18th century) part of the series the number of stations used in calculating the average rainfall is less than in later years; and the stations missing are those in regions of higher winter rainfall. It is believed that the series underestimates rainfall in the 18th century, and the results presented here confirm that this is the case.

This brief analysis has therefore three important conclusions:

i. the synoptic charts of the 1780s show no evidence of systematic errors when compared with rainfall figures and the greater number of cyclonic days in the period 1781–85 must be attributed to a real increase in cyclonicity,

ii. the early 1780s was a period of unusually high climatic variability on the month-to-month time-scale, especially in the frequencies of cyclonic and of anticyclonic days,

iii. there is good reason to suspect that the early portions of the England and Wales rainfall series underestimates rainfall in the months November to February.

7. Climate in the 1780s: Its Impact and Explanations Offered at the Time

It is clear from the impetus that was given by official establishments, especially in France and Germany, to the organisation of networks of meteorological stations in the early 1780s, that there was growing concern at governmental level about the impact of climate on social and economic affairs in the late 18th century. It can also be inferred that the scientific community of the period was seriously considering the causes of climatic fluctuations, with Benjamin Franklin (1706–1790) and William Herschel (1738–1822) formulating ideas for future debate as to which was producing the most effect on climate – cooling due to volcanic or meteoric dust veils or warming due to increased solar activity.

Several major volcanic eruptions occurred in Iceland and Japan during the 1780s, in particular the greatest outpouring of lava in historic times from the Laki eruption in Iceland in June 1783:

> Violent explosion on 8 and 18 June 1783. The eruption continuing over the next 7 months produced the greatest lava flow on Earth in historical times, variously estimated at from 12 to 27 km^3 . . . Dust from this and the Eldeyjar eruption [May 1783] fell over all Iceland, the Faeroe Islands and northern Scotland, where it was enough to destroy crops in Caithness. A thick dry haze spread over Europe, first reported at Copenhagen on 29 May, in France from 6 June onwards, noted in northern Italy from 18 June, reaching Syria and the Altai in central Asia by 1 July, when it stretched from North Africa to Scandinavia. (Lamb, 1970, p. 509)

Huge clouds of volcanic dust were ejected into the atmosphere and a bluish haze, probably containing sulphur dioxide, lay over Iceland throughout the summer, stunting grass growth and causing a disastrous famine, still referred to in Icelandic history as the 'Haze Famine'. The dust veil must have become exceptionally extensive and dense since from the middle of June 1783 its noxious and optical effects aroused considerable attention all over Europe and a special investigation was carried out by the *Societas Meteorologica Palatina* at Mannheim. First-hand descriptive reports abound in the material that has been collected for this research. For example, William Youell, a Norwich miller, recorded in his journal:

> *27 June 1783:*
> The sky very muddy and the Sun has been so immersed in vapours for above a week that it looks like a red hot ball and the oldest people don't remember the like.
>
> *13–15 July 1783:*
> A foggy atmosphere – the Sun and Moon look like blood.

And Gilbert White at Selborne commented:

> The summer of the year 1783 was an amazing and portentous one, and full of horrible phenomena; for, besides the alarming meteors and tremendous thunderstorms that affrighted and distressed the different counties of this kingdom, the peculiar haze, or smoky fog, that prevailed for many weeks in this island, and in every part of Europe, and even beyond its limits, was a most extraordinary appearance, unlike anything known within the memory of man. [From 23 June to 20 July] the Sun, at noon, looked as blank as a clouded Moon and shed a rust-coloured ferruginous light on the ground, and floors of rooms. . . but was particularly lurid and blood-coloured at rising and setting. All the time the heat was so intense, that butchers' meat could hardly be eaten on the day after it was killed and the flies swarmed so in the lanes and hedges that they rendered the horses half frantic, and riding irksome. The country people began to look with a superstitious awe at the red louring aspect of the sun; and indeed there was reason for the most enlightened person to be apprehensive; for, all the while Calabria and part of the isle of Sicily, were torn and convulsed with earth-quakes; and about that juncture a volcano sprung out of the sea on the coast of Norway.

In 1784 Franklin, writing at Passy near Paris, suggested that the severe winter of 1783/84 might have been due to the dry fog or haze that had been prevalent during the previous summer. He proposed that the turbidity had been caused by particles introduced into the Earth's upper atmosphere either by the volcanic activity in Iceland during the previous

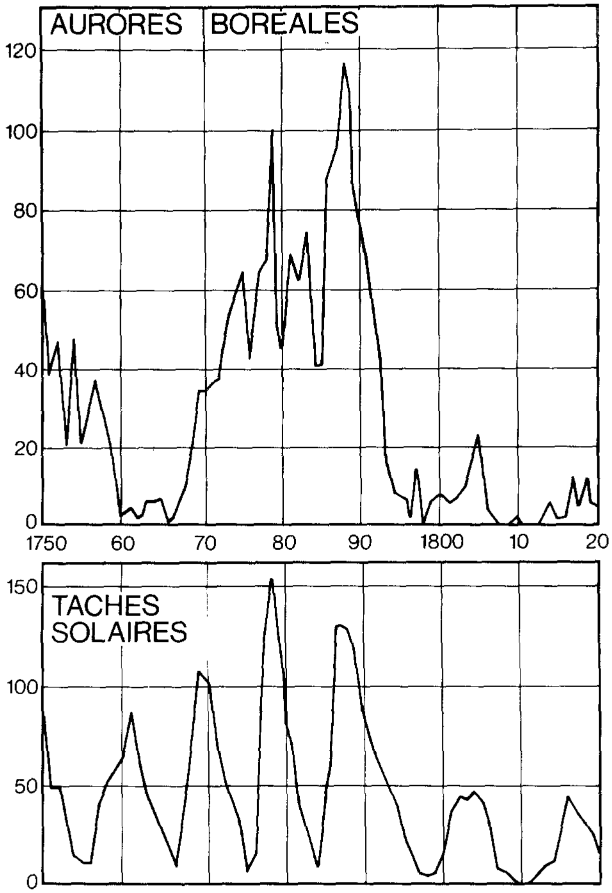

Fig. 9. Comparison of the frequency of aurorae in Europe south of 55°N (1720–1874) with sunspots. (From Angot, 1895).

summer or by the disintegration of meteorites.* According to Franklin, the subsequent decline in surface temperatures was caused by the fog or haze absorbing some of the incident sunlight, and thereby reducing the amount that would normally have reached the Earth's surface (Sparks, 1838).

Herschel attempted to correlate changes of climate with fluctuating solar activity. Since he did not know that the necessary weather records existed, he used a series of wheat prices at Windsor as an index of annual harvests and therefore of the climate in different years (Dreyer, 1912). According to the sun-spot series from 1700, solar activity was very high in the 1780s, with two consecutive vigorous cycles (nos. 3 and 4) having maxima in 1778 and 1787. Another indicator of increased solar activity was the more

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* Meteorites were frequently observed in 1783; on 18 August one of the largest meteors on record was seen by many observers (including the 11-year-old Luke Howard), over a wide area of western Europe (Howard, 1843, pp. 145–152).

frequent occurrence of aurorae borealis between 1770 and 1790. A comparison of the frequency of aurorae in Europe south of 55°N with sun-spots is given in Figure 9; there were some remarkably vivid displays observed during the five-year period 1781–1785 over wide areas of Europe south of 55°N.

8. Historical Case Studies

Climatological research is showing that present climate and circulation patterns differ markedly in their frequency and persistence from those which were characteristic during the first half of the present century. It has been recommended that well-documented case studies from earlier climatic periods will be of considerable relevance and value to the present and future socio-economic planning (National Research Council, 1978).

In a case study of volcanic dust in the atmosphere from 1500 to 1975 (Lamb, 1970) the Eldeyjar and Laki-Skaptar Jökull eruptions in Iceland of 1783 received the third highest Dust Veil Index (DVI) value of 2300 (compare: Coseguina, Nicaragua – DVI of 4000 in 1835 and Tambora, Indonesia – DVI of 3000 in 1815). From the figures given for individual contributory eruptions (Eldeyjar, Laki, Skaptar Jökull, Asama Yama, Heckla, Quezaltenango and Vesuvius), the total veil assessment for the period 1783–1786 ranks fifth, with 1826–1830, with a DVI of 2500 (see Table III).

The possibility of examining the correlation of dense volcanic dust veils and intercontinental economic disturbances marked by high agricultural commodity prices has been suggested for the historical periods 1597–1601, 1638–1641, 1693–1698, 1709–1712, 1766–1771, 1783–1786, 1811–1818, 1835–1841 and 1845–1850, and a comprehensive study has already been made of the period 1811–1818 (Post, 1977). A similar investigation for the period 1783–1786 is in progress based on the present series of *daily* weather maps from 1781. One aspect which has already been noted is the remarkably low frequency of westerly airstreams over the British Isles in 1785 (45 days) deviating from an already depressed average value of about 71 days per year in 1781–1784 (see Figure 10).

It has been suggested that, as a result of the increased frequency of volcanic activity between 1780 and 1840, repeatedly replenished dust veils might have had an important

TABLE III: Lamb's Volcanic Dust Veil Index (DVI). The five largest total veil assessments

Rank	DVI	Period
1	4400	1811–1818
2	4200	1835–1841
3	3400	1766–1771
4	3000–3500	1693–1698
5	2500	1783–1786 1826–1830

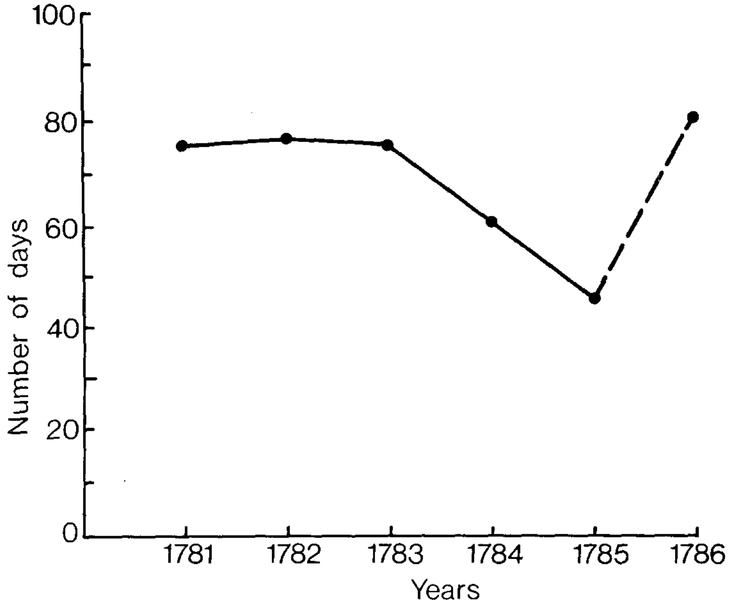

Fig. 10. Annual values of the Lamb British Isles Westerly type, 1781–1786. The totals include the appropriate shares from hybrids involving Southerly, Anticyclonic and Cyclonic types.

effect in prolonging the Little Ice Age into the first half of the 19th century, when purely meteorological trends would otherwise have suggested an earlier reversal to warmer conditions (Lamb, 1970).

In another case study concerning agricultural records from Scandinavia it has been demonstrated that there was an increased incidence of natural disasters such as floods, landslides and avalanches during the Little Ice Age (Grove, 1972). Following an inquiry from authorities responsible for water-power engineering projects on the Glomma River in Norway,* a synoptic-climatological study based on daily historical weather maps has recently been made of the 'Storofsen' – the disastrous flood and related events which occurred in the Glomma valley and neighbourhood in eastern Norway in July 1789. The 1788/89 winter had been very severe and the following spring so cold in Norway that the subsoil remained frozen and impervious to water until July. This, combined with warmer weather and prolonged spells of heavy rain associated with large and complex areas of low pressure which covered Scandinavia and the British Isles for several days in July 1789 (see Figure 11), brought about a snow-melt and rain-flood in the valley (Kington, 1979).

9. Agriculture and Industry

The 1780s are providing some interesting climatological analogues for certain circulation patterns which are more prevalent today. Besides the already mentioned similarity to

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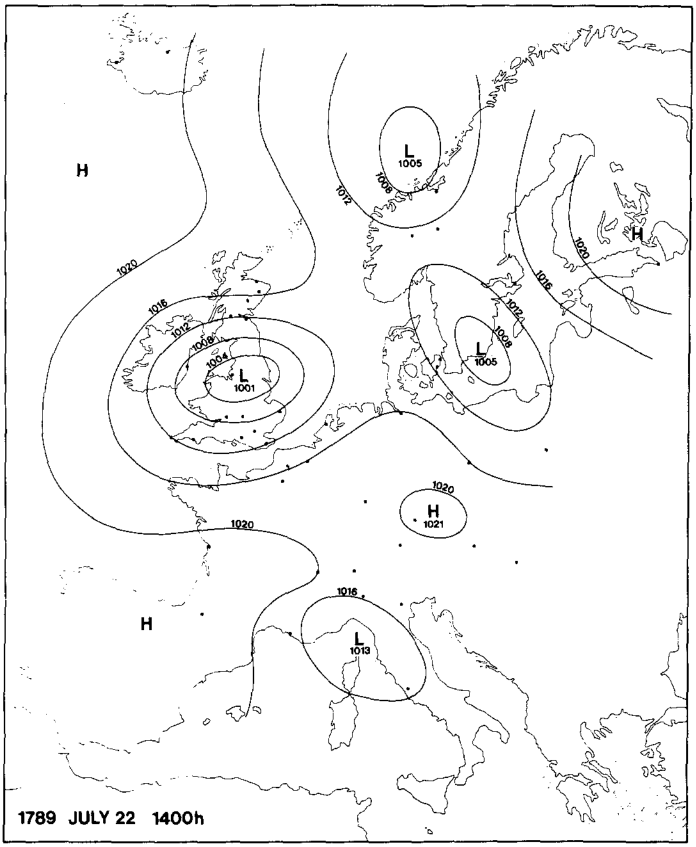

Fig. 11. Synoptic weather map for 22 July, 1789 by J. A. Kington.

recent years with the decline in the frequency of westerly airstreams over the British Isles, the cold, wet spring of 1979 can be compared with that of 1782 (Kington, J. A. and Kington, B., 1979), and the prolonged drought of 1975–76 had a close parallel with a similar event in 1784–85. These events and comparisons are described further below.

1781–82 can be thought of as a turning point both for weather and for agriculture: it marks the end of a series of good summers for wine harvests. Vine growers on both the French and German sides of the Rhine bear witness to the hot summers, early wine harvests and excellent wine production of the years 1779–1781. In the Champagne region, the quantity of wine produced had passed from average in 1779 to abundant in 1780 to exceptional and superabundant in 1781 (Le Roy Ladurie, 1971). Even in England John Fenton of Nacton, Suffolk reports that 1781 was:

> remarkable for an early spring and a dry forward summer. Grapes in ordinary places were ripe in August, the harvest was begun betimes, and ended by the time in some other years that they had but just begun.

The two or three years prior to 1781 had not only been good for vines; for instance, wheat harvests in 1780 and 1781 were also excellent in France. However, it appears that conditions were not entirely beneficial for good crops. In England Gilbert White made some comments about the relation between hot summers and wheat and fruit production:

> A notion has always obtained, that in England hot summers are productive of fine crops of wheat: yet in the years 1780, and 1781, tho' the heat was intense, the wheat was much mildewed, and the crop light . . . The heat of the two last summers has scalded and scorched the stems of the wall-fruit trees, and has fetched off the bark.

In southern Scotland tobacco-growing on a commercial basis was even contemplated during the period of favourable seasons between 1778 and 1781; prompted, it must be added, by the scarcity brought about by the slump in the import of tobacco into Glasgow due to the American War of Independence. However, with the ending of hostilities and the imposition of a tax on the home-grown product equal to that paid upon imported tobacco, together with a return to less favourable weather, further experiments were discouraged (Handley, 1963).

1782 was a disastrous year for harvests, especially in Scotland, where it became known as 'black auchty-twa'. Following wintry weather in March, the months of April and May were very cold and wet, giving rise to a very late spring. The total rainfall for spring 1782 in the England and Wales series was 315 mm (179% of average), the wettest spring in the record from 1727. A close parallel occurred in the spring of 1979 with 313 mm being recorded (178% of average), the second wettest spring in the series. The values from the rainfall series for Kew, Surrey (Wales-Smith, 1971) can be similarly compared: spring total for 1782, 244 mm (189% of average) ranking 3rd, and that for 1979, 270 mm (209% of average) ranking 2nd in the series from 1697. The springs of 1782 and 1979 were also cold with deviations of −2.5 and −1.1°C respectively in the Central England temperature series (Manley, 1974). There were also marked similarities in the circulation patterns, for example, the total of 32 days for the Cyclonic type in the spring of 1782 is the same value as recorded in spring 1979, which was the greatest number of Cyclonic-type days recorded in spring since 1861, that is, twice the seasonal average (Kington, J. A. and Kington, B., 1979). The summer, especially July and August, was exceptionally cold and wet over the British Isles with widespread flooding. It was the second wettest July on record at Kew (Wales-Smith, 1973), and on 16 August the heaviest rainfall in one day was recorded at Gordon Castle in northeast Scotland in the period 1781–1827 (Buchan, 1880).

Although much of the grain crop of 1781 was still on hand, it became clear early in the summer of 1782 that the crops would be inadequate over much of Scotland and, by September, owing to late bad harvests, there was widespread alarm. Grain prices rose by over 40% and committees were formed in various counties of Scotland to estimate the probable harvest and take steps to supplement it (Handley, 1963). The summer was so cold and wet that the oat crop was already beginning to shoot at the end of August. Early and severe frosts followed in the autumn. At the end of November, the coldest on record in the temperature series for Central England from 1659 (Manley, 1974), the corn was still green and uncut in many parts of Scotland. In December shearers were ploughing through snow to cut off the tops of the oats, blackened by the frost but not ripened (Handley, 1963). Before Christmas it was obvious that the crops would not suffice to feed the population of Scotland and a million pounds were expended in buying grain from England.

1783 was no better for the farmer. This time harvest failures were not through cold and wet conditions, but because of the damage caused by frequent and heavy thunderstorms in July (the warmest on record in Central England (Manley, 1974)), volcanic dust and the lack of seed-corn brought about by the disastrous harvest of 1782. The 'ill years' of 1782 and 1783 ruined many farmers especially in northern Britain, with some being induced to emigrate to America. However, this period also had the effect of stimulating improved farming methods: earlier and better varieties of grain were introduced, greater attention was given to the cultivation of root crops, and longer leases were offered (Alexander, 1877). But the most beneficial result for Scotland of those lean years was the institution of a Society whose main objective was the economic and social improvement of the Highlands (Handley, 1963).

The winter of 1783–84 was severe with almost continuous frost from late December to late February. The River Thames was completely frozen in February 1784 and traffic crossed on the ice. 1784 was a cold year with a backward, cold spring and a cool summer. August 1784 saw the beginning of a twelve-month long dry period. Although the recent drought of 1975–76 lasted longer, the period from August 1784 to July 1785 is the driest run of any consecutive twelve months in the England and Wales rainfall series from 1727. This coincided with an exceptional decrease in the frequency of the Westerly weather type over the British Isles, with only 37 days being recorded from August 1784 to July 1785. The winter of 1784–85 was severe with frost and snow from early December to early January 1785, and during most of February and the first half of March, the River Thames was again frozen. 1785 and 1786 were both cold years and a feature of all the years from 1782 to 1786 was the coldness of the month of March, with that for 1785 being the coldest on record, both in England (Manley, 1974) and on the Continent (Baur, 1975).

Besides causing difficulties to the farmer, climatic extremes such as severe frosts and prolonged droughts adversely affected many 18th century industries and trades which were either directly or indirectly dependent upon running water for motive power and processing; for example, flour milling, the manufacture of textiles and dyeing. William Youell made reference in his journal to these problems at the mill in Norwich:

Severe frost:

30 December 1783:
. . . froze very sharp last night, the engines and all the water wheels quite fast . . . the people skating on the Mill Damm.

31 December 1783:
Froze the sharpest last night for these 7 years past . . . 4 hours in cutting away the ice from Flour Mill wheel and the engines. Hundreds of people upon the Mill Damm, skating, sliding, etc.

Prolonged drought:

23 June 1785:
Did not try to sell any flour today, the water run so short.

29 June 1785:
The water terribly short indeed. I am almost crazy with the Dyers, Duffel makers, Bakers and Water Tenants.

30 June 1785:
Did not go round to the Bakers today, having no flour to sell nor cannot make any.

1 July 1785:
Got down our new running stone in Flour Mill but no water to work it, did nothing all day.

It is of interest to the study of urban climatology that instances of air pollution were already making an impact on society in the 1780s, especially in and to leeward of large cities. An early example of the London urban plume or 'London Smoke', as it was then referred to, was occasionally observed under certain weather conditions to the west of the metropolis by Gilbert White at Selborne, and the present series of daily weather maps is allowing case studies, relating air pollution to meteorological conditions, to be extended back into the 18th century (Brimblecombe and Wigley, 1978).

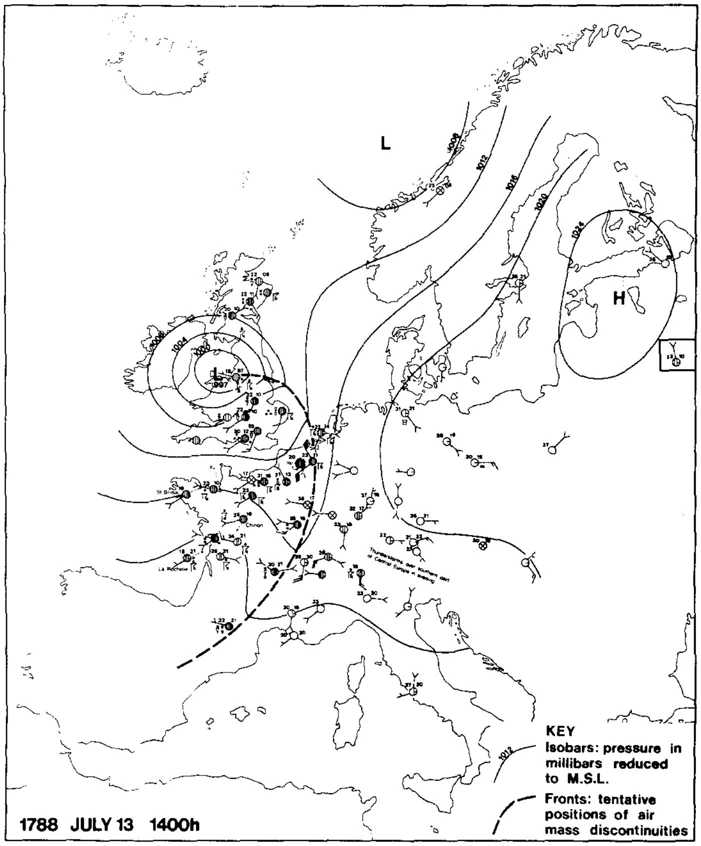

Fig. 12. Synoptic weather map for 13 July, 1788, by J. A. Kington.

At present, the chart series extends to the end of 1786 and climatological events which occurred in the period 1781–86 are now being synoptically analysed. Data have been collected for the preparation of charts from 1787. and it will soon become possible to examine the daily circulation patterns that gave rise to the adverse weather conditions which presaged the bad wheat harvest of 1788, which in turn led to the food shortage in France during 1789. Several synoptic weather maps for this later period were prepared out of sequence from the main series for presentation at the International Conference on Climate and History held at the University of East Anglia, Norwich, in 1979. One of these was for 13 July 1788, the day a large area of France was affected by catastrophic hailstorms (see Figure 12). This chart shows that the hailstorms were associated with an active cold front which extended from Liverpool to the southern North Sea and then from Brussels through the Massif Central to the Pyrenees; it has been estimated that it was moving steadily east at about 20 miles per hour, and at the time of the chart (1400h) it was situated about 100 miles east of Paris. Temperatures in the warm air ahead of the front were 30°C and above, and fell by about ten degrees in the cold air behind. According to eye-witness accounts of the storm, the cold front passed over Paris at about 0900h, giving violent thunderstorms with hailstones the size of grapefruit measuring 16 inches and more in circumference, and causing widespread damage to crops and property (Neumann, 1977).

The winter that followed, 1788–89, was both long and severe. The frost lasted from the end of November to the middle of January and a frost fair was held on the Thames for the first time since the severe winter of 1739–1740. The severity of the weather caused much hardship, distress and unemployment (Brazell, 1968). During five years spent in Paris before the outbreak of the French Revolution, Thomas Jefferson (1743–1826) had observed at first hand much of the unrest that had led to the conflict. After noting in his autobiography that all attempts at progressive measures were nullified by the influence of Queen and Court, he commented about the winter of 1788–1789:

> . . . while laboring under the want of money for even ordinary purposes, in a government which required a million of livres a day, and driven to the last ditch by the universal call for liberty, there came on a winter of such severe cold, as was without example in the memory of man, or in the written records of history. The Mercury was at times 50° below the freezing point of Fahrenheit and 22° below that of Réaumur. All out-door labor was suspended, and the poor, without the wages of labor, were, of course, without either bread or fuel. The government found its necessities aggravated by that of procuring immense quantities of fire-wood, and of keeping great fires at all the cross streets, around which the people gathered in crowds, to avoid perishing with cold . . . (Koch and Peden, 1944, pp. 91–92)

After quoting these lines, in his introductory study of the atmosphere., Riehl remarks that Jefferson had made a powerful analysis of how weather, especially extreme weather, can affect the affairs of man and poses the question: "What causes temperatures of −18°F at Paris?" (Riehl, 1965). With the extension of the present series of daily historical weather maps into the late 1780s, it will soon be possible to answer this interesting query in synoptic terms from an examination of the actual circulation patterns that occurred during the severe winter of 1788–1789.

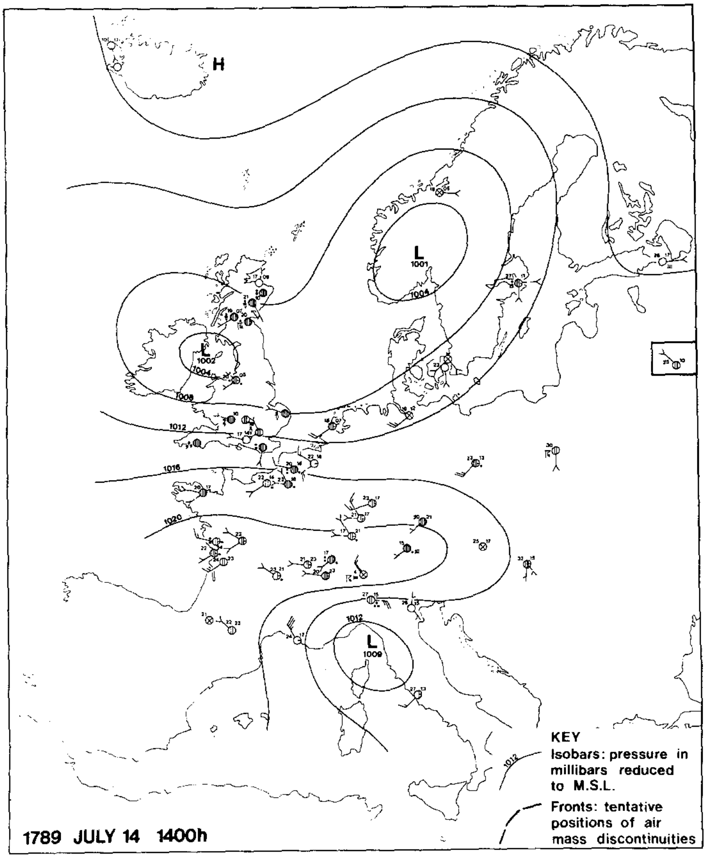

Fig. 13. Synoptic weather map for 14 July, 1789 by J. A. Kington.

10. The Weather as Background to Historical Events

The present series of daily weather maps also provides the historian with detailed information about atmospheric circulation patterns associated with particular historical events.

An example from the French Revolution illustrates the kind of material that this synoptic–climatological project is now providing for the historian. The synoptic situation which prevailed on 14 July 1789 is illustrated in Figure 13. With a ridge of high pressure extending east over France, the weather was partly cloudy with occasional showers; there was a light to moderate westerly wind and a temperature of 22°C. The weather in Paris would not have deterred participants in a popular disturbance such as the Storming of the Bastille (see Figure 14): it was a perfect day for outdoor activity!

Acknowledgements

The suggestions made and help given by colleagues in the Climatic Research Unit, in particular Dr T. M. L. Wigley, Dr P. D. Jones and Dr P. M. Kelly, with the preparation of

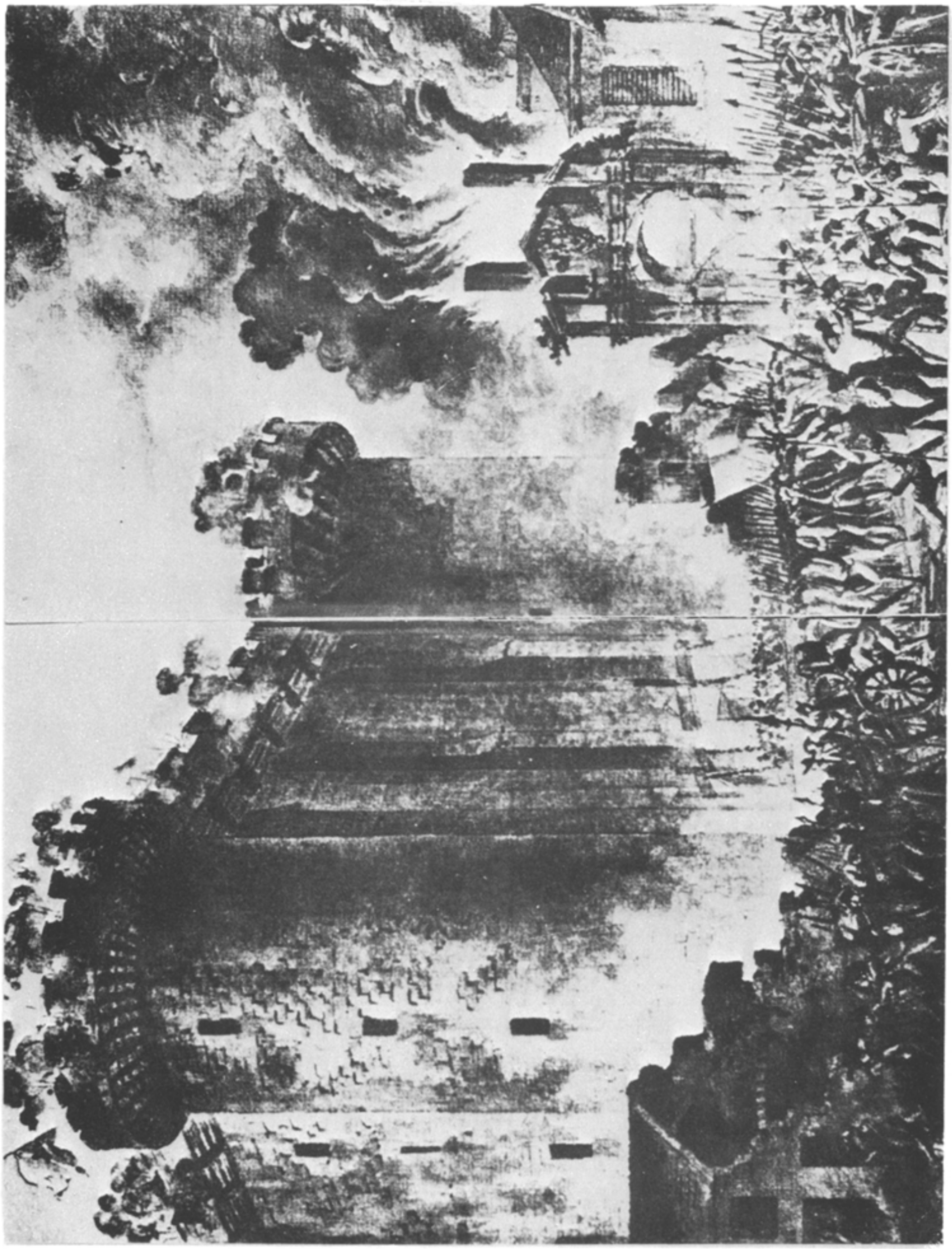

Fig. 14. The storming of the Bastille on 14 July, 1789. (From Michelet, 1967).

this paper are gratefully acknowledged. Mr D. B. Mew and Mr P. G. Scott are thanked for their cartographic and photographic work.

This work has been supported by grants from the U.K. Meteorological Office Research Committee and the Wolfson Foundation.

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(Received 13 February 1980: In revised form 27 May 1980)