Reprint[ed] from 'Climate Since A.D. 1500', edited by
R.S. Bradley and P.D. Jones, Routledge London (1992)

6 Monthly temperature and precipitation in central Europe 1525-1979: quantifying documentary evidence on weather and its effects

C. Pfister

6.1 From weather accounts to climate history

The growing consciousness that the world is undergoing a period of significant warming has triggered a wave of research activity into past climates. Within this context observations in historical sources are an essential ingredient of any study dealing with the reconstruction of climate in the period between the Middle Ages and the beginning of instrumental network observations in the 19th century.

Proxy data from natural archives cover periods up to hundreds of thousands of years. However, their time resolution is restricted to individual years or to periods of several months in the best case. Moreover they respond to a variety of meteorological variables making it difficult to disentangle the climatic information. Documentary material from anthropogenic archives, that is highly specific with regard to time, place and meteorological parameter, covers a period of roughly seven hundred years. This provides a safer basis for assessing the natural variability of climate than the shorter instrumental period. In particular this holds for the interpretation of exceptional events, such as the very mild winter 1989-90 in Central Europe (Pfister 1990).

Seasonal and monthly estimates of temperature and precipitation for the pre-instrumental period are obtained from the interpretation of documentary material. They provide a broad basis for calibrating natural proxy information and a new testing ground for climatic models, that need still to be much improved regarding regional and seasonal scenarios.

Assessing and modelling impacts of past climates upon past societies requires a very detailed record of past changes which is in fact a history of weather. Among agrarian scientists and demographic historians there is agreement on the point that monthly temperature and precipitation data are needed in order to quantify the influence of meteorological factors upon yield formation and upon diseases in a meaningful way. (Hanus and Aimiller 1978; Georgelin 1979). This holds also for the climatic interpretation of demographic patterns (Flinn 1981:100).

The types of data used for the reconstruction of past climates have been described in great detail by Lamb (1981). Within the same volume Ingram, Underhill and Farmer (1981) have provided a survey of documentary sources. The classification scheme shown in Figure 6.1 groups the evidence firstly into natural and anthropogenic data according to their origin. The data fall into descriptive and proxy data with respect to the kind of information which they contain. The term 'proxy' is used to denote any material, that provides an indirect measure of

ORIGIN / INFORMATION	NATURAL		MAN-MADE		
Direct: weather patterns and meteorological parameters			Documentary Sources	**Descriptive Reports** – extreme events – rough sequence of weather situations – daily weather	**Instrumental Observations** – barometric pressure – temperature – precipitation – water-gauge
Indirect (proxy data): phenomena governed or affected through meteorological parameters	**Geophysical** – isotopes – sediments – moraines etc	**Biological** – marine plankton – pollen – tree rings etc	Documentary Sources	**Geophysical / para-meteorological** – water levels – snow falls – duration of snowcover – freezing-over of water bodies	**Biological** – time of blossoming and ripening of plants – yield and sugar content of vine – time of grain harvest and vintage
			Material Sources	paintings, prints and photographs; maps and charts buildings, settlements, roads, waterways abandoned farms and fields archeological remains	

Figure 6.1 A survey of evidence for reconstructing past weather and climate.

climate. It comprises both natural and man-made evidence. One kind of proxy data is related to geophysical and para-meteorological phenomena, mostly snow-cover and the freezing of water bodies, the second one refers to phenophases or other signs of biological activity. Anthropogenic data may also be grouped into documentary sources and material sources according to their form and to the place where they are found. Written sources, manuscript or printed, are preserved in libraries and archives or owned by private individuals. Moreover inscriptions referring to climatic anomalies are sometimes painted on the front of houses. In some locations the height of floods is marked on buildings, or the level of low water at certain times is engraved on rocks. Objective data are found in museums or in the field, pictorial data are stored in libraries, archives and displayed in museums or on private property.

The present approach attempts to demonstrate, how to bridge the gap between climatic history and weather history by cross-dating different kinds of documentary proxy data with descriptive evidence. The aim is to produce a combined record which provides both the quantitative estimates of temperature and precipitation needed by the scientist, the economist and the policy maker and the detailed weather account which the historian requires for reconstructing the past. The procedure starts by collecting the smallest bits of evidence available, weather observations, early instrumental data and proxy information. The resulting 'weather history' is coded, homogenized and calibrated according to the type of data and stored in a data-bank (Figure 6.2). All the evidence is then boiled down to a numerical wetness and temperature index for each month. In the last step this data is converted into a 'climate history' by computing transfer functions for estimating decennial temperature and precipitation. The results of the reconstruction of climate and the bearing that climatic fluctuations have upon the economy and demography of Switzerland are discussed in considerable detail in the '*Klimageschichte der Schweiz*' (Pfister 1984) from which this article is mainly drawn.

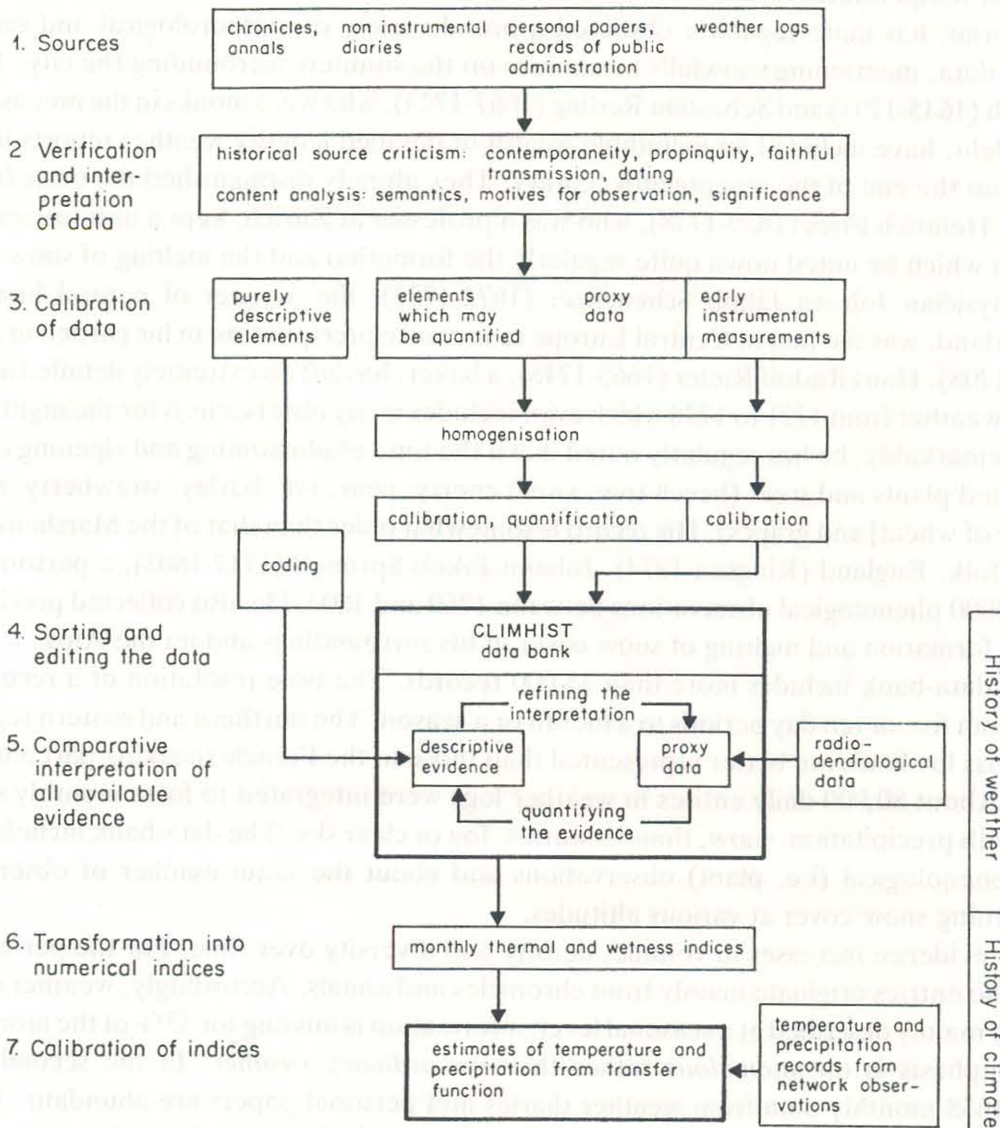

Figure 6.2 Flow diagram illustrating the procedures used in obtaining climatic information from historical documents.

6.2 Survey of sources and data

The human evidence which documents the study has originated principally from chronicles, from personal papers (diaries, calendars) containing intermittent meteorological entries, from non-instrumental weather diaries to weather logs, that contain both instrumental measurements and visual observations. More than 118 manuscripts and over 150 printed sources with weather evidence were found in the Swiss libraries and archives.

Some of the main observers and sources are briefly described in the following: Wolfgang Haller (1525-1601), Arch-deacon of the Cathedral of Zürich, kept a non instrumental weather diary for thirty years (1545-1576) in which he describes the daily weather with one or two words such as 'rather warm', 'rain', 'snow', 'dull' etc. Flohn (1949) has shown the decline of winter temperatures after 1560 from this source. Renward Cysat (1545-1613), Chancellor in Lucerne, has quite regularly observed a broad variety of meteorological and environmental data, mentioning snowfalls in summer on the summits surrounding the city. Joseph Dietrich (1645-1704) and Sebastian Reding (1667-1724), who were monks in the monastery at Einsiedeln, have included an incredible wealth of detailed lengthy weather reports in their diaries an the end of the seventeenth century. They already distinguished the basic form of clouds. Heinrich Fries (1639-1718), who was a professor at Zürich, kept a non-instrumental diary in which he noted down quite regularly the formation and the melting of snow-cover. The physician Johann Jakob Scheuchzer (1672-1733), the pioneer of natural history in Switzerland, was the first in Central Europe to measure precipitation in his garden in Zürich (from 1708). Hans Rudolf Rieter (1665-1748), a baker, has left an extremely detailed account on the weather from 1721 to 1738 which even includes many observations for the night hours. Most remarkably, he has regularly noted down the time of blossoming and ripening of eight cultivated plants and trees (beech tree, sweet cherry, pear, rye, barley, strawberry, spelt [a variety of wheat] and grapes). His record is somewhat older than that of the Marsham family in Norfolk, England (Kington 1974). Johann Jakob Sprüngli (1717-1803), a parson, made some 4000 phenological observations between 1760 and 1802. He also collected precise data on the formation and melting of snow cover in his surroundings and on the Alps.

The data-bank includes more than 33,000 records. The time resolution of a record may vary from five or ten day periods to a month or a season. The northern and eastern regions in the Swiss lowlands are better represented than those in the French-speaking part and in the Alps. About 80,000 daily entries in weather logs were integrated to form monthly sums of days with precipitation, snow, thunderstorms, fog or clear sky. The data-bank includes some 3000 phenological (i.e. plant) observations and about the same number of observations concerning snow-cover at various altitudes.

The evidence increases in volume, density and diversity over time. For the period 1525-1549 the entries originate mainly from chronicles and annals. Accordingly, weather sequences are mainly described at a seasonal level; information is missing for 43% of the months and the emphasis is on *anomalous* rather than on *ordinary weather*. In the second period 1550-1658 monthly data from weather diaries and personal papers are abundant. The few missing monthly data (7%) are concentrated in the months from October to December. From 1659 monthly meteorological data are continuous. From 1684 monthly precipitation is almost thoroughly quantified either by counting entries in weather diaries or from measurements (after 1708) and the thermal character of each month is derived from a body of reliable para-meteorological and phenological proxy data.

The thermometric evidence dates from 1755 and is based on the Basel series. In order to document conditions in mountain environments, the thermometric series from the Great St. Bernard pass (2460 m above sea level) which originates in 1817, was included. Scattered series of rainfall measurements (e.g. Zürich, Bern) are available from 1708. The Geneva precipitation series (from 1778 to the present) is the longest continuous record of this kind in Switzerland. The creation of the national weather service in Switzerland in 1864 was chosen as a dividing line between the periods of the 'historical' and the 'modern' data.

6.3 Data verification

Only a decade ago it was discovered, that documentary sources of information about past climates are not equally reliable. Compilations often contain a mishmash of valuable and worthless data. Their main flaws are inaccurate or uncertain dating of particular events, acceptance of accounts which are distortions or amplifications of original observations and spurious multiplications of events through mis-dating (Alexandre 1987; Bell and Ogilvie 1978; Ingram *et al.* 1981, Pfister 1984). An example of mis-dating comes from Central Europe. The well-known chronicle of Thann (Alsace) which Klemm (1974, p.409) takes to be "extremely valuable" has been used again and again as a source of information for reconstructing past climate. In vain, the editor himself, Abbé Merklen, had cautioned, that the chronicle contains a lot of contradictory evidence and incorrect dating.

Historians have developed a standardized methodology for evaluating sources and rejecting unreliable information. The most important critical tests are those based upon the principles of contemporaneity, propinquity and faithful transmission. Recorded statements cannot be regarded as reliable and valuable, unless it can be shown either, that the writer lived close in time and space to the events he purports to describe, and recorded his observations immediately or within a short space of time after these events had taken place, or that he had access to first hand oral or written reports and can be presumed to have accurately transmitted the information derived from them. (Ingram *et al.* 1981). In the context of the *Klimageschichte der Schweiz* (Pfister 1984, 1985a) non-contemporary material was not completely rejected. Where a reliable picture of weather patterns had already been obtained from contemporary data, second hand reports which contributed to the understanding of weather situations were included. In order to clearly mark their lower quality, the name of the author was omitted in the printout of the data-bank (see Section 6.6).

Accurate dating was one of the thorniest problems. Up to the end of the eighteenth century the Gregorian and Julian calendars were simultaneously in use, often within the same village or district. In the data-bank all the dates have been converted to Gregorian style and every dating correction is made explicit. Apparent contradictions arise, when weather reports from catholic and protestant cantons refer to the same month. In those cases a time resolution of the individual records from ten days to ten days, such as it is provided in the CLIMHIST data-bank, becomes indispensable for an appropriate interpretation. Moreover the reference to ten day-periods is very convenient for handling the dating related to Saint's days, which do not fit into the scheme of calendar months.

For events in 'winter', dating becomes a problem particularly when the source gives just one year for identification. Then it must be derived from the context or from other sources, whether the 'old' or the 'new' year is meant in order to prevent spurious multiplication of events. The term of 'Winter' itself was related to the duration of snow-cover rather than to specific months. Likewise 'Herbst' (autumn) described the time of the vintage.

6.4 Calibration of proxy data

The following types of data are included in the data-bank:

1 Miscellaneous observations from descriptive sources

1.1 Purely descriptive data
1.2 Non-serial proxy data

1.2.1 Freezing of water bodies
1.2.2 Snowfall and snow-cover
1.2.3 Phenological data
1.2.4 Floods and low water levels

2 Daily non-instrumental observations
3 Monthly frequencies of rainy, sunny, foggy, snowy days etc. obtained from weather logs
4 Instrumental records for precipitation
5 Instrumental records for temperature
6 Serial proxy-data:

6.1 Dates of auctions of tithes paid in grain
6.2 Grapevine harvest dates
6.3 Grapevine harvest yields
6.4 Phenological series
6.5 Dendroclimatic data

The descriptive evidence (without the 'serial' data) was standardized by the use of a numerical code (Pfister 1981a). Calibration has to be done separately for each type of data.

6.4.1 *Freezing of water bodies*

From the cases documented with thermometric measurement it has been established, that lakes in the alpine borderland freeze in a specific rank order, according to their surface, depth and individual characteristics. The freezing is primarily a function of the sum of below-freezing-point daily mean temperatures, plus such other factors as wind-speed. Frequently it is specified in the sources, whether the ice was thick enough to carry men and cargoes and how long the ice-cover remained. This provides an additional clue. For the Lake of Zürich, which has the highest number of entries in the CLIMHIST data-bank, it is known that a sum of at least 350°(C) freezing degree days is needed to form an ice cover which is thick enough for a safe walk.

The freezing of rivers cannot be properly calibrated, because in the past these events are not adequately documented with thermometric measurements. Moreover river-beds have been changed because of river regulation schemes in the nineteenth and twentieth centuries. However, it may be hypothesized from the scanty thermometric evidence, that such events did occur, when temperatures were between -25° and -30°C. Temperatures in this range were also associated to the formation of frost cracks in trees. This produces repeated claps similar to gunfire which are described in some sources as symptoms of a bitter cold.

6.4.2 *Snowfall and snow-cover*

The ratio of the number of snowy days to the number of rainy days may be computed from weather-logs and used as a proxy for temperatures in winter (Flohn 1949). Moreover frequent snowfalls reported for October, November, March and April point to below average temperatures in those months.

Snow cover is an eye-catching meteorological element used in chronicles to describe extremely long winters. From the end of the seventeenth century the formation and melting of snow-cover has been quite regularly described in weather logs. For the Mittelland (250 m to 600 m a.s.l.) there is at least one observation for 271 out of 306 winters from 1684 to the present; from the mid-eighteenth century the date of thaw is known for higher elevations, too (Pfister 1985b, 1990).

The persistence of snow-cover is related to the sequence and duration of weather situations favouring accumulation or ablation. In most cases this may be drawn from weather reports. A very small number of days with snow cover is mostly related to warm winters, occasionally also to dry and cold anticyclonic situations. For the pre-instrumental period the hypothesis of warmth needs, therefore, to be supported with observed signs of vegetation activity. Altitude and orographic factors (such as windward or leeward slope) of the locations of observation were considered in interpreting the data (Schüepp 1980; Witmer 1986).

For calibrating the series from the Mittelland a separate model has been developed for every winter month, which yielded fair estimates for temperatures (Pfister 1977). The date of alpine thaw, which depends primarily on temperature and radiation patterns, was compared among stations in the Swiss alps located at similar altitudes. It turned out to be highly correlated and closely related to phenological data, such as flowering and ripening of the vine, (Pfister 1985b).

6.4.3 *Phenological data*

In order to describe temperature patterns during the vegetative period observers in the pre-instrumental period frequently referred to stages in the growth and maturity of cultivated plants, which were known to be more accurate yardsticks of warmth and coldness than impressions of individuals.

The evidence enables the development of long phenological series, that cover almost the entire vegetative period: blossoming of sweet cherries (from 1721), the bloom of grapevines (from 1702), the start of rye harvest (from 1557), the ripening of early varieties ("Aeugstler") and ordinary varieties of the red burgundy grape (from 1721), the beginning of the wine harvest (from 1370) (Pfister 1988).

Two conditions must be met for interpreting and calibrating pre-instrumental observations.

1. Corresponding phenophases should have been regularly observed for at least ten years close to a meteorological station, where temperature, precipitation and duration of sunshine were measured.
2. Phenophases for the pre-instrumental and for the instrumental period should be compared in order to determine, whether significant shifts did occur in the averages. Moreover the knowledge of averages within the pre-instrumental period allows for the interpretation of isolated observations for anomalous years.

Calibration of the historical data was based upon series of corresponding phenophases carried out at three meteorological stations in the Canton of Schaffhausen from 1875 to 1950.

It turned out that most phenophases are significantly correlated with temperature patterns: the beginning of cherry blossom depends on conditions in March and April, the beginning of vine flower is primarily an indicator of temperatures in May, the beginning of the rye harvest is tied to temperatures in May and June, the ripening of both varieties of the red burgundy grape is a function of temperatures in June and July.

In the central frame of Figure 6.3 the average dates of ten phenophases observed in the pre-instrumental period are given below the line. The corresponding averages from the Schaffhausen series are represented above the line. The days of the year are marked on the x-axis. There is a good agreement between the two sets of observations, when differences in altitude are considered. The advanced blooming of vine in the eighteenth century is bound to the specific climatic conditions of the period.

Above the frame, the earliest phenophases known from 1525 are provided. For those observations which fall into the instrumental period the deviation of temperatures from the 1901-60 mean in the months preceding the phenophases is marked by means of horizontal bars. The bars indicating positive deviations point to the left. The merger of evidence from the two periods allows us to compare the earliest known springs and summers within the pre-instrumental period with those which are documented with thermometrical series.

Below the frame, the latest phenophases and thus the chilliest springs and summers known from 1525 are shown in the same way. The horizontal bars pointing to the right indicate negative deviations from the 1901-60 mean in the months preceding a given event.

In the following those extremes are discussed.

Cherry flowering: advances by two weeks or more are mostly connected to summerlike temperatures in February or March (1822, 1897, 1794). In 1990 sweet cherries began flowering around March 20 which is equivalent to the earliest springs which are known (Pfister 1990). A delay of flowering by three weeks or more suggests that the March-April period may have been more than 5°C below the 1901-60 average. March 1785 was 8°C below this average!

Vine flowering: we should consider the observations which were carried out in an open vineyard only. Plants which are sheltered by the wall of a house will flower considerably earlier. Differences in varieties, however, can be neglected prior to the late nineteenth century. The first flower is advanced or delayed mainly according to temperatures in May, an early flower may also follow a very warm April (e.g. 1811, 1893) and, according to descriptive evidence, in 1723. The times of the full bloom and the last flower vary with temperatures in both May and June. Extreme delays (1542, 1627, 1628, 1642, 1675, 1740) were much more frequent and much more pronounced than extreme advances.

Start of the rye harvest: While the three-field system was in use (i.e. until the early nineteenth century) agreement was reached jointly by the farmers of a village to begin the harvest. The maturity of rye is controlled by temperatures in June and, to a lesser extent, by those in May.

Wine harvests: In all those years for which an early flowering of vine or an early cereal harvest was reported (e.g. 1540, 1616, 1636-38, 1660, 1718 1719, 1811, 1822) wine harvests throughout Central and Western Europe were also very advanced. On the other hand the latest wine

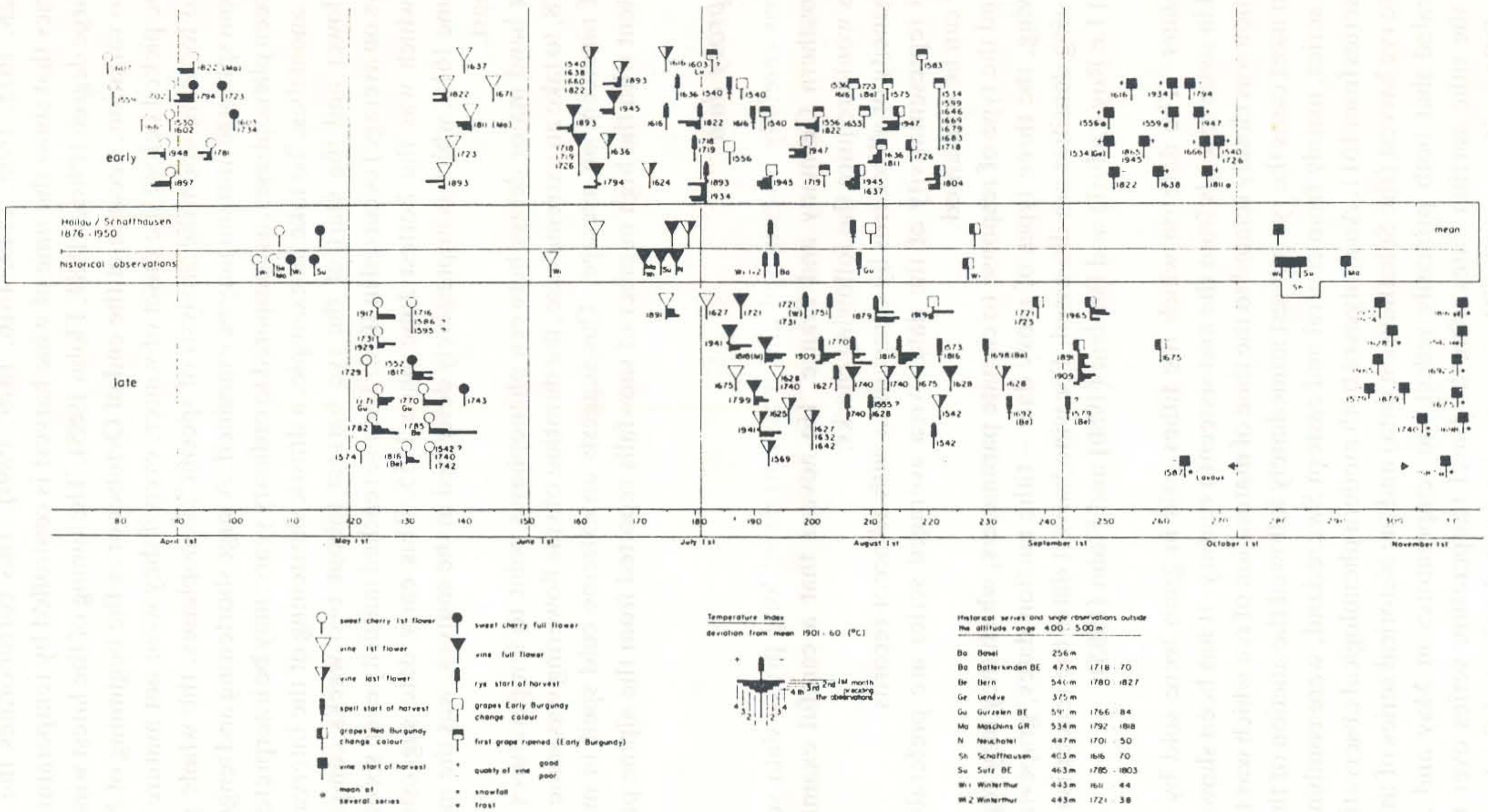

Figure 6.3 Dates of phenological events in Switzerland. Central panel shows the average dates of ten phenophases observed in the historical period (below center line) compared with the corresponding averages in the period 1876-1950 (above center line) based on observations in the Canton of Schaffhausen. Symbols above central panel indicate the earliest phenological events since 1525, those below the line indicate the latest events. For further explanation of symbols, see text.

harvests go along with a delayed bloom of the vine or a delayed cereal harvest (1542, 1555, 1573, 1627, 1628, 1675, 1698, 1740, 1816, 1879, 1980). This corroborates the results of statistical analyses that show the time of wine harvest is controlled by temperatures in May and June to a large degree (Pfister 1984; Flohn 1985). The timing of the latest wine harvests shows almost no variation, because at the end of October or at the beginning of November grapes had to be picked before the onset of winter, even if they were not mature yet.

In addition to focusing upon the analysis of specific phenophases, the whole pattern of phenophases from spring to autumn may be examined. A large shortening and lengthening of the period between phenophases, as compared to ordinary years, may be interpreted in terms of temperature anomalies. To take an example, a drastic shortening of the interval between the first vine flower and the start of the rye harvest (about two weeks compared with thirty-three days on average) occurred in 1616. The rye reached maturity even six days earlier than in 1822, which was the hottest June since 1755. This early date suggests that the heat-wave in June 1616, which is impressively described in the sources, was the most severe since 1525 at least.

On the other hand major delays between phenophases point to temperatures far below average. In 1628, to take an extreme case, the duration of vine flowering was some thirty-five days instead of nineteen, on average. This suggests an extreme cold spell in midsummer which is consistent with the high number of snowfalls reported from the alpine pastures.

6.4.4 Serial proxy data

Flohn (1985) has carefully investigated and cross-correlated long proxy data series from Switzerland, southern Germany and France. He advises that a careful examination of historical series would require the following checks:

1. the homogeneity of all records by comparison with adjacent records
2. the spatial representativity of the data. Area averaged series are preferable if their coherency can be warranted.
3. the time and the type of response to climate parameters, which they may represent.

In the following, the three types of proxy data – tithe auction dates, grapevine harvest yields and tree-ring densities are discussed. For wine harvest dates the reader is referred to Legrand (1979) Le Roy Ladurie and Baulant (1980) and Flohn (1985).

Tithe auction dates The date on which the tithes paid in grain were sold by auction is regularly listed in some records from the mid-sixteenth century. It has been shown, that the date of the auction was closely related to the time of maturation of rye which was the earliest winter grain. In most cases the rye harvest immediately followed the auction of the standing crops. 42 local series, mainly from central and eastern Switzerland, were combined into an area averaged series from 1611. An analysis of both modern phenological observations on the beginning of the rye harvest (the Schaffhausen data) and the historical series of tithe auction dates has revealed that both primarily reflect the temperatures in May and June. The correlation of the tithe auction dates with the Basel temperature series over the period 1755-1825 is $r=-0.8$ (significance <0.001). A comparison with the Central England temperature series over the period 1659-1758 has still yielded an astonishing $r=-0.68$ (significance <0.001) despite the large distance between the two countries. It follows from the model that an advance or a delay of the mean tithe auction dates of seven days corresponds roughly to a positive or a negative deviation of temperatures of 1°C in May and June taken together.

The area averaged series of Swiss tithe auction dates is highly correlated (r=>0.70) with the area averaged series of wine harvest dates (Le Roy Ladurie and Baulant 1980) which shows again that the latter are primarily tied to temperature patterns in May and June (Flohn 1985).

Grapevine harvest yields Until very recently (Pfister 1981b; Lauer and Frankenberg 1986) very little research has been devoted to fluctuations in grapevine harvest yields in historical times. This may be due to the fact, that modern investigations focus upon conditions in single vineyards, where local weather conditions, in particular late frosts, prevail over the large scale effects of temperature and rainfall. Moreover, reliable data from the pre-instrumental period are difficult to find and their interpretation is controversial. For the analysis long area-averaged series had to be established as a first step. Most of the secular series found in Swiss archives refer to vineyards owned by public institutions and authorities, which were cultivated by tenants according to share-cropping agreements. The production was divided between the tenant and the landlord, the latter's part being listed in the document. Some series give also the acreage of the vineyard. The earliest long record begins in the early sixteenth century; a sufficient number of series are available for the period after 1550.

Four regional series for different parts of the Swiss plateau, compiled from 17 local series, for which the acreage is not known show highly significant correlations (from r=0.56 to r=0.76) between each other. A Swiss area-averaged series was compiled from those four regional series. Likewise an area-averaged series was established from 20 local series, for which the acreage is known. In turned out that the two main series were highly correlated (r=0.85) (Pfister 1981b). Thus we may conclude that the former series, which goes farther back in time and which represents a larger volume of wine harvested, also reflects yields per acre for the most part. A stepwise regression analysis of this multisecular area-averaged series with the Basel temperature record yielded that July had the greatest weight, with R^2=0.29, June had R^2=0.16 whereas July of the previous year had R^2=0.13. The coefficients for August are not significant.

According to present day knowledge yearly fluctuations in wine yields are chiefly related to weather patterns in summer. High yields can be expected if temperatures in midsummer (June-July) are high, unless the water supply is deficient. On the other hand, cool and wet weather during and after flowering will hamper fertilization and the flowers may drop in the following. It must be stressed, however, that the effects of a widespread late frost, if it occurs repeatedly can almost annihilate the harvest, even when temperatures are favorable for growth and maturity in the following period. The statistical models should therefore always control for years with severe late frosts which are well known from the descriptive record. Flohn (1985) who from his models advised to use wine yields only cautiously as climatic indicators, did not exclude the years with heavy late frost. This was the reason while his results were not that convincing.

To conclude, the grapevine has three major advantages as a proxy:

1 The plant remains the same for twenty to fifty years. No annual planting is required.
2 The entire length of the growing season from March-April to September-October is needed to bring the grapes to maturity.

3 Harvest date, yield per acre and sugar content can be used as climatic proxy evidence for three different periods of the growing season: late spring-early summer, midsummer and late summer-early autumn (Pfister 1981b).

Dendroclimatic data Representative results can be expected from trees at the alpine timberline, where the temperature of the short vegetative period controls the growth rate. Significant progress has been made through the Roentgen density measurements of wood, which allow the evaluation of a quantitative parameter such as the density of late wood which is produced mainly during late summer. This data is a good proxy for temperatures in July, August and September (Schweingruber 1983; Flohn 1985). The well known series from Lauenen (Bernese Oberland) is included in the CLIMHIST data-bank (Schweingruber *et al.* 1978). A cross correlation with the Basel temperature series has revealed a weakness of these data. Whereas low densities are very reliable indicators for cool summers, some of the hottest summers in the last 450 years (1616, 1719, 1947) do not stand out in the record (Pfister 1985c). This suggests that cross-checking with anthropogenic evidence would certainly be helpful in the interpretation of tree-ring density data in this region.

6.4.5 Survey of proxy-data used as substitutes for thermometric measurement

Table 6.1 gives a survey of the proxy-information which has been used as substitutes for thermometric measurements. The data type taken as the best indicator for the temperature of an individual month is underlined. The winter months are primarily documented on the basis of snow and ice features, while plant indicators are the best evidence for the vegetative period. Most of the biological proxy-data used reflect the temperature pattern over a period of several months. The longer the period involved, the higher the precision of the estimate. No equivalent proxy exists for October and November. Moreover even descriptive observations are sometimes missing for those months before 1658.

6.5 Proxy substitutes for measured precipitation

6.5.1 Weather logs

Weather diaries can easily be quantified by counting the frequencies of events such as rain, snow, thunderstorms etc. Whether it pays to attempt the cumbersome operation of counting depends on the quality of the observation. Comparing frequencies based on qualitative data with frequencies based on measurements provides a useful check of reliability. We may rely on the assumption that the meteorological framework does not change dramatically over time. Yearly averages of days with precipitation obtained from the weather-logs of careful observers differ only insignificantly from those which are based upon measured daily precipitation of >0.3 mm. The quantified historical data may therefore be compared to 1901-60 statistics from the same or from a neighboring station. However, considering the diary of Wolfgang Haller (1545-1576) it turned out that the average was even somewhat below the days with measured precipitation of >1mm. In order to get at least a source-specific rough criterion for assessing the wetness of the individual months from this unique evidence the

Table 6.1 Survey of indicators used for the determination of the thermal charater of individual months.

Month	Cold	Warm
Dec., Jan.	Uninterrupted snow cover freezing of lakes	Scarcity of snow cover signs of vegetation
March	Long snow cover, high snow frequency	Sweet cherry first flower (±1.3°)
April	Snow cover and snow frequency, beech tree leaf emergence, sweet	beech tree leaf emergence (tithe auction date)
May	Tithe auction dates (±0.6°) Vine first flower (±1.2°) Barley harvest beginning	
June	Tithe auction dates (±0.6°) Vine full flower (±1.2°) Vine last flower Coloration of first grapes	
July	Vine yields (±0.6°) Coloration/maturity of first grapes	
April-July	Wine harvest dates (±0.6°)	
August	Wine yields (±0.6°) Tree ring density (±0.8°)	
September	Vine quality Tree-ring density (±0.8°)	
October	Snow cover, snow frequency	Reappearance of spring vegetation (cherry flowering etc.)
November	Long snow cover, high snow frequency freezing of lakes	No snowfall, cattle in pastures

The figures give the standard error of estimate in °C.

duodecile distribution (cf. Table 6.4) of the days with observed precipitation in the diary was computed for every calendar month.

6.5.2 *Floods and low water levels*

Evidence that bears on floods and low water marks is found in written sources and also in form of marks on buildings. From the eighteenth century water-gauges have been installed on the major rivers and lakes. In order to exclude local events the analysis has focussed upon the large rivers (Rhine, Rhone, Aare) and on the major lakes in the Swiss lowlands.

A quantitative estimate on floods may be obtained by cross checking marks of historical floods on buildings with measured discharge or precipitation. In Basel, where the Rhine drains almost two thirds of the surface of Switzerland, monthly discharge of the river has been measured since 1808. Some hundred meters upstream from the water-gauge the level of some of the major floods within the last few centuries is marked on the building located at Oberer

Rheinweg 93. A comparison of this evidence allows 'calibrating' the descriptive data with the measured discharge record. Moreover, the old observers often compared the observed floods to previous ones, sometimes in quantitative terms or with reference to marks on buildings which have since been pulled down. Combining all the existing evidence has allowed the rank order of the most severe floods at Basel since the mid sixteenth century to be established.

In interpreting flood records it is essential to consider the time of the year and the nature of the drainage basin. Heavy floods of the major Swiss rivers in early summer are sometimes the result of the melting of unusually large amounts of snow in the mountains (e.g. 1817). Therefore we must also consider the snow record in order to assess the relative proportion of snow-melt and heavy rainfall for the event. The interpretation must also allow for corrections of the river and for changes in the level of buildings which might have occurred over time.

Low water levels are quite reliable indicators of precipitation patterns. They occur mostly in winter and spring during long spells of anticyclonic weather. Because they had almost no economic impact they are less frequently described in the sources than floods. Sources specify for some cases, how far one could walk in a river-bed which had partially dried up. Occasionally, extremely low water levels were marked on rocks which emerged, when the water was very low. This evidence is again 'calibrated' by comparing the older marks to more recent ones and to that of water-gauges.

6.6 Coding and editing the evidence: the CLIMHIST data-bank

The collected material was analyzed by a set of computer programs which had been specifically developed for this purpose. The descriptive evidence was converted into numerical form by means of a comprehensive code. Those observations which couldn't be expressed by the code, were literally written on a specific file to be included into the final version of the output in form of footnotes. Moreover, each type of serial proxy-data had to be homogenized and calibrated by means of standard software, before it was included into the data pool. Finally the entire evidence was pre-processed and sorted according to time, type of data and region. Subsequently the resulting data-bank was reconverted into a weather chronology called CLIMHIST-CH. It lists each of the 33,000 records including all the attributes, that are necessary for the interpretation, such as place and altitude of observation, name of the observer (if the data is contemporary) the style of the original observation etc. (Pfister and Schwarz-Zanetti 1986). Weather patterns and their impacts upon the hydrosphere, the biosphere and society (agricultural prices, diseases etc.) are given in a temporal frame of ten day periods, months or seasons. Serial information such as the number of days with precipitation or early instrumental measurements is compared to that of the 1901-60 reference period. The date of phenological observations is converted to days of the year. Serial proxy-data are given as deviations from their average or in terms of standard deviations.

The program sequence conveniently allows for error-correction or updating when new evidence is discovered, even including new footnotes (Pfister 1985a). At present four routines are availble that reconvert the numerical code into English, French, Italian or German. Routines for any additional language might be set up from corresponding translations of the code-book. Originally the program was tailored to Swiss data. In the meantime improved versions have been devised that handle data from all over Europe.

Table 6.2 provides the information for August 1723 as an example. Each record is explained by a number of attributes: **R** indicates to the meteorological region in which the place of observation is located. If the name of the observer is listed, this means that the data is contemporary. **S** is related to the source number in the bibliography. **F** followed by a number would refer to a footnote in the appendix.

Table 6.2 Example of an entry in the CLIMHIST data bank (Pfister 1985a) (see discussion of coding in text).

1723 August

1st ten day period
Warm/Hot. Preponderantly sunny (shorter periods of rain). **R**:2 Winterthur: 442m (Rieter, S 90).
Continuing rain (no statement). **R**:10 Stans:452m (Buenti, S 146)

2nd ten day period
Warm. Preponderantly sunny (isolated thunderstaorms). **R**:2 Winterthur: 442m (Rieter, S 90)
Preponderantly sunny (no statement). **R**:10 Stans: 452m (Buenti, S 146).
First red berries 8 11th (223) R:2 Winterthur:442m (Rieter, S 90)

3rd ten day period
Hot. Preponderantly sunny (isolated rain). **R**:2 Winterthur:442m (Rieter, S 90).
Preponderantly sunny (no statement). **R**:10: 452m (Buenti, S 146)

Entire month
Hot. Continuing rain. **R**:8 St. Blaise NE:433m (Peter, S 220)
Warm. Preponderantly sunny. **R**:5 Baetterkinden, Be: 473m (Wieniger, S 268).
Dry 87mm (mean:132mm). **R**:6 Zuerich:408m (Schuechzer, S 237)
Dry 10 days of PR (M:14 days) Warm **R**:2 Winterthur:442m (Rieter, S 90)

Temperature Index: 2, Warm. **Precipitation Index**: -2, Dry.

The first three paragraphs in Table 6.2 give information which is available according to ten day-periods (five day-periods are separated with a slash). The last paragraph is related to the data that refer to the entire month. In the example, rainfall at Zürich measured by Scheuchzer, and the number of days with precipitation computed from the Rieter diary, are compared to the duodecile statistic for the period 1901-60 at the same place. The thermal and wetness indices listed on the last line are estimates for temperature and precipitation derived from all the evidence by the interpreter (see the following section).

6.7 Deriving monthly indices

Estimates for temperatures and precipitation are estimated from regression models, that include series of proxy data and instrumental measurements. Significant results are obtained for periods of two or three months only. The models cannot account for shorter periods, because the variety of the underlying pattern of cold and heat spells is too large. However, this missing information is obtained from descriptive sources. To take an example, the opening of the first vine flower in a vineyard is bound to temperatures in April and May. An early flowering at the end of May may occur after an exceptional heat-wave in April followed by an average temperature in May, or after a long warm spell in May preceded by average weather in April. Based upon detailed descriptive evidence we might be able to decide which of the two patterns is more likely to have occurred. This then allows a monthly temperature profile, i.e. the 'excess of warmth' to be estimated for the entire period from the regression attributed to an individual month in an interpretative way. This takes into account all the quantitative and qualitative information available for the period. From this example it has been demonstrated, how the two kinds of evidence, proxy data and descriptive sources, control and complement each other. We may conclude that they form a coherent body of information, from which estimates of monthly temperature and precipitation patterns are obtained, based upon a synthesis of statistical reasoning and contextual interpretation.

Two types of indices, a weighted and an unweighted index, have been derived. For the weighted index, the frequency distribution of monthly means for the period from 1901-1960 was adopted as the standard of comparison (Table 6.3).

Table 6.3 The definition of the weighted temperature and precipitation index values over the period 1901-1960.

	lowest <------						-------> highest
	8.3%	16.6%	16.6%	16.6%	16.6%	16.6%	8.3%
Duodecile	1	3	5	7	9	11	
Index	-3	-2	-1	0	+1	+2	+3

The value of 0 was used for 'normal' weather conditions and for all months for which the evidence is missing. The values of +3 and -3 were applied to those cases which can unmistakably be considered as "extreme" by twentieth century standards. The values of +2 to -2 were adopted for the less marked gradations. The values of +1 to -1 were applied to all months for which only descriptive evidence is available as well as to those months which according to proxy information fall in the corresponding range of temperature and precipitation (cf. Table 6.3).

For precipitation two separate indices have been computed. The first, a frequency index, draws from the number of rainy days in Basel and Geneva, while the second, a rainfall index, is based upon measured precipitation at Geneva, Zürich and Bern. Subsequently, the two indices have been merged (cf. Pfister 1984, Table 1.26). Within the instrumental period the indices were computed from measured temperature and precipitation according to the duodecile distribution of the values (cf. Table 6.4). The unweighted index downgrades all the positive or negative weights to three gradations: +1, 0 and -1. Accordingly this index is more homogeneous than the weighted one, but is does not fully exploit the informative potential of the data. Which of the two indices is more 'realistic' depends on the quality of the evidence.

Table 6.4 Standard errors in estimating temperature (°C) and precipitation (%) from indices for the period 1864-1979.

Month/ Season	Temperature Index *unweighted*	*weighted*	Precipitation Index *unweighted*	*weighted*
January	0.4°	0.26°	12.8%	6.5
February	0.34°	0.26°	12.6%	11.4%
March	0.28°	0.18°	11.6%	9.2%
April	0.21°	0.11°	9.8%	9.6%
May	0.29°	0.16°	8.2%	7.1%
June	0.22°	0.16°	7.5%	6.7%
July	0.21°	0.11°	8.0%	6.6%
August	0.22°	0.14°	3.8%	5.0%
September	0.25°	0.14°	7.0%	11.7%
October	0.27°	0.13°	18.9%	18.1%
November	0.34°	0.19°	18.8%	13.7%
December	0.55°	0.35°	13.8%	12.6%
Spring	0.15°	0.1°	7.7%	7.2%
Summer	0.15°	0.1°	4.2%	2.9%
Autumn	0.15°	0.13°	9.4%	7.5%
Winter	0.25°	0.2°	9.5%	7.5%
Year	0.12°	0.08°	6.4%	5.2%

An earlier version of the indices has been published in Pfister (1981a). However, the indices have been considerably improved since, as new evidence has been found. The reader is therefore referred to the values published in Pfister (1984) and to the CLIMHIST data-bank in which all the basic evidence can be scrutinized (Pfister 1985a).

6.8 Estimates of temperature and precipitation from transfer functions

In order to bridge the gap between the history of weather and the history of climate, monthly temperature and precipitation patterns for the pre-instrumental period have been estimated from the indices. For every calendar month and for every season a model has been set up which, for the period of network observation from 1864, compares the weighted and unweighted indices (computed from the record) with the record itself. This has yielded a set of transfer functions for estimating temperature and precipitation patterns on the basis of the indices.

For temperatures, the deviations of the Basel series (1755-1979) from the 1901-60 average were included in the regression model . Precipitation series covering the whole country for the entire period, were not available in sufficient number. Instead the analysis was done by means of six series from the Swiss 'Mittelland' – Geneva, Bern, Zürich, Basel, Einsiedeln and St. Gallen – where precipitation has been measured from 1864 to 1979. It turned out that the models yielded excessively large standard errors for individual months. Thus estimates were attempted for decennial averages only. In interpreting the standard errors for the decennial averages (Table 6.4) we should bear in mind, that they are obtained from the transformation of measured data. For the pre-instrumental period, the 'true' standard deviations are certainly larger for the weighted indices, because the nature of the evidence and the process of interpretation involves additional biases. On the other hand, they are probably smaller than those obtained for the unweighted indices (Table 6.4), because the evidence allows for more than just simply distinguishing between 'warm', 'cold' and 'average' months (provided that we ignore the period prior to 1550 and the data for autumn prior to the late seventeenth century).

6.9 Patterns of temperature and precipitation since the time of the Reformation

The results of the reconstruction will only briefly be discussed. Figure 6.4 shows deviations from the means of the 1901-1960 reference period in form of 11 year moving averages. Positive temperature deviations are shown above the line, negative deviations below. Precipitation is shaded and shown in the same way as temperature.

Considering the long time-scale temperature and precipitation patterns, no clear pattern emerges for the four seasons and the year. A 'Little Ice Age', that might be associated with the known fluctuations of glaciers, is hard to detect. In contrast to the twentieth century three features are common to the preceding centuries :

1 Winter and spring months tended to be colder and drier. This holds especially for March.
2 The climate was more variable – in particular around 1600 – and in many cases the extremes were more marked than those registered in the instrumental period.
3 Fluctuations of the same type occurred repeatedly and often simultaneously in winter, spring and summer (e.g. 1569-1574, 1586-1589, 1688-1694, 1769-71).

However, summer periods were not significantly colder in the 'Little Ice Age' than in the present century, although it is well-known that glacier fluctuations are generally related to temperature in summer. A tendency towards increased precipitation is apparent, in particular for the late 16th century and for the 18th century. Quite often a warm and dry period in August followed after a rainy and cool spell in June and July.

Temperature patterns in the autumns are rather balanced up to 1670, and this season was rather dry over this period. Up to the early twentieth century autumns were colder than since and they included both wet and dry phases.

If changes over time are considered, a marked contrast stands out between the second third and the last third of the 16th century. Apart from the winters, the weather conditions that predominated from 1530 to 1560 proved nearly as favorable as those that have prevailed during the climatic optimum of the twentieth century. Over the following decades, then, annual mean temperatures declined by more than 0.6°C. Summers became about 0.8°C colder and more than 20% wetter. A marked increase in summer wetness was also observed in northern Germany (Lenke 1968). By the 1580s the broad Denmark Strait between Iceland and Greenland was often found entirely blocked by pack-ice during the summer (Lamb 1982). In Switzerland the frequency of severe floods in the last third of the 16th century

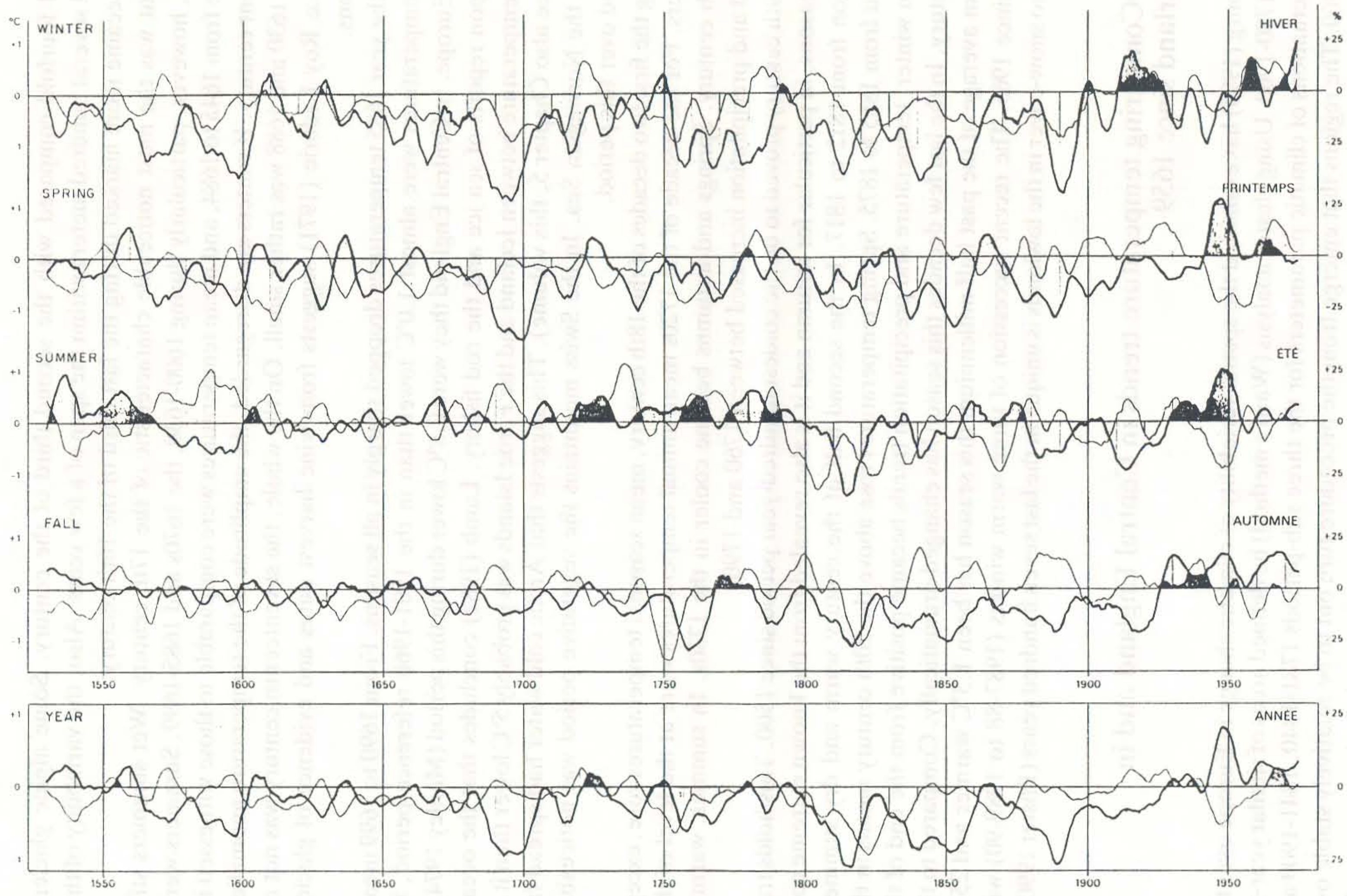

Figure 6.4 Temperature and precipitation estimates for Switzerland (11 year moving averages) expressed as departures from the mean for 1901-60.

increased fourfold compared with the second third of the century. Some alpine glaciers advanced several hundred meters within the span of a few years. Also, the variability of the climate became more marked during the last third of the 16th century.

Drought was the most noticeable characteristic of the 17th century. Wet summers still occurred, however, particularly during 1600-1630, the 1670s and 1685-1699. Summers were moderate from 1645 to 1684, and mean temperatures were comparable to those witnessed in the present century. If winters are disregarded, the amplitude of the temperature anomalies between 1630 and 1688 was rather small. On the whole, the seventeenth century was not as cold as Le Roy Ladurie (1971) suggests from wine harvest dates and evidence of glacier fluctuations.

After the year 1685 temperatures dropped sharply in all seasons. From 1690 to 1699 mean annual temperatures were almost 1.0°C lower than in the 1901-1960 reference period, in Central Europe. In Central England they were 0.8°C lower during this period (Manley 1974). Based upon reports of sea ice and the cod fishery, Lamb (1982) concludes that the ocean surface temperature between Iceland and the Faroe Islands was probably 5°C lower than it is today (see also Chapter 5, this volume). This suggests that Arctic cold water had spread far south to the Norwegian Sea. In the Swiss mountains the vegetative period was noticeably shortened over this period.

During the first two decades of the 18th century, mean seasonal temperatures rose, except for winters. For the decade of the 1720s mean annual temperatures were at the level of the twentieth century. Springs and autumns became cooler in the 1730s. In summer, warmth persisted and precipitation increased between 1760 and 1790.

The 19th century proved to be the coldest hundred-year period since 1500. This holds true for all seasons, in particular for autumn and it is also revealed from the known extreme cold fluctuation from 1812 to 1817. In the second half of the century warm and dry summers prevailed from 1855 to 1875. Spring temperatures rose above the 20th century means in the 1860s. In winter, temperature and precipitation trends became positive from the end of the 19th century. In the last few decades this season has changed dramatically. Compared to the long term average of the past half millennium this season has been 1.3°C warmer and 25% wetter since 1965. The recent succession of three warm winters (1987-88 to 1989-90) with almost no snow-cover in the lowlands is unique in the last seven hundred years (Pfister 1990).

6.10 Comparing temperature trends in Central England and in Switzerland since 1659

Lauterburg (1990) has examined the spatial variability of climatic change in Europe over the period 1780-1960. Using cluster analysis (Ward's method) he defined areas of similar year-to-year fluctuations of climatic parameters for the three sub-periods 1781-1840, 1841-1900 and 1901-1960. The regions that emerge from the procedure turn out to be relatively stable over time from one sub-period to another for spring and summer, whereas they change somewhat for autumn and winter.

Based upon the Swiss temperature indices and the Central England temperature series (Manley 1974) this comparison was extended back to 1659. From this year the Manley series begins, and monthly weather in Switzerland is described continuously, i.e. the series of temperature indices doesn't include any missing months. The entire period of three hundred years was split into three sub-periods of approximately equal length for the analysis. In the first one (1659-1754) the Swiss indices are based upon descriptive and proxy data. The second period (1755-1863) is covered by instrumental measurements. The third period (1864-1960) is that of the detailed observational network.

The Central England series was transformed into indices to adjust it to the level of measurement of the Swiss series (cf. Table 6.5). The Gamma coefficient (which is a symmetrical measure for association of two ordinal variables) was used for the correlation, because of the Pearson correlation coefficient is not appropriate for ordinal data. Gamma can achieve limiting values of -1.0 or + 1.0 regardless of the number of ties (Loether and McTavish 1974).

All coefficients between the two series are highly significant, even those for the first period, which is not covered by instrumental measurement (Table 6.5). This confirms the reliability of the Swiss data. However, the seasonal and yearly correlations (autumn excepted) are somewhat lower for the first sub-period 1659-1754. This is almost certainly due to the semi-quantitative evidence on which the Swiss indices are based. On the other hand it might also be due to changes in the frequency of weather patterns to some extent. Considering correlations of monthly variables, the difference between the first sub-period and the two others is particularly large for July and August. This might be related to the fact that phenological indicators for summer temperatures are more related to June than to July and August (tree-ring densities excepted).

Table 6.5 Gamma correlation coefficients between the Central England temperature series and the Swiss temperature series 1659-1960.

Month	1659-1980	1755-1754	1864-1863	1959-1960
January	0.669	0.594	0.734	0.668
February	0.645	0.578	0.648	0.677
March	0.612	0.544	0.667	0.653
April	0.667	0.619	0.678	0.678
May	0.609	0.501	0.682	0.635
June	0.471	0.452	0.490	0.540
July	0.658	0.467	0.664	0.786
August	0.540	0.396	0.560	0.619
September	0.571	0.502	0.650	0.600
October	0.498	0.483	0.478	0.566
November	0.461	0.467	0.391	0.510
December	0.548	0.588	0.564	0.589
Winter(12-2)	0.552	0.509	0.582	0.564
Spring	0.544	0.496	0.598	0.588
Summer	0.461	0.374	0.487	0.530
Autumn	0.438	0.437	0.436	0.455
Year	0.484	0.431	0.554	0.499

Significance: < 0.0001 for all pairs of variables

Surprisingly, correlations for October, November and December are somewhat higher in the first sub-period, when the Swiss series is based on semi-quantitative data, compared to the second one, when it is based on measured temperature. This might be related to prevailing weather patterns that differ somewhat from those prevailing in the preceding and the following period.

6.11 Beyond time series analysis: establishing historical weather maps

Most reconstructions of climate from natural or man-made archives are presented in the form of time series. The climatic variations shown refer to areas, that have the dimension of a German Bundesland, an Italian Province or a small nation such as Switzerland. The focus is primarily on improving the time resolution of the findings down to seasons and month and on interpreting the results by the means of statistical techniques that become more and more sophisticated.

Compared to time-series analysis the investigation of the spatial dimension of climatic change has been neglected so far. It has not been sufficiently realised that regional time series are not isolated pieces of evidence, which may be interpreted for their own sake, but that they should be related to a larger entity which is the global climate system. A comparison cannot be done just by comparing fluctuations in time series as it has been done so far. In order to provide a coherent picture of climatic change in space and over time we need to focus upon

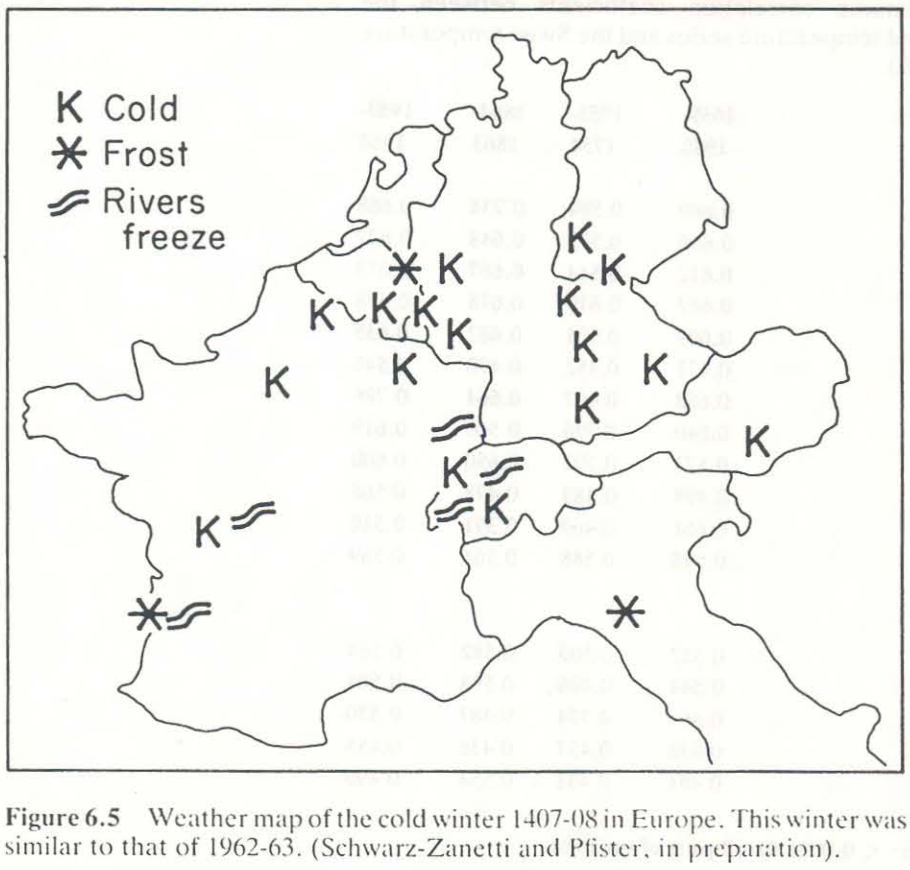

Figure 6.5 Weather map of the cold winter 1407-08 in Europe. This winter was similar to that of 1962-63. (Schwarz-Zanetti and Pfister, in preparation).

the analysis of this system. All reconstructions of climatic change that have already been obtained at a regional scale need to be compared on a common basis. This requires a common standard of representation for scholars from all over Europe. On this continental level, analysis of climatic change should be represented in terms of historical weather maps, that show the spatial dimension of outstanding anomalies (Figure 6.5) and trends related to coherent regions (Lauterburg 1990).

In order to initiate international cooperation directed towards this goal, a workshop was held recently by the European Science Foundation (E.S.F.) at the Academy in Mainz. Scholars from 14 European countries and from Japan discussed the standardization of historical climatology and the creation of an international data-bank for the history of climate which might become the basis for a new spatial image of climatic change (Frenzel and Pfister, in preparation).

References

Alexandre, P., 1987: *Le Climat en Europe au Moyen-Age. Contribution à l'histoire des variations climatiques de 1000 1425, d'après les sources narratives de l'Europe occidentale.* Paris Ed. de l'Ecole des Hautes Etudes en Sciences Sociales.

Bell, W and Ogilvie, A. E., 1978: Weather Compilations as a Source of Data for the Reconstruction of European Climate during the Medieval Period. *Climatic Change*, 1 (4) 331-348.

Flinn, M., 1981: *The European Demographic System 1500-1820*. Baltimore Md.

Flohn, H., 1949: Klima und Witterungsablauf in Zürich im 16. Jahrhundert. In: *Vierteljahrsschrift der Naturforschenden Gesellschaft*. Zürich, 94 (1) 28-41.

Flohn, H. 1985: A critical assessment of proxy data for climatic reconstruction. In: *The Climatic Scene*, ed. by M. J. Tooley & G. M. Sheail. Allen & Unwin, London, p.93-103.

Georgelin, J., 1979: L'écologie du froment en Europe occidentale. *Cahiers des Etudes rurales* IV. S. 569-582.

Hanus, H. and Aimiller, O., 1978: Ertragsvorhersage aus Witterungsdaten. *Beiheft z. Zeitschrift für Acker- und Pflanzenbau* Jg. 5, Berlin.

Ingram, M., Underhill, D., Farmer, G., 1981: The Use of Documentary Sources for the Study of Past Climate. In: *Climate and History*, ed. T. M. L. Wigley *et al.*, Cambridge University Press, Cambridge, p. 180-213.

Kington, J. A., 1974: An application of phenological data to historical climatology. *Weather*, 29 (9), 320-328.

Klemm, F., 1974: Die Entwicklung der meteorologischen Beobachtungen in der Schweiz bis zum Jahre 1700. In: *Viertejahrsschrift der Naturforschenden Gesellschaft* Zürich, 119 (4), 405-454.

Lamb, H. H., 1981: An approach to the study of the development of climate and its impact in human affairs. In: *Climate and History*, ed. T. M. L. Wigley *et al.*, Cambridge University Press, Cambridge, p. 291-310.

Lamb, H. H., 1982: *Climate, history and the modern world*. Methuen, London.

Lauer, W. and Frankenberg, P., 1986: *Zur Rekonstruktion des Klimas im Bereich der Rheinpfalz seit*

Mitte des 16. Jahrhunderts mit Hilfe von Zeitreihen der Weinquantität und Weinqualität. Stuttgart (Fischer).

Lauterburg, A., 1990: Klimaschwankungen in Europa. Raum-zeitliche Untersuchungen in der Periode 1841-1960. *Geographica Bernensia* G 35. Bern Geographisches Institut der Universität, Bern.

Legrand, J. P., 1979: L'expression de la vigne au travers du climat depuis le Moyen-Age. In: *Revue Française d'Oenologie*, 75, 23-50.

Lenke, W., 1968: Das Klima Ende des 16. und Anfang des 17. Jahrhunderts nach Beobachtungen von Tycho de Brahe auf Hven im Sund DK, Leopold III. Treuttwein in Fürstenfeld Oberbayern und David Fabricius in Ostfriesland. *Berichte des dt. Wetterdienstes*, 15. Offenbach.

Le Roy Ladurie, E. 1971: Times of Feast, Times of Famine. A history of climate since the year 1000. London (Allen & Unwin). (Translation of the 1967 French edition: L'histoire du climat depuis l'an mil. Paris).

Le Roy Ladurie, E. and Baulant, M. 1980: Grape Harvests from the fifteenth through the nineteenth Centuries. In: *J. of Interdisciplinary History* 10 (4) 839-849.

Loether, H. J. and McTavish D. G., 1974: *Descriptive Statistics for Sociologists. An introduction*. Allyn and Bacon, Boston.

Manley, G., 1974: Central England temperatures: monthly means 1659 to 1973. *Quarterly J. Royal Meteorological Society* 100, 389-405.

Pfister, C., 1977: Zum Klima des Raumes Zürich im späten 17. und frühen 18. Jahrhundert. In: *Vierteljahrsschrift der Naturforschenden Gesellschaft Zürich*, 122 (4) 447-471.

Pfister, C., 1979: Getreide-Erntebeginn und Frühsommertemperaturen im schweizerischen Mittelland seit dem frühen 17. Jahrhundert. *Geographica Helvetica*, 34, 23-35.

Pfister, C., 1980: The Little Ice Age: Thermal and Wetness Indices for Central Europe. *Journal of Interdisciplinary History*, 10 (4) 665-696.

Pfister, C., 1981a: An analysis of the Little Ice Age climate in Switzerland and its consequences for agricultural production. In: *Climate and History*, ed. T. M. L. Wigley *et al.*, Cambridge University Press, Cambridge, p.214-247.

Pfister, C., 1981b: Die Fluktuationen der Weinmosterträge im Schweizerischen Weinland vom 16. bis ins frühe 19. Jahrhundert. Klimatische Ursachen und sozio-ökonomische Bedeutung. *Schweiz Zeitschrift für Geschichte*, 31 (4) 445-491.

Pfister, C., 1984: *Klimageschichte der Schweiz 1525-1860. Das Klima der Schweiz von 1525-1860 und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft*. 2 volp. Bern. 3rd. ed. 1988.

Pfister, C. 1985a: *CLIMHIST – a weather data bank for Central Europe 1525 to 1863*. May be ordered from METEOTEST, Fabrikstr. 29a, CH 3012 Berne.

Pfister, C. 1985b: Snow Cover, snow lines and glaciers in Central Europe since the 16th century. In: *The Climatic Scene*, ed. by M. J. Tooley and G. M. Sheail. Allen and Unwin, London, 154-174.

Pfister, C., 1985c: Veränderungen der Sommerwitterng im südlichen Mitteleuropa von 1270-1400 als Auftakt zum Gletscherhochstand der Neuzeit. *Geographica Helvetica* 4, 186-194.

Pfister, C. 1988: Variations in the Spring-Summer Climate of Central Europe from the High Middle Ages to 1850. In: Wanner, H. and Siegenthaler, U. (eds.) *Long and Short-term variability of Climate*, Springer, Berlin p. 57-82.

Pfister, C. 1990: Einmalig in 700 Jahren: Drei warme Winter hintereinander. Unser Wetter im Lichte der historischen Klimaforschung. *Neue Zürcher Zeitung* 82, 7(8). April, p. 23-4. Pfister, C., Schwarz-Zanetti W. und G., 1986: Ein Programm- und Methodenpaket zur Rekonstruktion von Klimaverhältnissen seit dem Hochmittelalter. In: *Datenbanken und Datenverwaltungssysteme als Werkzeuge historischer Forschung*, Historisch-sozialwissenschaftliche Forschungen, ed. Bd. 20, p. 75-92.

Schüepp, M., 1980: Methoden und Probleme der Bearbeitung langjähriger meteorologischer Beobachtungsreihen. In: *Das Klima, Analysen und Modelle, Geschichte und Zukunft*, ed. H. Oeschger, B. Messerli, M. Svilar. Berlin, p. 191-206.

Schweingruber, F., *et al.*, 1978: The X-Ray Technique as Applied to Dendroclimatology. *Tree-Ring Bulletin*, 38, 61-91.
Schweingruber, F., 1983: *Der Jahrring. Standort, Methodik, Zeit und Klima in der Dendrochronologie.* Bern (Haupt).

Witmer, U., 1986: Erfassung, Bearbeitung und Kartierung von Schneedaten in der Schweiz. *Geographica Bernensia* G 25. Bern.