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Abstract: The present contribution concerns with the course of temperatures in central Europe since the year 1000 A.D. Based on index calculations the various climatic phases, such as the Medieval Thermal Optimum and the Little Ice Age are discussed at the decennial level. For the time after 1500 A.D. a monthly subdivision is presented which especially lends itself to more detailed interpretations e.g. in the fields of agricultural and social history. By means of regression analysis temperature levels and annual mean temperatures are calculated, allowing an assessment of the major periods. The study reveals the great dimensions of natural fluctuation in the course of temperature in central Europe, hopefully contributing to a better understanding of Man-and-Environment relationship.

1. Introduction

It is the aim of historical climatology to establish concrete and long time series, as long as possible, extending into the modern climate-measuring period or being related to it. Also of interest are unique extreme events which may serve as analogies to modem climate-induced natural catastrophies which may climatologically be rated as anomalies. A further approach is concerned with historical synoptic weather analysis, the results of which may then become part of global scenarios and the modeling of future climatic conditions.

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In the first place it yields the kind of insights that lead to a better assessment of climatic developments because of the broadened time base. Furthermore it will contribute to a better understanding of the system of man-environment interrelationship, as any analysis must remain incomplete without a thorough knowledge of the climatic side, which in turn cannot be developed without including the climatic past.

Historical climatology is based on a broad array of data types, ranging from direct information on climatic events, which tend to be more or less sporadic, but which may also be systematic when occuring in the form of diaries, to proxy data such as catastrophic flood records or agricultural production figures. It goes without saying that the various types of data and their decoding with respect to climatic information call for a whole range of methods taken from natural science and historical research (cf. *Pfister* 1985, *Alexandre* 1987, *Birrong & Schönwiese* 1987, *Bradley & Jones* 1992, *Chernavskaya* 1994, *Rodrigo, Esteban-Parra & Castro-Diez; Brazdil & Kotyza* 1995, *Munzar* 1995, *Glaser* 1996).

There are two sets of problems to be tackled with respect to the presentation of these diverse data types: one - because of this diversity - is the search for a common system of extracting and presenting the data in order to make them comparable, the other one is concerned with time scale and subdivisions. There is a number of possible approaches. A common one is the derivation of indices. In this approach rankings are derived from the semantic analysis of the descriptive information and the proxy data, leading to a not insignificant level of abstraction. Taking in account certain restrictions it is possible to recalculate these indices into climatic figures. Good results have been obtained for monthly, seasonal and annual time series. As from the more distant past (roughly between 1000 and 1400 AD) information tends to be rather sporadic or refers to longer periods of time in a generalizing way, time series at best go to the level of decades. With the larger amount of data available and with higher time subdivision of time monthly indices can be calculated. Beginning around 1700 A.D. continuous instrument records are available.

The following chapters present the results obtained from those index calculations at various temporal scales.

2. The course of temperatures over the last 1,000 years in central Europe based on decennial indices

For the first presentation an approach was chosen in the tradition of *Brooks* (1954), *Baron* (1982), *Lamb* (1977), *Ladurie* (1983), *Pfister* (1985) and *Alexandre* (1987). Base and backbone of the time series are the descriptive monthly or seasonal data placed in hierarchical order and with index numbers attached to them. They make up the bulk of the sources for the chosen period, and though rather incomplete until 1200 A.D., they get increasingly dense both in space and time. The value levels given are ranging from -3 to +3. For several periods after the year 1400 A.D. daily weather observations can be retrieved. Data extracted of various weather elements with a standard deviation of 0.75 were equally transformed into positive and negative indices. Of special importance for the establishment of index series are the proxy data which cover the complete time interval, and especially a number of dendrochronological data series. To this we can add the historical instrument records which date back to the end of the 17th century, and, finally, the first official records which begin in 1810 (cf. *Rudloff* 1967; *Brumme* 1981; *Demarre, van Engelen & Geurts* 1994).

In the time series presented here, which are beginning with the year 1000 A.D. and are referring to 10-year intervals, seasons that have unequivocally been warm or hot are juxtaposed to others described as cool or cold. The hatched area shows the difference and gives an idea of the overall thermal regime. The time series are regional averages for the area of the Federal Republic of Germany, with emphasis on the western and southern segments. The indices were not weighed up, i.e. the positive or negative deviations in the sources were listed only with regard to their intensity. As mentioned before, the results obtained by means of this simple but informative method are subject to certain restrictions that should be taken into consideration when the data are interpreted. The sources are rather incomplete, both with regard to time and region, and especially the time aspect reflects in the quality of the results. The further back in time we go, the more incomplete records become. For only about 35% of the years between 1000 and 1099 A.D. information is available. For the period between 1100 to 1299 the figure rises to 85%, for the time between 1300 to 1499 it is 90%, and from 1500 A.D. onwards every year is documented. Prior to 1500 A.D. western and southern Germany, especially the Rhine valley, are overrepresented in the regional distribution of data, while after 1500 with the larger amount of data a more differentiated picture can be drawn of northern and eastern Germany.

In spite of the different concentration of data with regard to time and region, index series show marked positive and negative deviations from the mean value. Differences in the density of data also present themselves on the seasonal level: winter and summer conditions are more frequently referred to than the intermediate seasons. This is due to the fact that during the Middle Ages the year was generally subdivided in two parts only. The same observation can be made for the later centuries, but there it may be due to the greater importance for agriculture.

2.1 An interpretation of decennial index series

Any reference given to a complete decade is a deliberate generalization of the course of climate, but it allows to present an superordinate trend of such long series. At the same time a presentation like this protects from overinterpretation. By way of analyzing these climatic series the continuous variations of the curve catch the eye immediately. The courses of summer and winter temperatures have always displayed a high fluctuation, both to the „positive" and to the „negative" side. There are distinctive periods showing such a deviation for a longer period, which are of special interest to the analyst. In a joint analysis of the two time series it becomes evident, however, that - all through the centuries - during the winter season there is a tendency towards the negative, and during the summers towards the positive side. The mean of the decennial values of the total period is at 0.9 Celsius for the summers and -1.4 Celsius for the winters. This may be taken as an indication that the winter seasons were predominantly cold, while the summers in correspondance were warm to hot, what is confirmed in the sources. Consequently the mean values give an idea of the basic characteristics of the respective seasons. At the same time it gets evident that average seasons are not worth mentioning, or that there was a general tendency to push summer temperatures up and winter temperatures down. An objective assessment of the deviations might be made by comparision with the seasonal variations only, that are derived from the instrument readings beginning in 1810. It must be repeated here that the figures presented here allow a rough estimate of the tendency, average course and intensity of a deviation only, which in turn correspond to derived temperature levels.

2.1.1 The course of winter temperatures

Taking all winter indices together there is a bias towards negative values for the winter temperatures. This observation, which also finds its expression in the mean value of -1.4 for the whole observation period, may be interpreted to mean that even average winters were perceived as being cold, resulting in the overrepresentation of cold winters in the decennial figures. Therefore, in interpreting the data series, not only the zero line, but also the -1.4 mean value should be taken into consideration.

The winter weather conditions of the 11th century, similar to the course of summer temperatures, can be reconstructed, though in rather an incomplete way only. Yet it is interesting to note that the few records existant give evidence of negative, i.e. clearly cold winter conditions only. Taken as a whole the winter balances of the entire 11th century are from below average to average. The most significant event on this scale were the extremely cold winters between 1071 and 1080. One should be aware, though, that as the same winter might be referred to in two consecutive years, there is a hazard of double counts, which might sum up to an artificial extreme. But even with the most

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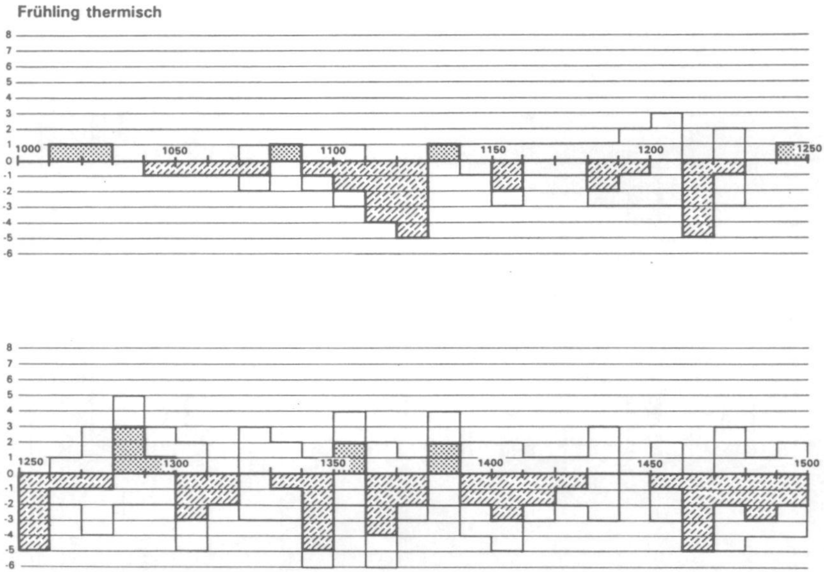
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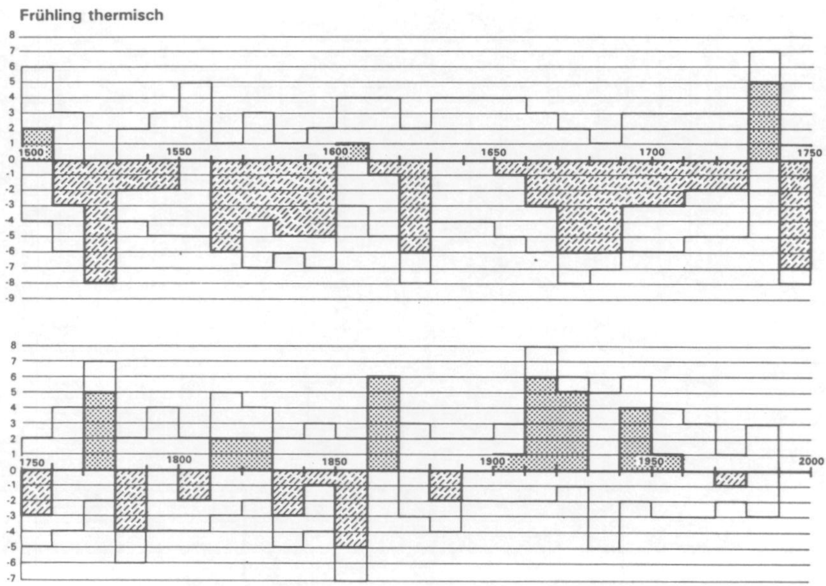
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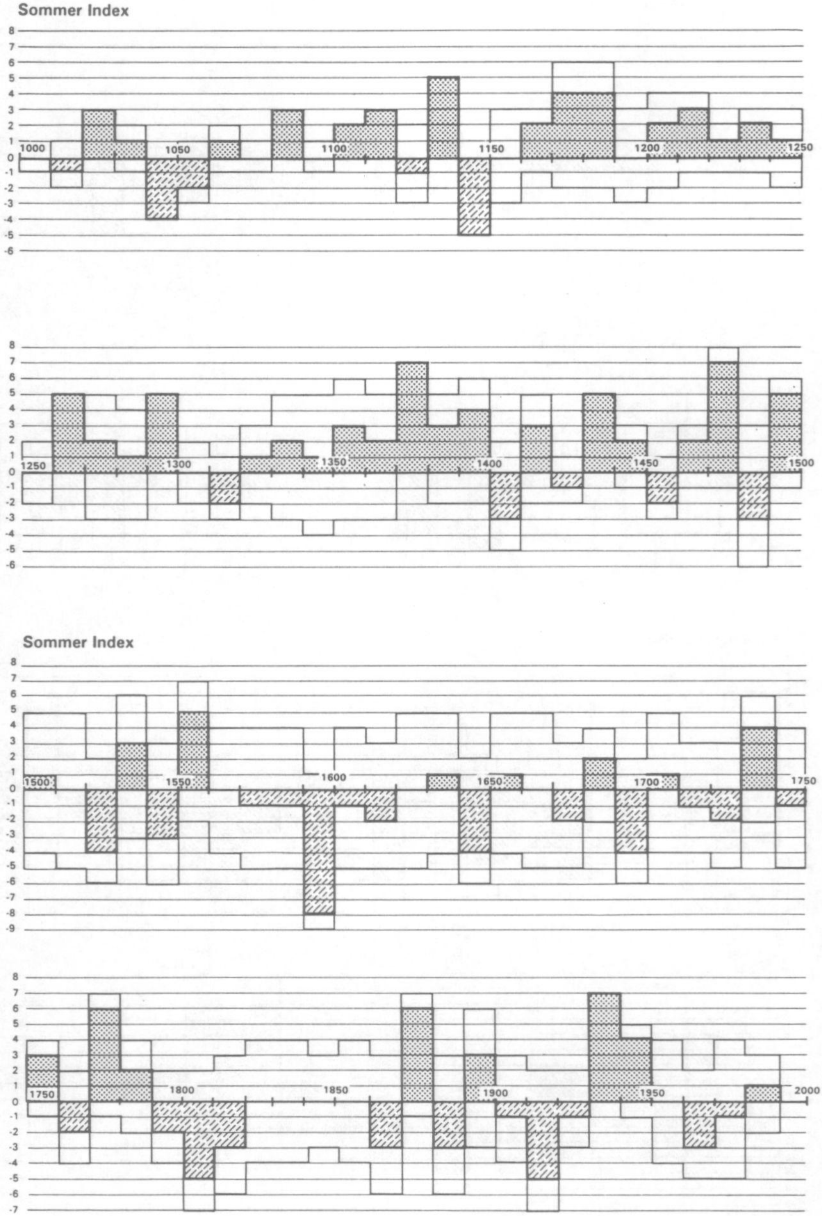
Figure 1: continued.



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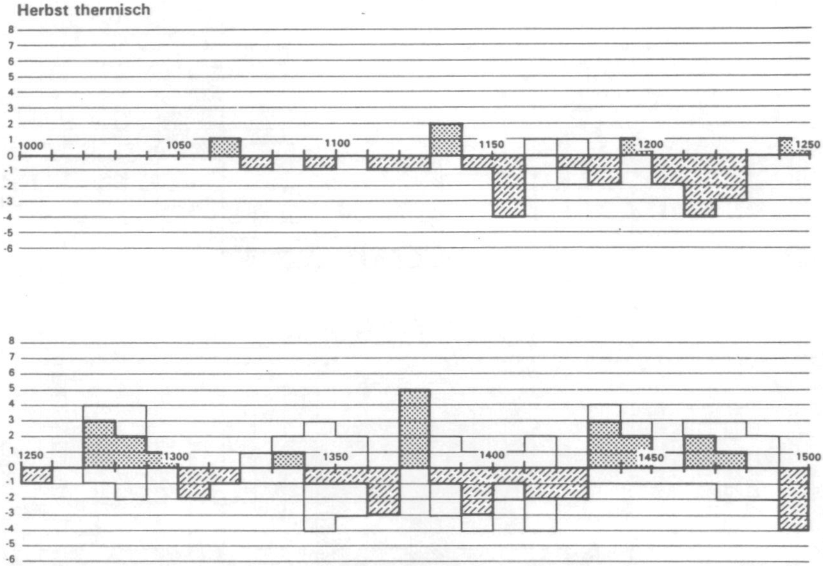

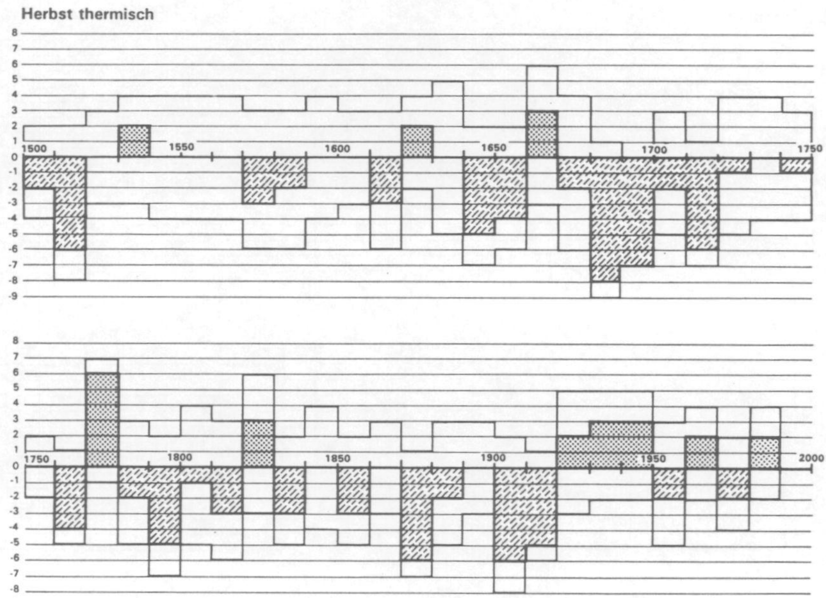

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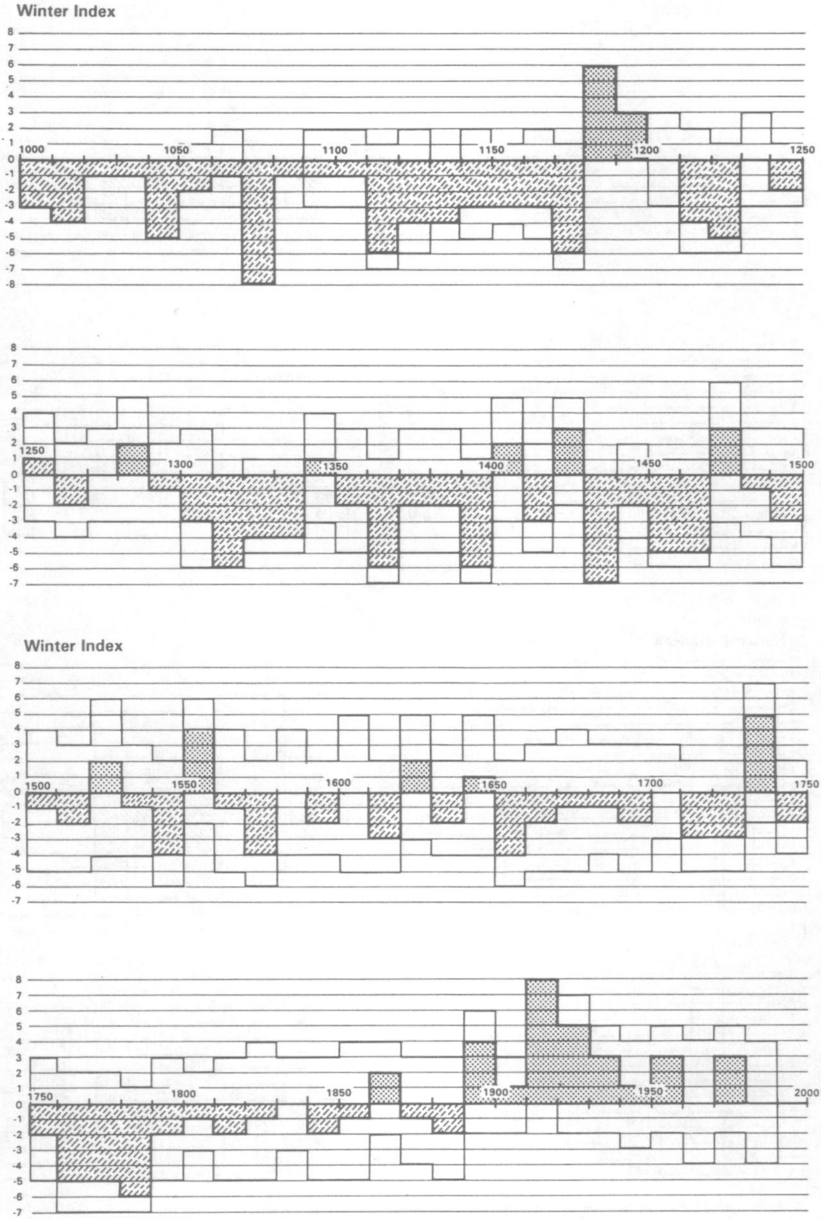


cautious approach a low temperature winter phase has to be assumed for the decade mentioned. Because of more and better sources available about the following century it is possible to make more concrete statements. Above all a prolonged phase of cooling can be deducted from a generally negative trend and its first absolute minimum in the 1120s, whereas the preceding decades had a rather average temperature level if based on the mean value of the index figures themselves. In the following decades winter conditions improved, but, nevertheless, the winter balance figures remained below average. After a second secular minimum in the 11711180 decade there was a conspicuous shift towards prevalently mild winters. The mild phase lasted for about two decades, and combined with the sharp contrast of the preceding decades, their duration and absolute height may be considered as the special characteristics of this phase. In absolute terms 1181-1190 is the decade with the warmest winters of the whole millenium. Analizing the years individually it seems that rather mild winters tend to go with rather cool summers, as e.g. in 1141 or 1157 A.D. These years and similar medium-length phases might be interpreted as phases of more pronouncedly zonal circulation, while a simultaneous occurence of hot summers and cold winters speaks for a meridional pattern.

There is a negative trend even in the winter optimum, followed by a more neutral situation after 1200 A.D, which sank deep below average in the next decades. It was not before the 1230s that the negative trend was replaced by a decade of balanced winter temperatures again. Over the following decades the index values fluctuated rather weakly around the zero line, an indicative of rather balanced and stable winter conditions, even including a few decades with positive deviations. The decade of 1281-1290 was the last one for 50 years that showed a slight prevalence of mild winters. The winter balances became worse with each decade well into the next century and arrived at a relative minimum between 1311 and 1320. After that the index value remained far below the average for rather a long time, to be interrupted only by a short improvement in the 1341-1350 decade, after which it remained at a negative level again. Nevertheless, after 1350 an increasing number of mild winters occured, so that the negative deviations of the 1370s and 1380s result somewhat less notable and can be described as average, comparable to the decades classified as average in the centuries before. At the level of annual bases mere are also sequences of mild winters, as for instance during the first half of the 1380s decade. It is interesting to note that in this decade, which by some authors is regarded as the most pronounced phase of warming of the medieval temperature optimum, the winter temperatures are an indicative for conditions that will be found again during the Little Ice Age.

In the second half of the 1380s and in the 1390s a phase of predominantly cold winters set in which, together with a deterioration of summer temperatures, may be seen as a first precursor to the Little Ice Age. Other authors even regard this phase as the onset of the Little Ice Age. As the reconstructions of this phase were derived from dendrochronological data, and as oaks generally react to winter coldness, this interpretation seems justified. With regard to the winter conditions one cannot speak of a medieval temperature optimum, as the winter pessima in the second half of the 14th century had been between 1361 and 1370 as well as between 1391 and 1400.

With the turn of the century there came, after a long time, the first phase of mild winters, especially in the 1400s and 1420s. But after that the balance again became clearly negative, reaching an absolute minimum which had been reached before rarely. After these onsets the winter balance continued to be negative for a long time. This long-lasting phase of distinctly cold winters ended by one single decade of positive deviation in the 1470s, being followed immediately periods with a negative trend, where below average values prevail again. These slightly below average conditions prevailed beyond the next turn of the century into the 1520s, a decade with a new onset of severe winter conditions. With regard to the mean value of the index series the values for the preceding phase lie in the range of average conditions, what is applicable too for the only decade in this period with a positive orientation. A short but very pronounced recovery in the 1550s is replaced by a longer phase with a negative trend immediately during the next decade, but, seen in the long run, the trend turns out towards the positive with more and more accentuation Earlier publications place the beginning of the Little Ice Age in the time around 1560 (GLASER 1991), what is corroborated by this method of analysis. This 'beginning' refers to the core of that period, as a result from a combination of other seasonal figures, especially, as has been shown earlier, comparatively low temperature levels had been reached in earlier phases. The dominance of severe winters continued until 1580, weakened over the next three decades, when the temperature level with regard to the mean value of the index series was within the average range and became positive again after 1620. During the decade from 1651 to 1660 winter temperatures plummeted again, causing conditions that in other publications were regarded as the climax of the Little Ice Age.

After this period of low temperatures, the winter temperatures became more moderate again, yet they remained on the negative side for quite a long time. The prevalence of undoubtedly cold and severe winters continued beyond the turn of the century to the 1730s. After that there followed a phase which called Maunder Minimum, what is confirmed too through the present set of data. In analogy to the summer temperatures the winter conditions of the 1730s showed a distinctly positive deviation, which is also confirmed by other proxy data. Once again, thereafter, winter conditions became more severe and remained on a negative level, but on the long run average temperature level lasted for the next two decades. The prevalence of cold and severe winters distinctly increased after 1760 and continued to do so up to the end of the century, with only a slight break in the 1790s.

After the turn of the century the values fluctuated around the zero line, with a prevalence of negative values and a few balanced decades only, e.g. from 1841 to 1850. All in all the winter balances follow a positive trend, interrupted by „relapse" phases as in between 1871 and 1890, but also by positive deviations, as in between 1861 and 1870. A pronounced warming of the winters did not occur before the second phase of the present century. The strength and duration of the positive winter anomalies is unique for the observation period, but they weaken again towards the middle of the century, reaching balanced conditions in the 1960s and a new positive trend in the 1970s. With respect to the winter conditions this phase is justly described as the much-quoted „modern thermal optimum".

2.7.2 *The course of spring temperatures*

A first overview of the decennial figures for the spring conditions indicates tendencies similar to those identified for the two other seasons. In addition to longer-lasting trends there were medium and short term oscillations with outright breaks as well as anomalies to the positive and to the negative side. The higher representation of cool and cold years finds expression in a mean value of -1.2° C, comparable to the deviation of the winter temperatures at the zero line. Cool to cold spring seasons seem to have been more frequent or were at least more frequently referred to by the chroniclers. The sources reveal that the basic character of a spring was often determined by the course of the weather in March. If this month was too cool or - what was the case quite often - still had the characteristics of a winter month, and was called „late year", even if the following two spring months had an average level. The sources therefore may give a misrepresentation underrating the frequency of average or even mild springs. Frequent onsets of cold air in April, and more so in May similarly contributed to the negative connotation of springs. Frost damage done to the grain, vine shoots and fruit trees contributed to the negative assessment of the spring conditions. Similar to the winter temperatures curve, here again in addition to the zero line that stands for a balanced presentation of positive and negative estimates, the mean value line must be taken into account too .

In consideration of the low density of data available for the first decades of the millenium these should not be overinterpreted. As mentioned before, historical sources refer to summer and winter more often than to autumn or spring. Gradually sources improved and with it more reliable statements can be made. A negative temperature trend does not show before the beginning of the 12* century, which, however, should be described as significant, even if we have in mind that the data are not complete. This negative trend lasted until 1130, when there was following a sudden change in conditions which may be described as average. Starting from a below-average level, a prolonged positive trend began in 1180 A.D., followed by a marked decrease in spring temperatures in the 1211-1220 decade. After that they stabilized again. Temperatures remained at a more or less average level, with the next low temperature period between 1251 and 1260. The next two decades were inconspicuous. But afterwards a fundamental change in the temperature structure occured. In between 1281-1290 spring conditions deviated distinctly to the positive quite beyond the common level. Warmth prevailed during the next decade, though at a somewhat lower level. With the beginning of the new century the spring temperatures dropped again, but remained at an average level for the next three decades. A distinctly negative deviation can be identified for the 1340s, followed by another warm springtime phase during the next decade. These were the conditions during the following decades too, though less pronounced. Conditions after 1400 A.D. deteriorated to such an extent that there is not a single positive spring balance up to 1500 A.D. But this doesn't mean, however, that conditions were bad in general: with a few exceptions the conditions were average and inconspicuous. There are some few decades only, such as the decennium 1441-1450 and 1461-1470, that were negative. After 1500 A.D. the indices got more accentuated again.

It should be mentioned here that for every year following 1500 there is information on the spring conditions. The more distinct negative trend observed may therefore be influenced by the higher concentration of available data and hence should be interpreted with caution. The first decade with a positive balance that was noted after a long time of negative ones was immediately followed again by two decades of rapid decline to a relative minimum during the 1521-30 decade. For the next three decades the curve kept on a quite inconspicuous level to become clearly negative again in the 1560s. The following phase of relative relaxation did not reach the former inconspicuous level; obviously the mean temperatures remained on a lower level than usual. This interpretation is supported by another relative minimum which was the end of the negative phase in the 1591-1600 decade. After that conditions improved considerably. For the first time in hundred years a figure of positive balance was reached. Similar to the following decade, yet with a negative prefix here, the figures continue at an inconspicuous level. Conditions changed again between 1621 and 1630 reaching another minimum. This time the return to normal conditions occurred in the following decade. Simultaneously with the beginning of the Maunder Minimum, after 1650, there began a phase in which spring temperatures dropped continuously. The absolute minimum of this trend was reached during the 1680s and continued on a similar low level during the next decade. It is this phase that presents the most marked negative deviation of the whole curve. A rapid and prolonged change to the positive side brought an end to this negative series: the 1701-1710 decade was charcterized mostly by average or warm spring conditions. Even though the temperatures dropped below average again during the next two decades, they still remained at a rather normal level. It is the 1731-1740 decade that again showed a pronounced positive anomaly both in spring and winter temperatures, yet of short duration as there was real downfall to a relative minimum in the following decade. The contrast could not be greater. After that, once again, conditions improved. Positive deviations were frequent in the decades 1771-80, 1811-30 and 1861-70. They contrasted to the negative decades, which once again showed pronounced oscillations to the cold side. Among others these were the decades 1781-90 and 1851-60. The most conspicuous event of the modern period is the positive anomaly at the beginning of our century, beginning in 1911 and lasting for two decades. Much has been written about this phase of summer-like conditions in spring, to make further description unnecessary. Quite conspicuous, however, is the long-term negative trend that followed to this maximum.

2.1.3 The course of summer temperatures

Statements on the general course of summer weather in the 11th century rest on a rather restricted data base. Yet it is interesting to note, that - though information handed down to us is scarce - it comprises all major traits of the later periods: the climate was subjected to mediumrange changes to both sides, and there were major and sometimes abrupt changes that were likely to have had their effects on the population and their conditions of life. It would be preposterous to draw far-reaching conclusions from such restricted number of data. Nevertheless, the dominance of positive deviations give rise to the supposition that this was a century with aboveaverage summer conditions, with positive deviations between 1020 and 1040 A.D. as well as during the 1090s, and a negative one between 1040 and 1060 A.D.. There are better sources available for the next century. These better data sources on positive and negative deviations allow the identification of an accentuated pattern; in particular there was an increase in the amplitude of the changes. A characteristic for the 12th century, beside of the annual ups and downs, is the continuous increase in the number of warm summers which appears as a positive trend in the decennial figures, only interrupted in the 1120s and 1140s by a pronounced temperature depression, and in the 1150s and towards the end of the century, when the „0" index level was reached.

Attention should be drawn to the marked change of the summers from the 1130s to the 1140s brought about with an index change of 10. In the annual disaggregation the positive temperature trend clearly appears after 1160. This positive trend beginning in 1160, with a first absolute temperature maximum in the 1190s, could be described as a phase of the medieval temperature optimum. During these decades there was a concentration of positive summer temperature deviations. The prevalence of positive deviations continued after this first extended maximum beyond the turn of the century and reached far into the middle of the 13th century, with just a slightly negative trend which fell to an average level for the decade 1251-1260. After that the summer situation improved again, and up to the year 1300 A.D. all the figures are on the positive side. For the next three decades the number of extreme years decreases, indicating a stable and balanced climatic phase. Whereas the situation in the first decade was still balanced, for the following decade a prevalence of cool to cold summers can be stated.

It was followed by a phase during which - as the considerably increased data base is showing - the summer weather remained at a slightly positive level, before reaching a definite positive prevalence in the 1350s and the 1370s. At the annual disaggregation level the positive deviations show as several clusters of similarly warm to hot summers. Undoubtedly this is another (the second) main phase of the (late) medieval thermal optimum which, according to the data available, lasted until 1400 A.D. Not only the high level of the maximum between 1371 and 1380 is of significance here, but also the length of this positive deviation. With an 80 years' duration this is the lengthiest constant positive deviation of summer temperatures on record for the millenium.

At the turn of the century there was an utter break. However, temperatures did not drop as low as those between 1140 and 1150. Pointedly expressed one might say that the first two decades of the new century were the first of a striking depression of summer temperatures similar to that we will notice again during the Little Ice Age. From now onwards phases get shorter, there are no long-lasting and definite periods of warming up, which had been so typical for the earlier periods of observation, with the exception of the 1550s and the modem thermal optimum. The course of temperature became more accentuated and dynamic, changing faster changes than it had done so far. After the thermal maximum of the 1370s, the positive deviations followed a negative trend, not unlike that between 1100 and 1300. There is no new positive trend until 1430, when there are two decades of positive balance. The decade of 1451 to 1460 has a negative balance again. After this period of fluctuations in a definitely low level of summer temperatures, a strikingly positive development was observed in the 1471-1480 decade which, in its intensity, got close to the level of the 1370s. Yet during the next decade a shift to a sequence of below-average summers, was again followed by positive deviations in the following decade. This rather negative and lasting turn as far as summer temperatures are concerned, may be considered as the transition to the Little Ice Age, as warm phases became much less frequent in the decades or even centuries to follow, during a number of phases the level remained below average, and the pattern of thermal summer weather seems to be more or less inverse to what it was in the preceeding phases.

Obviously a fundamental change in the course of summer temperatures had taken place in this phase. There were mostly well-balanced summers as e.g. from 1511-1520, when there was an equal number of warm to hot and cool to cold summers, and this was typical for the time afterwards. Quite in contrast to the positive course in the preceding centuries, the phase from 1500 to 1550, taken as a whole, is the first one of a long-lasting and pronounced deterioration in the thermal summer weather. After a positive deviation in the 1550s and, with some concessions made, in the next rather balanced decade, which was the last phase of a constantly positive summer temperature deviation, the temperatures dropped to a definitely negative level. In the 1590s the trend continued dropping to a marked depression which is quite unique for the period of observation at this level of temporal disaggregation. The absolute minimum of summer temperatures was reached. For the first time too, negative summer values were observed in the course of more than two decades; a pattern that repeated itself in the decades and centuries to come. For the time until 1550 water level data mention a number of large inundations. With the extreme retreat of summer temperatures in the 1590s a long-lasting predominantly negative summer phase began. With the exception of a slight temperature increase in the 1630s and 1650s, when the overall balance of summer conditions reached an above-average level again, all the other decades were either negative or at best average. Even the positive balance of the 1680s and the 1700s were not sufficient to change the dominance of negative summers. They are characterizing one of the most conspicuous temperature depressions within the Little Ice Age, the afore-mentioned so-called Maunder Minimum.

For the time that followed, the course of the climate can be analyzed more exactly thanks to the first data available from instrument readings. After 1700, as mentioned before, a decade with a slight predominance of warm summers followed, but during the next two decades the temperatures dropped again. In the 1730s the level of the summer temperatures rose considerably, reaching values similar to those of the warmest phases of the period observed. This positive interval has already been referred to several times. During the following decades such positive deviations become more frequent, as e.g. in the 1750s, but, above all, between 1771 and 1790, separated each by only two decades of negative deviations. The temperature level, as it seems, in general had been higher, and a distinct accentuation and increased dynamics, with rapid shifts and short phases are characteristic for these decades. This first phase of more permanent summer warmth and short-term shifts lead into a period of predominantly positive summer temperatures, yet not immediately so, as there are several below-average phases, e.g. those between 1791 and 1820, which contributed to the image of the Little Ice Age as a time of definitely low summer temperatures. The following decades are more or less balanced, up to the new summer temperature pessimum of the 1860s. In the 1870s there is another shift, comparable to that of the preceding warm phases. The next decade is negative, though, followed again by positive figures. Thus it can be stated that an 80-years phase of relatively cool summers was followed by four decades of more dynamic and positive temperature sequences. At the turn of the century another break is noticed, which is evident in three decades with negative values, and taking in consideration its length it is an obvious anomaly.

Afterwards there was a fundamental change of summer conditions. The summer optimum at that time was in correspondance with that of earlier centuries. This seems to be, though with a negative trend, an indicative of developments which, in present-day view may be connected with the phases of anthropogenic climatic change. Especially during the 30s and 40s of our century the positive summer temperatures were remarkably high. This positive deviation got weaker during the following decades and reached an average level again in the 1970s. Seen in this light, from the beginning of the century we have been living in a phase of warmth, though, in the mean time this trend is evidently in decline. All observations taken together, there is a striking similarity between the present part of the „modern thermal optimum", both in its intensity and duration, and the phases of the medieval thermal optima.

2.1.4 The course of autumn temperatures

The autumn curve makes evident that the availability of data describing autumn conditions during the first two centuries of the millenium is even worse than that of the spring season. It may be assumed that this season, which from an agrarian point of view was of little significance for the yield of most cultivated plants, and consequently was of little interest to the chroniclers. The dearth of written sources concerning this season may, to some extent, be compensated by proxy data of the same region. The mean of the autumn values lies at -0.9° C. Comparable to the observations in spring conditions, there was a strong interest in eventual cold waves that damaged the vine shoots, while warm autumn conditions did not seem to have attracted igual attention. After a first period of total „silence" of the sources a gradual improvement in the availability of information can be observed which, however, are not yet sufficient for far-reaching conclusions.

Records that really lend themselves to an interpretation began around 1150 A.D., which is considerably later than those for the other seasons. A cautious estimate of the availabe records suggests that the first period after 1150 was characterized by rather cool autumn conditions, with a first minimum during 1151-60 and a longer negative deviation between 1201 and 1230. The following decades are inconspicuous. Yet after 1271 the data situation improved again, iniciating a warm phase that lasted for three decades. Sources are rare for the next two decades. This might be interpreted as consequence of normality of this phase or as reflex of the other sourcerelated aspects referred to above. With more sources in existance after 1340 a slightly negative trend can be noted from the balances, though still close to the average. With the 1371-80 decade there was a shift towards a markedly higher temperature level, which, during the following decades, had again a negative turn. The time that followed is characterized as inconspicuous, and had mostly slightly negative balances, all in all an evidence for a rather stable climatic phase. This tendency changed after 1430. The decades that followed are characterized by either positive or average values that they may be regarded as a rather agreeable phase. Only during the last decade of the 15[th] century there was another shift of temperatures to the negative side. Analogous to the data situation of the spring seasons, after 1500 there are data available for every year. The negative level, that had been reached shortly before the turn of the century, lasted for the next two decades, but changed to the reverse during the next two decades. The phase between 1561 and 1570 had normal autumn conditions. In the next decade the balance was negative again, but returned to a more average level right afterwards. The following three decades can be rated again as inconspicuous and average. After that there was a definite accentuation of the autumn weather situation, the pendulum swinging first to the negative, and in the following decade to the positive side again.

The decades that followed are again average, but afterwards the temperature sunk to a comparatively low level for two decades. The short improvement of the 1660s was the last positive deviation for a long time. Following it the temperatures mostly kept on the negative side. The temperatures first fell to a relative minimum level, and between 1681 and 1690, to an absolute minimum level. Conditions became somewhat better during the following decade, but remained at a low level and did not return to average conditions before the 1701-10 decade. After that they plunged to a record depth again, but rose to an average level during the next decade, where it remained during the next four decades. After this long phase of stability of autumns temperatures the course of autumn temperatures became accentuated again, first to the negative, and then to the positive side. After 1780 the temperatures for some time remained at a negative level . An improvement between 1821-30 and a phase with alternatingly negative and average values passed gradually into a phase of only negative values which lasted for two decades. The 1890s were characterized again by normal conditions, but afterwards there was the next rapid shift to the negative side. This was followed by a continuously positive phase lasting for three decades, and finally by a time with more accentuated autumn conditions.

2.7.5 *Conclusion of the index interpretation*

The analysis of the index series shows that in addition to the ups and downs of the weather regime with its alternating phases of positive and negative deviations which either are derived from clusters or from the balance of selected periods, there is an obvious pattern of the so-called medieval thermal optimum and the Little Ice Age in central Europe. The beginnings and endings of these phases are different according to the seasons studied. This explains why many authors, concentrating on data from one season only , have come to different positions regarding the exact time of these events. The medieval thermal optimum, to begin with, is identified by summer temperatures; some phases of the Little Ice Age can only be identified from the joint analysis of summer and winter conditions. There are also phases characterized by meridional or more continental circulation, whereas others were dominated by more zonal circulation pattern leading to a more oceanic climate. Those phases were identified as meridional, and were characterized by warm to hot summers and cool to cold winters, while decades with an oceanic regime are recognizeable by their moderate and mild winters and rather cool summers. Phases with various characteristics cannot that easily be attributed to a specific circulation pattern. They are described as mixed types that also display interesting pattern. Significant in this respect is the number of phases of rather short duration with their dynamic and accentuated weather regime and sudden shifts, standing in marked contrast to phases of longer duration following a more uniform trend. Both types are likely to reflect different pattern of the northern hemispheric circulation.

2.2 Calibration of the decennial index values

It is one of the frequent demands on the historical climatology to present relative data, but to proceed to quantification and absolute figures. This demand is taken into account in the present paper. Although the decennial indices are not metrically scaled data *sensu stricto,* a calibration was nevertheless achieved by means of the regression method. On the one hand the indices are based on equidistant value intervals that may be taken to represent temperature intervals; on the other hand the range of values from -10 to +10, the maximum possible at the temporal resolution decided upon, was deemed to be sufficiently differentiated for the application of this method. In addition to the distributary function of the values, it largely corresponds to a Gaussian normal distribution, which is another important prerequisite for the regression analysis. To be exact the precondition of metric data is not related to the in-going variables, but to the residuals, a condition that is also fulfilled. The calculations are based on the decennial temperature means of the Wuerzburg weather station and the corresponding decennial values of the index series derived from them for the period of 1804 to 1980. All the calculations showed the interrelationship to be highly significant ($p<0.01$), so that the following equations could be derived for the summer and winter temperature indices:

Winter temperature [° C] = 0.22 + 0.19 * (Decennial winter index), Standard error 0.09 bzw 0.03; r=0.84, ($p<0.01$)

Summer temperature [° C]= 17.51 + 0.08 * (Decennial summer index), Standard error 0.05 bzw 0.01; r=0.83, ($p<0.01$)

The temperature values respectively their deviations for the index classes based on decades are listed in Table 1.

With the help of this formulation it was possible to reconstruct the temperature levels for each decade of the last 1,000 years in relation to the

Table 1: Decennial index values and temperature deviations in °C based on the Wuerzburg weather station

Index	10	9	8	7	6	5	4
Winter	1,90	1,71	1,52	1,33	1,14	0,95	0,76
Summer	0,80	0,72	0,64	0,56	0,48	0,40	0,32

Index	3	2	1	0	-1	-2	-3
Winter	0,57	0,38	0,19	0	-0,19	-0,38	-0,57
Summer	0,24	0,16	0,08	0	-0,08	-0,16	-0,24

Index	-4	-5	-6	-7	-8	-9	-10
Winter	-0,76	-0,95	-1,14	-1,33	-1,52	-1,71	-1,90
Summer	-0,32	-0,40	-0,48	-0,56	-0,64	-0,72	-0,80

Temperature deviation in °C. The standard deviation lies at index +- 6.

standard period of the Wuerzburg weather station. Theoretically this formulation allows the presentation of variations in the winter temperature levels of the decennial values with respect to the comparative station in the range of +2.1° C to -1.7° . As a matter of fact the variations only lay between 1.6° C and 1.3° C, which is considerable though, especially when taking into account that the prognostic climate models currently discussed regard a temperature change of at least 1° C as certain, and 2° C to 3° C as likely. The historical variations that occured over the last 1000 years lie thus in the same order of magnitude as the changes that are expected for the future!

The suitability of the model also proved in comparing the value levels obtained with the current estimates and modem recorded data which, within the period of 1804 to 1980, encompass both a marked cold phase of the Little Ice Age and the warm phase of the so-called modern accelerated greenhouse effect. In none of the decades the class levels of +10 or -10 were reached, which means that the range of values is broad enough for presenting all the fluctuations over the last 1,000 years.

2.3 Was there a medieval thermal optimum?

The results presented above clearly show that there have been considerable deviations from a course of climate regarded as normal or average. Being placed into a larger context, these originally isolated results of regional climatic history have been given names such as Medieval Thermal Optimum (**mto**) or

Little Ice Age. In the following paragraphs the results obtained in the present study are to be compared with the state of knowledge in general. Among the questions to be asked are those concerning verification, the simultaneity of these marked climatic phases, their when and where, and also the results on which the identification of those phases is based.

With the pioneering book by *Lamb* (1977), at the latest, both the Medieval Thermal Optimum and the Little Ice Age became the much-quoted, and, as it seems, well documented climatic phases, creating the impression that they were definitive and unequivocal segments of the climatic curve in all the regions studied. That it is not really so becomes evident very soon by analyzing the regional results from a methodological point of view. The wide range of indicators made use of today reaches all the way from dendrochronological data, sedimentary layers, inland-ice cores, agricultural yield data or geomorphological evidence to descriptive written sources. This spectrum results in an equally large number of methodologies with different temporal, spatial and content-related resolutions. It is almost unavoidable that with each of them a different view of the Medieval Thermal Optimum is obtained, and one gets the impression that there is no consent.

Because of these inconsistencies the term „method-specific" results („Methodenergebnisse" *Glaser* 1991, *Hagedorn & Glaser* 1991) was coined. The criticism has to be repeated here in the light of more recent results. To what large extent there are still questions concerning the Medieval Thermal Optimum, becomes obvious in viewing the number of publications that appeared as a special issue in „Climatic Change" at the beginning of 1994. Evidence of this phenomenon at the world-wide scale exists for North and South America *{Luckman* (1994); *Villalba* (1994); *Petersen* (1994) and traditionally for Europe *{Lamb* (1977), *Alexandre* (1987), *Serre-Bachett* (1994), *Brazdil & Kotyza* (1995)), together with the comparative study by *Flohn* (1993). In trying to arrive at a synthesis of the results presented, a nominal agreement appears on the existence of the optimum somewhere between the 9th and the 14th century. According to these data a long-lasting warming occurred in northern and western Europe, in northern North America, in China and Tasmania, which found its expression mainly in a significant deviation of summer temperatures in comparison to the course of temperature in the time that followed. Other regions, such as the Mediterranean, and the southwestern United States show little differences in temperature, but changes in the hygric development however. Locations of higher level show a higher degree of conformity, which may be the result of the specific methodological approaches applied to the study of these special locations. At that locations morphological evidence, especially moraines and dendrochronology data are regularly used which, because of their specific reaction patterns to weather and climate, may lead to a more coherent picture. In spite of the large number of coincidences between many regional data sets *Hugues & Diaz* (1994) nevertheless, do not find evidence for a global MTO. It is mainly *Lamb's* inspiring work, whose regional interest was mainly focused on western Europe and whose results have a certain model function, that has shaped the image of a MTO. In this way a regional result became a world-wide pattern which calls for further differentiation with an increasing regionalized data base. Concrete statements with regard to Europe have also come from *Alexandre* (1987) who, for the time between 1150 and 1200 A.D. finds no evidence of a MTO and who recognizes the time around 1300 as a time of marked warming. *Ogilvie* (1994), on the other hand, in analyzing sea-ice data around Iceland, could support the results obtained by LAMB, which is not surprising because of the proximity of the regions, but he pointed out too that many facts that had been assumed of resting on a solid base derived from highly doubtful data. There are other results that indicate a short period of warming in the middle of the 14th century, an observation that can be confirmed for the summer weather predominance from the data presented in this paper. According to published literature a cold winter predominance was observed between 1150 and 1330 A.D., which basically is also in agreement with my own data, with the difference that in Germany this phase was both preceded and followed by similarly cold phases. Indeed the data on the winter conditions show a predominance of cold winters over mild winters. A stronger accentuation of winter cold in the middle of the 12* century, at the beginning of the 13th and during the first decades of the 14* century is assumed to have also affected central Europe north of the Alps. These results can be confirmed too, although there are some inaccuracies: the accentuation of winter coldness referred to became considerably stronger in the transition to the Little Ice Age and more so during its further course, with an unusually low percentage of mild winters. It is interesting to note that even reliable sources for the mediterranean region do not indicate any warming for the middle of the 14th century. For western Europe the interpretations are contradictory too. To those of *Alexandre* will be referred to again farther below. They are in opposition to statements speaking of a dominance of dry summers between 1200 and 1310, in stark contrast to wet phases in the second half of the 12th and the first half of the 14* century. The course of the spring temperatures showed a lasting positive deviation between 1220 and 1310 A.D., followed by a marked worsening during the 1th century, with a minimum between 1340 to 1350.

Discussion has shown that regional and methodological results cannot simply be transferred from one region to the other, and that statements on the climatic history of a region should be based on originating data coming from this zone. It will be possible to proceed to a synoptic view or to the analysis of certain time slices on the global level before a dense web of methodically comparable results from different regions has been built up. This statement is made the basic principle of the author's studies. All the information included in the weighted and unweighted indices is based on original data from the region.

Of all the studies published, those by *Alexandre* come closest to my own in their regional and methodological approach. His results, which were mainly obtained for the French-speaking part of western Europe, with occasional references to central Europe with regard to Latin-written sources, speak of a thermal optimum around 1300 A.D., an observation that from the present data cannot be confirmed. By viewing the here presented results with the current state of knowledge, there are as many agreements as disagreements. The MTO is not a temporally synchronous event, neither world-wide nor in Europe. Even those results that are methodically comparable do not indicate a uniform position of the individual phases in time. Viewed in this light the MTO can only be regarded as a nominal entity, a semantic arabesque, which has its justification in the fact that there have been marked warm phases with regional accentuation during the Middle Ages. Any further differentiations have to be understood as methodological or regional characteristics. One should also abandon the idea that the MTO refers to a long-lasting and uniform climatic phenomenon. There were a multitude of phases or periods instead, each of which or all of them taken together may be defined as the Medieval Thermal Optimum. It is definitely too early to decide on a generally valid definition of the MTO. Nevertheless, in spite of all the reservations the basic characteristics of the course of climate during the Middle Ages justify the further use of the term MTO, as the term is very descriptive and as such has already found its way into a whole range of other disciplines. The statements given here with regard to the Medieval Thermal Optimumare are applicable too for the phases that make up the Little Ice Age.

2.4 The monthly temperature regime from 1500 to 1700 A.D.

As mentioned before the data base on the weather regime became much better for the time after 1500. There is also an increase in the number of weather diaries that allow especially far-reaching conclusions to be drawn on the course of the weather. No wonder that most reconstructions of climate refer to this period. Thus *Lauer & Frankenberg* (1986) reconstructed the climate of the Rhenish Palatinate (Rheinpfalz) with a quantifying approach based on the yield data of wine and some descriptive data. Because of the application of multiple statistical methods the results are rather abstract and call for further interpretation. Of more qualitative character are the Studies by *Glaser* (1991) for this period, whereas *Pfister* (1985) in his well-known study of the Swiss climatic situation arrives at absolute quantifications. Some of the long-distance correlations, as those with data sets from the English midlands, should be considered as climatologically problematic.

For the present contribution there is at first a presentation of the monthly thermal unweighted indices which means that the positive or negative deviations from what was considered normal in the sources used were ranked between +1 and - 1. Seasonal and annual estimates were derived from the sum of the corresponding periods (cf. Table 2).

Compilations of this kind already yield specific indications which by themselves may be of importance for the more far-reaching approaches of agricultural and social history. Even for climatological purposes this type of presentation has its decisive advantages, as it visualizes the course of the weather, also in relation to singularities. For the obvious reason of insufficient data availability the weather characteristics cannot be presented for all the years.

2.5 Calibration of the annual temperature indices

In order to serve the needs of the climatic modeling community an absolute quantification of the data series was undertaken, based on the temperature records for Wuerzburg 1804-1980. In a first step the monthly temperature values were transformed into unweighted index values. Starting from the standard period 1951-80 the range of values within the 0.75 positive and negative standard deviation was defined as normal and given the index „0", the values above with „+x", those below with „-x". The annual index was derived from the sum of the monthly indices. The 0.75-fold standard deviation was chosen as it had been shown in earlier works to be the most adequate one. In addition it resulted in a larger share of explained variance in comparison to other intervals.

The regression equation for the Wuerzburg model, rounded to two digits behind the decimal point, is as follows:

(1) Annual temperature [° C] = 8.98 + 0.24 * annual index; $r=0.81$ $p<0.0001$.

In Fig. 2 the annual temperature values are presented, calculated from the values listed in Table 2, and in per cent deviations from the mean of the Wuerzburg reference station. The course of the reconstructed temperature curve illustrates the various temperature phases within those two centuries and specifies the seasonal information already given above. The temperature depressions in the middle and at the end of the 16th century is equally well visible as the one towards the end of the 17th century, the so-called Maunder minimum. As the curves are self-explanatory, no further interpretation is intended here.

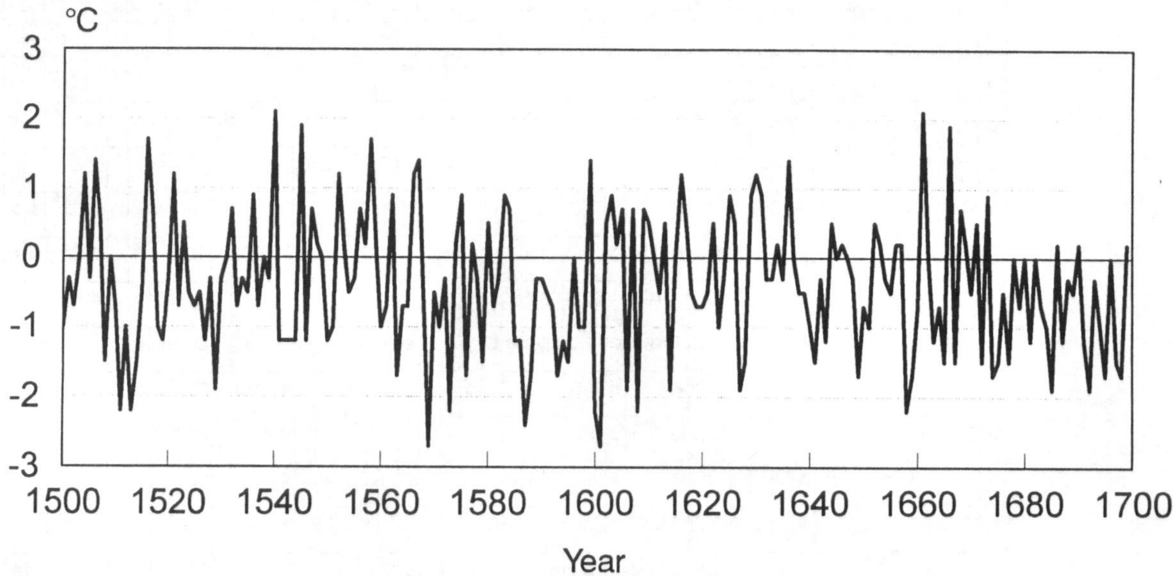
Table 2:

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Winter	Spring	Summer	Autumn	Year
1500	□	□	□		□	●	●	□			□	□	0	-2	1	-1	0
1501	●	●			●		□	□	●	□	□		1	1	-2	-1	-1
1502	□	□	□		□	●		●	□			□	-2	-2	2	-1	-3
1503	□	□	□	●	●	●	●	●			□		-3	1	3	-1	0
1504	□	□		●	●	●	●	●	●	●		●	-2	2	3	2	5
1505	●		□			□	□		●		□	●	2	-1	-2	0	-1
1506	●	●			●	●	●					●	3	1	2	0	6
1507		●	□	●	●	□	□		●			□	2	1	-2	1	2
1508		□	□	□			□	□	●		□		-2	-2	-2	0	-6
1509	□	□			●		●	●	●	□	□		-2	1	2	-1	0
1510			□		□		□	●			□	□	0	-2	0	-1	-3
1511	□	□	□	□	□		□	□	□			□	-3	-3	-2	-1	-9
1512		□	□		●		●	●	□		□		-2	0	2	-2	-2
1513	□	□	□	□		□		□	□	□	□	□	-2	-2	-2	-3	-9
1514	□	□	□	□		□	●	●		□	□	●	-3	-2	1	-2	-6
1515	●	●	□		□		□	□	●	□	□	●	3	-2	-2	-1	-2
1516	●		□	●	●	●	●	●	●	●	□	□	2	1	3	1	7
1517	□	□	●	●	●	●	●		□	●	●		-3	3	2	1	3
1518				●		□		□	□	□	□		0	1	-2	-3	-4
1519	□	●		□	□	●	□	□	□	□			0	-2	-1	-2	-5
1520	●	●	□	□	□	●	●		□		□		2	-3	2	-2	-1
1521	●	●				□	●	●	●	●			2	0	1	2	5
1522	□	□	□		□	●							-2	-2	1	0	-3
1523	●	●	□	●	□	□		●	●				2	-1	0	1	2
1524		●			□	□		□				□	1	-1	-2	0	-2
1525	□				□								-2	-1	0	0	-3
1526		□				□	●	□					-1	0	-1	0	-2
1527	●		□	□			□	□	□	□			1	-2	-2	-2	-5
1528	●			□	□			□	●	●	□		1	-2	-1	1	-1
1529	□	□		□	□	□	□	□	□			●	-2	-2	-3	-1	-8
1530	●	●		□			□	□		□			3	-1	-2	-1	-1
1531	●	●	□	□	□	□		□	●	●	●	□	2	-3	-2	3	0
1532		●	●	□	●	●	●	●			□	□	0	1	3	-1	3
1533	●					□			□		□	□	0	0	-1	-2	-3
1534	□	□	□		●	●	●	●	□				-3	0	3	-1	-1
1535	□		□	□	□	●	●						-1	-3	2	0	-2
1536	□	□			●	●	●	●	●	●		□	-2	1	3	2	4
1537					□	□	□				●	●	-1	-1	-2	1	-3
1538	●		□	□			□	●					2	-2	0	0	0
1539			●		□		●			□	□		0	0	1	-2	-1
1540		●	●	●	●	●	●	●	●	●			1	3	3	2	9
1541	□	□	□		●	●	□	□		□	□	●	-2	0	-1	-2	-5
1542	●		□	□	□	□	□	□			□		2	-3	-3	-1	-5
1543	□	□	□		□	□	□			●			-2	-2	-2	1	-5
1544	□	□	□	□			□						-2	-2	-1	0	-5
1545	●	●	●		●		●	●	●	●			2	2	2	2	8
1546	□	□	□		□		□	□	●				-2	-2	-2	1	-5
1547					●	●	●						0	1	2	0	3
1548	□					□	●	●	●				-1	0	1	1	1
1549					●					□		□	0	1	0	-1	0

Table 2: continued.

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Winter	Spring	Summer	Autumn	Year
1550			□		□			□		□			-1	-2	-1	-1	-5
1551	●	□	□		□	□	●			□	□	□	0	-2	0	-2	-4
1552	●	●			●	●				●	●	●	1	1	1	2	5
1553		□	□	□			●		●	●			0	-2	1	2	1
1554	□	□		●		□	●	●	□	□		●	-2	1	1	-2	-2
1555		●	□			□		□		●	□		2	-1	-2	0	-1
1556	●	●	□			●	●	●			□	□	2	-1	3	-1	3
1557	□		□			●	●		●	●		□	-2	-1	2	2	1
1558	●	●	●	●		●	●		●	●			1	2	2	2	7
1559		●		□	□		●	●				●	1	-2	2	0	1
1560			□			□	□			□	□	□	1	-1	-2	-2	-4
1561	□	□	□	□			●				●	●	-3	-2	1	1	-3
1562	●	●			□				●		●	□	3	-1	0	2	4
1563	□	●	□	□	□	□	□			□		●	-1	-3	-2	-1	-7
1564	□	□	□	●	□	●	□		●	□	□	□	-1	-1	0	-1	-3
1565	□	□	□		□		●	●				●	-3	-2	2	0	-3
1566		●	□		●		●	●	●				2	0	2	1	5
1567	●		●	●		●	●		●				1	2	2	1	6
1568	●	□	□		●	●	□	□		□	□	□	0	0	-1	-2	-3
1569	□	□	□	□	□	□	□	□	□	□			-3	-3	-3	-2	-11
1570	●	●		□	□		□	□				□	2	-2	-2	0	-2
1571	□	□	●	●	□	□	□	●	●	□	□	●	-3	1	-1	-1	-4
1572	□	□	□	●	●		●			□	□	□	-1	1	1	-2	-1
1573	□	□	□	□			□	□	□	□		□	-3	-2	-2	-2	-9
1574					●	●	□	●	□		●		-1	1	1	0	1
1575				□		●	●	●	●		●	□	0	-1	3	2	4
1576				□	□	□	□		□	□		●	-1	-2	-2	-2	-7
1577	●	●	□	□			●		□				3	-2	1	-1	1
1578		□		□			●	□	●	●	□		-1	-1	0	1	-1
1579		●	●	□	□	□	□	□	□	□	□		1	-1	-3	-3	-6
1580			□			●	●		●				0	-1	2	1	2
1581			□	●			□	□	●	□	□		0	0	-2	-1	-3
1582	●	●					□			□	□	●	2	0	-1	-2	-1
1583				●	●	●							1	2	1	0	4
1584	●		□		●	●			●				1	0	1	1	3
1585	●	●	□	□	□	□	□	□	□			□	2	-3	-3	-1	-5
1586	□		□	□							□	□	-2	-2	0	-1	-5
1587	□	□	□	□	□	□	□		□	□			-3	-3	-2	-2	-10
1588			□		□	□	□	□	□	□			0	-2	-3	-2	-7
1589		□			□	□	●	□		●	●	□	-1	-1	-1	2	-1
1590	□	□	□		□	●	●	●	●			□	-3	-2	3	1	-1
1591	□	□		●	●		□		●	□			-3	2	-1	0	-2
1592	●	□	□	●	□	□	□	●	●	□	□	□	0	-1	-1	-1	-3
1593	□		□	□				□		□	□		-2	-2	-1	-2	-7
1594	●	□		□	□		□	□			□	□	0	-2	-2	-1	-5
1595	□	□	□	□		□	□	□	●	●			-3	-2	-3	2	-6
1596		●	●	□		□	□	□	●	●		●	1	0	-3	2	0
1597	●		□	□				□	□	□	□	□	2	-2	-1	-3	-4
1598		●		□	□	□	□		●	□			0	-2	-2	0	-4
1599	□	□	●	●	●	●	●	●	●	●			-2	3	3	2	6

Figure 2: Reconstructed mean annual temperature for the 16th century (deviation from the long-term mean of the Wuerzburg reference station).



The index values were calculated with a 0.75-fold standard deviation.

3. Final remarks

The present contribution is concerned with temperature reconstructions for central Europe since the year 1,000 A.D: based on index calculations. Because of differences in the regional and temporal density of sources the study had to be carried out at various scales. A temporally complete, though rather abstract temperature curve reaching back very far can be achieved at the decennial index level. This level is sufficient for the recognition of the different phases of temperature development with marked warming and cooling phases at a seasonal resolution. By means of a regression analysis the decennial values can be related to temperature levels, thus catering the demand of quantification for the modeling community. Thanks to the much better source monthly data base indices can be determined for the time after the end of the 15th century. This improved disaggregation may be used for more detailed interpretations, for instance in agricultural and social history. By means of regression analysis annual mean temperature curves can be derived, thereby allowing the assessment of the major phases of the so-called Little Ice Age in central Europe which has its beginnings in this period.

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