Lecture notes in earth sciences Vol. 16: Long and short term variability of climate / H. Wanner, U. Siegenthaler (Eds.), Berlin 1988, p. 57-82.

VARIA TIONS IN THE SPRING-SUMMER CLIMATE OF CENTRAL EUROPE FROM THE HIGH MIDDLE AGES TO 1850

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1. Does the climate of the High Middle Ages include elements for a warming scenario?

Warm periods in the past may provide elements for assessing the climatic and human consequences of the global warming which is predicted for the next century, if the present trend in concentration of greenhouse gases in the atmosphere continues (WMO, 1986). It is assumed that the sea ice around Greenland would retreat towards its northern coast in the early stage of a warming period and then completely disappear in a later stage. The Arctic Ocean would become ice free while the continental ice-dome at the Antarctic would persist. Such a situation existed during the Late Tertiary for the last time. Flohn (1984: 7, 265) concludes from the climatic evidence of this period that the northern coasts of the Mediterranean together with the Alps and south-central Europe (up to latitudes 48- 50 N) might obtain a warm-temperate climate with some reduction of summer rains, i.e. with frequent warm season droughts, while the vegetation period would be increased by 1 - 2 months (Flohn, 1984: 9). On the other hand Frenzel concluded from the botanical evidence available from the warm interglacial periods over the past 700'000 years that the vegetation in Central Europe was not Mediterranean at that time although summer temperatures may have been 2 - 3 degrees above the present average. This suggests a warm and moist summer climate.

What do we know about the warm period in the High Middle Ages? AD 985 Norse colonists from Iceland settled in Greenland around modern Narsaq, Julianehaab and Godthaab districts (Mc Govern, 1981: 407). The colonists were able to bury their dead deep in soil that has since been permanently frozen. In the mildest period in the early twelfth century the water in the fjords was at least sometimes 4° C, or more, warmer than the present normal (Lamb, 1982: 165 f). Drift ice reached the coasts of Iceland only on the average for a few weeks per year (Koch, 1945). In Central and Western Europe cultivation of the vine was spreading farther north, medieval vineyards in England are known up to a latitude of 53° N (Lamb, 1982: 170), reports on grape harvests from Bohemia, Thuringia and Belgium are included in medieval sources (Alexandre, 1986), vines were grown on altitudes of 600 to 700 m in the prealpine valley of Toggenburg (Scherer, 1874). In Norway, also, farm settlements were spreading up to 200 m higher than before on the hill country; wheat was grown almost to the latitude of the Polar Circle (Lamb, 1984: 36); in the Alps pastures could be grazed up to 2800 m (Röthlisberger, 1976). According to Lamb (1984: 37) midsummers during this "Little Optimum" were probably between 0.7 and 1.0° C warmer than the twentieth-century average in England and 1.0- 1.4° C warmer in Central Europe (Lamb, 1982: 170).

A detailed analysis of the climate in the Middle Ages might therefore allow us to learn more on the seasonal weather patterns and on the anomalies that might be connected with the warming trend. This knowledge may be helpful for assessing the economic and societal impacts of a warming in the future. In the following the weather patterns in the spring-summer period between 1270 and 1425 will be investigated, and this data will be compared with the known variations in climate until the end of the so-called "Little Ice Age".

2. Man-made data and their limitations

For the 350 years before the creation of the national weather service in Switzerland the monthly patterns of weather and climate could be described and quantified based upon a body of data that are mostly man-made. It comprises explicit weather data (early instrumental measurements, quantitative and qualitative descriptions of daily, weekly and monthly weather patterns) and proxy-data, i.e. a variety of information which reflects the combined effect of several weather factors during a period of several months (e.g. observations on the freezing of lakes and the ripening of grapes and measurements of maximum tree-ring density on logs from the upper timberline). The synchronous display of all types of evidence in the CLIMHIST weather data bank (Pfister, 1985 a) has allowed to compare and to mutually check the different types of data, to refine the interpretation and to derive monthly indices for temperature and precipitation (Pfister, 1984).

Prior to the early sixteenth century man-made sources become at the same time less abundant and less rich in meteorological entries. This has two consequences: the time resolution of the reconstruction de- creases, and the spatial dimension of the analysis must be increased. The data are scattered within a large area, which begs the problem of interpolation in space and reduces the reliability of the estimates, in particular for precipitation. Also, continuous quantitative and homogeneous proxy-data that are required for estimating the temperature patterns of the vegetative period are more difficult to obtain. Occasionally phenological observations have also been made in the Middle Ages in order to determine and compare temperature patterns in out- standing years: a friar of the order of St. Dominic, who was born in 1221 and lived in Basel and in Colmar, has included phenological observations in his Annales Basilienses et Colmarienses. In 1283, one of the earliest springs of the present millenium, he w rote for instance: the first rye ears appeared around January 8th, the rye was in bloom on March 19th, the vine got leaves on April 1st, the first new rye was sold on May 17th, the peas could be harvested from June 8th, the same date strawberries and cherries were ripe (Annales, 1861). But these observations were not systematically carried on for some years, such as those made in the eighteenth and nineteenth century. Thus they only allow quantifying roughly the thermic character of climatic anomalies.

Grape harvest dates are available from the mid fourteenth century when several chroniclers and annalists began to keep track of the date when the wine harvest was fixed by public proclamation (Le Roy Ladurie, 1971: 50). However the records are often incomplete for many years. Measurements of the maximum density of tree-rings at the upper timber- line are the only continuous evidence for this time. The series of Lauenen (Bernese Oberland) originates in 1269 (Schweingruber, 1978). In a near future it will be extended back to the year 1000 (communication by Dr. Schweingruber).

3. Guidelines for the spatial extrapolation of data

Given the insufficient density of man-made and natural data in the Middle Ages, it is essential to assess which biases might occur from extrapolations within large areas. For this reason the spatial patterns of temperature variation in Europe must be known for the present century. Moreover we need to know to what extent those patterns are bound to change over time with the changing climate. For this reason the analysis of spatial correlations should be extended back to the beginning of instrumental measurements. This type of analysis will be attempted for Europe at the Geographical Institute of Berne based upon a large number of long series readily available in machine readable form (US Dept of Energy, 1985).

In the present context the spatial correlations of temperatures in the vegetative period (April to September) and in summer are provided for 1901-60 and 1851-1900 (table 1).

If Zurich is chosen as a reference station the covariance of temperature patterns in the vegetative period is very high (R2 of 65%) up to the shores of the Atlantic over a distance of almost 800 kilometers and still remarkable across the Alps to Northern Italy and to the Eastern Alps (Vienna). The covariation between the summer temperatures (June- August) is somewhat weaker in most cases. These results are in agreement with the significant correlations that have been found between series of vine harvest dates over distances of 800 kilometers (e.g. between Geneva and Vienna) (Flohn, 1985: 96).

4. The use and misuse of historical sources

The meteorological evidence contained in the chronicles and annals of the Middle Ages has been included in large compilations. At first sight these compendia seem to provide a convenient ready-made data bank and it is therefore not surprising that they have been much used by scientists seeking to reconstruct past climates. Historians in their turn have drawn on the results of these reconstructions.

Table 1 Temperature correlations for summer months 1851-1900 and 1901-1960

First coefficient 1851-1900 Second coefficient 1901-1960

Kilometers: distance between the stations

a) April-Sept.:	Nantes	Paris	Milano	Zürich	Munich
Paris	332km .88/.88				
Milano	832km .30/.43	624km .50/.68			
Zürich	752km .81/.78	480km .84/.90	210km .84/.70		
Munich	1005km .63/.65	690km .76/.82	345km .46/.68	255km .82/.94	
Vienna	1350km .41/.47	1020km .55/.67	630km .44/.55	585km .69/.81	360km.85/.88

b) June-August:					
Paris	.85/.87				
Milano	.18/.39	.30/.63			
Zürich	.66/.72	.74/.87	.79/.70		
Munich	.60/.60	.75/.80	.45/.66	.85/.94	
Vienna	.50/.43	.63/.66	.41/.50	.80/.78	.88/.86

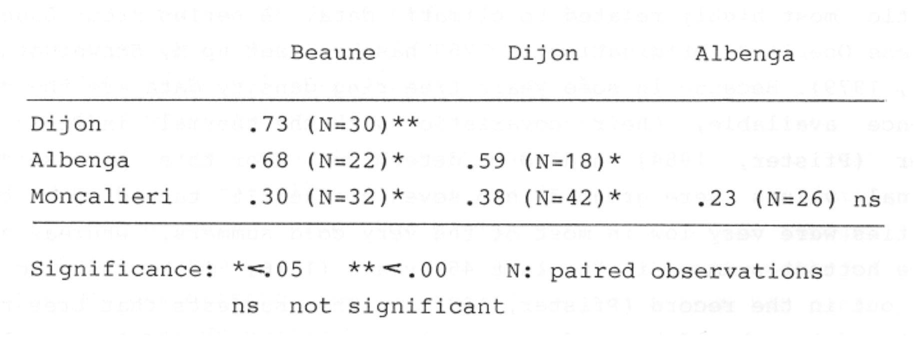
Only a decade ago it was discovered that documentary sources of information about past climate are not equally reliable, and indeed much material which purports to record historical events is gravely misleading. As far as the Middle Ages are concerned, the current compilations have been analysed in detail by Bell and Ogilvie (1978). Their main weaknesses are inaccurate or uncertain dating of particular events, acceptance of accounts which are distortions or amplifications of original observations, inclusion of events for which there is no re- liable evidence whatever and spurious multiplication of events through misdating. The consequences can be far-reaching. If for example a cold winter is misdated, which can easily occur, given that this season falls into two calendar years, this event may be included in a later compilation in an artificially multiplied way. Most fundamentally, the majority of works do not distinguish adequatly (if at all) between reliable and unreliable sources, and therefore they contain a mishmash of valuable and worthless data (Bell, Ogilvie, 1978). To take the well known Swiss compilation by Amberg (1890, 1892, 1897) as an example: for the medieval period half of the records are worthless. On the other hand Amberg did not include 30% of the reliable evidence that was available in print (Alexandre, 1986). Though the weaknesses of these compilations have been repeatedly demonstrated in the last years (Ingram et al., 1981: 192; Pfister, 1984: 40 f.) they are still uncritically used as data sources for climatic reconstruction (Burga, 1985), which is inacceptable. It is not necessary to comment on the value of sophisticated statistics that are based upon data from non contemporary sources (Pavese, Gregori, 1985).

Historians have been more cautious in selecting their sources. Schmitz (1968) has drawn from chronicles in order to investigate the links between meteorological variables and the prices for grain and wine from 800 to 1350. Buszello (1982) has illustrated the fluctuations in the standard of living of the "common man" in late medieval Switzerland, Baden and Alsace and their meteorological causes from 35 contemporary chronicles. A model of critical awareness is the recent work of the Belgian Pierre Alexandre (1986) who has brought together a new critical compilation of climatic evidence for Western and Central Europe up to 1425 (including Bohemia, Silesia and Northern Italy, but excluding England). He has taken care to assess the reliability of every source and to check every bit of information. All unreliable records were discarded. Alexandre only retained first hand observations from contemporary chroniclers. This is in itself an enormous task given the fact that most medieval sources only contain fragments of meteorological information. As far as man-made data are concerned this evidence will provide the basis for the following reconstruction.

5. The representativity of tree-ring and grape harvest data

Tree-ring data from humid Western and Central Europe do not allow very convincing climatic reconstructions, mainly because of their long climatic memory (Hughes et al., 1982). 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. Maximum density of the late wood is the single tree-ring characteristic most highly related to climatic data. A series from Lauenen (Bernese Oberland) originating in 1269 has been set up by Schweingruber (1978, 1979). Because in some years tree-ring density data are the only evidence available, their covariation with the thermal indices for summer (Pfister, 1984) had to be determined. For this purpose the original values were grouped into seven classes. It turned out that densities were very low in most of the very cold summers, whereas some of the hottest summers in the last 450 years (1616, 1719, 1947) do not stand out in the record (Pfister, 1985 c). This suggests that tree-ring density data should be used cautiously as climatic indicators unless they can be cross-checked with man-made observations or grape harvest dates.

One of the most representative series of grape harvest dates has gradually been built up by Le Roy Ladurie and Baulant (1980); they area-averaged 103 series of wine harvest data for eastern/central France, western Switzerland and a few villages from southwestern Germany. The final series originating in 1484 was tested with the Parisian temperature series for the period 1797-1879. The coefficient of correlation is .86 which ought to reassure anyone to the reliability of phenological sources (Le Roy Ladurie, Baulant, 1980: 263). For the period before 1484 wine harvest data for Dijon are contained in the work of Angot (1883) from 1366 , who, in his turn, relied upon Lavalle (1855). The climatologist Jean-Pierre Legrand (1979 a, b) has used this evidence after 1400, when it is almost complete, in his careful investigation on temperature anomalies and sunspot activity over the last 580 years. New data for the fourteenth century have been discovered by historians who became sensitive to this type of evidence after reading Le Roy Ladurie's History of Climate (1967, 1971). Rotelli (1973) has included several series in his work on agrarian history of the Piemonte. The longest and the most complete (Moncalieri) covers the period from 1331 to 1424. A series from Beaune (Dubois, 1976) made it possible to bridge the frequent gaps contained in the Dijon series in the late fourteenth century. Another series from the plain of Albenga (N Italy) has been set up for 1364-1796 (Mazzei). Data for fifteenth century Anjou in form of a small graph (Le Mene, 1982) were discarded, because they were too difficult to check. For the period after 1371 a regional C8te d'Or series was computed from Dijon and Beaune; some missing values were interpolated using Albenga and Moncalieri (see Appendix). Previously the covariance between the four series was determined:



	Beaune	Dijon	Albenga
Dijon	.73 (N=30)**		
Albenga	.68 (N=22)*	.59 (N=18)*	
Moncalieri	.30 (N=32)*	.38 (N=42)*	.23 (N=26) ns

Significance: *<.05 **<.00 N: paired observations
ns not significant

With r > 0.7 the correlation between the two series from the Cote d' Or is almost at the same level as in the later centuries (Le Roy Ladurie, Baulant, 1980: App. II). Remarkable also is the result of Albenga (across the Alps) while the covariance of Moncalieri with the Cote d'Or is weak and not even significant with Albenga.

The value of the Côte d'Or series for climatic reconstruction critically assessed in cross correlating the series with the tree-ring maximum density series of Lauenen. In order to test the stability of the correlations, the series were split into two shorter periods. It turned out that the correlations between the two series were in the same order of magnitude as between the Lauenen series and the area-averaged series of wine harvest dates from Western Europe (Flohn, 1985: 98):

1370-1399: -.65 (N= 29)

1400-1499: -.43 (N= 94)

This result suggests that the Cote d'Or series can be used as a valid climatic indicator.

6. Outstanding anomalies

6.1. Definition and interpretation

In table 2 years with strong temperature anomalies in the vegetative period are listed from 1270 to 1524 as far as they appear in the tree- ring density record, in the series of wine harvest dates or in both. The two data sets complement each other: grape harvest dates primarily reflect temperatures in the spring-summer period (Pfister, 1984: 86; Flohn, 1985: 95 f.), maximum densities those in August and September (sometimes July through September), but also in April-May. However heat-waves in June, that may precipitately advance the maturation of grapes (Legrand, 1979 c: 43), as occurred e.g. in 1616 and in 1976, appear to have little effect on maximum density (Schweingruber, 1978: 78). Also the weather patterns in the Alps may be somewhat different than those in the lowlands. A more complete list of temperature anomalies may therefore be derived from a comparison of the two records and a cross-checking with additional unsystematic phenological observations and weather descriptions. Years in which the grape harvest began prior to September 10th or later than October 20th are considered anomalous, whereas for the tree-ring densities the limits of warm and cold anomalies are set to 1090 g/cm3 and to 880 g/cm3 respectively. A value above 1090 g/cm3 corresponds in most cases to extremely high temperatures in August and September whereas densities below 880 g/cm3 point to late summers that were colder than the chilliest of the present century (Pfister, 1985 c: 187).

Table 2 Temperature anomalies in the warm season 1270-1524 in Central and Western Europe

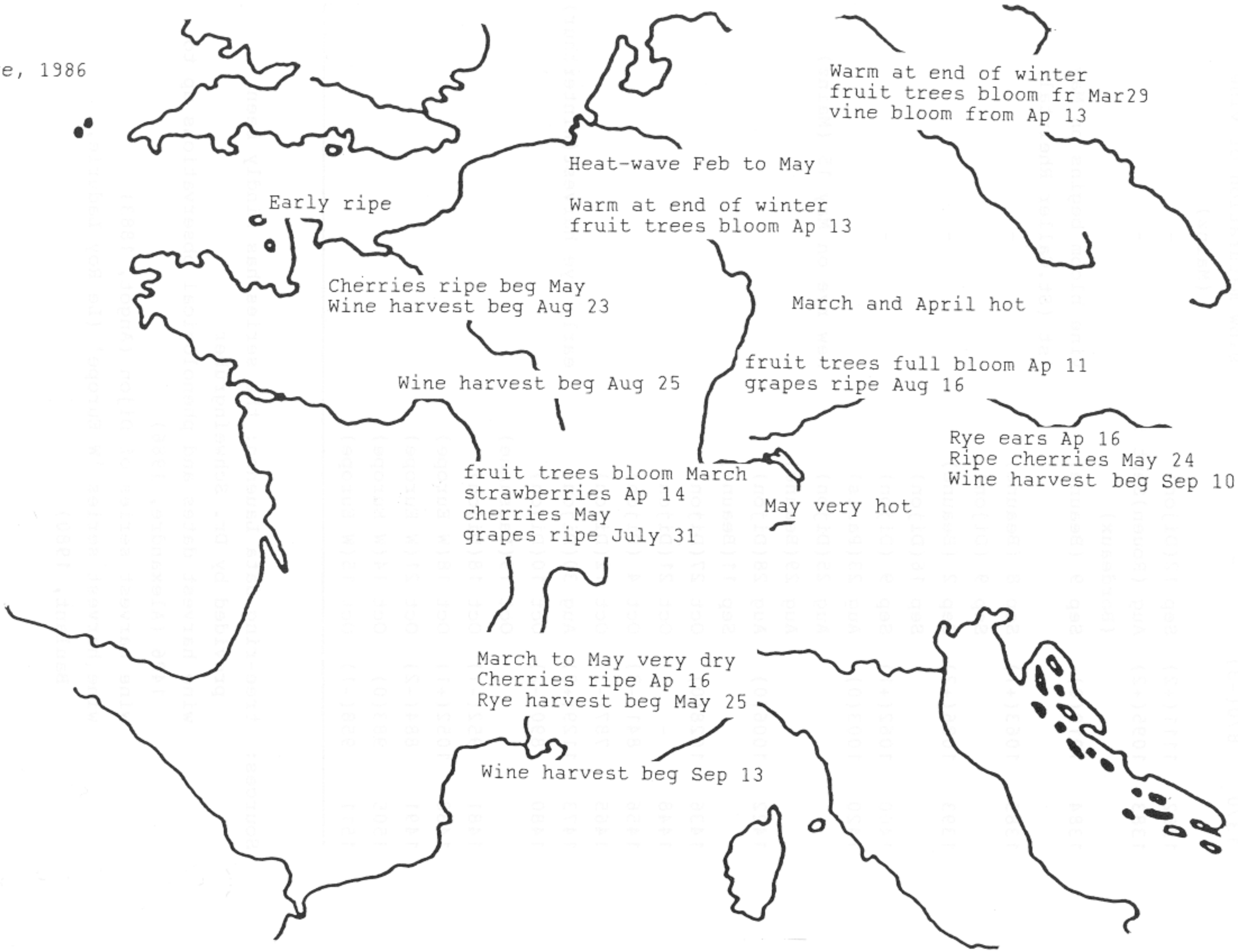
year	tree-ring density	wine-harvest dates	unsystematic phenological observations
1270	1170(+3)	-	first ripe grapes of early burgundy July 13 (Alsace)
1273	1180(+3)	-	-
1274	989(0)	Nov 18 (Basel)	
1282	1028(0)	new wine Aug 22 (Strasbourg)	-
1287	1124(+3)	end around Sept 22(Ribeauville)	-
1300	1138(+3)	-	-
1302	873(-3)	Oct 23(Limoges)	
1304	1090(+2)	-	first ripe grapes of early burgundy July 1st (Alsace)
1315	829(-3)	Nov 9 (Quimperlé) Nov 19 (Vienna)	-
1319	1123(+3)	-	-
1330	1075(+1)	Nov 9(Maillezais)	-
1331	1130(+3)	beg of Sept(Liege) Aug (Paris)	cherries ripe at beg of May (Maillezais)
1333	1169(+3)	-	-
1335	723(-3)	-	slow maturation of vine (Paris)
1336	1138(+3)	Aug(Liege)	very high sugar content (Zürich)
1345	831(-3)		slow maturation of vine (Paris, Torino)
1346	858(-3)		vine still in bloom on Aug 2nd (Lindau)
1347	909(-2)	Nov 9(Krems)	vine still in bloom on Sept 1st (Lindau)
1350	822(-3)	-	-
1359	724(-3)	-	-
1361	1010(+2)	Sept 9(Constance)	-
1366	778(-3)	Oct 17(Dijon)	slow maturation of vine (Mainz)

1370	870(-3)	Weinlese: Anfang Nov, Rheintal! -	slow maturation of vine (Mainz)
1382	1111(+2)	Sep 12(Dijon)	-
1383	1095(+2)	Aug (Rouen)Sept 5 (Bordeaux)	-
1384	1019(0)	Sep 9 (Beaune)	vine bloom begins on May 1st (St.Galler Rheintal)
1385	1063(+1)	Sep 8 (Beaune) Sep 9 (Dijon)	-
1393	1086(+2)	Sep 2 (Beaune) Sep 16(Dijon)	-
1400	1062(+1)	Sep 9 (Dijon)	-
1420	1003(0)	Aug 23(Paris) Aug 25(Dijon) Aug 29(Beaune)	new rye on May 15 (Mainz)
1422	1006(0)	Aug 28(Dijon) Sep 11(Beaune)	
1436	1028(0)	Oct 27(Dijon)	
1448	-	Oct 21(Dijon)	
1456	841(-3)	Oct 4 (Dijon)	
1465	787(-3)	Oct 12(Dijon)	
1473	1129(+3)	Aug 30(Dijon)	early rye harvest(Winterthur)
1480	890(-2)	Oct 10(Dijon) Oct 19(Lausanne)	
1481	952(-1)	Oct 18(Dijon)	
1488	1052(+1)	Oct 18(W Europe)	
1491	884(-2)	Oct 21(W Europe)	
1505	983(0)	Oct 14(W Europe)	
1511	958(-1)	Oct 15(W Europe)	

Sources: tree-ring data Lauenen: the series has kindly been provided by Dr. Schweingruber
wine harvest dates and phenological observations up to 1426 (Alexandre, 1986)
wine harvest series of Dijon (Angot, 1883)
wine harvest series 'W Europe' (Le Roy Ladurie, Baulant, 1980)

Graph 1: The early spring-summer 1420 in Central Europe

Data: Alexandre, 1986



6.2. Examples of warm anomalies

In 1420 wine harvest in Western and Central Europe began at the end of August, even on altitudes of 500 to 700 m (Bern, Toggenburg). This is the earliest date ever recorded. Because the contemporaries considered this year outstanding, it was described in most chronicles, even in those in which meteorological observations were marginal. The anomaly extended from southern Thuringia to the Po valley and from Central France to the Vienna basin (graph 1). For the adjacent regions no data are available at present. In order to explain the weather patterns of this year the phenological evidence is compared to the pattern observed in 1540 (Pfister, 1984, 1985 a) and to comparable phenological extremes documented with thermometrical measurements (table 3).

In 1420 the warm phase started in February. In March summer began already. The vine bloom was two weeks earlier than in 1893- the most advanced year within the instrumental period. Based on the date for Lichtensteig (600-700 m) and according to a gradient of 3.6 days per 100 m (Becker, 1969 : 142) it has been estimated that the end of the bloom may have occurred in the last days of May around Basel (260 m) i.e. almost a month before the mean date of the present century. The first new wine ("Sauser"), probably from early burgundy grapes, was sold at the beginning of August. The wine harvest was advanced by a month compared with the long term average for Western Europe (Le Roy Ladurie, Baulant, 1980). In 1540 the heat-wave began in April (as in 1893). It is reported that the development of the vegetation was slowed down by drought. The meager evidence available for 1270, 1304, 1331 and 1336 (cp. table 2) suggests that phenological patterns may have been comparable to those observed in 1420 and in 1540: in 1270 and 1304 the early burgundy grapes were ripe at about the same time as in 1540, whereas in 1331 the ripening of the first cherries in Western France and the beginning of the wine harvest in Paris coincided roughly with the corresponding phenophases in 1420.

The comparison of the phenophases in 1420 and 1540 with the corresponding extremes documented with thermometrical evidence suggests that in 1420 all months from February to August (in 1540 from April to August) may have been 2 to 3 degrees above the 1901-60 average.

Table 3 Pattern of the phenophases in Southern Central Europe in 1420 and 1540 compared to the earliest known phases within the instrumental period

	1420	1540	within instrumental period	cumulative temperature deviations (°C)
Trees in bloom	March (Berne)	-	March 29,1948 (Hallau)	+ 9 (Jan. to March)
Ripe Strawberries	Apr. 23 (Basel)	-	-	
Vine in bloom	May 2 (Basel)	-	May 17,1893 (Hallau)	+ 4 (Apr., May)
Ripe cherries		beg.June (Zürich)		
Bloom ends	June 6 (Lichtensteig)	June 10 (Schaffhausen)	June 13,1811 (Schaffhausen)	+ 6 (Apr. to June)
New rye	May 15 (Metz)	June 16 (Zürich)	June 30,1822 (Schaffhausen)	+ 6.5 (May, June)
Grapes ripe		July 10 (Zürich)		
New wine	July 31 (Metz) Aug. 10 (S.Baden)	Aug. 15 (Zürich)		
Wine harvest beg.	Aug. 28 (Lichtensteig) Aug. 31 (Berne)	Sep. 9 (Zürich)	Sep. 9,1822	+ 6.5 (May, June)

PFISTER (1985 b)

Sources: Pfister 1984, 1985a; Alexandre 1986.

Precipitation patterns may only be got for 1540. Heinrich Bullinger, who was antistes in Zurich, recorded a total of six days with precipitation during the 26 weeks from mid March to the end of September. After two rainy days at the beginning of October the weather turned to warm and dry again. On New Year boys were still swimming in the Rhine near Schaffhausen. The record of this outstanding year suggests that a mediterranean type of climate persisted for about ten months. Annual precipitation may not have exceeded 300 to 400 mm (Pfister, 1984: 138). The summer of 1304 may have been similar. According to the Annales Colmarienses flour became scarce because many mills fell dry; wine was abundant, but the casks couldn't be loaded on boats because the level of the Rhine was too low (Annales, 1861: 231).

The most outstanding spring-summer period since 1269 probably is 1473, because in this year a very early grape harvest coincided with a tree- ring density that is close to the maximum recorded (cp table 2). There is an abundance of observations for this anomaly, but the documentation is not available yet.

6.3. The ice-age summers of the 1340's

From the climatic history of the last centuries it is well known that cold summers have a certain tendency to cluster (e.g. 1812 to 1817). A similar pattern stands out in the 1340's: for 1345 a slow maturation of the vine is reported from Paris and Torino, in 1346 the vine was still in bloom at Lindau after August 2nd, a retardation of vegetative growth that may be compared only to the two coldest summers since 1500 (1628 and 1816). In 1345 and 1346 maximum tree-ring densities are among the twenty lowest contained in the Lauenen series. In 1347 the vine was still in bloom at the beginning of September. This points to a cold anomaly in July and August that is unique in the last six centuries (Pfister, 1985 c: 192).

7. Climatic trends in spring and summer from the High Middle Ages to 1850

For the warm period of the High Middle Ages continuous proxy-data are not yet available. A historical custom introduced by the order of Cluny in 1018 nevertheless allows estimating the average date of the grape harvest in Northern and Central France. At the mass of the Transfiguration (Aug. 6) the new wine was dedicated at the altar and afterwards presented to every friar. When the maturation of the, vine was delayed, the juice of some soft grapes was taken instead. If the correction for the Gregorian rule is made the average date of this celebration was around August 13. This roughly corresponds to the earliest date of the wine harvest ever recorded (August 13, 1893 in the region of Bordeaux). In this year the mean temperature from April to August was 2.6 degrees above the long term average (Legrand, 1979 b: 42 f.). But presumably spring-summer temperatures in the High Middle Ages were somewhat lower. Legrand admits that we do not know whether the grapes for the first new wine were grown on an espalier sheltered from the cold. Also it must be assumed that the wine was made from an early variety of burgundy grapes. In Switzerland the early burgundy grapes were ripe around August 10 in very warm summers (Pfister, 1984: 84). In 1420 the first "new wine" from these grapes was drunk at the beginning of August, in 1540 on August 15 (table 3), about twenty days before the wine harvest was opened. If this delay was the same in ordinary years, the mean grape harvest date would be around September 1st in the High Middle Ages, which is a few days earlier than in the warmest summers documented with thermometric measurement. From a regression approach comparing the decennial means of wine harvest dates and temperatures from 1370 to 1850 it has been estimated that an opening of the harvest on September 1st corresponds to a mean temperature from April to September that is 1.7 (+ -0.2) degrees above the average for 1901-60.

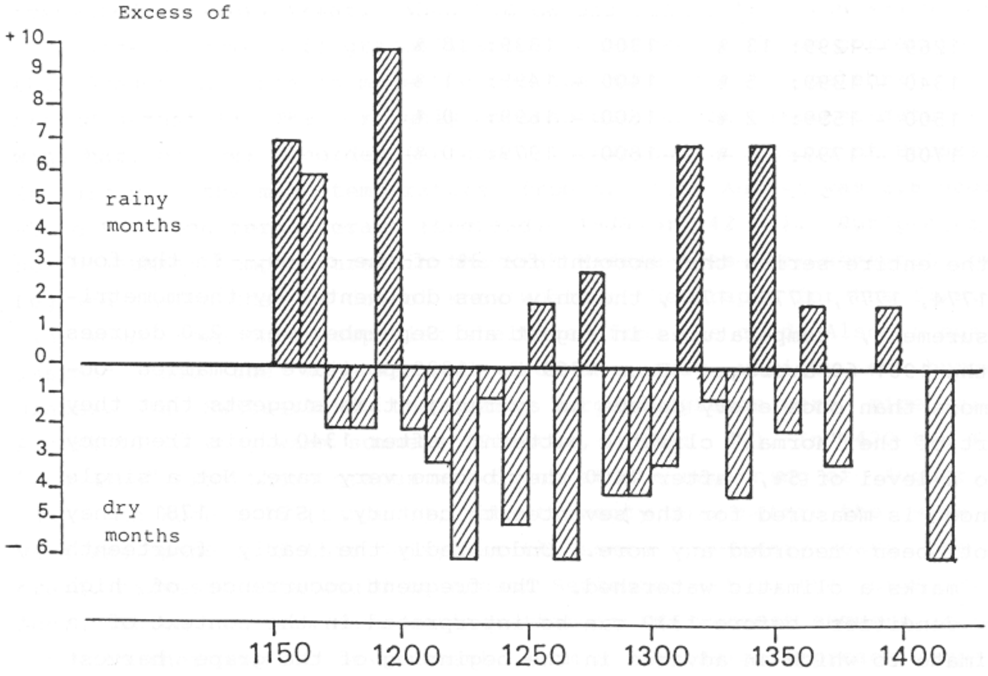
From the spreading of the vine and the cereals to higher altitudes and latitudes in the High Middle Ages it has been primarily concluded to temperature patterns in midsummer. However, as the maturation of both crops is mainly promoted by temperatures in May and June (Pfister, 1984: 86) this evidence is rather conclusive for conditions in late spring and early summer (Legrand, 1979 b: 43). An advance in the mean date of the grape harvest also suggests an earlier date of snow-melt in the Alps since phenophases of the vine are significantly correlated with the melting dates at different levels of altitude (Pfister, 1985 b: 168 f.).

In the Lauenen series of tree-ring densities the warm period of the High Middle Ages can be documented by assessing the frequency of positive anomalies exceeding 1089 g/cm3.

1269- 1299: 13 %
1300- 1339: 18 %
1340- 1399: 5 %
1400- 1499: 1 %
1500- 1599: 2 %
1600- 1699: 0 %
1700- 1799: 5 %
1800- 1979: 0 %

Within the entire series they account for 3% of the cases. In the four years 1774, 1777, 1779, 1781, the only ones documented by thermometrical measurement, temperatures in August and September were 2.0 degrees above the 1901-60 average. From 1269 to 1339 positive anomalies occurred more than once every decade on average; this suggests that they were part of the "normal" climatic pattern; after 1340 their frequency drops to a level of 5%, after 1400 they became very rare. Not a single occurrence is measured for the seventeenth century. Since 1781 they have not been recorded any more. Undoubtedly the early fourteenth century marks a climatic watershed. The frequent occurrence of high maximum densities before 1330 can be interpreted in the context of a warm climate to which an advance in the beginning of the grape harvest is connected. It may be hypothesized that summers which were outstanding according to the standards of later periods, such as those of 1420, 1473 or 1540 were within the normal range of fluctuations during the High Middle Ages. This could explain why extreme anomalies in the warm period such as the summer of 1331 are only briefly described in a few chronicles whereas similar events after the mid-fourteenth century have evoked extensive comments in a multitude of sources. The evidence on precipitation does not contradict this hypothesis. From 1200 to 1310 only two decades had a moderate excess of wet summer months (graph 2).

Graph 2 Precipitation patterns in Summer (J, J, A) from 1150 to 1420
Difference of unmistakably rainy and dry months per decade



The year indicates the beginning of the decade

Source: Alexandre, 1986

The frequency of the very cold summers can be documented from the Lauenen series by assessing the frequency of negative anomalies below 880 g/cm^3.

1269 - 1299: 0 % 1300 - 1339: 5 %
1340 - 1379: 18 % 1380 - 1429: 0 %
1430 - 1499: 3 % 1570 - 1599: 17 %
1600 - 1699: 4 % 1700 - 1810: 0 %
1811 - 1860: 10 % 1861 - 1979: 0 %

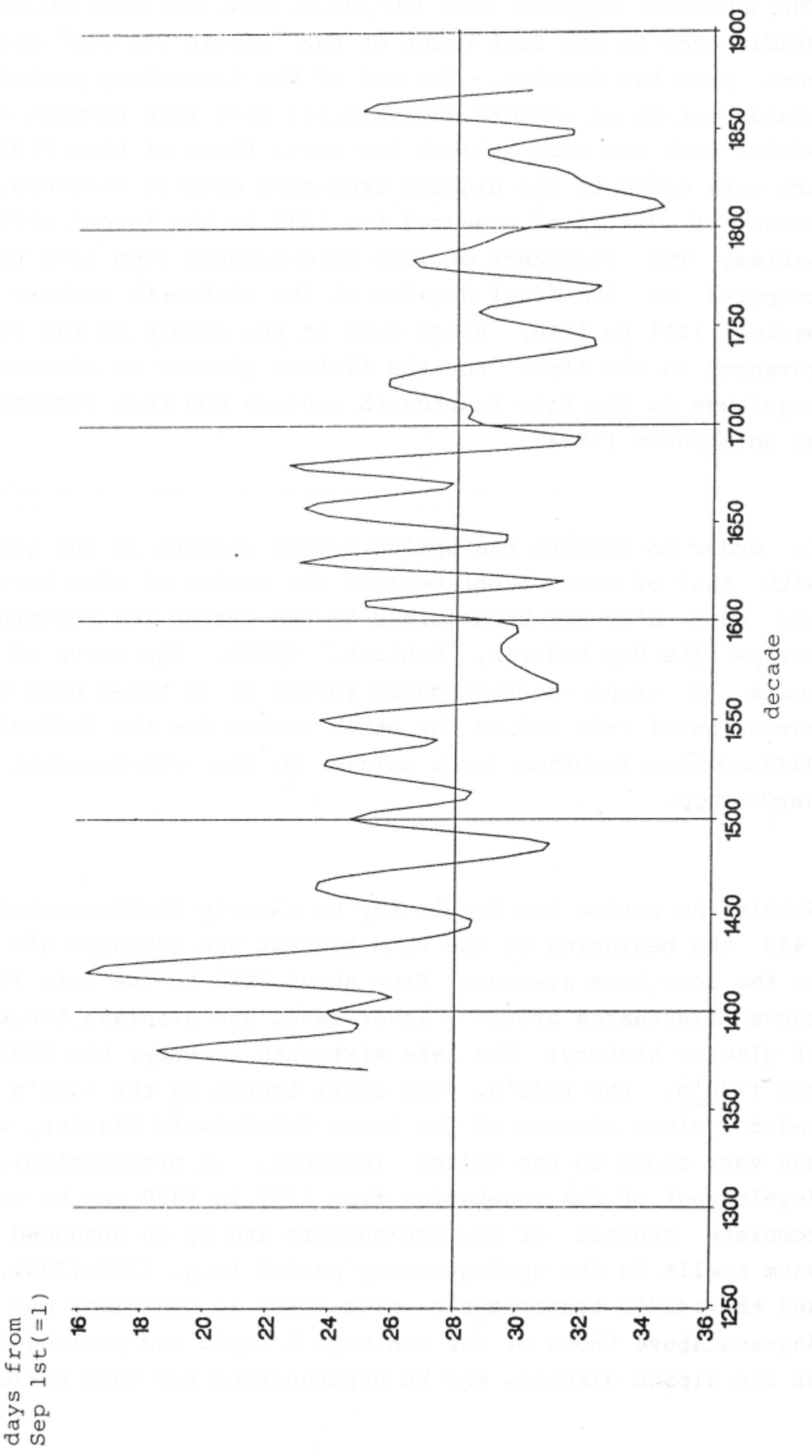
The evidence suggests that the shift from the warm climate of the High Middle Ages to the full brunt of the "Little Ice Age" did not take much more than two decades. The end of the transitory period in the 1330'5 stands out by an extreme variability: five late summers out of ten were either much too cold or much too warm: three of them (1331, 1333, 1336) are very close to the highest tree-ring density recorded, whereas the value of 723 g/cm3 measured for 1335 is the lowest within the entire series. The frequency of very cold summers from 1340 to 1379 may be compared to the final decades of the sixteenth century and to the period 1811 to 1860, which were at the origin of far reaching glacier advances in the Alps. For the Aletsch glacier an advance of a similar magnitude in the late fourteenth century has been recently demonstrated by Holzhauser (1984).

In order to compare the spring-summer climate in the Late Middle Ages with that of more recent periods the series of wine harvest dates for the C8te d'Or has been joined to the series for Western and Central Europe (Le Roy Ladurie, Baulant, 1980). The curve of the decennial means of grape harvest dates (graph 3) is based upon the c8te d'Or series until 1500 and on the other series for the following period. The differences between both series in the overlapping period may be neglected.

Within the series two levels may be clearly distinguished: from 1380 to 1430 the beginning of the wine harvest was advanced six days compared to the long term average; from about 1450 to the late 19th century the curve fluctuates around a lower level and displays the known advances of glacier history: the late sixteenth century, the 1690's, the 1740's, the 1770's, the 1820's. The small trough in the 1490's may have pre- ceded a minor advance of the Lower Grindelwald Glacier, which, in 1535, was very close to the valley (Pfister, in preparation). The advanced development of the vegetation from 1380 to 1430 may be explained by the complete absence of ice age summers and by an enhanced frequency of warm spells in the spring-summer period (e.g. 1382-1385). In the 1380's and the 1420's temperatures from April to September may have been 0.5 degrees above those of our century. A rapid and prolonged melting back of the alpine glaciers may be hypothesized for this period.

Graph 3   Mean date of grape harvest in Western Europe 1370-1880

Decennial averages. The years give the beginning of the decade (e.g. 1500 = 1501-1510)



Source: 1370 to 1500   Series Mont d'Or
1500 to 1880   area-averaged series W Europe (Le Roy Ladurie, Baulant, 1980)

APPENDIX - GRAPE HARVEST DATES (DAYS FROM SEPT. 1ST = 1)
ORIGINAL AND INTERPOLATED SERIES

YEAR	ALBENGA	MONCALIERI	AVIGNON	BEAUNE	DIJON	COTE-D'OR	W.-EUROPE
1370	.	25	.	.	.	28M	.
1371	.	23	.	.	.	26M	.
1372	.	26	.	27	.	29	.
1373	.	18	.	20	.	22	.
1374	.	26	.	31	.	33	.
1375	.	32	.	20	.	22	.
1376	20	28	.	16	.	18	.
1377	22	20	.	.	.	22A	.
1378	.	26	.	23	.	25	.
1379	.	26	.	22	.	24	.
1380	.	23	.	21	.	23	.
1381	26	30	.	21	20	21	.
1382	.	21	.	13	12	13	.
1383	16	34	.	5	.	7	.
1384	5	19	.	6	.	8	.
1385	19	13	.	7	9	8	.
1386	24	29	.	18	.	20	.
1387	24	29	.	20	33	27	.
1388	15	29	.	28	25	27	.
1389	27	24	.	24	24	24	.
1390	20	29	.	.	.	20A	.
1391	25	29	.	17	.	19	.
1392	30	22	.	38	33	36	.
1393	17	14	.	1	16	9	.
1394	22	32	.	.	38	38	.
1395	21	.	.	.	.	21A	.
1396	.	25	.	.	.	27M	.
1397	23	23	.	.	22	22	.
1398	.	.	.	.	25	25	.
1399	29	.	.	.	26	26	.
1400	13	26	.	.	10	10	.
1401	23	16	.	14	11	13	.
1402	.	25	.	13	20	17	.
1403	25	29	.	21	19	20	.
1404	25	29	.	28	.	30	.
1405	23	.	.	26	.	28	.
1406	23	.	.	24	.	26	.
1407	20	22	.	25	29	27	.
1408	23	.	.	27	33	30	.
1409	24	23	.	17	30	24	.
1410	.	.	.	10	24	17	.
1411	.	.	.	38	37	38	.
1412	.	.	.	17	18	18	.
1413	20	18	.	10	29	20	.
1414	.	.	.	27	33	30	.
1415	.	22	.	20	22	21	.
1416	.	.	.	24	31	28	.
1417	.	.	.	20	22	21	.
1418	.	.	.	9	14	12	.
1419	.	.	.	17	25	21	.
1420	12	20	.	-3	-6	-5	.
1421	.	.	.	23	22	23	.
1422	.	.	.	10	-3	4	.
1423	.	.	.	22	23	23	.
1424	.	.	.	10	11	11	.
1425	.	.	.	.	16	16	.
1426	.	16	.	24	14	19	.
1427	.	.	.	.	25	25	.
1428	.	.	.	.	36	36	.
1429	.	.	.	.	24	24	.
1430	.	.	.	.	15	15	.
1431	.	.	.	.	19	19	.
1432	.	.	.	.	18	18	.
1433	.	.	.	.	12	12	.
1434	.	.	.	.	1	1	.
1435	.	.	.	.	25	25	.
1436	.	.	.	.	56	56	.
1437	.	.	.	.	28	28	.
1438	.	.	.	.	.	.	.
1439	.	.	.	.	27	27	.
1440	.	.	.	.	28	28	.
1441	.	.	.	.	18	18	.
1442	.	.	.	.	13	13	.
1443	.	.	.	.	26	26	.
1444	.	.	.	.	22	22	.
1445	.	.	.	.	36	36	.
1446	.	.	.	.	.	.	.
1447	.	.	.	.	.	.	.

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INTERPOLATION : 'A' FROM ALBENGA
'M' FROM MONCALIERI

Ø 25 >

APPENDIX - GRAPE HARVEST DATES
ORIGINAL AND INTERPOLATED SERIES

YEAR	ALBENGA	MONCALIERI	AVIGNON	BEAUNE	DIJON	COTE-D'OR	W.-EUROPE
1448	.	.	.	.	50	50	.
1449	.	.	.	.	29	29	.
1450	.	.	.	.	25	25	.
1451	.	.	.	.	39	39	.
1452	.	.	.	.	24	24	.
1453	.	.	.	.	27	27	.
1454	.	.	.	.	34	34	.
1455	.	.	.	.	31	31	.
1456	.	.	.	.	33	33	.
1457	.	.	.	.	14	14	.
1458	.	.	7	.	18	18	.
1459	.	.	28	.	36	36	.
1460	.	.	18	.	.	22V	.
1461	.	21	13	.	16	16	.
1462	.	13	5	.	.	9V	.
1463	.	.	33	.	35	35	.
1464	.	.	20	.	14	14	.
1465	.	.	35	.	41	41	.
1466	.	.	28	.	27	27	.
1467	.	.	.	.	27	27	.
1468	.	.	.	.	32	32	.
1469	.	28	.	.	20	20	.
1470	.	.	.	.	37	37	.
1471	.	.	.	.	11	11	.
1472	.	.	.	.	23	23	.
1473	.	.	.	.	-2	-2	.
1474	.	.	.	.	39	39	.
1475	.	.	.	.	31	31	.
1476	.	.	.	.	28	28	.
1477	.	.	.	.	41	41	.
1478	.	.	.	.	19	19	.
1479	.	.	.	.	16	16	.
1480	.	.	.	.	39	39	.
1481	.	.	.	.	47	47	.
1482	.	.	.	.	16	16	.
1483	.	.	.	.	15	15	.
1484	.	.	.	.	20	20	31
1485	.	.	.	.	43	43	37
1486	.	.	.	.	20	20	20
1487	.	.	.	.	22	22	26
1488	.	.	.	.	42	42	47
1489	.	.	.	.	31	31	27
1490	.	.	.	.	25	25	27
1491	.	21	.	.	45	45	50
1492	.	.	.	.	.	.	.
1493	.	21	.	.	35	35	36
1494	.	.	.	.	18	18	18
1495	.	14	.	.	12	12	12
1496	.	.	.	.	42	42	40
1497	.	18	.	.	41	41	31
1498	.	29	.	.	26	26	26
1499	.	21	.	.	28	28	28
1500	.	12	.	.	14	14	14
1501	.	21	.	.	19	19	19
1502	.	.	.	.	29	29	26
1503	.	.	.	.	28	28	17
1504	.	.	.	.	14	14	17
1505	.	.	.	.	43	43	43
1506	.	29	.	.	28	28	29
1507	.	10	.	.	21	21	19
1508	.	17	.	.	30	30	32
1509	.	.	.	.	20	20	25
1510	.	.	.	.	30	30	30
1511	.	36	.	.	44	44	44
1512	.	.	.	.	24	24	24
1513	.	.	.	.	.	.	28
1514	.	29	.	.	37	37	29
1515	.	.	.	.	35	35	31
1516	.	.	.	.	12	12	11
1517	.	.	.	.	26	26	22
1518	.	.	.	.	32	32	28
1519	.	29	.	.	40	40	37
1520	.	7	.	.	35	35	23
1521	.	16	.	.	.	.	23
1522	.	29	.	.	5	5	24
1523	.	1	.	.	-5	-5	17
1524	.	.	.	.	.	.	14
1525	.	.	.	.	21	21	20

INTERPOLATION : 'V' FROM AVIGNON

APPENDIX - GRAPE HARVEST DATES
ORIGINAL AND INTERPOLATED SERIES

CORRELATION AND DIFFERENCE OF MEANS IN THE COMMON YEARS

	ALBENGA	BEAUNE	DIJON	MONCALIERI	AVIGNON	W.-EUROPE
ALBENGA	-	22 0.677 -3.46	18 0.579 1.50	26 0.230 3.27	1 -	-
BEAUNE	22 0.677 3.46	-	30 0.734 2.75	32 0.300 4.78	-	-
DIJON	18 0.579 -1.50	30 0.734 -2.75	-	42 0.379 -2.35	8 0.174 -8.63	41 0.825 0.36
MONACALIERI	26 0.230 -3.27	32 0.300 -4.78	42 0.379 2.35	-	5 -	23 0.354 10.22
AVIGNON	1 -	-	8 0.174 8.63	5 -	-	-
WEST-EUROP	-	-	41 0.825 -0.36	23 0.354 -10.22	-	-

1ST LINE : NUMBER OF COMMON VALUES, COEFFICIENT OF CORRELATION
2ND LINE : DIFFERENCE OF MEANS : TOP-SERIES MINUS LEFT-SERIES

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Acknowledgments are due to Prof. John Post, Boston, for reading the manuscript and for making helpful suggestions, to Andreas Lauterburg and Hannes SchUle for providing invaluable help in programming and to Dr. P. Alexandre, Embourg (Belgium), for sending additional data.

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