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DAILY WEATHER OBSERVATIONS IN SIXTEENTH-CENTURY EUROPE

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Abstract. Thirty-two weather diaries written in astronomical calendars in central Europe in the late fifteenth and sixteenth centuries are presented and discussed. Systematic weather observations were promoted by the rise of planetary astronomy and its application in astro-meteorology. The practice of keeping weather diaries spread from Cracow (Poland) to Ingolstadt (Germany) and from there to other universities. The data obtained from these sources provided the backbone for setting up series of precipitation indices for Poland, Geffi1any and Switzerland. Month1y statistics of days with precipitation, snowfall and frost were computed by counting the relevant entries in the most important diaries. The results were compared with either those obtained from instrumental measurements in the same place or with those from modem instrumental measurements in a neighbouring place. The final Results show that autumn was considerably colder in the early sixteenth century .April was considerably drier and July was wetter during the period 1508-1531 than during 1901-1960. In order to highlight the impact of weather patterns on grain prices in a year of crisis, the timing of wet and dry spells in southem Poland and southern Germany is compared for the year 1529. Winters became 1.7°C colder from 1564 to 1576 and the month of July tended to be wetter than in 1901-1960. Details noted in the diaries kept between 1585 and 1600 by the astronomers Brahe (near Copenhagen) and Fabricius (in the Ostfriesland region of northwestern Germany) closely agree. It rained more often in June and July and temperatures dropped. The winter months were more frequently dominated by winds from easterly directiol1s, the frequency of snowfall was higher and a deficit occurred in precipitation. This points to a higher frequency of high pressure in the Fennoscandian area with cold air advection from the east or northeast.

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1. Introduction

The earliest known daily weather observations in Europe -for the brief period 1269-1270 - appear in a volume written by Roger Bacon (ca. 1214-1294), one of the forerunners of empirical methods in scientific studies (Long, 1974). The Reverend William Merle in Lincolnshire (England) kept a weather diary from January 1337 to January 1344 (Lawrence, 1972). A further journal, covering the period 1399-1405, is anonymous. It belonged to a Dominican monastery in the town of Basle (Switzerland) and is now in the manuscript collection of the university library there. It is not clear whether the observations recorded therein were made in Basle or in the adjacent region of France (Thorndike, 1949, 1966; Frederick et al., 1966; Klemm, 1974). In Japan, several weather diaries were already being kept from about AD 1000 (Maejima, 1966).

The keeping of weather diaries in Europe became a scientific practice from the late fifteenth century, i.e. at the beginning of the Early Modern Period. Examples of early diaries are known from Poland (Gorczynski, 1922; Walawender, 1932; Rojecki, 1966), the various regions of Germany (He11mann, 1883, 1901; Klemm, 1973, 1974, 1976, 1979, 1983), the Czech lands (Pejrn1 and Munzar, 1968a, 1968b [dealing with Bohemian records from Basle]; Klemm, 1983; Munzar, 1984, 1994, 1995; Brazdil and Kotyza, 1995a, 1995b, 1996a, 1996b, 1996c), Switzerland (SMB, 1872, 1873, 1885) and Denmark (La Cour, 1876).

The information recorded in weather diaries is used in various ways. Firstly, it allows the reconstruction of basic climatic parameters for the time it covers (e.g. Lenke, 1968; Pfister and Bareiss, 1994). Secondly, it can be transformed into continuous seasonal temperature and precipitation indices (see Glaser et al., this volume). Thirdly, certain observations, in particular those of wind direction and strength, are highly valuable for the reconstruction of month1y atmospheric circulation patterns (Frich and Frydendahl, 1994; Jacobeit et al., this volume). Finally, it allows the study of features below the time resolution of a month, such as weather spells and singularities (e.g. Flohn, 1949; Lenke, 1968). Sixteenth- century weather diaries included in the analyses of Glaser et al. (this volume) and Jacobeit et al. (this volume) are presented in this paper and the reconstruction of month1y statistics for certain climatic parameters is shown. Where necessary , all dates have been converted from the old style of the Julian calendar to the modified style of the Gregorian calendar used throughout most of the Western world (see Pfister et al., this volume).

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2. Early Weather Diaries

2.1. THE SCIENTIFIC ENVIRONMENT

The keeping of systematic weather records from the late fifteenth century was promoted by three main factors:

- the growing use of planetary astronomy as a means of weather prediction (astro-meteorology)
- the mass publication of astronomical almanacs, known as ephemerides
- the growing interest in meteorological factors known to affect grain production and food prices.

The Greek astronomer and geographer Claudius Ptolemy (ca. 85-160) believed that the constellations of the planets (including the sun and the moon) affected the atmosphere. The scientific study and prognosis of astrological conjunctions were seen as ways to formulate long term predictions of weather and climate. In an agrarian society , weather was the most important risk factor because food prices main1y depended on the outcome of the harvests. Weather was chiefly perceived as an economic risk factor and forecasting was therefore of much importance. Prediction is the process in which risks are subjectively or intuitively understood and evaluated. Perceiving a pattern of events is one of the ways in which the uncertainty associated with probabilistic phenomena is dealt with psychologically. This can provide an individual with a sense of control over the environment or allow him to believe that he is under the control of an higher authority who has both motivation and command (Whyte, 1985). The art of astro-meteorology was improved by the Arabs and reintroduced to Europe in the twelfth century .It remained, however, an elite phenomenon (Frisinger, 1977; Barton, 1994). The population at large believed the dominating idea that environmental stress was the product of a malevolent will (see Behringer, this volume). Planetary astronomy rose to be the leading hypothesis of science during the sixteenth century (Thoren, 1989). In this context, the keeping of daily weather observations was promoted to improve and test the reliability of astro-meteorological predictions (Hellmann, 1927).
The mass publication of astronomical calendars from the late fifteenth century provided a suitable medium on which such observations could be based (Pejml, 1985). Astronomer Johannes Müller (1436-1476) established a printing press in Nurernberg in 1474 and published the first German astronomical calendar entitled De Monte Regio Ephemerides ab anno 1475-1506 (Müller, 1475; Bepler and Bürger, 1994). This booklet listed the name of the ruling saint followed by the planetary and zodiacal constellations for every day of each month during that period.

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At the end of every line some space was left empty for the possible use of writing notes, such as personal observations on the weather (Körber, 1989). Because the space was restricted, weather diarists had to 1imit their notes to a few keywords or they had to resort to abbreviations. Müller's Ephemerides became one of the early best sellers in the history of printing. Eleven editions appeared during the sixteenth century and some 100,000 copies were sold (Knappich, 1982).

From the mid-sixteenth century the ephemerides were somewhat altered to better fulfill the function of memorandum books. Daily astro-meteorological prognoses combined with instructions on agricultural activities and personal hygiene (e.g. cutting of hair and nails, medicinal blood-letting, weaning of babies, etc.), appeared 011 one page and on the opposite page an entire line per day was left vacant for possible notes to be made (Bepler and Bürger, 1994). Thus, meteorological entries in these calendars could be potentially augmented. Even after the new Gregorian calendar was introduced in 1582, former Julian calendar dates continued to appear in the almanacs for some time in order to facilitate a comparison with the Gregorian dating style and also to maintain the selling market in Protestant countries. The oldest known copy of an ephemeris containing meteorological entries is deposited in the university library in Cracow (Poland). The entry dated 9 April 1468 reads: "...in sabbato dominice Palmarum A.D. millesimo CCCCLXVIII frigore temperato", i.e. "On Palm Sunday 1468 it was moderately cold." This entry was transitory; it was not followed by a systematic effort. However, at the time, the Cracow Academy, which was founded in 1364 and named Jagellonian University in the nineteenth century, was a leading center for astrological and astronomical studies in Europe. This was because of Marcin Bylica (1433-1493) of O1kusz, who taught astronomy there in the mid-fifteenth century , and Albert Blarer (1445-1495) of Brudzewo, who taught mathematics, geography and astronomy from 1474 to 1494 (Barycz, 1935). Perhaps the latter's most famous student was astronomer Nicolaus Copernicus (1473-1543), who became the author of the modern, sun-centered model of the solar system and universe.

Concluding from the great number of weather diaries that were kept by graduates of the university in Cracow in the early sixteenth century (see Table I), it seems that the recording of meteorological observations must have been promoted by Blarer and his successors. Two of them -geographer and astronomer Conrad Celtis (1459-1508) and Johannes Turmair (1477-1534), became leading scholars at the Bavarian university in Ingolstadt founded in 1472 (Rischar, 1974). Ingolstadt therefore became the main intellectual center in Germany to promote the systematic keeping of weather diaries. Most of the early German diarists, including Rotenhan, Stöft1er, Rose, Krafft, Leib and Aichholz, graduated from the University of Ingolstadt. Later on, the practice of keeping meteorological diaries spread to other

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universities, such as Tübingen and Wittenberg, and perhaps also Basle, which became centers of Protestant theology (see Figure 1).
Iconoclastic excesses and the secularization of monasteries in the wake of the Reformation and the Peasants' War may account for the fact that the monastic tradition is rather poor in the Protestant parts of the German Empire. Weather notes in Latin for the years 1543 to 1556 are preserved in an almanac published in Tübingen (Pitati, 1543). Additional entries indicate that notes were recorded by some of the people most closely associated with Philip Melanchthon (1497-1560), the famous humanist, religious reformer and supporter of Martin Luther (1483-1546). Austrian-born Johann Aichholz (1520-1588) supplemented Stöfl1er's Ephemerides, in Latin, for the years 1545/46, 1547/48 and 1549. Luther himself did not make daily weather notes. However, severa1 references to extreme weather events and their consequences are found in his correspondence, e.g., the widespread forest fires during the hot summer of 1540 and the severe floods of the Saale and Mulde rivers following the snow-rich winter of 1545/46 (Luther, 1948). Beginning apparently in 1576, Prince Elector Augustus of Saxony (1526-1586) ordered daily observations to be taken from the tower of Dresden Castle at the hours of the changing of the guard (Falke, 1868).
Overall, thirty-two diaries yielding a minin1um of 100 daily weather observations in central Europe are known to be extant (see Table I).
More diaries are expected to come to light if and when systematic searches can be made. From the spatial distribution of these weather diaries (Figure 1), it may be concluded that this type of source was known mainly in southern central Europe.

2.2. DISCUSSION OF SELECTED DIARIES

Selected diaries from Table I will be presented in the following section in somewhat more detail to highlight the characteristics of this type of evidence. The descriptions include the background of the authors, their motivation to keep a diary , the weather elements which they observed and described, the terms they used and the number and location of gaps in their record.

2.2.1. Antonius von Rotenhan (ca. 1458- ca. 1504)
Antonius von Rotenhan is the earliest known weather diarist in Germany. Little is known about his biography. He studied law in Ingolstadt from 1476 and received his doctorate from the same university in 1482. He made his entries in a copy of the ephemerides De Monte Regio as of 28 February 1481 through 1486 (Klemm, 1973).
His meteorological glossary comprises about 50 terms, a few in Latin and the majority in Middle High German. On 2 June 1482, for example, he writes that it

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Table I
Basic characteristics of important weather diaries in central Europe 1481-1613

	Observer	Occupation	Places of observation	Period	No. of entries
1	von Rotenhan, Antonius	Studies in law	Bamberg (D)	1481-1486	500
2	Walter, Bernhard	Unknown	Nuremberg (D)	1487	100
3	Leonard z Dobczyc	Professor	Cracow (PL)	1487-1493	299
4	Schöner, [NN]	Professor	Gemünden, Karlstadt, Hallstadt (D)	1499-1506	100
5	Nicolaus z Wieliczki	Professor	Cracow (PL)	1501-1531	125
6	Biem, Marcin	Professor	Cracow (PL)	1502-1540	5635
7	Aurifabra, Stanislaw	Professor	Cracow (PL)	1503-1528	38
8	Krafft, Peter	Bishop	Regensburg (D)	1503-1529	100
9	Stöffler, Johannes	Professor	Tübingen (D)	1507-1530	5500
10	Rose, Hieronymus	Unknown	Ingolstadt (D)	1508-1518	2000
11	Turmair, Johannes (Aventinus)	Professor	Munich, Abendsberg, Ingolstadt, Landshut (D)	1510-1531	1200
12	Bernard z Biskupiego	Med. & theol. prof.	Cracow (PL)	1510-1531	1685
13	Werner, Johannes	Studies in theology, math. & astronomy	Nuremberg (D)	1513-1520	100
14	Rosenbach Johannes	Astrologer, parson	Main and Rhine region (D)	1513-1522	1000
15	Leib, Kilian	Prior, abbot	Eichstätt (D)	1513-1531	5200
16	Sokolnicki, Nicolaus	Medical professor	Cracow (PL)	1521-1530	934
17	Jan z Kunovic	Nobleman, politician	Uherský Brod, Uherský Ostroh (CZ)	1533-1545	1166
18	Michal z Wislicy	Theol. & astrol. prof.	Cracow (PL)	1534-1540	1601
19	Haller, Wolfgang	Parson, manager	Zurich (CH)	1545-1576	10200
20	Aichholz, Johann	Medical professor	Wittenberg (D), Vienna (A)	1545-1550	1000
21	Schreckenfuchs, Erasmus Oswald	Unknown	Freiburg in Breisgau (D)	1551-1556	110
22	Hájek, Thaddeus	Astronomer	Prague (CZ)	1557-1558	121
23	Strialius, Johann	School administrator, scribe	Wittenberg, Meissen (D), Prague, Litoměřice, České Budějovice, Žatec (CZ)	1558-1582	1372
24	Torda, Gyulai Zsigmond	Clerk	Bratislava, Prešov (SK)	1558-1565	410
25	vom Staal, Hans Jakob	Owner of estate, politician	Solothurn (CH)	1573-1607	240
26	Augustus, Prince Elector of Saxony	Prince	Dresden (D)	1576-1583	700
27	Brahe, Tycho	Astronomer	Island of Hven (DK)	1582-1597	4962
28	Fabricius, David	Astronomer, parson	Resterhave, Osteel (eastern Friesland) (D)	1586-1612	ca 8000
29	Treuttwein, Leonhard III	Abbot	Fürstenfeld (Munich) (D)	1587-1593	2541
30	Cysat, Renward	Naturalist, politician	Lucerne (CH)	1588-1612	--

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Table I
(Continued)

	Observer	Occupation	Places of observation	Period	No. of entries
31	Karel starši ze Žerotina	Nobleman, politician	Náměšť nad Oslavou, Prague (CZ); Germany, Austria	1588-1591	547
32	Borbonius, Matthias	Physician	Basle (CH), Napajedla (CZ)	1596-1598	949

Legend: CH-Switzerland; CZ-Czech Republic, D-Germany; DK-Denmark; PL-Poland; SK-Slovakia

Note: Table 1 only includes diaries with ≥ 100 daily observations. The source references are quoted in the bibliography.

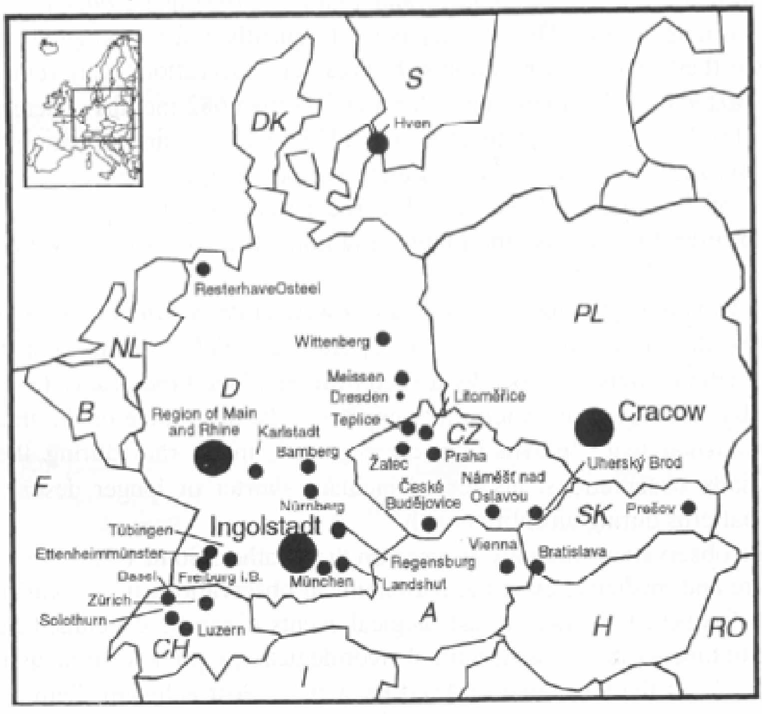

Figure 1. Places where weather diaries were kept in sixteenth-century central Europe.

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was "gewulckig wintig und frisch" (cloudy, windy and cool) which probably relates to broken clouds after the passage of a cold front.

2.2.2. Marcin Biem (ca. 1470-1540)

Marcin Biem was born in Olkusz, about 40 km north of Cracow, into a wealthy middle-class family that owned a lead mine. In accordance with the rules of his time, young men went to university if they could read and write. In the winter term of 1486/87 Biem was admitted to the Arts Faculty of Jagiel1onian University in Cracow. On 6 March 1500 Biem was appointed to the position of Dean of the Collegium Maius, the major college. In July 1514, Pope Leo X proposed that Biem investigated a reform of the Ju1ian calendar .Two years later Biem sent his first results to Rome, but as of the last session of the fifth Lateran \council (March 1517), they stil1 had not been- discussed (Birkenmajer, 1918). Biem received a Ph.D. degree in theology in 1517. From 1521 to 1528/29 he held the position of Dean of the Theological Faculty. In 1529 he was elected Rector of the University. In 1538 he achieved the highest university dignity, viz. that of "Podkanclerstwo Wszechnicy" (deputy chancellor of the academy) (Barycz, 1935; Rybka, 1975).

Biem's observations (Figure 2) are recorded in two astronomical calendars: Almanach nova 1499-1531 (Stöffler and Pflaum, 1499) and Ephemerides 1534- 1551 (Gauricus, 1533). The weather notes frequently refer to singular days and quite often they cover over half a month. Weather observations were regularly and carefully noted on a day to day basis for now less than 682 months. There are three phases -1502 to 1507, 1524 to 153-1 and 1535 to 1540 - during which the notes are almost continuous. In the intermediate periods they are ephemeral. With the exception of the period 1507-1513, when Biem was staying in his native town of Olkusz in order to supervise the family lead mine, the observations were made in Cracow. From the very beginning, his observations were quite systematic. They comprise one or two descriptive terms (e.g. "[dies] clara et calida", sunny and hot day), which sometimes were preceded by a specification of the time of day (e.g. "plus", afterwards) or fol1owed by a term that expresses the magnitude or the intensity of the phenomenon (e.g. "pluvia in nocte copiosa", much rain during the night). Besides daily observations, his record includes shorter or longer descriptions of weather patterns during an entire month.

Biem's observations not Ol1ly focused on the weather. Some of his notes refer to agriculture and medicine, others to astronomical observations (Gorczynski, 1922). From the frequent references to astrological events it can be concluded that Biem was attempting to derive long-term meteorological prognoses from astrological conjunctions. At the beginning of 1540 he wrote: "Post eclipsim illam subsecuta fuit magna siccitas per universum fere orbem", i.e. "after this solar eclipse [it is not clear to which one he refers] a severe drought fol1owed almost throughout the

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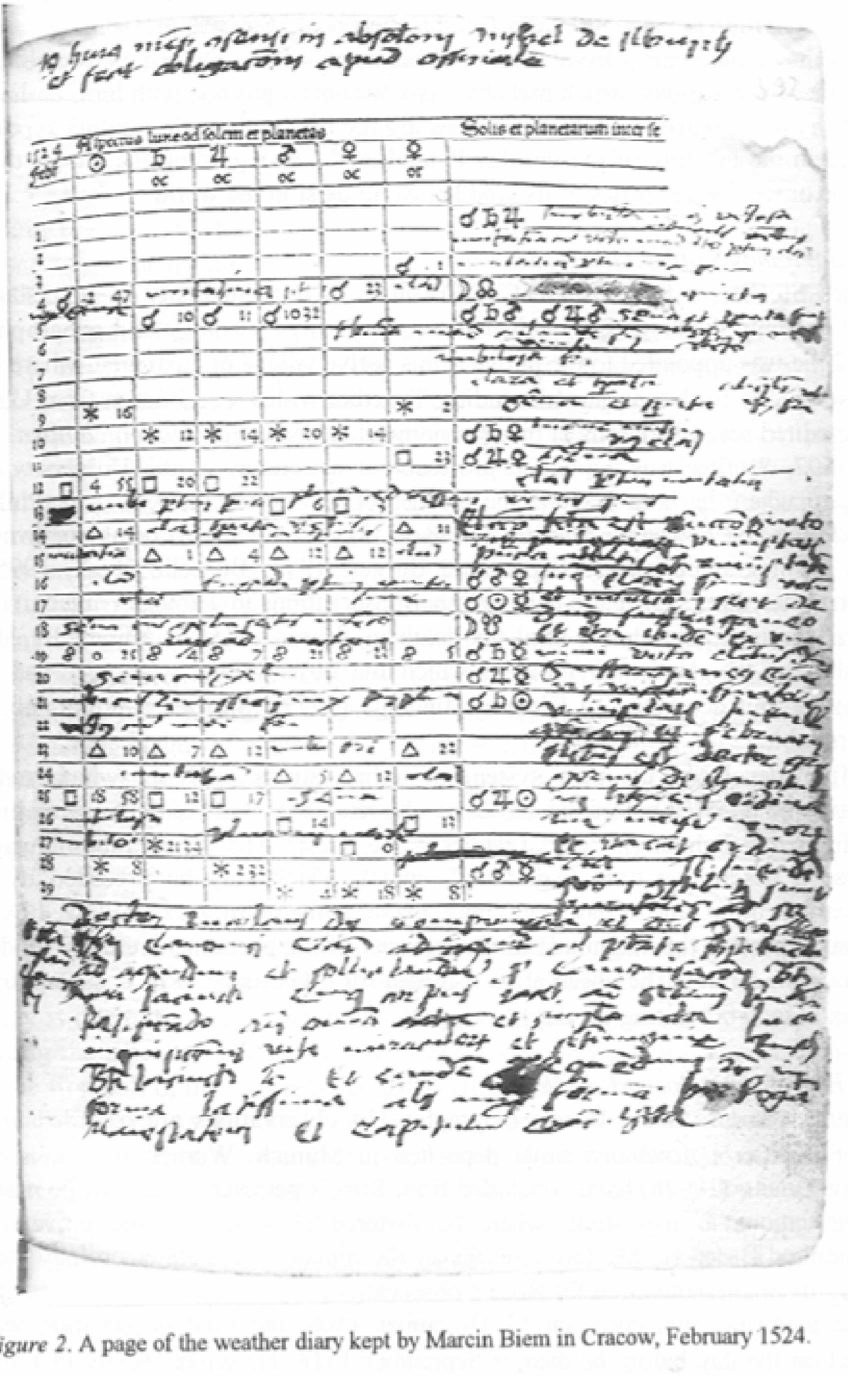

Figure 2. A page of the weather diary kept by Marcin Biem in Cracow, February 1524.

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whole universe". The drought of 1540 throughout central Europe was the most outstanding within the last 500 years (see Jacobeit et al., this volume).
For thirty-eight years -from 1502 until his death- Biem never failed to record his weather observations, which had obviously become a passion with him, perhaps because he never married. His observations are the first systematic weather reports recorded in the territory of present-day Poland, and -disregarding the gaps -they form one of the longest series of its kind known to exist in the world.

2.2.3. Johannes Stöfler (1452-1531)
Johannes Stöfi1er, a fellow student of Rotenhan at the University of Ingolstadt, studied not only theology , but mathematics, astronomy, astrology and geography. In 1477 , he was appointed to the parish of his native village of Justingen, where he was also able to further pursue his studies. Together with Jacob Pflaum from Ulm, Stöff1er edited several editions of his astronomical calendar, the Almanach nova .
In 1507, Stöfi1er was appointed professor of astronomy at the University of Tübingen, where he later became the teacher of the Protestant reformers Philip Melanchthon and Sebastian Münster (1488-1552), the latter also being renowned for his cosmographic works (Bepier and Bürger, 1994; Buszello et al., 1995). Stöfi1er initiated his systematic daily weather observations in Tübingen and carried them on continuously, almost until his death in February 1531. Admittedly, the ownership of the Almanach nova in which the observations were recorded is anonymous, but according to Klemm's findings (1979), Stöfi1er's authorship is most probable.
Stöfi1er developed his own system of abbreviations in Latin which must necessarily be decoded before his diaries can be read, e.g. "cal" (calidum = warm), "fu" (fulmen = lightning), "gla" (glacies = ice, frost). His observations always comprise a descriptive term (e.g. "nix", snow), which may be preceded by a specification of the time of day (e.g. "ma", mane, in the morning) or followed by a term that expresses the magnitude or the intensity of the phenomenon (e.g. "mod", modicus = moderate). The observation recorded for 6 February 1515 is exemplary: "Die nix" (snowfall during the day).

2.2.4. Hieronymus Rose (d. 1518)
Very little is known about Rose's biography. His observations are recorded in a copy of Stöffier's Almanach nova deposited in Munich. Werner and Gabriela Schwarz-Zanetti (1992b) have concluded from Rose's personal notes that he made his observations in Ingolstadt, where he fostered close ties to the university surroundings. Based on his few remarks in the almanac, astro-meteorology was probably the main motivation for Rose's observations.
Rose made his first entry on 12 December 1508; the final observation was recorded on the day before he died, 9 September 1518. He wrote mostly in Latin

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and squeezed up to three lines in the small empty space on the right-hand side of the almanac, thus making it difficult to decipher his handwriting. Klemm (1979) hardly commented on Rose's observations because of this very problem. However, Gabriela Schwarz-Zanetti has succeeded in converting most of his observations into intelligible script (Schwarz-Zanetti 1992a).

2.2.5. Kilian Leib (1471-1553)

Another copy of Stöftler' s Almanach nova provided the setting for the observations of Kilian Leib, comprising the period from April 1513 to the end of 1531 (Klemm, 1973). Leib was admitted to the Augustinian monastery in Rebdorf near Eichstätt (Bavaria) in 1486 and in 1503 he was elected abbot.

He never attended an university and was less an academic than a pragmatist who turned to weather observations in the hope of improving his ability to assess the volume of harvests in the current crop year. He used all available prognostic knowledge in his forecasting, whether astro-meteorology or peasant farmers' rules. An essay published after his death in 1557 shows that he came to disprove both astro1ogical forecasts and farmers' rules as a result of the systematic comparison between predicted and personally observed weather (Klemm, 1973). Leib' s meteorological observations are recorded in the same manner as those of Biem and Stöftler, but his vocabulary is richer and includes adjectives of a rather subjective nature, such as "crudelis" (cruel), "intolerabilis" (intolerable), "mirus" (miraculous) or "horridus" (inclement). Moreover, Leib quite regularly observed eye-catching stages of plant development, including the diversities of the greening of meadows, the foliation of beech trees and the beginning of the harvest. As far as is known, he is the first scholar who attempted systematic phenological observations .

2.2.6. Jan z Kunovic (1482-1545)

The first daily weather observations in Czech lands were made by Jan z Kunovic in 1533. This is rather late when compared with Poland and Germany; perhaps the delay is due to the economic and intellectual stagnation caused by the Hussite war during the fifteenth century. A revival of the economy and the sciences took place in the first half of the sixteenth century (Petran. 1983).

Jan z Kunovic was born in August 1482, the son of Lord Duchek z BydZova a Kunovic, owner or a large estate, and Lady Zuzana z Prostejova, sister of the bishop of Varadin. After the premature death of his father in 1485, Jan z Kunovic received a good education, first in Olomouc (Moravia), then in Leipzig (Saxony) and finally in Bologna (Ernilia-Romagna, in northern Italy). The Moravian nobleman further expanded the domains he had inherited and eventually became the wealthiest man in the region between the rivers Olsava and Morava. As such, it is of little surprise that he also held important social and political positions; in the

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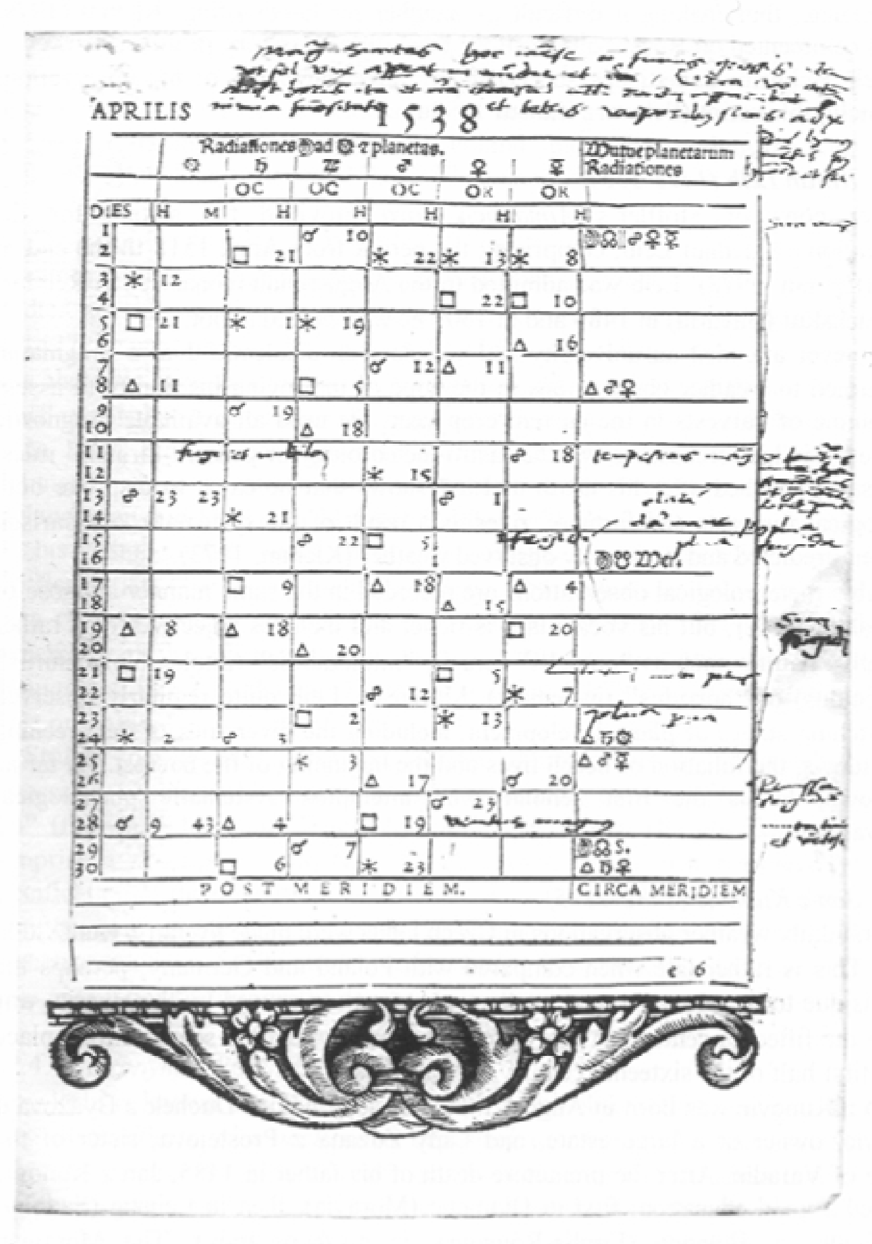

Figure 3. A page of the weather diary by Jan z Kunovic, April 1538.

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period 1523-1526 he occupied the position of supreme chamberlain of the Moravian Margraviate and from 1527 until his death in 1545 he held the important post of vice-chamberlain (Brazdil and Kotyza, 1996a).

Jan z Kunovic recorded his weather observations (Figure 3) in a copy of Stöffler's ephemerides (Stöffler, 1531) over the period 1533-1545. Most of the entries were made at his residence in Uhersky Brod (southeast Moravia). Occasionally he refers to other Moravian place~ such as Uhersky Ostroh, Olomouc and Brno. Most of his observations focus on the winter months (November to March). He often recorded the onset of winter, followed by descriptions of its course (Brazdil and Kotyza, 1996a). Mostly written in Czech, the entries are in the brief style which is typical for such diaries: "Ianuarius 1534, 14: Zima. Vitr snih metelice" (i.e. Cold. Wind, snow, blowing snow); "Martius 1540," 29: Jasno vitr veliky teplo" (i.e Clear sky, strong wind, warm).

2.2.7. Johann Emerich Aichholz (1520-1588)

Johann Emerich Aichholz was born in Vienna (Austria) in 1520. He enrolled at the University of Vienna in 1536 and later studied at the universities in Ingolstadt and Wittenberg (Germany), Paris (France) and, finally, in Padua (Italy), where he received his Ph.D. degree in medicine and philosophy. In 1557 he settled permanently in Vienna as a practicing physician. Shortly thereafter, although a convert to Catholicism, he became chair professor of anatomy. In addition to his position as health administrator ("Magister sanitatis"), which he assumed as the youngest member of the faculty at the time, Aichholz served as dean five times as of 1559 before being appointed in 1574 as rector of the University of Vienna. In 1581 he accepted a call to the court of Emperor Rudolph II in Prague. Aichholz died in Vienna on 6 May 1588 (Hartl and Schrauf, 1893; Schadelbauer, 1953).

Johann Emerich Aichholz's weather record begins in December 1539. He noted his observations in a copy of Johann Stöffler's widely known ephemerides for the years 1532-1551 (Ms. Aichholz) which had previously been used by his foster- father, Royal University Superintendent Johann Pillhammer in Vienna, for the recording of dates directly involving university matters. Although the physician's name does not appear in the almanac, Wacha (1963) proved that Aichholz was the author of the entries, based on the accounts of specific travels and places of residence recorded therein and augmented with a note in the matriculatory registers of the University of Wittenberg.

Background details as to how Aichholz began recording daily weather observations on 1 January 1545 in Wittenberg remain unknown. However it may be assumed thal his occupation with the weather was the direct result of his medical and botanical interests (Aichholz set up a botanical garden in Vienna which even Carolus Clusius admired). Upon his return to Vienna and a short interruption of the entries, he began his entries again on 25 April 1546 upon noting

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"redii". Aichholz's extensive notes in the following months thus become the oldest daily weather observations in the Vienna region known to be extant, even though partially interrupted by travels in Styria (January-July 1547), to Wittenberg (end of July/early August 1547-fall 1548), in Styria once again (October 1548) and to Wittenberg (January-October 1549, where however, in this instance, only his departure and arrival were noted). During most of these travels Aichholz recorded nearly continuous weather observations along with the precise designation of place names. His record was continued between 17 November 1549 and 25 July 1550 and simultaneously completed.

Aichholz made his weather observations once a day and the individual records describe the characteristics of the weather conditions on any given day. The entries, written in Latin, consist mainly of abbreviations, and in addition to particulars concerning the sky's cloudiness or the rain, they also include sporadic comments about the temperature or the wind, and in a few rare cases, precise details as to the direction of the wind were also noted. Even though Johann Emerich Aichholz's intentions in regularly recording weather observations are not specifically known, the results reflect his wide- ranging interests in the natural sciences, particularly in medicine, botany and even meteorology.

2.2.8. WolfgangHaller (1525-1601)

The keeping of systematic daily weather observations in Switzerland begins with Wolfgang Haller in 1545, i.e. half a century later than in Poland and Germany and a decade later than in today's Czech Republic. To account for this delay, it could be argued that during the second quarter of the century the Reformation and the ensuing civil war absorbed the intellectual energies of most of the inhabitants in the Swiss cantons.

Wolfgang Haller was born in Thun (Canton Bern), the son of the Bernese Reformer Johannes Haller (1487-1531). His father was killed in the civil war against the Catholic cantons alongside of the leading Swiss Reformer Huldrych Zwingli (1484-l.531). The boy went to school in Kappel near Hausen am Albis (Canton Zurich) During the academic year 1543/1544 he matriculated at the University of Basle (Wackernagel, 1956). In 1545, he became the schoolteacher in his native Kappel. Two years later Haller was named as pastor of the parish in Meilen, a village situated on the shores of Lake Zurich. In 1552 he was appointed as archdeacon at Zurich Minster. As of 1555 Haller additionally assumed the very time-consuming management of the chapter property .He was therefore discharged from his religious functions as of 1557 (Klemm, 1974).

Haller recorded his weather observations during the period 1545-1568 in copies of anonymous almanacs published in Zurich. Physician Caspar Wolffis is named as the editor of the Zurich almanac in which Haller noted his observations from

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1569 to 1576. The manuscript was first discovered by Rudolf Wolf (1816-1893), the astronomer and meteorologist who was one of the pioneers of Sunspot research. Wolf published Haller's observations in extenso (SMB, 1872, 1873, 1885) and scientific analyses of the data based on these publications have been made by several authors (e.g. Flohn, 1949; Pfister, 1988a).

It is hypothesized that Wolfgang Haller became familiar with daily weather observations during his studies at the University of Basle. From 1 January to 23 July 1545, for the entire year 1546, and then from 1 January 1550 to the end of 1576, he noted the weather from day to day. Overall, Haller w rote some 10,200 entries; only l% of his observations are missing (Flohn, 1949). Klemm (1974) concludes that Haller only interrupted his observations after 23 July 1545 for the remaining part of the year, and he thinks that the manuscripts for the three years 1547-1549 are lost.

The observation sites not mentioned in the manuscript are derived from Haller's biography. Before he came to Zurich in 1552, he lived in the villages of Kappel near Hausen am Albis and Meilen, both of which are situated only a few miles outside the tOWll. It thus seems reasonable to speak of Haller's Zurich observations from 1545 to 1576.

Writing in German, Haller describes the daily weather with one or two terms, "rather warm" or "rainy", occasionally colored by his native Swiss dialect, such as "clear, Föhn" (south wind). His observations are written in the same manner as those of other observers, such as Leib, i.e. they are composed of one or two features and sometimes preceded or followed by the time of day or an indication of intensity.

Some of Haller's terms, such as "wild" (wild), "veränderlich" (variable), "wüst" (bad), "gut" (good) and "zimlich", need further interpretation. "Zimlich" is probably equivalent to "ziemlich", i.e. fair (partly cloudy but dry). "Wild" seems to correspond to stormy and rainy, westerly weather; "veränderlich" was used as an equivalent to variable weather with sunshine and showers (" Aprilwetter", as Haller remarks). "Bad" expresses a rainy day and "good", in Swiss-German, a day without rain. Accordingly, the wild, the variable and the bad days (probably with low clouds, dark and foggy) were included with the category of days of precipitation.

Undoubtedly, Haller's observations are the most important source for the history of climate in central Europe for the third quarter of the sixteenth century (Klemm, 1974).

2.2.9. Gyulai Zsigmond Torda (d. 1568)

Gyulai Zsigmond Torda is the first known weather diarist in ancient Hungary (today's Slovakia). He was educated at the University of Padua (Italy) and other universities in central Europe. Torda first worked as a clerk, but later he became

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the chairman of the Hungarian Royal Chamber. In that capacity he traveled a great deal between Bratislava (formerly Pozsony) and Presov (formerly. Eperies), both centers of the Royal Chamber located in present-day Slovakia.
Torda wrote his diary (1558-1568) in Latin. Generally, he describes the character of temperature and precipitation with a few words, e.g. "first snowy day" or "clear day with frost". Besides his daily observations, Torda summarized the weather patterns for an entire month. Moreover, his remarks included comments on epidemics, wheat and grape harvests, and price fluctuations (Rethly, 1962).

2.2.10. *Tycho Brahe (1546-1601)*
Danish astronomer Tycho Brahe was educated at Leipzig (Saxony) and other universities in central Europe. Returning to Denmark in 1572, he devoted himself to astronomy and alchemy. In November 1572, Brahe discovered one of the brightest supernovas ever recorded, called "Tycho's star" from that time on, and the discovery made him one of the most famous astronomers in Europe. In 1576, the King of Denmark offered him the small island of Hven (8 km2, situated in the Danish Sound half-way between the Swedish province of Schonen and the island of Seeland, as a site on which to build an observatory .During the following twenty years, Brahe made precise observations of the positions and motions of the planets. After a series of difficulties, he left Hven in 1597 and upon the invitation of Tadeas Hajek z Hajku (Thadeus Hagecius), Brahe settled in Prague in 1599. There he met the German astronomer Johannes Kepler (1571-1630) and passed on to him the observations made at Hven (Thoren, 1989). Brahe's highly accurate observations enabled Kepler to formulate his laws governing planetary motion.
Brahe also left a detailed meteorological diary in Danish for the period 1582 to 1597. It was probably kept by his assistants, Olsen and Goldschmidt. The manuscript was published in extenso by La Cour (1876) under the auspices of the Danish Academy of Sciences (Ekholm, 1901); only about 7% is missing during the period cited. The entries provide a concise description of weather including wind directions during the day and quite often also during the night. For example (La Cour, 1876): "1595. Martius. 6. Suduest med storm och biest och Jisen begynte at offnis paa stranden, och vklart vnderthiden med Regn, imod afften thill noruest med bIest och mogit klart den gandske nat igiennom och Jisen var slet borte" ("March 6, 1595: Stormy and southwesterly winds. Some showers, at times clear. The ice on the beach began melting. In the evening wind from northwest, clear sky during the whole night, the ice was fading away more and more").

2.2.11. *David Fabricius (1564-1617)*
Details concerning David Fabricius, who is primarily known as an astronomer, are based upon the careful research by Lenke (1968) and Dreyer (1963). Fabricius was appointed as pastor in the parish of Resterhave near Aurich in the Ostfriesland

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region of Germany in 1583. In 1603 he assumed the leadership of the parish in Osteel, both locations being near the North Sea coast. Fabricius was slain with a spade by a village dweller in the graveyard in Osteel in 1617.
According to an entry in his diary , Fabricius met Tycho Brahe in the latter' S observatory , Uraniborg, on the island of Hven, in 1585. It is not known whether the exchange of views between the two astronomers motivated Fabricius to attempt daily meteorological observations in the following years. His purpose in keeping such records seems to be related to formulating astro-meteorological predictions.
Fabricius recorded his observations in the free spaces of an old book. The observations made between 1586 and 1612 are complete for the year 1590 and for the twenty years from 1593 to 1612, as well as for isolated months in the years 1586, 1589, 1591 and 1592. Most of the entries are written in German in a tiny handwriting that is extremely difficult to decipher. In general, Fabricius gives a characterization of every day. On I May 1588, for example (Klemm, 1976): "Herrlich schön wedder, Norden" (pleasant weather, northerly winds). Fabricius made his wind observations according to a wind rose, which was divided, into 32 parts. In many cases he noted the changes in wind direction throughout the course of the day; calms were also recorded, thereby underscoring the accuracy of his observations. Fabricius tried to describe daily weather as precisely as possible using a broad variety of different terms, e.g. Lenke (1968) cites more than seventy different expressions under "frost" .

2.2.12. *Renward Cysat (1545-1614)*
Renward Cysat, the son of an immigrant from Italy, succeeded as a self-made man in Switzerland. He was able to acquire a pharmacy in Lucerne and thus laid the foundation of his wealth. He created a well known botanical garden near his home and thereby laid the foundation for his scientific reputation. Furthermore, he became one of the most influential Swiss politicians working in favor of the Counter-Reformation.
Cysat's weather observations, made over the period 1570-1612, are included in his large collection of miscellaneous information (Collectanea) edited by Schmid (1969, 1972). The data scattered throughout this publication were compiled by Pfister (1985a). Some of Cysat's observations relate to the thaw on Alpine summits near Lucerne, notably on the Rigi (1797 m) and Pilatus (2121 m) peaks climbed by the naturalist during the summer months. Cysat often bad discussions with herdsmen on the Alps, something which was quite unusual at that time for a man of his status. It was in that very way, however, that he came to learn how these people suffered from the harsh climate around the turn of the century .
Cysat's way of describing monthly weather patterns changed profoundly over time. Untill587 he just focuses on anomalies, in the style of a chronicle. Suddenly, in 1588, he states the number of rainy days for every month. Over the following

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years this tendency to quantify the days of similar weather characteristics is extended to other features. For example (Schmid, 1969): "1613 Maius [...]. Hat ghebt 25 regentag darunter 9 wol ergiebig and wassers gnuog meertheils tag und nacht. Küele, na.')se, unlustige, melancholische zyt von dem 14ten dannen bis ans end des monats, [...] 2 tag grosse hitz, 3 aber mittelwarm" ("May 1613. [...] This month included 25 days with rainfall. On 9 of them, abundant rain fell almost all day and night. The period from 14 May to the end of the month was a cool, wet, unpleasant and melancholy time, [...] 2 days were very hot, .3 days were temperate"). The reference to quantitative indications of this kind suggests that Cysat kept a detailed weather diary, which no longer exists.

2.2.13. *Karel starsi ze Zerotina (1564-1636)*

Karel starsi ze Zerotina was born on 15 September 1564 in Brandys nad Orlici (eastern Bohemia), the eldest son of nobleman Jan z Zerotina. Young Karel was educated at the famous school of the Moravian Brethren at Ivancice. Afterwards he went to the Protestant universities of Strasbourg (France), Basle and Geneva (both in Switzerland). Following a period of traveling, he took over the family heritage from his father in 1588. During his lifetime he managed several large estates in Moravia and Bohemia.

The young nobleman joined the army of French Calvinists in 1591, but after ten months he was disappointed and returned home. In 1593 he fought against the Turks in the army of Emperor Rudolf II. In 1594, the emperor appointed him as a member of the Moravian Land Court, from which he was expelled in 1602. Karel starsi ze Zerotilla opposed the emperor in 1608 and was successful in the separation of Moravia form Bohemia. He was elected as land administrator in 1608, a position he held until 1615. Though he remained faithful to the emperor during the uprising of the Estates in 1618, he was nonetheless accused of treason in 1619 and barely escaped defenestration. After the defeat of the uprising Estates in the battle of White Mountain (1620), Karel starsi ze Zerotina offered shelter to many of the Moravian Brethren parsons on his estates in Bohemia and Moravia. When the emperor banished the non-Catholic nobility in 1627, Karel starsi ze Zerotina sold a large number of his estate holdings and moved to Wroclaw (in present-day western Poland). He died in 1636 in Prerov (Moravia).

Zerotin ' s weather observations are recorded in various almanacs (Ephemerides 1588, 1589, 1591; Diarium, 1590) between 1 January 1588 and 18 December 1591. Generally, the entries are written in Latin, however those in 1589 are written in Czech. His observations relate mainly to Namest' nad Oslavou (where he lived); other reports were made during frequent journeys to Prague and other places in the Czech lands. A few of the entries are from his travels in Germany (June -August 1588, October 1591) and Austria (for more details, see Brazdil and Kotyza, 1995b).

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His vocabulary is richer but less consistent than that of earlier observers, thus occasionally making an interpretation somewhat difficult. Most of his observations deal with cloudiness, while others describe the temperature characteristics of the given days, atmospheric phenomena, precipitation and wind patterns (Brazdil and Kotyza, 1995b).
Zerotin ' s motivation for keeping daily weather records is not evident from his diary .It is hypothesized that it was related to the management of his estates, and he may have retained the custom in order to keep a diary of his travels.

2.2.14. *Summary*
Weather diaries were kept for several motives, but all seem to be related to risk perception. Many early diarists, such as Biem, Wemer, Stömer, Rosenbach, Hajek, Brahe and Fabricius, were astronomers and astrologers who believed that weather patterns were governed by a conjunction of planets. By attempting astro- meteorological predictions they hoped to link their scientific observations of celestial bodies to weather and life on Earth in order to justify their studies. This is supported, for instance, by the comments of Prince Elector Augustus of Saxony in a calendar notebook for the year 1576 (Klemm, 1976). Those, however, who systematically compared their observations with the astro-meteorological predictions over some period of time, such as Kilian Leib, the Bavarian abbot, came to the conclusion that astro-meteorological predictions were unsystematic in nature (Klemm, 1973). Leib belongs to a second group of record keepers, including Jan z Kunovic, Haller, vom Staal and Karel starsi ze Zerotina, who had close links to agricultural production. For them, the immediate economic motivation prevailed.
Many observers, such as Haller, vom Staal and the Bohemian scribe Jan Petfik z Benesova (Brazdil and Kotyza, 1995b, 1996c), believed in the so-called prognostic days ("Lostage"). The weather on a prognostic day was believed to be indicative for some specific period in the future. The most widely known prognostic period was the so-called Christmas prognosis: the weather during the twelve days between Christmas and Epiphany (6 January) was seen as a forecast of the weather during the twelve months of the corning year .Another important prognostic day was 8 June ("Medardi") which, it was concluded, indicated the weather during the corning harvest (Hauser, 1973; Pfister, 1988a; Rebetez Beniston, 1992).
During the first eight decades of the century , most observers described daily weather with one or two expressions which were sometimes preceded or followed by specifications concerning the time of day or the intensity of the phenomenon described. This emphasis on one dominant feature is the result of the restricted space which was left in the astronomical calendars for personal notes. At the same time, this is the source of most of the problems associated with the meteorological interpretation of such weather diaries, because the neglect of features of a more

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Table II

Number of meteorological terms used by selected weather diarists

	Biem	Stoef	Leib	Haller	Kuno	Fabric
Precipitation	18	6	20	7	24	39
Temperature	10	9	29	5	37	238
Wind	12	4	11	4	11	32
Thunderstorm	4	2	5	2	2	66
State of sky	18	5	14	10	5	--
Ambiguous	--	--	7	8	6	--
Total	62	26	86	36	85	375

Legend: Stoef: Johannes Stöffler; Kuno: Jan z Kunovic; Fabric.: David Fabricius

limited duration often precludes a meaningful quantification needed for a comparison within an instrumental period.

The number of terms used to describe meteorological features depends chiefly on the style of the individual observers. Stöffler and Leib used a rather limited vocabulary , whereas first class observers, such as Biem and Leib, used a more differentiated terminology (see Table II). The quantity of the reported features and the quality of the observations increased markedly after 1580. This is mainly due to the observations of the astronomers Brahe and Fabricius who systematically recorded items such as wind directions, along with noting several observations a day and not using a restricted terminology .A tendency for summarizing monthly weather patterns by means of quantification becomes obvious after 1588 in the records kept by the naturalist Cysat.

3. Examples of Synoptic and Impact Analysis

The repetitive nature of daily weather observations is not particularly attractive for a critical edition. In his publication of Haller's data, Wolf (SMB, 1872, 1873, 1885) used abbreviations of one or two letters instead of the original wording in order to keep the number of printed pages low and he expressed a weak or a strong emphasis given by Haller with indices ("0" and "2"). Among the thirty-two weather diaries listed in Table I only those of Tycho Brahe (La Cour, 1876), Jan z Kunovic and Thaddeus Hajek (Brazdil and Kotyza, 1996a) were published in accordance with the rules of a critical text edition (Ingram et al., 1981). Even if a critically verified text edition becomes available, the analysis of the data is only accessible to people with a good knowledge of the language in which the observations are written, including, for example, old terms known only to present- day specialists .

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Another possibility is converting the data to a numerical code which allows printouts to be produced in several languages. The data of the Cracow professors, Haller' s data and the data of most of the early German diaries were entered in the EURO-CLIMHIST code (Pfister et al., 1994). The late Werner Schwarz-Zanetti, who devoted his best years to the dedicated and sustained study of historical climatology, and his wife, Gabriela, took time to carefully transcribe and code more than 15,000 individual entries of twelve German observers as a working model for their analysis (Schwarz-Zanetti and Schwarz-Zanetti, 1992b). However, the English-language printouts produced from the EURO-CLIMHIST software are too detailed for a systematic publication, except perhaps on a CD-Rom.
The most appropriate way of "publishing" selected parts of weather diaries consists in the representation of the entries in the form of icons. The use of icons allows the weather patterns to be rapidly grasped throughout the course of a year , thereby providing a basis for synoptic analysis. Frontal passages, as well as high and low pressure systems may be identified in this manner. The use of icons also enables a comparison of the historical sequences of types of weather with those of today as well as the identification of differences. An appropriate set of icons based on WMO symbols was developed for the multi-proxy mapping of EURO-CLIMHIST data (Pfister et al., 1994). It was suitably adapted for the graphical representation of the Biem and Leib diaries (Figures 4 and 5)
The following description of weather patterns in 1529 in southern central Europe only focuses on the long spells that can be clearly attributed to dominant weather situations: the clear sky and frost from 21 January to 3 February point to a spell of cold, anticyclonic weather and the advection of continental air from the northeast. It may be concluded from the sequence of rainy days that a westerly flow prevailed from 19 to 25 February. A sequence of long rainy spells began in May. It rained on 24 days during the month; rain fell almost without interruption from 18 June to 5 July, from 22 July to 6 August, from 9 to 23 August, from 31 August to 8 September and again from 25 September to 6 October. This indicates that westerly or northwesterly flows predominated. The Azores' anticyclone only rarely and briefly) extended over western central Europe.
There were 24, 7 and 13 days respectively with frost during the first three months of the year 1529. A similar sequence may be found in 1970 when anticyclonic synoptic situations prevailed with the advection of air masses from the east. In February (in 1529, on 3 February, the same as in southern Germany) the pattern changed to a cyclonic circulation with the advection of warm westerly air , which promoted a melting of the snow cover (see Figure 5). March and April were dominated by cold and rather dry air masses. The predominance of long rainy spells from May is also obvious in Cracow, although their timing is somewhat different. May was less rainy than in southern central Europe, and the first half of June was rather warm and dry. On the other hand -and this must be stressed –not

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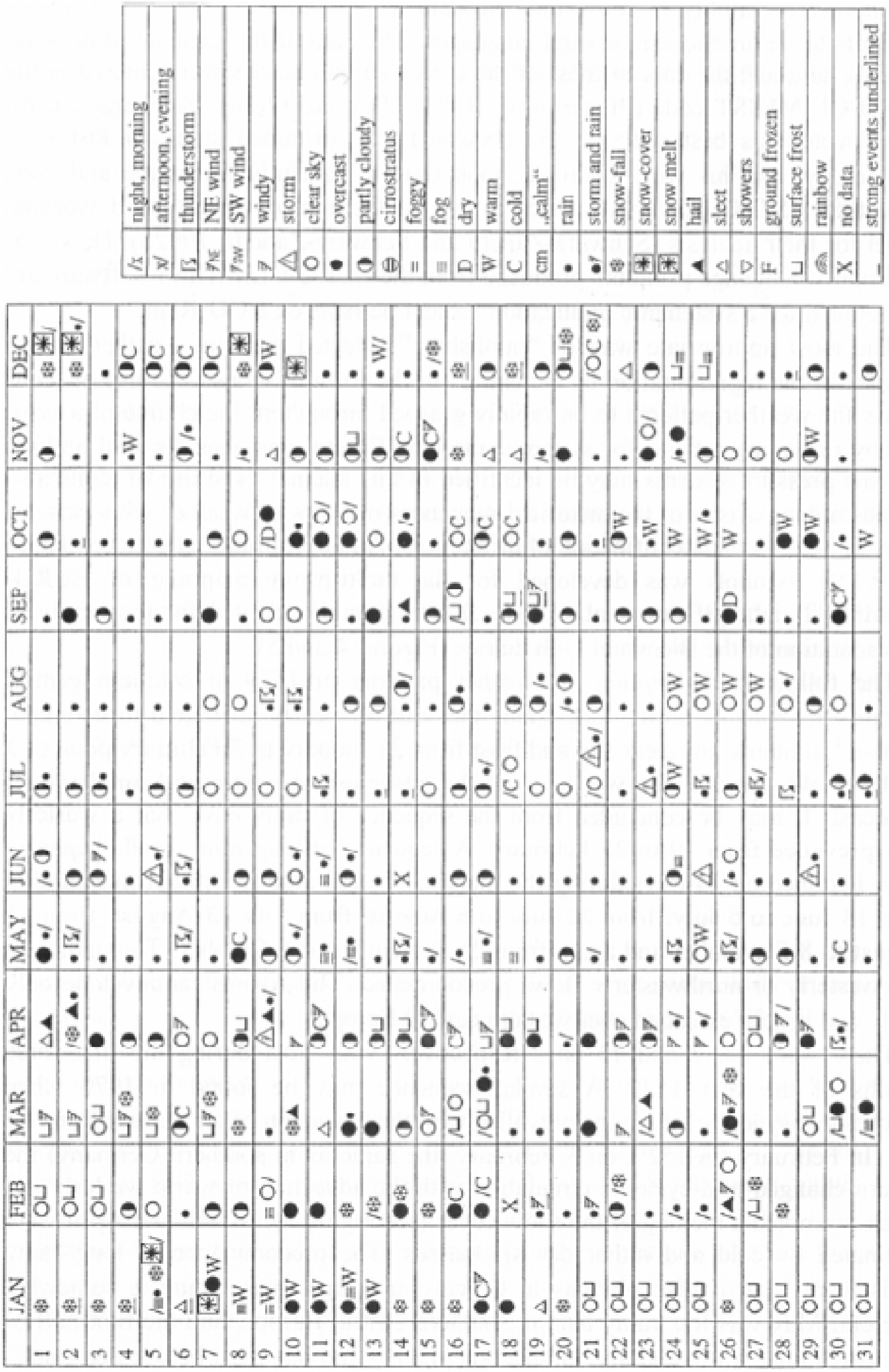

Figure 4. Graphical representation of the weather diary by Kilian Leib in Eichstätt, 1529.

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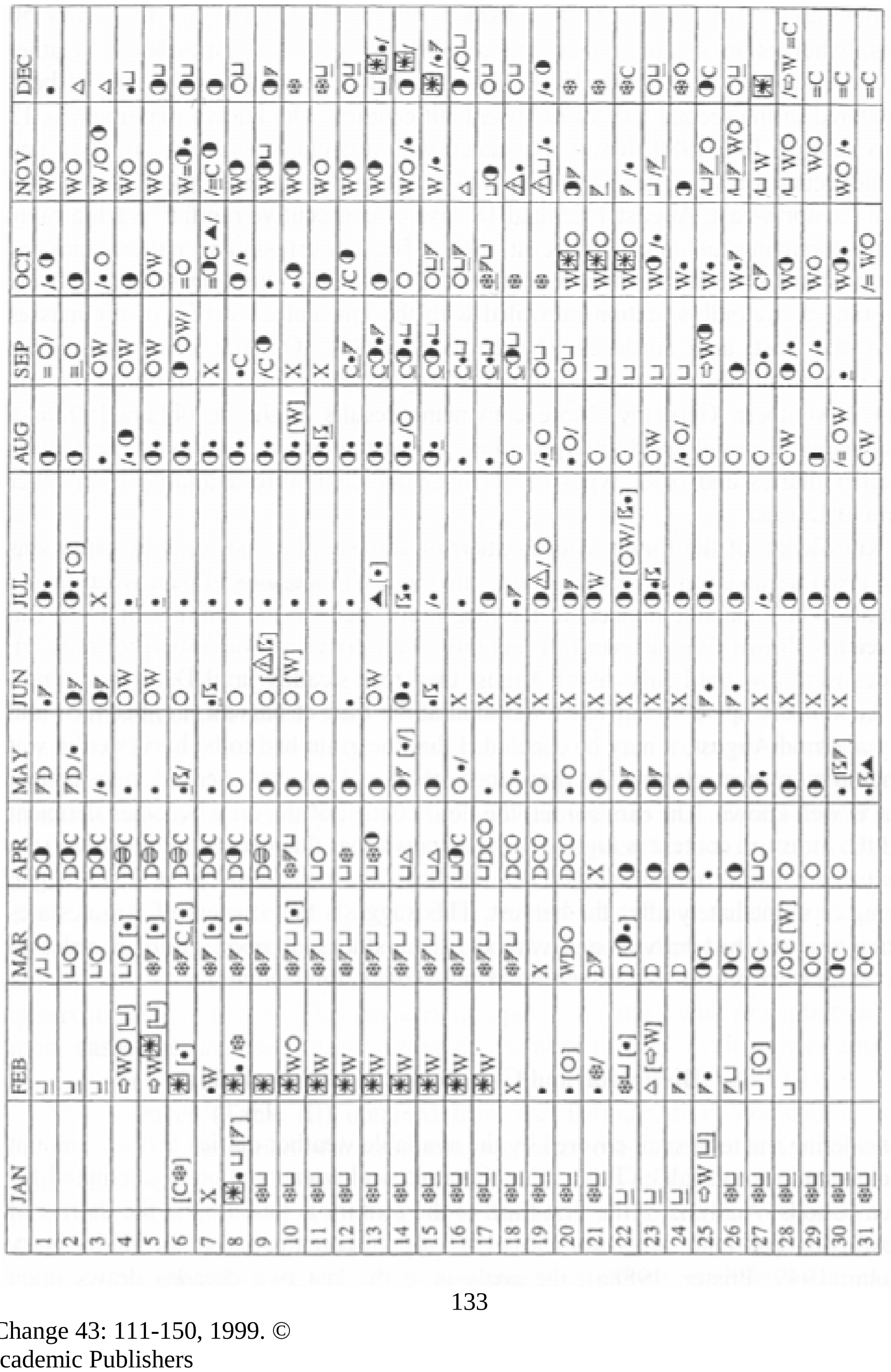

Figure 5. Graphical representation of the weather diary by Marcin Biem, Cracow for 1529.

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a single anticyclonic spell occurred from 1 July to 20 August, i.e., for nearly 50 days, whereas in southern Germany two short spells of anticyclonic weather occurred in July. A sequence of 16 days of constant rainfall in July has not been registered in the second half of the twentieth century .The known maximum is 12 rainy days in July 1980. It was associated with a cyclonic synoptic situation and the advection of air masses from the west, and in the second half of the month, from the north-east. August 1529 had 18 days of consecutive rainfall. Such a rainy summer remains unknown in recent times. The closest similar pattern may be observed in 1968 with 10 days of constant rainfall in July and 6 in August. During this time a cyclonic situation prevailed with the unusual advection of air masses from the east and northeast (Niediwiedz, 1988). On the other hand, the anticyclonic situation in the second half of August had a longer duration in Poland than in southern Germany. More convincing results might be obtained from a systematic meteorological interpretation, in particular, if additional first class weather diaries and other types of documentary data were available from other parts of Europe.

Knowledge of the timing and duration of anticyclonic and westerly situations also provides an excellent tool to assess the human dimensions of past weather and climate. The economic impacts of the long rainy spells in the summer of 1529 can be readily drawn from a record of monthly grain prices at Nuremberg (Figure 6). Prices were low until July; as of August they rose steadily until December. From the lack of dry spells of sufficient duration at the time of harvest, i.e. between mid July and mid August, it may be concluded that the grain had to be harvested in wet conditions in most places. The disastrous effect of long wet spells during harvest time is well known. The ears sprout, the flour content of the crop becomes deficient and the moisture content is high. It is well known that this caused high losses from mould and insects in storage (Pfister, 1988b). The rise in prices in 1529 began during or immediately after the harvest. This suggests that owners of large estates anticipated the bad harvest and withlleld their stocks of good grain in order to maximize their profits (see Bauernfeind and Woitek, this volume).

4. Discussion and Climatological Interpretation

Considering the time-span covered by the available weather diaries and the anlount of observations available (Table I), a climatological interpretation is attempted for three periods. Analysis of the first third of the century is based upon the diaries of Biem, Rose and Leib; the years 1550-1576 are investigated using the Haller diary (Flohn, 1949, Pfister, 1988a); tlle analysis of the last two decades draws upon Cysat' s data (Pfister, 1988a), upon a careful analysis of the diaries of Brahe and Fabricius (Lenke, 1968) and upon Glaser (1996), who worked out semantic

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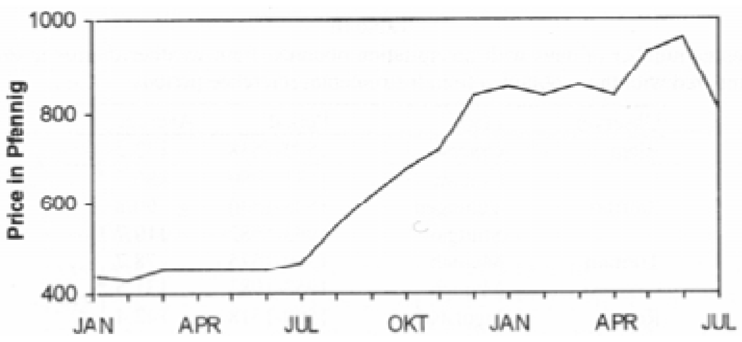

Figure 6. Prices for 1 "sümmer" (318 l) of rye in Nuremberg (Germany), January 1529 to July 1530 (Bauernfeind, 1993; Pfister, 1998).

profiles of the Treuttwein data and attempted a reconstruction of winter temperatures from the Fabricius data. These data provided the backbone for the series of precipitation indices (Glaser et al., this volume).

4.l. PERIOD 1500-1576

The information obtained from weather diaries is quantified by counting the number of entries describing rain, snow, sleet, hail, sunshine, etc. per month and by comparing the monthly average counts to those obtained from instrumental measurements at the same place or from modem instrumental measurements at a neighbouring place. Many meteorologists have used weather diaries to investigate characteristics of past climates (Flohn, 1949, 1979; Manley, 1953; Maejima, 1966; Lenke, 1968; Tagami, 1991). The problem of finding suitable data for a reference period in the twentieth century should not be underestimated. Sometimes appropriate data are only available from distant stations, or the criteria of observation are different. This particularly applies to "days with precipitation". In most cases the analysis focuses upon the number of days with precipitation in comparison with similar statistics from the instrumental period (Table III).
The averages (Table III) obtained from the Turmair diary are considerably below those of the period of instrumental measurements; Stöflller and Haller do a little better. Obviously, these three diarists tended to overlook smaller amounts of precipitation or they did not record them because of the restricted space in the almanac. Biem, Rose and particularly Leib seem to have paid a great deal of attention to rainfall. It may be that the abbot also registered slight precipitation during the night when he had to go to pray.

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Table III

Annual average number of days with precipitation obtained from weather diaries in the sixteenth century compared with those obtained from instrumental reference periods

Observer	Place	Period	Average
Biem	Cracow	1502-1538	132.2
	Cracow	1931-1990	186.7 *
Stöffler	Tübingen	1508-1530	90.8
	Stuttgart	1953-1982	110.7 *
Turmair	Munich	1510-1525	78.7
	Munich	1953-1982	131.5 *
Rose	Ingolstadt	1509-1518	142.4
	Ingolstadt	1891-1930	170.1 **
Leib	Eichstätt	1514-1531	160.6
	Weissenburg	1891-1930	199.6 *
Haller	Zurich	1545-1576	117.5
	Zurich	1901-1960	137.0 *

Legend: * days with ≥ 0.1 mm ** days with ≥ 1.0 mm

Because of the physical relationships between certain elements of the weather, such as the days with snowfall as part of the total number of days with precipitation in winter being related to winter temperatures, suitable statistical tools such as regression analysis may be employed for arriving at absolute figures. Even so, the data are often sufficient for the synoptic analysis of a collection of observations plotted on weather charts.

The analysis of Biem's diary takes into account three sub-periods (1502-1507, 1527-1531, 1535-1538) for which the entries are almost complete. The average number of days with precipitation obtained from his diary was computed for these 15 years in order to obtain a representative result (Table III).

The annual average of 132.2 days obtained from Biem's diary is then compared with the statistics available from the Jagellonian University .These include either days with ~ 0.l mm, where the average is 186 days per year, or days with ~ l.0 mm, where the annual average is 109 days. It is assumed that Biem's observations are close to days with ~ 0.3 mm, which are common in the English-speaking world. In the absence of suitable statistics for the instrumental period, the monthly distribution of days with precipitation are computed for the data from the pre- instrumental period and for those from the instrumental period. Thereafter, the monthly values from both data-sets are compared.

It may be concluded from Table IV that the months from March to September (particularly July) tended to be wetter than today, whereas the months from October to February, particularly December and January, were drier.

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Table IV
Mean values of the number of days with precipitation for Cracow (Poland), obtained from the weather diary kept by Marcin Biem, in comparison to data from the instrumental period at the same station

	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pre-instrumental														
1	1502-1507	9.8	9.0	12.0	11.1	11.8	13.8	14.0	10.8	9.0	8.0	12.0	10.8	132.1
2	1527-1531	7.0	11.4	11.6	11.2	13.0	13.4	17.0	13.0	12.6	12.8	13.0	7.0	143.0
3	1535-1538	8.0	8.0	9.0	9.0	14.5	12.7	13.7	13.5	10.5	6.7	5.5	6.0	117.1
p: Ø1-3	1502-1538	8.4	10.1	12.4	10.5	12.9	13.3	14.3	12.2	10.6	9.2	10.6	8.7	132.2
p%	1502-1538	6.3	7.5	9.3	7.8	9.7	10.1	10.7	9.1	8.0	7.0	8.0	6.5	100.0
Instrumental														
i	1931-1990	18.0	16.0	15.0	14.0	15.0	16.0	16.0	14.0	13.0	14.0	17.0	18.0	186.0
i%	1931-1990	9.6	8.6	8.0	7.6	8.0	8.6	8.6	7.6	7.0	7.6	9.2	9.6	100.0
Difference (p% - i%)		-3.3	-1.1	1.3	0.2	1.7	1.5	2.1	1.5	1.0	-0.6	-1.2	-3.1	

Legend:
p: average of the pre-instrumental period (intervals 1-3).
p%: monthly distribution of days with precipitation from the pre-instrumental period over the calendar year (100%).
i: average of the instrumental reference period (days with ≥ 0.1 mm) (Source: unpublished data from the archives of the climatological station of Jagiellonian University, Cracow, Poland)
i%: monthly distribution of days with precipitation from the instrumental period throughout the calendar year (100%).

The average number of days with snowfall for 1502-1538 is only 23.6, i.e. less than half of the average number of days with snowfall with z 0.l mm (49.5) obtained from measurements over the period 1901-1990. This is hardly surprising, considering the small amount of ♦ 0.l mm, in particular because light snowfall tends to be overlooked, especially during the night. The number of days with snowfall and also percentage of days with snowfall during the number of days with precipitation declined continuously over the first third of the sixteenth century. This suggests that winters tended to become somewhat warmer and that agrees with the tendency in Germany (see Glaser et al., this volume).
The average number of thunderstorms obtained from the Biem diary is 12.6 compared to 23.5 for the period 1901-1990. But it is well known from the present period that data on thunderstorms are difficult to compare between two stations or two observers. Therefore, a climatological conclusion cannot be drawn from this comparison.
The Latin term "gelu" used by Biem may be translated as "frost", in the sense of a freezing of water and/or the ground. This feature is not ambiguous and it is easily determined by an alert eye observer. It may be concluded from Table V that frost (i.e. temperatures < 0°C during the day) was somewhat more frequent in the

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Table V
Mean values of the number of days with frost in Cracow (Poland), obtained from the weather diary kept by Marcin Biem, in comparison with data from the instrumental period

	Winter	Spring	Fall	Year
Pre-instrumental				
1: 1502-1507	26	7	10.8	44.1
2: 1527-1531	33	3	17	53
3: 1535-1538	54	5	13.5	72.5
p∅1-3: 1502-1538	35.8	5.1	13.5	54.4
Instrumental				
i: 1901-1990	29.5	2.5	2.2	34.2
Difference (p-i)	+6.3	+2.6	+11.3	+20.2

Legend:
p: observations from the pre-instrumental period
i: observations from the instrumental period

Table VI
Mean values of the number of days with precipitation for Ingolstadt (Germany), obtained from the weather diary kept by Hieronymus Rose, in comparison with data from the same place (days with ≥ 0.1 mm)

	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pre-instrumental														
p	1508-1518	12.3	9.8	9.2	10.6	11.6	13.0	16.1	11.5	9.0	13.0	11.7	14.6	142.4
p%	1508-1518	8.6	6.9	6.5	7.4	8.1	9.1	11.3	8.1	6.3	9.1	8.2	10.3	100.0
Instrumental														
i	1891-1930	15.2	12.2	13.6	14.7	15.4	14.4	15.1	14.8	12.6	13.0	13.8	15.6	170.4
i%	1891-1930	8.9	7.2	8.0	8.6	9.0	8.5	8.9	8.7	7.4	7.6	8.1	9.2	100.0
Difference (p% - i%)		-0.3	-0.3	-1.5	-1.2	-0.9	0.6	2.4	-0.6	-1.1	1.5	0.1	1.1	

Legend:
p: average of the pre-instrumental period
p%: monthly distribution of days with precipitation from the pre-instrumental period throughout the calendar year (100%)
i: average of the instrumental reference period (days with ≥ 0.1 mm) (Source: Flohn, 1979)
i%: monthly distribution of days with precipitation from the instrumental period throughout the calendar year (100%)

early sixteenth century .The large difference for autumn suggests that this season tended to be considerably colder in early sixteenth-century Poland than in the twentieth century.
The period from January to Mayas well as August and September tended to be relatively drier than today, particularly March, April and September, whilst the remaining months, particularly July and October, tended to be wetter (Table VI).

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Table VII

Mean values of the number of days with precipitation for Eichstätt (Germany), obtained from the weather diary kept by Kilian Leib, compared to data from Weissenburg (days with ≥1.0 mm)

Location	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pre-instrumental														
p: Eichstätt	1514-1531	13.4	14.3	14.2	10.1	13.4	13.7	16.2	15.2	13.0	12.7	12.3	12.1	160.6
p%: Eichstätt	1514-1531	8.3	8.9	8.8	6.3	8.3	8.5	10.1	9.5	8.1	7.9	7.7	7.5	100.0
Instrumental														
i: Weissenburg	1891-1930	16.4	13.8	15.4	16.4	15.7	14.9	14.9	15.5	14.0	16.0	15.0	17.7	185.7
i%: Weissenburg	1891-1930	8.8	7.4	8.3	8.8	9.2	8.4	8.0	8.3	7.5	8.6	8.0	9.5	100.0
Difference (p%-i%)		-0.5	1.5	0.5	-2.5	-0.9	0.1	2.1	1.2	0.6	0.7	0.3	-1.9	

Legend:
p: average of the pre-instrumental period
p%: monthly distribution of days with precipitation from the pre-instrumental period throughout the calendar year (100%)
i: average of the instrumental reference period (days with ≥ 0.1 mm) (Source: Flohn, 1979)
i%: monthly distribution of days with precipitation from the instrumental period throughout the calendar year (100%)

Table VIII

Average number of days with precipitation, obtained from the weather diary kept by Wolfgang Haller in Zurich (1545-1576), in comparison with data from the instrumental period

	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pre-instrumental														
p	1545-1576	9.9	10.8	10.2	10.6	9.9	11.2	12.0	10.2	8.8	6.2	9.6	8.1	117.5
p%	1545-1576	8.4	9.2	8.7	9.0	8.4	9.5	10.2	8.7	7.5	5.3	8.2	6.9	100.0
Instrumental														
i	1901-1960	10.7	10.4	10.3	12.0	12.4	13.2	12.6	12.4	10.5	9.8	10.2	10.6	137.0
i %	1901-1960	7.8	7.6	7.5	8.8	9.1	9.6	9.2	9.1	7.7	7.2	7.4	7.7	100.0
Difference (p%-i%)		0.6	1.6	1.2	0.2	-0.7	-0.1	1.0	-0.4	-0.2	-1.9	0.8	-0.8	

Legend:
p: average of the pre-instrumental period (Pfister, 1988a)
p%: monthly distribution of days with precipitation from the pre-instrumental period throughout the calendar year (100%)
i: average of the instrumental reference period (days with ≥ 0.1 mm) (Source: Uttinger, 1965)
i%: monthly distribution of days with precipitation from the instrumental period throughout the calendar year (100%)

Abbot Kilian Leib was a somewhat more careful ob server. His results come close to those of days with ♦ O.l mm in the instrumental period (Table VII). The

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results of a preliminary analysis of the Leib diary by Flohn (1979) diverge from those obtained from the careful transcription by Schwarz-Zanetti and Schwarz- Zanetti (1992a), e.g. for summer 1515 Flohn gives 62 rainy days, whereas Schwarz-Zanetti's found only 42, this being because Flohn interpreted the weather patterns in a synoptic context and included those days in his calculation on which it might have rained, despite the fact that this is not mentioned in the diary .

The results obtained from the Leib diary are similar in some respects to those obtained from the Rose diary. The deficit of precipitation in April as well as the excess of precipitation in July and October are common to both data-sets. Marked changes in sign between the two periods stand out in December (which became considerably drier) and March (which became considerably wetter) after 1518.

Monthly precipitation in the third quarter of the century , reconstructed from the diary of Wolfgang Haller in Zurich, are given in Table VIII.

Disregarding minor differences, it may be concluded from Table VIII that the months from January to March as well as July and November tended to be wetter in 1545 to 1576 than in 1901 to 1960, whereas May, October and December tended to be drier. A closer analysis reveals that the number of rainy days in July increased after 1560.

Flohn (1979) attempted an estimate of winter temperatures for the periods 1508-1531 and L545-1576 by computing the proportion of the monthly average number of days with snowfall to the total number of days with precipitation from the diaries kept by Rose and Leib. He concluded that winter temperatures in Bavaria for the period 1508-1532 were in the same order of magnitude than for the period 1881-1930.

Flohn (1949) demonstrated that for the period 1545-1576 the snow-frequency obtained from the diary of Wolfgang Haller (see 2.2.8.) comes close to the average for 1864-1938.l'he same holds for the reference period 1901-1960 (Table X). This suggests that winter temperatures in the period 1545-1576 were almost at the same level as those from the late nineteenth to the mid-twentieth centuries.

The months from October to December and the spring months were somewhat colder, whereas temperatures in January were higher in the mid-sixteenth century compared to the reference period.

Breaking down the results of Table IX into two sub-periods of equal duration yields the results seen in Table X. Both the number of days with snowfall and the share of the total number of days with precipitation (i.e. snow-frequency) increased markedly between the periods 1551-1563 and 1564-1576. This applies equally to the number of days which Haller denoted "cold" and "very cold". Uttinger (1933) demonstrated that average snow-frequency increases linearly with altitude and that it is closely related to temperature. According to his formula, a 19 increase of snow-frequency in winter (December to March), as obtained from the evaluation of the Haller diary, corresponds to a decline of temperature of l.7°C (Flohn, 1949).

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Table IX
Days with snowfall in relation to the total number of days with precipitation (%) in Zurich, 1545–1576 and 1901-1960

Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Dec-Mar
1: 1545-1576	10	34	54	51	59	49	23	4	53
2: 1901-1960	7.6	24.8	44	59.8	59.2	44.8	20.7	3	52
Difference (1-2)	+2.4	+9.2	+10	-8.8	-0.2	+4.2	+2.3	+1	+1

(Source: Flohn, 1949; Pfister, 1988a)

Table X
The cooling of winters from 1551-1563 to 1564-1576 in Zurich, as based on the Haller diary

Period	Days			
	cold	v. cold	snow (d)	snow (%)
1: 1551-1563	34.9	8.5	12.4	43.8
2: 1564-1576	39.0	12.8	19.7	63.1
Difference (2-1)	+4.1	+4.3	+7.3	+19.3

Legend:
cold: average number of days denoted "cold"
v. cold: average number of days denoted "very cold"
snow (d): average number of days with snowfall
snow (%): percentage of days with snowfall in relationship to days with precipitation (Source: Flohn, 1949)

4.2. PERIOD 1585-1600

This section is based on the analysis of monthly data compiled by Cysat (Pfister , 1988a) as well as on the analysis of diaries kept by Brahe and Fabricius (Lenke, 1968).
In his Collactanea, Cysat gives the number of rainy days for some years in the late sixteenth and early seventeenth centuries. The annual average of all his data is 163.4 days, which comes very close to the average figure of 163.8 days with ♦ 0.3 mm obtained in Lucerne for 1901-1960. Figure 7 gives deviations from that mean for the period 1588-1613 for all the months for which evidence is available.
It is obvious that the seasonal distribution of rainfall in Lucerne around the turn of the seventeenth century differed from that in the period 190i-1960. Winter months, particularly December and February, were much drier, whereas June and July were considerably drier than nowadays. Moreover, Cysat calls attention to the fact that thunderstorms were rare, that most of the rainfalls were "cold" and that snow on the "Alps" -i.e. on the Rigi (1797 m) and Pilatus (2121 m) peaks -fell "almost every fortnight" (Schmid, 1969). The very peak of Mt. Pilatus "usually became snow free in July". Compared to the twentieth-century average, this remark suggests that the timing of snow-melt at this altitude was delayed by a month

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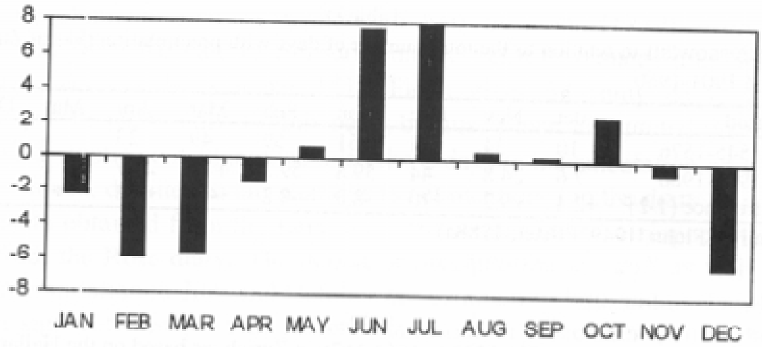

Figure 7. Deviation of average number of days within precipitation in Lucerne 1588-1613 from the mean 1901-1960. Data basis: 1589, 1609, 1610, 1612, 1613: all months of the year. 1588: Jan. through to Aug.; 1596 March through to Dec., 1611: Jan. through to May. Source: Pfister (1988).

(Pfister, 1985b). These tendencies are in close agreement to those based on the diaries kept by Brahe and Fabricius and obtained by Lenke (1968).

Fabricius undoubtedly was the most meticulous among the sixteenth-century diarists. The average number of days with precipitation obtained from his diary (1585-1612) is only 12 lower than those of the days with ♦ 0.l mm measured in Emden (1891-1930). Based on the observations made by Fabricius, Lenke (1968) was even able to assess the number of days with frost, i.e. frozen ground and/or water with negative temperatures, and "calibrate" the number of "warm" and "hot" days using content analysis. The results of his analysis can be summarized as follows:

- Easterly winds were significantly more frequent at the expense of southwesterly winds. This holds in particular for February, March, October and December. An increase of easterly winds points to a higher frequency of blocking "cold" anticyclones during these months.
- The days with winter frost and snowfall were relatively greater than in the period 1891-1930, particularly in February. This suggests that for the period 1585-1600, February was considerably colder than in the twentieth century.
- The extreme occurrence of late frosts was delayed 27 days, whilst that of early frosts occurred 37 days in advance. Thus, the period without temperatures below freezing was considerably reduced in comparison with the values measured in Emden for the period 1891-1930.
- The number of "wann" days in the summer half-year (April to September) was 36 lower than in those same months with a daily maximum of > 25.0°C measured ill Emden and Jever for the period 1881-1930. The deficit is particularly large in July.

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- The number of rainy days was somewhat larger in late spring and in summer (May to August), particularly in July, whereas the other months display deficits in precipitation, especially from October to December. This agrees with the changes in average wind direction mentioned above.
- Local (thermal) thunderstorms in the summer months were less frequent. In his analysis of the diary kept by Tycho Brahe, La Cour (1876) argued that climate in the late sixteenth century did not differ from that of the mid-nineteenth century .He based his argument on the fact that the timing of the singularities was roughly the same as in the nineteenth century. Flohn (1949) came to a similar conclusion concerning the period 1545-1576 in Zurich. Lenke (1968) attempted a careful reinterpretation of the Brahe diaries and obtained quite different results:

- The number of days with snowfall and also those with frost was greater in all months of the year than in the twentieth century , particularly in winter. This points to lower temperatures.
- In the winter half-year, easterly and southeasterly winds were predominant in comparison with the westerly winds in the twentieth century .This points 10 a greater frequency of blocking anticyclones centered over Fennoscandia (Flohn, 1949) and to a southward displacement of the westerlies into the Mediterranean, a situation that corresponds to an extreme mode of the North Atlantic Oscillation (NAO).
- The number of days with precipitation in the winter half-year was lower (which is coherent with the change in the mean wind direction) and somewhat higher in July and August-
- Local (thermal) thunderstorms were less frequent in the summer months.

Despite the considerable distance between the three places of observation, it may be concluded that based on the diary entries recorded by Cysat in Lucerne (Switzerland), by Brahe on the island of Hven in the Danish Sound and by Fabricius in Ostfriesland (northwestern Germany), the overall picture of the climate in this period agrees well. Summers were colder; it rained more often and thunderstorms were less frequent than in the late nineteenth and early twentieth centuries. The winter half-year (October-March) was more often dominated by winds from northeasterly directions. Accordingly, days with precipitation were less frequent and a greater percentage of precipitation fell in the form of snow.

5. Conclusions

Weather diaries must be included among the five most valuable kinds of non- instrumental meteorological evidence (Manley, 1953) for the following number of reasons: this type of source yields direct-eye observations of the weather; such weather diaries have an absolute dating control, a daily resolution, and they are

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seasonally continuous. Daily information is needed to get an idea of "average" conditions. If the entries are on an acceptable degree of homogeneity, some of them, particularly those relating to rain and snowfall, can be quantified, submitted to statistical analysis and compared with average conditions in some reference period in the twentieth century .This was shown for the diaries of Marcin Biem, Kilian Leib, Wolfgang Haller, Tycho Brahe and David Fabricius. Quite often daily observations are the only sources that shed some light on conditions in October and November. Weather in these months is rarely described by other types of documentary data, because it had almost no significance for crops .
Information obtained from daily observations is mainly used to reconstruct anomalous monlhly atmospheric circulation patterns (see Jacobeit et al., this volume) and to underlay continuous seasonal temperature and precipitation indices (see Glaser et al., this volume). In turn, these indices are used to assess mean monthly surface pressure situations in Europe for the pre-instrumental period (Luterbacher et al., 1998).
The weaknesses of daily weather observations, of course, may not be overlooked. Bach ob server had his own focus and his own vocabulary .Often, the observations are interrupted or continued at another place. After the death or the retirement of an excellent observer, his work is not continued in the same place. The universities of Cracow (Poland) and Ingolstadt (Germany) may be an exception in this respect, because keeping track of the weather became a scientific tradition in these places for some time. As a consequence, simultaneous first class weather diaries are available for the early sixteenth century and they overlap and complement each other. This allows the cross-checking of information.
The list of weather diaries mentioned in this article is far from being exhaustive. It would be rewarding to systematically explore the libraries of central Europe in search of this special kind of record. It is not unlikely that a continuous set of daily observations for several places could be discovered as a result of such a search.

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