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A historical declination curve for Munich from different data sources

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Abstract

Long series of geomagnetic field changes are important for studying processes in the Earth's core. We have compiled 635 historical declination values for southern Germany and surrounding areas. Indirect estimations, including the oldest ones from back in the 15th century, come from 185 sundials and compasses with declination information, and 15 historical maps. Measurements carried out by monks in the time interval 1668 to 1854 amount to 122 annual mean values and data related to the orientation of mine shafts contributes by 313 annual values for several locations. All these data can be useful to improve historical geomagnetic field models. Previously compiled German church orientations, however, are shown to be no reliable sources of the past declination. The compiled new declination curve for Munich shows general agreement with previously published curves for London and Paris and allows to detect geomagnetic jerks with a temporal uncertainty of ± 10 yrs. More or less regular impulses, on a decadal time-scale ranging from 30 to 60 years, are identified for most of the time interval 1400 to 2000, but the century from about 1760 to 1860 seems to be devoid of sudden secular variation changes.

Key words: Geomagnetism, declination, historical data, geomagnetic jerks

1 1. Introduction

The Earth's magnetic field generated by dynamo processes in the core varies on a broad range of time-scales, from years to millions of years, known as secular variation. A highly

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detailed picture of the current secular variation is obtained from satellite magnetic vec-4 tor measurements (Ørsted and CHAMP satellite), available since 1999. Systematic vector 5 measurements at locations all over the world, leading to the present network of geomag-6 netic observatories, started in the early 19th century with the initiative of Alexander von 7 Humboldt and Carl Friedrich Gauss. Moreover, a major improvement was the develope-8 ment of a method to determine the absolute field intensity by Gauss (Gauss, 1833). Time 9 series longer than 200 years are, however, desirable to study decadal to centennial secu-10 lar variation processes. Archaeo- and paleomagnetic data provide information on longer 11 intervals, but mostly with limited time resolution and lower accuracy than direct measure-12 ments. Magnetic data from historical sources are then an important complement to study 13 the field evolution of the past centuries. 14

The first measured geomagnetic field element was the declination, linked to the early 15 use of compasses. The magnetic compass has been known in Europe since the 12th century 16 (e.g. Merrill et al., 1996), but it is not clear when its deviation from geographic north, i.e. 17 declination, became known there. In China, both the compass and declination had been 18 known some centuries before. The earliest known European declination measurements 19 start with an observation by Hartmann in Rome in 1510 (Hellmann, 1899). The discovery 20 of declination in the European area has often been ascribed to Christopher Columbus 21 in 1492, but Chapman and Bartels (1962) describe evidence from ancient sundials and 22 compasses indicating that the deviation of a compass needle from geographic north was 23 known in Europe at least since the early 15th century. This knowledge, however, might not 24 have been widely distributed. Moreover, some of the first observed deviations might have 25 been interpreted as resulting either from the construction of specific instruments (see e.g. 26 Wolkenhauer, 1904) or from different magnetisation directions of the loadstone, used to 27 magnetise the needle, depending on its location of origin (see e.g. Balmer, 1965; Körber, 28 1965). The oldest declination value given by a magnetic compass known to us dates from 29 1451 (Zinner, 1939). This instrument was made by Peuerbach in Vienna. However, it is 30 not clear if Peuerbach understood the deviation from geographic north as a property of the 31 magnetic field or as one of the specific instrument. Three more compasses made by him at 32

the same location between 1451 and 1456 indicate different declination values, although the discovery of change of declination with time (i.e. secular variation) is generally assumed to lie only in the early 17th century. It has first been described by Henry Gellibrand in 1634 and probably been noticed before by Edmund Gunter in 1622 (Chapman and Bartels, 1962). It is generally assumed that inclination was discovered in 1544 by Georg Hartmann at Nuremberg but probably first measured correctly by Robert Norman in 1576 (e.g. Chapman and Bartels, 1962).

Measurements of the two field directions, declination and inclination, date back further 40 than full vector observations. Frequent measurements were taken particularly from ship-41 board for navigational purposes from the late 16th century on, and Jonkers et al. (2003) 42 compiled a large global set of such data. Their database also contains a few land measure-43 ments prior to the start of systematic observations. Individual time series of declination 44 and sometimes inclination have been compiled by Malin and Bullard (1981); Cafarella et al. 45 (1992); Barraclough (1995); Alexandrescu et al. (1996) and Soare et al. (1998) for London, 46 Rome, Edinburgh, Paris and Romania, respectively. 47

When we noticed a historical declination curve for southern Germany based on declina-48 tion information from sundials (Wagner, 1997) and a number of historical measurements 49 carried out at monasteries and not included in the Jonkers et al. (2003) database, we 50 started new efforts of finding historical data over Germany and surrounding areas. In the 51 course of this work we noticed even more largely unexploited sources of declination data: 52 compass roses printed on old maps (Mandea and Korte, 2007), declination measurements 53 used for mining activities and probably even orientations of churches. These data sources 54 have also been mentioned by Knothe (1987, 1988), who actually compiled declination data 55 from mining activities in Europe, but only published and preserved resulting curves and 56 not the values. 57

Here, we first give an overview of the previously published data compilations for the German region from 1300 on. Then, we discuss the different data sources explored in this study and present the new data compilation for (southern) Germany. We compare the data to predictions from the *gufm1* global geomagnetic field model (Jackson et al., 2000),

which covers the time interval from 1590 to 1990, and to the archeomagnetic data from earlier times. A smoothed declination curve for Munich is obtained. Its similarities and differences to the declination curves for London and Paris are shown and the occurence of geomagnetic jerks from 1400 to present is investigated.

66 2. Existing German declination data since 1400

67 2.1. Geomagnetic observatories

Started in the early 19th century and initiated by Alexander von Humboldt, regular 68 measurements of the geomagnetic field were carried out on a daily basis at fixed times at 69 a growing number of geomagnetic observatories. At the Sternwarte Berlin such measure-70 ments were carried out from 1836 to 1865 (Encke, 1840, 1844, 1848, 1857, 1884). The 71 annual mean values are included in the supplementary data file. In the late 19th and 72 early 20th century the magnetic field was recorded at several locations in and nearby Ger-73 many, and annual mean values are archived at the World Data Center (WDC) Edinburgh 74 (http://www.wdc.bgs.ac.uk). The time series of three active geomagnetic observatories go 75 back to the 19th century when they are combined with data from one or two predecessing 76 stations located not far away from the present observatories. Table 1 indicates them with 77 their location changes. The data are published in the yearbooks of the observatories and 78 are also available from the WDC Edinburgh. We only consider the MNH-MAS-FUR time 79 series in the following, as most of our newly compiled data come from southern Germany 80 and our aim is to construct a regional declination curve from all values adjusted to Munich. 81

83 2.2. Gufm1 and its data basis

82

A global compilation of historical geomagnetic data has been published by Jonkers et al. (2003). It spans the times from 1510 to 1930 and consists mainly of measurements made on ships for navigational purposes during the voyages over the oceans, but also some measurements on land. From that database, we have extracted declination values for the region 47-55°N, 6-15°E, covering the present day German territory and parts of some



Figure 1: Locations of declination data sources. Stars mark locations of found declination values from sundials, compasses and historical maps. Direct measurements at mines and monasteries are marked by black dots. Crosses mark the locations of historical data available from the Jonkers et al. (2003) database (region 47-55°N,6-15°E) and gray diamonds of archeomagnetic data compiled for Germany by Schnepp et al. (2004). Labels (letters) are given for some locations referred to in the text.

	location 1	location 2	location 3
Name	Wilhemshaven	Wingst	
IAGA Code	WLH	WNG	
Time interval	1884-1932	since 1939	
Name	Potsdam	Seddin	Niemegk
IAGA Code	POT	SED	NGK
Time interval	1890-1907	1908-1931	since 1932
Name	Munich	Maisach	Fürstenfeldbruck
IAGA Code	MNH	MAS	FUR
Time interval	1841-1926	1927-1935	since 1939

Table 1: German geomagnetic observatories with long data series

⁸⁹ surrounding countries. The locations of the resulting 326 declination values from 1523 to
⁹⁰ 1895 are shown in Fig. 1.

Jackson et al. (2000) constructed a global, time-varying magnetic field model spanning 91 the time 1590 to 1990, named *gufm1*. Predictions of declination for the area of Germany 92 from the *gufm1* model, in 100 year intervals, are shown in Fig. 2a, complemented by the 93 declination prediction of the International Geomagnetic Reference Field (IGRF) for 2000 94 (Macmillan et al., 2003). In Fig. 2b the declination curves from the qufm1 model for the 95 four corners of the considered region and its center (51.0°N, 10.5°E) are shown. A strong 96 change of the declination gradient with time in east-west direction is very clear. Around 97 1700, declination values all over Germany are on the order of -8°, while around 1900 they 98 range from -13° (western part) to -9° (eastern part). The epoch without strong spatial 90 declination gradient around 1700 also marks a change in the isogonic lines over Germany, 100 from more easterly declination values in the west than the east to more westerly declination 101 values in the west than the east (see Fig. 2b). 102

103 2.3. Archeomagnetic data

A catalogue of German archaeomagnetic data has been compiled by Schnepp et al. (2004). Among others, this catalogue contains a consecutive time series of data from a



Figure 2: a) Declination distribution over Germany from 1600 to 2000 according to global models gufm1 and IGRF. b) Declination predictions from gufm1 for the center and four corners of the region shown in a).

¹⁰⁶ bread oven-floor sequence in Lübeck (Schnepp et al., 2003), spanning approximately the ¹⁰⁷ time interval 1300 to 1800. The locations of 51 declination values available since 1300 from ¹⁰⁸ that catalogue are also shown in Fig. 1. The mean age uncertainty of these archeomagnetic ¹⁰⁹ data is 75 yrs, and the mean declination data uncertainty we computed based on the ¹¹⁰ given α 95 uncertainties is 3.6°. Both the previous historical and archaeomagnetic data are ¹¹¹ discussed together with the newly compiled data in section 4.

¹¹² 3. Newly compiled declination data

Reports of direct declination observations are the most reliable sources of information about this magnetic element. However, additional historical sources of declination exist. Here, we describe the different sources we have explored during this study, and discuss their accuracy and reliability. The new data are supplied in the supplemental data file. The locations of the newly compiled declination data are shown in Fig. 1.

118 3.1. Sundials and compasses

Portable sundials have to be oriented in the right direction in order to show the correct 119 time. The easiest way to achieve this is by means of a magnetic compass. The manu-120 facturers of sundials obviously were aware of the deviation of the compass needle from 121 the true north since the 15th century (Hellmann, 1899; Zinner, 1939). Ancient sundials 122 or compasses often have a mark of declination angle (Körber, 1965), and this information 123 can generally be found in books and catalogues describing collections of historical sundials 124 (e.g. Körber, 1964; Gouk, 1988; Wagner, 1997). The southern German cities Nuremberg 125 and Augsburg (N and A in Fig. 1) were centers of sundial manufacturing from the 15th to 126 18th century. For many of the ancient sundials an indication about the place and the epoch 127 when they were made is included in the descriptions. Wagner (1997) compiled a list of 128 declination values given by well-dated historical sundials mainly produced at Nuremberg. 129

¹³⁰ Wagner (1997) only included data from instruments of which the exact years of man-¹³¹ ufacturing were known. Here, we also include values from instruments that were only ¹³² approximately dated. The assigned age error estimates depend on the accuracy of the ¹³³ dating. If a time interval was given we assigned the mean time \pm the difference between

mean and interval borders. A dating of, e.g., 16th century became 1550±50, of , e.g., first half of 16th century became 1525±25, and datings like "about 1670" became 1670±5. Note that these are not statitical error estimates and probably not even completely consistent within the dataset due to the many different formulations for the age estimates by different authors. In general, they should be close to the maximum age uncertainties and like that useful when error bars are used to decide on data consistency and reliability.

We do not have a clear idea what uncertainty to expect as we do not know by which method exactly and under which conditions the values were determined. In general the values are given as full degrees. Körber (1965) notes that the values might have been given according to a 32- or 36-parts wind rose, where approximately 6° or 5° is half a mark on the rose. We assume that 1° to 3° is a reasonable estimate for the general uncertainties of these data.

Appendix A lists the declination values obtained from sundials and compasses, together 146 with the references, and data are plotted in Fig. 3a for comparison with other data. Fig. 4 147 is an enlargement of that panel with error bars when the year of manufacturing is unknown. 148 Interestingly, the ages of the older instruments, in general, are better known than of those 149 from 18th and 19th century. The older declination data with known manufacturing dates are 150 much more consistent than the most recent ones. Unless the declination has not been taken 151 into account properly for those instruments, either several of the estimated ages are not 152 correct, or those sundials have been built for significantly different locations. The number 153 of data from sundials amounts to 133 values from instruments with known locations, plus 154 52 values from unknown locations. 155

156 3.2. Historical maps

Printed historical maps occasionally show compass roses with an indication of declination. Assuming that geographic north is at the top of the map, the declination can be read from the orientation of the printed compass needle. The accuracy to which the declination can be estimated is in the order of 1° to 5° and 15 declination values from historical maps have been compiled here. Further values, including earlier ones (Wolkenhauer, 1904,



Figure 3: Declination data for the indicated locations provided by several sources: a) from sundials and compasses b) from historical maps; c) from measurements in monasteries and d) from measurements in mines (due to the close agreement several of the mine data are hardly distinguishable). In c) and d) predictions from the gufm1 model for the same locations are shown. Abbreviation letters refer to those shown in Fig. 1.



Figure 4: Declination data from sundials and compasses from Fig. 3a with estimated error bars when the year of manufacturing is unknown.

1907), certainly exist, but as it will be discussed in the following this kind of data seems 162 less reliable than the sundial data. Here, we limited our work to the easily verifiable values 163 published by Körber (1965) and Kleinschmidt (1989). Indeed we found some discrepancies 164 between the values provided by these two sources and confirmed all values from the atlas 165 of historical maps (Bachmann, 1941, 1942, 1961). All these values, including differing pub-166 lished ones, are listed in Appendix B and plotted in Fig. 3b. All declination values compiled 167 here come from within one century. The figure clearly shows a large scatter among these 168 values, indicating a much lower reliability of these data compared to those obtained from 169 sundials. Apparently the printed compass roses do not represent very exact declination 170 values or the maps themselves are not oriented accurately to geographic north. The three 171 strongly westward declination values even suggest that declination has been applied with 172 the wrong sign to these maps. 173

174 3.3. Monasteries and meteorological stations

During the 18th and 19th centuries, measurements of declination were carried out at several places in southern Germany and Austria by monks.



Figure 5: Declination data measured at monasteries from Fig. 3 enlarged to show the differences in detail.

At Hohenpeissenberg, magnetic declination measurements were initiated together with 177 meteorological measurements in 1781 by the Societas Meteorologica Palatina, the Academy 178 of the Palatinate. Declination measurements were conducted three times a day by monks 179 and local priests until 1839. Annual means from these measurements, published in year-180 books (e.g. Hemmer, 1783) and a later compilation by Lamont (1851) have been digitized. 181 Results from magnetic observations carried out at monasteries at Augsburg and Kremsmünster 182 (Austria) are published in a series of yearbooks, like Stark (1814) and Reslhuber (1857), 183 respectively. Monthly mean values based on at least three measurements a day exist for 184 Augsburg from 1813 to 1837, and we computed annual means based on them. The time 185 series for Kremsmünster consists of single data points between 1740 and 1790. From 1815 186 on the digitized values are means of several measurements per year and from 1832 several 187 measurements per month with a declinatorium manufactured by Brander in Augsburg. 188 This is the same instrument as was used in Hohenpeissenberg and Augsburg. Around 1840 189 a gradual shift to classic geomagnetic observatory intruments and routines with regular 190 daily observations started. 191

The locations and time series of these observations are included in Figs. 1 and 3c. Fig. 5 shows the same data on an enlarged scale to visualize the detailed differences between these data mainly coming from the time interval 1750 to 1850. The data show a good internal consistency and generally good agreement with the *gufm1* model. The Augsburg data, however, present somewhat suspect values as they are nearly constant over the whole time

¹⁹⁷ span they cover.

The overall number of data from these sources amounts to 122 values spanning the time 199 1668 to 1854.

200 3.4. Mining activities

Since the 13th century, compasses were also used in mining to determine the direction 201 of the mine legs (Ludwig and Schmidtchen, 1997). Christian Doppler first realized that 202 declination information can be gained either by comparing old mining maps with newer ones 203 or that declination values are given in mining publications (Doppler, 1849). Knothe (1987, 204 1988) compiled several data from differnt European locations, but only plots and no values 205 are published or have been preserved by the author (Knothe, pers. comm.). Schreyer (1886) 206 compiled a large number of declination measurements carried out for mining purposes in 207 Saxony (at that time Kingdom of Saxony) from 1575 to 1885. A number of measurements 208 in Berlin and Regensburg between 1717 and 1788 are included. 209

For two main mining areas in Freiberg and Clausthal 10 year interval data series from 1545 to 1885 are given by Schreyer (1886). All found data within each decade have been reduced to the central epoch by a simple assumption of secular variation and averaged "taking into account their reliability" (Schreyer, 1886), but details of this averaging are not given. A few measurements reported by Schreyer (1886) from Freiberg between 1773 and 1790 come from different, insufficiently documented sources and are averages of 9 to 24 measurements over the year or individual measurements.

Annual data for several locations for the 19th century are best documented. Those 217 values had mostly been published annually in a series of mining calendars, e.g. Königl. 218 Bergakademie zu Freiberg (1850), which have been scanned by the Technical University 219 Bergakademie Freiberg and today are available on a website (http://www.tu-freiberg.de/ub/el-220 bibl/jb_sachsen/jb_sachsen.html). Schreyer (1886) reports that if several observations ex-221 isted within a year, they have been reduced to the middle of the year by an estimate of 222 secular variation for that time and averaged. Moreover, if the time of observation was 223 given the values had first been reduced to the daily mean by rules determined by Johann 224

von Lamont for Munich. The values are rounded to 0.1'. The individual measurements on which these averages are based were done by means of mine surveyors' compasses and their accuracy is estimated as 10' for the earlier and 3-5' for the later years by Schreyer (1886). Note, that the signs of all these values in our digital supplement are opposite to the ones in the Schreyer (1886) publication, in order to agree with today's convention of positive sign for eastern declination and negative for western.

Time series of all these 313 declination measurements are shown in Fig. 3d. A good accuracy of these data with very good agreement to *gufm1* from 1700 onward can be seen. The long data series from Clausthal (Ct in Fig. 1) further west and Freiberg (Fb) further east clearly reflect the change in declination gradient around 1725 again. Assuming that the accuracy of these averaged declination data is nearly equally high throughout the 17th century, these data have the potential to improve details of models like *gufm1*, which fits the earlier data less well.

238 3.5. Church orientations

A few publications describe church orientations as a possible source of magnetic decli-239 nation values. Motivated by historical documents proving the use of a compass for church 240 orientation in 1516, Wehner (1905) studied the deviation from the geographic east of the 241 axes of some 300 churches. He concluded that several churches were oriented by magnetic 242 compass and provides a list of 45 German churches with orientations. However, his claim 243 that most of them were oriented by magnetic compass is based on the assumption that 244 the declination varies strictly periodically. Figure 6 shows the declination values resulting 245 from the deviation of church orientations from the geographic east. The associated ages 246 are the years of the church foundation and error bars of 50 years are shown when the year 247 is not exactly known. Nippold (1916) supports Wehner's conclusion (Wehner, 1905) by 248 direct comparison of church axes deviations and geomagnetic field data, however, for lack 249 of available data, again under the assumption of periodicity. Today we know from archeo-250 and paleomagnetism that we cannot expect a strictly periodic declination variation. Abra-251 hamsen (1985) picked up the topic again by studying Romanesque churches in Denmark 252



Figure 6: Declinations for 45 locations in Germany, as determined from church axes deviations from the geographic east under the assumption that orientation was done by magnetic compass. Black dots are the values presumed to represent magnetic declination by Wehner (1905), stars are the ones he considered not in agreement with orientation by magnetic compass. Archeomagnetic declination data (gray dots, see sec. 2.3) and the *gufm1* model prediction for the center of Germany (gray line) are also shown for comparison.

²⁵³ in the 12th century. From a statistical analysis of orientation of more than 500 churches he ²⁵⁴ concluded that about 25% of all Danish Romanesque churches were oriented by means of ²⁵⁵ a magnetic compass (Abrahamsen, 1990).

The declination values obtained from church orientations published by Wehner (1905) 256 are based on an a priori assumption about the geomagnetic field. Apart from the fact that 257 the assumption is most likely wrong, as e.g. a comparison with the archaeomagnetic data 258 described in section 2.3 (Fig. 6) suggests, the values are not independent and cannot be 259 used to study past declination. A rigorous statistical analysis of all German churches from 260 a given epoch might provide true information on past declination, but a complete dataset 261 is not readily available and such a study is outside the scope of this work. We did not 262 consider the values from church orientations any further in this work. 263

²⁶⁴ 4. A declination curve for southern Germany

All new and previous historical and archeomagnetic data from the German region, spanning the time interval 1300 to 1950 are combined in Fig. 7a on their original locations. Then the values D have been adjusted to the location M = (11.57E, 48.13N) of Munich (M in Fig. 1) from their original locations x = (longitude, latitude) (Fig. 7b) by using

adjustment values ΔD determined from the *gufm1* model for the respective epoch t:

$$D(M,t) = D(x,t) + \Delta D(t)$$
(1)

with

$$\Delta D(t) = Dg(M, t) - Dg(x, t), \tag{2}$$

where Dg(M,t) and Dg(x,t) are *gufm1* model predictions at time t for locations M and x, respectively. For data prior to the validity of the model, i.e. t < 1590, the adjustment values were computed with t = 1590. Data from the sundials without known location have not been considered and are omitted in Fig. 7b and in the following determination of a smoothed curve. From the historical map data, only the values determined/confirmed by us have been used. Most of the adjusted data are consistent within 10°, but some outliers exist among the sundials and maps data.

A smooth declination curve for Munich for the time span 1400 to 2000 has been created 272 by fitting a smoothing spline (Constable and Parker, 1988) to 1105 reduced data. In 273 order to avoid any artificial end effects of the spline function the archaeomagnetic data 274 have been considered from 1300 on and the combined annual declination means from the 275 geomagnetic observatories at Munich-Maisach-Fürstenfeldbruck from 1840 to 2000 and 276 reduced to Munich have been included (147 values). We do not have good uncertainty 277 estimates for the data and for this reason no weighting has been applied. The knot-point 278 spacing of the spline function has been set to 25 years. The minimum root mean square 279 (rms) misfit of this spline curve is 2.89°. The residuals between data and curve are not 280 normally distributed, but show a symmetric distribution with good fit to the majority of the 281 data and some significant outliers. In order to avoid an influence from obviously erroneous 282 data we rejected several outliers. As the residuals are not truly normally distributed and we 283 have no information on the uncertainty distribution of the data, we somewhat arbitrarily 284 rejected all data lying further than three standard deviations away from this initial curve 285 (26 rejected values). We fit a new smoothing spline to the remaining declination values, 286 which can achieve a new minimum rms misfit of 1.45° . In order to keep the variability 287 of the whole curve comparable with the recent end, the fit to the observatory values, we 288



Figure 7: All new (black symbols) data presented in Fig. 3a to d together with previously published historical and archeomagnetic data (gray symbols) on a) their original locations and b) adjusted to Munich (11.57E 48.13N). c) Historical declination curves for Munich (thick black line, see text), London (long dashed line, Malin and Bullard (1981)) and Paris (short dashed line, Alexandrescu et al. (1996)). The data used and rejected for the Munich curve are shown here as gray dots and stars, respectively. The time series from the observatories in Munich, Maisach and Fürstenfeldbruck (adjusted to Munich) is given as thin black line.

applied a slight smoothing. Our preferred curve has an rms misfit of 1.48° and is shown as
thick solid line in Fig. 7c. The curve is also provided in the supplemental data file.

²⁹¹ 5. Comparison to other declination curves

The declination curves by Malin and Bullard (1981) and Alexandrescu et al. (1996) for 292 London and Paris, respectively, are included in Fig. 7c. The agreement in general shape 293 of European declination variation is obvious. The intersection between the Munich and 294 Paris curves confirms again the change from more easterly declination further west (Paris) 295 to more westerly declination there than further east (Munich) in the early 18th century. 296 The new Munich curve shows a somewhat different variability in the 16th and 17th century 297 than the previous curves. Geomagnetic jerks, characterised by a sharp extrema of secular 298 variation like the 1969 event, can be identified as rather broad minimum or maxima in 299 the curve. The well-known 1978 and 1990 geomagnetic jerks, however, are not detected as 300 they occur near the very end of the investigated period. Moreover, a comparison of secular 301 variation in form of the first derivative of the spline function with first differences of the 302 MNH-MAS-FUR data series (Fig. 8a), slightly smoothed by an 11-yr running average, to 303 minimise the solar cycle related variations, shows that for the recent decades the spline 304 function is not able to represent the very short time-scale changes, recently defined as 305 "rapid secular variation fluctuations" by Mandea and Olsen (2009). 306

The occurrence time of maxima and minima of the curve, representing geomagnetic 307 jerks, can be determined more easily by looking for changes of sign in the second derivative, 308 secular acceleration, which is also shown in Fig. 8a. Note that the sharp angles in this 309 secular acceleration curve are a consequence of the 25 year knot-point spacing of the cubic 310 spline basis functions, but the zero crossings accurately represent the times where maxima 311 and minima occur in the secular variation curve. Indeed, the sign changes of the Munich 312 secular acceleration around 1932, 1889 and 1861 roughly agree with the known geomagnetic 313 jerks in 1925, 1901 and 1870 described by Alexandrescu et al. (1995, 1997). The comparison 314 between the observatory data and the smoothed historical curve around 1925 suggests 315 that the uncertainty in dating these jerks lies in the smoothed representation and we 316

consequently should adopt an uncertainty of about ± 10 yrs for all earlier events shown by our curve. The new Munich curve suggests events at 1763, 1741, 1708, 1693, 1661, 1558, 1508, 1448 and 1410, although the two earliest have to be regarded with caution because they are constrained only by few data. Two more geomagnetic jerks might have occured around 1598 and 1603, but are less clearly resolved.

Alexandrescu et al. (1997) describe five possible jerks between 1680 and 1870, based 322 on their study of the Paris data series. They are dated 1700, 1730, 1750, 1770 and 1785. 323 Considering the data noise and some baseline problems for the first two centuries of the 324 Paris curve, Alexandrescu et al. (1997) conclude that none of these jerks is deeply sup-325 ported by their data and the presence of any geomagnetic jerk between 1680 and 1870 326 could be doubted. Comparing their and our geomagnetic jerk occurrence times, the sign 327 change of secular acceleration (maximum or minimum of secular variation), and taking into 328 account the significant temporal uncertainties, the events dated 1700/1708, 1730/1741 and 329 1750/1763 could represent the same events. On the other hand, our compilation identifies 330 no events in 1770 and 1785. 331

The identification of geomagnetic jerks by Alexandrescu et al. (1997) was carried out on 332 a significantly less smoothed data series. We applied a similar spline fit to the Paris data 333 series for a more direct comparison to our analysis. We used the annual data presented by 334 Alexandrescu et al. (1996), which go back to 1541, and added 26 archeomagnetic declination 335 values from France for the time span 1300 to 1540, mainly compiled by Bucur (1994) and 336 digitally available from the global compilation by Korte et al. (2005) or the GEOMAGIA 337 V.2 database (http://www.geomagia.ucsd.edu). The declination series by Alexandrescu 338 et al. (1996) is adjusted to the location of Chambon-la-Forêt (2.27E, 48.02N), the location 339 of the present observatory near Paris. We adjusted the archeomagnetic data to the same 340 location using the qufm1 model as described for the German data in section 4. The data 341 were fit by smoothing splines for the same time interval (1300 to 2000) and with the same 342 knot-point spacing (25 yrs) as the Munich curve. A comparable variability of the curve was 343 obtained by applying weak smoothing and fitting the data to an rms misfit of 0.69°. Secular 344 variation and acceleration at Paris are represented by the first and second derivative of this 345

³⁴⁶ curve in Fig. 8b.

The comparison of the smoothed Munich and Paris secular variation is best described 347 in three time intervals: 1400 - 1580, 1580 - 1770 and 1770 - 2000. During the recent time 348 interval, from about 1770 onwards, secular variation and acceleration at both locations 340 broadly agree, with the jerk seen in 1901 in the original French data also represented slightly 350 earlier by the smooth Paris curve, but agreeing within our estimated dating uncertainty of 351 ± 10 yrs due to the smoothing. The earliest time interval from 1400 to about 1580, least well 352 supported by data particularly in the Paris curve, also shows surprisingly consistent secular 353 variation and acceleration between the smoothed curves from the two locations. Larger 354 time lags between similar patterns in this case might be influenced by relatively large 355 dating uncertainties associated with the archeomagnetic data, but artificial oscillations in 356 the spline fit resulting from the sparse data until 1550 can also not be ruled out. 357

Significant differences between the two locations are seen in the time interval between 358 1580 and 1770. The geomagnetic jerks suggested between 1580 and 1680 by the Munich 359 curve are not confirmed by the Paris curve. During this interval, however, the Paris 360 curve might lack some information as it is based only on 25 annual values derived from 361 35 individual measurements, while 128 data points support the Munich curve within this 362 interval. After 1680, when a reasonable amount of data exists for both locations, the 363 smoothed Paris curve only shows one of the five jerks suggested by Alexandrescu et al. 364 (1997) based on the original data (at 1700). However, no deceleration (i. e. secular 365 acceleration (0) appears in the smoothed curve for nearly two centuries after that event. 366 The existence and tentative link between suggested jerks about 1700/1708, 1730/1741 and 367 1750/1763 thus neither can be confirmed nor excluded by this comparison. Both analyses 368 agree, however, that the century from about 1765 to about 1865 is devoid of strong rapid 369 secular variation changes. This is the time when the declination in Europe has reached its 370 most western values and changes its trend, i.e. the minimum seen in the declination curve 371 (Fig. 7c). 372



Figure 8: Secular variation and acceleration for Munich (a) and Paris (b). Secular variation is given by the first temporal derivative of the smoothed curves fit to the declination data (black) and by first differences of the data series smoothed by 11-yr running averages (gray, MNH-MAS-FUR (a) and of the declination data from Alexandrescu et al. (1996) (b), respectively). Secular acceleration (dashed lines) of the declination curves is shown with right-side label axes.

373 6. Conclusions

We have compiled 635 historical declination values from southern Germany and sur-374 rounding areas from different sources. The accuracy of declination values determined from 375 sundials and old compasses from the 15th to 19th century are in the same order as that of 376 the available archeomagnetic data. Measurements in mines and those made by monks from 377 the 17th to 19th century show an accuracy better than 1°. All these data can be useful to 378 improve historical geomagnetic field models and to link archeomagnetic and historical field 379 reconstructions. Declination values obtained from church orientations, however, have to be 380 taken with caution. They require more comprehensive statistical investigations than cur-381 rently available for Germany in order to be considered as a source of historical declination 382 information. 383

The compiled data have been adjusted to the location of Munich together with available archeomagnetic and previously published historical data. A smooth declination curve has been fit to the data, extending the existing observatory record from MNH-MAS-FUR backward to AD 1400. The comparison to declination curves for Paris and London shows a broadly uniform European declination variation, but with a significant spatial gradient change in the early 18th century.

The smooth secular variation description provided by the Munich declination curve 390 indicates several geomagnetic jerks with an uncertainty of about ± 10 years, as can be 391 estimated for the well-known jerks of the 20th century. The geomagnetic jerk shown by 392 the Munich curve around 1861 is presumably the one proposed around 1870 based on data 393 from Paris and four other European locations by Alexandrescu et al. (1997). Three jerks 394 suggested by Alexandrescu et al. (1997) from the Paris data over the 18th century might 395 be confirmed by this new compilation: 1750/1763, 1730/1741 and 1700/1708 (first date is 396 based on the Paris original data, the second one is based on the smoothed Munich curve). 397 However, the two more recent events are not seen in the Paris curve smoothed in the same 398 way as the Munich one. Going back in time, several earlier events are suggested by the 399 Munich curve around the following epochs: 1693, 1661, 1558, 1508, and perhaps, but less 400

clearly resolved or supported by data, in 1603, 1598, 1448 and 1410. An analysis of the
similarly smoothed, sparse Paris data over the 17th and 16th century, however, suggests
significantly different secular variation and acceleration during these times and does not
support the suggested jerks.

More data are necessary and regional or global modelling might help to resolve whether 405 true small-scale field structure or insufficient data cause the observed differences. Note also 406 that jerks in relatively quick succession, like e.g. the 1979 and 1990 events, can in general 407 not be resolved by a smoothed declination reconstruction. In summary, our study suggests 408 that geomagnetic jerks, as defined by Mandea and Olsen (2009), occurred more or less 409 regularly on a decadal time scale (from some three to six decades) during most of the 410 studied six centuries. However, the time span from about 1760 to 1860 seems to have been 411 devoid of sudden secular variation changes. 412

We expect that this new data compilation will be useful to improve historical geomagnetic field models and to better track the different temporal variations revealed by the Earth's magnetic field. We also hope that our work will encourage the search for unknown ancient geomagnetic field data from all around the world.

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⁴²⁵ A. Declination from sundials and compasses

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426

Given Age								1464 -1467	1464 - 1467					1480 - 1486	presum. 1484	1480 - 1490						1^{st} half $16.^{th}$ cent.												about 1560								
Ref. No.				4525		122		VI 7	F 1361	12364	288		G 425			1893		94		WI 28	DI 65	Mat U 24				Rar 434	WI 182		WI 267	1681		N. 12		DI 63	MATB75	DI 12	DI 37	DI 22	MAT B 29			
Reference	Wagner (1997), Zinner (1979)	Wagner (1997), Zinner (1979)	Wagner (1997), Zinner (1979)	Zinner (1979)	Wagner (1997), Zinner (1979)	Zinner (1979)	Wagner (1997), Zinner (1979)	Zinner (1979)	Zinner (1979)	Zinner (1979)	Zinner (1979)	Zinner (1979)	Wagner (1997), Gouk (1988)	Zinner (1979)	Körber (1964)	Hamel (2000), Mackensen	Zinner (1979)	Wagner (1997), Gouk (1988)	Wagner (1997), Gouk (1988)	Zinner (1979)	Zinner (1979)	Wagner (1997), Gouk (1988)	Zinner (1979)	Wagner (1997), Bryden (1988)	Wagner (1997)	Wagner (1997), Syndram (1989)	Wagner (1997), Zinner (1979)	Kleinschmidt (1989), Körber (1964)	Hamel (2000), Zinner (1979)	Wagner (1997), Körber (1964)	Wagner (1997), Körber (1964)	Wagner (1997), Körber (1964)	Hamel (2000), Zinner (1979)	Wagner (1997), Zinner (1979)	Wagner (1997), Zinner (1979)	Wagner (1997), Zinner (1979)						
Manufacturer	G. Peuerbach	G. Peuerbach	G. Peuerbach	G. Peuerbach	G. Peuerbach	J. Regiomontan	J. Regiomontan	J. Regiomontan	J. Regiomontan	C. Dorn	W. Faber	C. Dorn	C. Dorn	C. Dorn	E. Etzlaub	E. Etzlaub	unknown	B. Emck	G. Hartmann	G. Hartmann	G. Hartmann	G. Hartmann	G. Hartmann	G. Hartmann	G. Reimann	J. Gebhard	C. Schissler	H. Reimann	C. Schissler	Göbe	unknown	unknown	C. Schissler	(C. Schissler)	C. Heiden	C. Schissler	C. Heiden	H. Tucher				
Location	Vienna	Vienna	Vienna	Vienna	Vienna	Budapest	Nuremberg	Nuremberg	Nuremberg	(Budapest)	(Budapest)	(Budapest)	(Budapest)	(Budapest)	unknown	(Budapest)	(Budapest)	Vienna	Nuremberg	Nuremberg	unknown	Kassel	Nuremberg	Nuremberg	Nuremberg	Nuremberg	Nuremberg	Nuremberg	Nurmeberg	Nuremberg	Augsburg	Nuremberg	Augsburg	Dresden	unknown	unknown	Augsburg	Augsburg	(Nuremberg)	Augsburg	Augsburg	Nuremberg
$_{\rm (deg.)}^{\rm D}$	10.0	11.0	14.0	10.0	12.5	13.0	6.0	6.0	10.0	10.0	14.0	10.0	14.0	10.0	14.0	7.0	12.0	11.0	10.0	15.0	10.0	7.0	10.5	10.5	11.5	10.25	10.25	9.5	12.0	7.0	10.0	9.5	9.0	5.0	8.0	12.0	10.0	5.0	25.0	8.5	6.5	8.0
ΔT	0	0	0	0	0	0	0	7	2	0	0	0	0	cî	2	ъ	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0
Year	1451	1451	1453	1455	1456	1463	1465	1466	1466	1476	1479	1480	1481	1483	1484	1485	1486	1491	1501	1511	1514	1525	1527	1535	1538	1539	1539	1542	1555	1556	1557	1558	1559	1560	1561	1561	1562	1565	1565	1567	1569	1574

Year	ΔT	D (Jog)	Location	Manufacturer	Reference	Ref. No.	Given Age
	'	(.gan)					
1579	0	8.0	Nuremberg	H. Tucher	Wagner (1997), Körber (1964)	1	
1580	0	9.5	Nuremberg	H. Ducher	Wagner (1997) , Syndram (1989)	N. 14	
1581	0	9.13	Augsburg	T. Klieber	Zinner (1979)		
1582	0	15.0	(Kassel)	J. Bürgi	Zinner (1979)		
1583	0	8.0	Nuremberg	P. Reinmann	Wagner (1997), Zinner (1979)		
1584	0	11.5	Nuremberg	P. Reinmann	Wagner (1997), Zinner (1979)		
1595	0	7.0	Nuremberg	H. Tucher	Wagner (1997), Lloyd (1992)		
1598	0	6.0	(Antwerpen)	unknown	Wagner (1997) , Syndram (1989)	Nr. 17	
1600	0	8.0	Bamberg	J. Bonius	Glasemann (1999)	Nr. 53	
1600	0	8.0	Nuremberg	H. Troschel	Wagner (1997), Lloyd (1992)		
1600	S	8.0	unknown	"R"	Hamel (2000) , Zinner (1979)	MAT B 72	about 1600
1601	0	6.0	Nuremberg	Troschel	Wagner (1997), Körber (1964)	2	
1602	0	6.5	Nuremberg	P. Reimann	Wagner (1997), Zinner (1979)		
1604	2	6.0	Nuremberg	unknown	Kleinschmidt (1989), Körber (1964)		after 1602
1605	2	9.0	Dresden	unknown	Kleinschmidt (1989), Körber (1964)	AI 44	after 1603
1607	0	12.0	Nuremberg	P. Reimann	Wagner (1997), Zinner (1979)		
1610	0	4.0	Nuremberg	Lösel	Wagner (1997), Körber (1964)	4	
1610	0	-20.0	(Augsburg)	L. Miller	Zinner (1979)		
1611	0	5.0	Nuremberg	H. Troschel	Wagner (1997), Lloyd (1992)	7534	
1611	0	7.0	Nuremberg	H. Tucher	Wagner (1997), Lloyd (1992)	7577	
1613	0	-6.0	Kassel	J. Bürgi	Zinner (1979)		
1613	0	2.0	Nuremberg	L. Miller	Wagner (1997), Gouk (1988)	1684	
1613	0	5.0	Nuremberg	L. Miller	Wagner (1997), Lloyd (1992)	7459	
1614	0	6.5	Nuremberg	H. Tucher	Wagner (1997)	H 5820	
1616	0	7.0	Nuremberg	L. Miller	Wagner (1997), Lloyd (1992)	7565	
1619	0	0.0	Nuremberg	G. Karner	Wagner (1997), Zinner (1979)		
1620	0	4.0	Nuremberg	C. Karner	Wagner (1997), Lloyd (1992)	7542	
1620	0	5.5	Nuremberg	C. Trechsler	Wagner (1997) , Syndram (1989)	N. 37	
1622	0	5.0	Nuremberg	C. Karner	Wagner (1997), Lloyd (1992)	7552	
1624	0	7.0	Nuremberg	H. Tucher	Wagner (1997), Zinner (1979)		
1625	0	6.0	Nuremberg	L. Miller	Wagner (1997)		
1625	0	6.0	Nuremberg	L. Miller	Wagner (1997), Zinner (1979)		
1626	0	5.0	Nuremberg	H. Troschel	Wagner (1997), Lloyd (1992)	7458	
1626	0	7.0	Nuremberg	C. Karner	Hamel (2000), Zinner (1979), Gouk (1988)		
1626	0	10.0	Nuremberg	H. Troschel	Hamel (2000), Zinner (1979), Gouk (1988)		
1626	0	22.0	changed	C. Karner	Hamel (2000), Zinner (1979), Gouk (1988)		
1629	0	4.0	Nuremberg	L. Miller	Wagner (1997), Lloyd (1992)	7560	
1630	0	3.0	Nuremberg	C. Karner	Wagner (1997), Lloyd (1992)	7553	
1630	0	4.0	Nuremberg	C. Karner	Wagner (1997), Lloyd (1992)	7554	
1630	0	7.0	Nuremberg	L. Miller	Wagner (1997), Lloyd (1992)	7567	
1634	0	6.0	Augsburg	L. Miller	Wagner (1997), Körber (1964)	5	
1636	0	4.0	Nuremberg	J. Karner	Wagner (1997), Lloyd (1992)	7550	
1636	0	4.0	Nuremberg	L. Miller	Wagner (1997), Syndram (1989)	N. 19	
1636	0	5.0	Nuremberg	L. Miller	Wagner (1997), Lloyd (1992)	7568	
1637	0	8.0	Nuremberg	L. Miller	Hamel (2000), Gouk (1988), Zinner (1979)		
1637	0	12.0	changed	L. Miller	Hamel (2000), Gouk (1988), Zinner (1979)		

Given Age												about 1650	ca. 17^{th} cent.	ca. 17^{th} cent.						approx. after 1670			1690-1700			about 1700	about 1700	about 1700	about 1700					beg. $18^t h$ cent.	early 18^{th} cent.	beg. $18^t h$ cent.	early 18^{th} cent.	about 1720	about 1720	\sim 1st half 18 th cent.	$1st$ half 18^{th} cent.	$1 st$ half 18^{th} cent.	2^{nd} quarter 18^{th} cent.			about 1750	41.
Ref. No.		634	1684	7562	1683		7563	184	1770	N. 21	1686	MAT B 81	7	compass	69503	7540		1880-36		11	MATB23		MAT 1997-6	26	7525	MAT B 25	MAT	MAT B 62	MAT B 62	DI 80	DI 64	DI 88	6625		Nr. 38	MAT A 27	Nr. 37	MAT B 49	DI 94	MAT B 21	MAT B 26	MAT B 78	Nr. 25	MATB59	MATB84	MAT B 61	
Reference		Wagner (1997), Gouk (1988)	Wagner (1997), Gouk (1988)	Wagner (1997), Lloyd (1992)	Wagner (1997), Gouk (1988)	Wagner (1997)	Wagner (1997), Lloyd (1992)	Wagner (1997), Gouk (1988)	Wagner (1997), Lloyd (1992)	Wagner (1997), Syndram (1989)	Wagner (1997), Gouk (1988)	Hamel (2000)	Körber (1964)	Körber (1964)	Wagner (1997), D.M.Mnchen	Wagner (1997), Lloyd (1992)	Wagner (1997), Zinner (1979)	Zinner (1979)	Wagner (1997), Zinner (1979)	Körber (1964)	Hamel (2000), Zinner (1979)	Wagner (1997)	Hamel (2000), Zinner (1979)	Wagner (1997), Körber (1964)	Wagner (1997), Lloyd (1992)	Hamel (2000) , Zinner (1979)	Hamel (2000), Zinner (1979)	Hamel (2000), Zinner (1979)	Hamel (2000), Zinner (1979)	Körber (1964)	Körber (1964)	Körber (1964)	Zinner (1979)	Glasemann (1999)	Glasemann (1999)	Hamel (2000), Hausmann	Glasemann (1999)	Hamel (2000) , Zinner (1979)	Körber (1964)	Hamel (2000)	72)	Hamel (2000), Gouk (1988), Zinner (1979)	Glasemann (1999)	Hamel (2000) , Zinner (1979)	Hamel (2000) , Zinner (1979)	Hamel (2000)	
Manufacturer		J. Karner	L. Miller	L. Miller	L. Miller	L. Hartmann	L. Miller	L. Miller	N. Miller	N. Miller	N. Miller	unknown	unknown	unknown	L. Miller	A. Karner	N. Miller	J. Koch	unknown	J. Martin	J.W. Schulze	M. Karner	S. Krigner	Richardus	G. Karner	J. Martin	J. Martin	J. Martin	J. Martin	(Krigner)	Höldrich	unknown	A. Braunmüller	J. Willebrand	unknown	H.G. Wellingen	unknown	J. Willebrand	J. Willebrand	unknown	unknown	L.A. Karner	unknown	L.T. Müller	L.T. Müller	unknown	
Location		Nuremberg	Nuremberg	Nuremberg	Nuremberg	South Ger.	Nuremberg	Nuremberg	Nuremberg	Nuremberg	Nuremberg	unknown	unknown	unknown	Nuremberg	Nuremberg	Nuremberg	unknown	Nuremberg	Augsburg	(Kassel)	Nuremberg	Cologne	unknown	Nuremberg	Augsburg	Augsburg	Augsburg	changed	unknown	Augsburg	unknown	Augsburg	Augsburg	German	unknown	German	Augsburg	Augsburg	unknown	(Hessen)	Nuremberg	unknown	Augsburg	$\operatorname{Augsburg}$	unknown	
D (Jor)	(deg.)	2.0	0.0	4.0	5.0	2.0	1.0	0.0	3.0	3.5	-5.0	-28.0	-10.0	-11.0	0.0	5.0	0.0	-17.0	-7.0	-22.0	-17.0	-5.5	-17.0	-11.0	-5.0	-7.0	-7.0	-7.5	-15.0	-21.0	-11.0	-13.0	-13.0	-10.0	-15.0	-15.0	-17.0	-5.0	-9.0	-9.0	-12.0	-20.0	-17.0	-14.0	-17.0	-15.0	1
ΔT		0	0	0	0	0	0	0	0	0	0	ъ	50	50	0	0	0	13	0	10	0	0	ъ	0	0	ю	5 C	5 C	5 C	5	50	50	50	10	10	10	10	ъ	10	25	25	25	12	0	0	ю	
Year		1639	1640	1640	1640	1642	1644	1646	1649	1649	1649	1650	1650	1650	1652	1652	1661	1666	1673	1680	1689	1694	1695	1699	1700	1700	1700	1700	1700	1700	1750	1750	1750	1710	1710	1710	1710	1720	1720	1725	1725	1725	1737	1750	1750	1750	()

Given Age	. 111 1040	middle 18^{ii} cent.	about 18 ⁴⁴ cent.	$18^{\prime\prime\prime}$ cent.	about 18^{th} cent.	18^{th} cent.	about 18^{th} cent.	about 18^{th} cent.	about 18^{th} cent.				about 1760	ca. 1760	about 1760	about 1760	about 1760		about 1775	2^{nd} half 18^{th} cent.	1775-1780	last third 18^{th} cent.	last quarter 18^{th} cent.	end 18^{th} cent.	end 18^{th} cent.	end 18^{th} cent.	late 18^{th} cent.	end 18^{th} cent.	end 18^{th} cent.	ca. after 1790	ca. after 1790		about 1800	about 1800	about 1800	about 1800	about 1800	about 1800	about 1800	about 1800	about $18/19^{th}$ cent.	$18/19^{th}$ cent.	$18/19^{th}$ cent.			
Ref. No.	11 11 HO	H-W 70	19 	MAT B 32	49 compass	MAT B 87	12	17	23	compass		22		Nr. 32	DI 94	DI 7	DI 96	80/239	DI 89	Nr. 30	Nr. 33	Nr. 41	Nr. 40	MAT B 93	M-H	Nr. 35	MAT B 63	MAT B 110	MAT B 67	Nr. 81	MAT B 113	MAT B 68		DI 91	DI 95	MAT B 3	MAT B 6	MAT B 65	MAT B 71	MAT B 69	MAT B 70	MAT B 88	MAT B 66	24	DI 85	DI 86
Reference	G 1 (1000)	Syndram (1989)	Korber (1964)	Hamel (2000)	Körber (1964)	Hamel (2000), Zinner (1979)	Körber (1964)	Körber (1964)	Körber (1964)	Körber (1964)	Wagner (1997)	Wagner (1997) ,	Wagner (1997), Körber (1964)	Glasemann (1999) Körber (1964)	Kleinschmidt (1989), Körber (1964)	Kleinschmidt (1989), Körber (1964)	Kleinschmidt (1989), Körber (1964)	Wagner (1997), D.M.Mnchen	Kleinschmidt (1989), Körber (1964)	Glasemann (1999)	Glasemann (1999)	Glasemann (1999)	Glasemann (1999)	Hamel (2000) , Zinner (1979)	Syndram (1989)	Glasemann (1999)	Hamel (2000), Zinner (1979)	Hamel (2000), Zinner (1979)	Hamel (2000), Zinner (1979)	Glasemann (1999)	Hamel (2000), Zinner (1979)	Hamel (2000), Zinner (1979)	Kleinschmidt (1989), Körber (1964)	Kleinschmidt (1989), Körber (1964)	Wagner (1997), Körber (1964)	Hamel (2000)	Hamel (2000)	Hamel (2000)	Hamel (2000)	Hamel (2000)	Hamel (2000), Zinner (1979)	Hamel (2000), Zinner (1979)	Hamel (2000) , Zinner (1979)	Körber (1964)	Körber (1964)	Körber (1964)
Manufacturer		J.F. Bihler	ĽĽ,	unknown	unknown	A. Vogler	Pfersich	unknown	"Х"	Vineron	L.A. Karner	A.F.	L.T. Miller	L.T. Mller	D. Beringer	J.G. Zimmer	J.G. Vogler	unknown	L. Grassl	A. Vogler	L. Grassl	unknown	unknown	D. Beringer	unknown	K.C. Keller	J.N. Hölderich	D. Beringer	D. Beringer	J.B. Bauer	P.P. Beringer	P.P. Beringer	J. Schretteger	J. Schretteger	I.C.R.	unknown	unknown	unknown	unknown	unknown	unknown	E. Schmaldt	Stockkert	unknown	unknown	unknown
Location	-	Augsburg	unknown	unknown	unknown	Augsburg	unknown	unknown	unknown	Lüttich	Nuremberg	unknown	Augsburg	Augsburg	Nuremberg	Reinharz	Augsburg	unknown	Augsburg	Augsburg	Augsburg	German	German	Nuremberg	German	Ansbach	Augsburg	Nuremberg	Nuremberg	Nuremberg	Nuremberg	Nuremberg	Augsburg	Augsburg	unknown	unknown	unknown	unknown	unknown	unknown	unknown	Cologne	Fürth	unknown	unknown	unknown
D (dow)	(1020)	-12.0	-5.0	-10.0	-15.0	-17.0	-19.0	-20.0	-22.0	5.0	-22.0	-22.0	-15.0	-15.0	-15.0	-15.0	-20.0	-17.0	-16.0	-13.0	-15.0	-15.0	-20.0	-17.0	-18.0	-17.0	-17.0	-20.0	-20.0	-20.0	-20.0	-20.0	-20.0	-22.0	-15.0	-7.0	-7.0	-17.0	-20.0	-22.0	-22.0	-7.0	-20.0	-11.0	-12.0	-13.0
ΔT	¢,	10 1	50 1	50	50	50	50	50	50	0	0	0	ъ	5	5 L	ъ	ъ	0	5 L	25	25	25	25	2	15	12	10	10	10	10	10	10	ъ	ъ	0	ъ	ъ	ъ	ъ	ъ	ъ	10	10	50	50	50
Year		175U	1750	1750	1750	1750	1750	1750	1750	1751	1752	1758	1760	1760	1760	1760	1760	1769	1775	1775	1775	1775	1775	1777	1780	1787	1790	1790	1790	1790	1790	1790	1795	1795	1798	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800

Given Age	begin. 19^{th} cent. about 1820 middle 19^{th} cent. 19^{th} cent. about 19^{th} cent. 19^{th} cent.	
Ref. No.	MAT B 14 DI 82 Nr. 35 MAT B 16 25 DI 77	
Reference	Hamel (2000) Kleinschmidt (1989), Körber (1964) Glasemann (1999) Hamel (2000) Körber (1964) Körber (1965)	
Manufacturer	unknown unknown unknown unknown unknown unknown	
Location	unknown unknown German unknown unknown unknown	
$_{\rm (deg.)}^{\rm D}$	-14.0 -18.0 -20.0 -7.0 -22.0 -10.0	
ΔT	10 10 50 50	
Year	1810 1820 1850 1850 1850 1850	

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B. Declination from maps 427

Differing declination estimates by different authors are given in one line of the table. 428 All values with references Bachmann (1941, 1942, 1961) are the values taken from these 429 reproductions of the original maps by us. 430

D (deg.)	Location	Reference
11	Zürich	Körber (1965)
6 / 11 / 8	Nuremberg	Körber (1965) / Kleinschmidt (1989) / Bachmann (1942)
6	Munich	Wagner (1997)
11 / 10 / 12	Bamberg	Körber (1965) / Kleinschmidt (1989) / Bachmann (1942)
16	Konstanz	Kleinschmidt (1989) (Bodenseekarte by J.G. Tibian)
8 / 11 / 11	Munich	Körber (1965) / Kleinschmidt (1989) / Bachmann (1942)
6 / 9	Landshut	Körber (1965) / Bachmann (1942)
25	Thierhaupten	Kleinschmidt (1989), Bachmann (1942)
-25	Donauwörth	Kleinschmidt (1989), Bachmann (1942)
13.5	Bunde	Kleinschmidt (1989) (map by J. Sems)
22 / 29 / 22	Bamberg	Körber (1965) / Kleinschmidt (1989) / Bachmann (1942)
-29 / -21	Wolfegg	Kleinschmidt (1989) / Bachmann (1961)
10	Leutkirchen	Kleinschmidt (1989), Bachmann (1961)
26	Giengen	Kleinschmidt (1989), Bachmann (1961)
11	Minden	Körber (1965), Bachmann (1941)
	D (deg.) 11 6 / 11 / 8 6 11 / 10 / 12 16 8 / 11 / 11 6 / 9 25 -25 13.5 22 / 29 / 22 -29 / -21 10 26 11	D (deg.) Location 11 Zürich 6 / 11 / 8 Nuremberg 6 Munich 11 / 10 / 12 Bamberg 16 Konstanz 8 / 11 / 11 Munich 6 / 9 Landshut 25 Thierhaupten -25 Donauwörth 13.5 Bunde 22 / 29 / 22 Bamberg -29 / -21 Wolfegg 10 Leutkirchen 26 Giengen 11 Minden

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