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Discussions

Historical geomagnetic observations from Prague Observatory (since 1839) and their contribution to geomagnetic research

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Abstract. Shortly after the introduction of the physical unit for the magnetic field in 1832 and the invention of the bifilar apparatus in 1837, both being extraordinary scientific achievements that took place in Göttingen, the Clementinum observatory in Prague became one of the first places where systematic observations of the geomagnetic field began. Karl Kreil was decisively responsible for this. In this paper, we focus on the very beginnings of geomagnetic observations in Prague, dating from the middle of 1839. We describe what archival materials with data exist from that time, how the main instrument for observing magnetic storms – the bifilar magnetometer – worked, how this instrument was calibrated, and we also describe the first magnetic survey in Bohemia. This study indicates the importance of historical geomagnetic observation materials to modern science, such as the space weather research.

1 Beginnings of the geomagnetic observations in Prague – the merit of Karl Kreil

Prague Astronomical Observatory was established at Jesuits Clementinum College (close to Prague Charles Bridge) in 1751. After the dissolution of the Jesuit Order, the college together with the observatory got completely into the state administration of Austria. The observatory director was thus appointed by the Emperor Office. Despite the official name of the observatory, astronomy was not the only subject of its activities and, in most cases, was not even the main subject of observers' interest. Meteorological observations at Clementinum started already in 1752. Uninterrupted series of meteorological observations dates back to 1775 and belongs to the longest climatological time series worldwide. In the 1780s and 1790s the observatory participated in the *Societas Meteorologica Palatina* (the Mannheim Meteorological Society) that coordinated, conducted and published weather observations of 39 predominantly European observatories. In that time, the Clementinum observatory did not publish its own yearbooks. The results of the meteorological observations were presented in various periodicals of scientific societies. Magnetic or aurora observations were included sporadically.

Regular magnetic observations were initiated by Karl Kreil in 1839. Kreil came to the Prague observatory from Milan in 1838. During his stay in Milan, he was visited by Gau[illegible]sistants and got excited by the quickly developing geomagnetism research. He introduced magnetic observations in Milan and became a member of the Göttingen Magnetic Union – the network of magnetic stations around the globe established by Gauss and Weber, having been slightly influenced by Humboldt (Glass-

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

meier, 2007; Wittmann, 2020). The preserved correspondence between Kreil and Gauss contains 31 letters, not counting those which contain only tables of results without significant accompanying text (Reich and Roussanova, 2018).

After Kreil was informed about his transfer to Prague, he took care of the acquisition of magnetic instruments for his new place of work. His goal was to make magnetic and weather observations as often as possible. As the budget of the observatory was quite limited, he tried to recruit volunteers. Kreil wrote: “As soon as I learned about my move to Prague, I tried to obtain instruments similar to those I used in Milan. Given the lively interest for science which was in Prague, I was hopeful of finding ready co-workers, because only using joint forces one can unearth secrets which are so tenaciously hidden by nature. And my hopes were answered. While instruments were unpacked, several young volunteers applied and offered assistance, so I was able to start regular observations shortly after my arrival. More observers applied during the first month of operation, and thanks to their eagerness and diligence in acquiring new skills I could extend the set of hourly magnetic and meteorological observations to period from 5 a.m. to 11 p.m., observation period which was before only wishful thinking” (Kreil, 1840). In a short time, Kreil managed to put together a group of six co-workers. The most important of them was Karl Fritsch, who, although a meteorologist by profession, also took part in magnetic observations. In spite of six volunteers, it became soon clear that the initially launched 19 observations a day were not sustainable in the long run and the number of observations was stabilised at 10 per day. Besides of regular observation, there were also two specific categories of measurements carried out in the first decade: (1) Observations of magnetic storms initiated when the observer noticed rapid changes in declination or horizontal intensity. (2) Term-day observations organised in the frame of the Göttingen Magnetic Union that continued even after the Union formally ceased its activities. The observations took place one day a month and were carried out with a frequency of 5 min.

Simultaneously with the beginning of the observations in July 1839, Kreil started publishing yearbooks entitled “Magnetische und meteorologische Beobachtungen zu Prag” (hereafter referred to as *Beobachtungen*) thanks to which all magnetic and meteorological data were preserved. The title was changed to “Magnetische und meteorologische Beobachtungen auf der k. k. Sternwarte zu Prag” in 1868. The scans of all 78 volumes of the *Beobachtungen* are accessible at https://www.ig.cas.cz/en/prague-observatory-yearbooks/. Between 1842 and 1845, Kreil also compiled four volumes of yearbook “Astronomisch-meteorologisches Jahrbuch für Prag”.

Kreil joined the Prague Observatory as an assistant and later, in 1845, was appointed director of the observatory. He soon became a respected scientific personality in Prague. Since 1841, he was a member of the Royal Bohemian Society of Sciences, and in 1848 its Director. At the same time, he was asked by the Imperial Academy of Sciences in Vienna to draw up a proposal for a meteorological observation system for Austria. Subsequently, in 1850, he was called up to Vienna to establish the Central Institute for Meteorology and Earth Magnetism and became its first director. Along with him, Karl Fritsch also went to Vienna. He later became the vice-director of the Central Institute and was also a co-founder of the Austrian Meteorological Society.

Despite the departure of two leading personalities, neither the activities of the observatory nor the publication of *Beobachtungen* were disrupted. Tables of daily observations were published in instrumental units until 1871, and in physical units from 1872 onwards. Due to increasing urban noise, the magnetic observations were reduced to declination in 1905. The last volume of the *Beobachtungen* series, the 78th in a row, contains the data of 1917. Volumes 79 to 81 covering the years 1918

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

to 1920 were published as bilingual Czech-French. The observations continued smoothly and the data set is complete even during the turbulent period of the end of the First World War and the establishment of Czechoslovakia. These last three volumes were published by the State Meteorological Institute, established in 1919 (SMI, 1923). Since 1921, this Institute has included the publication of Clementinum meteorological data in its yearbooks. In 1920, the State Institute of Geophysics (SIG) was established under the auspices of Faculty of Science of the Charles University. The observations of declination continued at Clementinum until 1926. Clementinum thus belongs to the few observatories that span the period from the 1840s to the beginning of the 20th century. The monthly and yearly means of declination were published in the SIG yearbook (SIG, 1927).

This paper is focused on documenting the beginnings of geomagnetic observations at Clementinum, which are associated with the merits of Karl Kreil. In particular, we deal with the methodology, the observed data structure and the form of their presentation in the early yearbooks of Beobachtungen (Kreil, 1841, 1842). Furthermore, we also analyse some aspects of the so-called bifilar magnetometer, which was a common variation observational device at the time, and describe a procedure of its calibration. We mention the first strong magnetic storm observed at Clementinum in 1839. We also report on the beginnings of the magnetic survey in Bohemia. More detailed information concerning the whole time span of geomagnetic observations at Clementinum can be found in Hejda et al. (2021a). The historical records of strong magnetic disturbances and term-day observations at Clementinum are discussed in Hejda et al. (2022) and comprehensive online databases are provided by Hejda et al. (2021b) at https://doi.org/10.1594/PANGAEA.936921.

2 Organisation of geomagnetic observations and their records in printed yearbooks

Based on the collection of printed yearbooks, *Beobachtungen*, whose first volumes were compiled by Karl Kreil, we focus on tracing the early years of geomagnetic observations in Prague. The observation of geomagnetic elements at Clementinum built on Kreil's experience acquired during his previous tenure at the observatory in Milan. In Prague, however, Kreil and his co-workers were successful in obtaining longer time series without interruption, mainly for the variations of inclination (Kreil, 1841, p. 1). Furthermore, the observations of individual geomagnetic elements were made here with more frequent daily repetitions of measurements. Along with collecting the geomagnetic data, also regular meteorological observations were performed. Kreil was aware of the complexity of the issue and hypothesised about the possible interconnection of geomagnetic and meteorological phenomena. Related to this idea was the sophistication of methodology used and consistency in performing and recording various types of observations.

For the current analysis of historical geomagnetic records it is important that together with the observational results in *Beobachtungen*, there are detailed comments on measurement procedures and description of measuring instruments. In the individual volumes of *Beobachtungen*, it is possible to follow how the observation technique gradually developed and improved over the years.

As in modern observatory practice, the early observations consisted of the absolute measurements and the recordings of geomagnetic field variations. As mentioned above, in addition to the regular observations carried out several times each day,

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

there were also the observations of disturbances in the case of unusually rapid changes in the magnetic field and finally the term-day observations. The main sections of *Beobachtungen* are in accordance with such a structure of observed data.

The absolute observations were performed in the open space of the Imperial Garden within the Castle District (aka *Hradschin* or *Hradčany*), where it was possible to avoid disturbing influences. The first *Beobachtungen* records of absolute observations of magnetic elements date to the end of August and the beginning of September 1840. The magnetic rods used were of the same shape and size as at the Göttingen Observatory. When measuring the inclination, several needles with the same weight and dimensions but differing by magnetisation were used. Kreil commented on various kinds of disturbing influences (temperature changes, humidity, air flow) as sources of random errors that can be eliminated by performing a sufficiently large number of measurements. There is a detailed description of the construction, geometry and settings of mechanical measuring instruments. The procedure for carrying out absolute measurements follows that used at the Milan observatory.

Variation magnetic measurements were performed at the College building of Clementinum. When establishing the observatory, there was an effort to eliminate disturbing influences as much as possible, and the installation location and the relative position of the devices also relied on this. The devices were arranged so that one observer could perform measurements of all magnetic elements at an interval of about $2\ \mathrm{min}$. In the first few years, the observers were probably aware of the existence of the effect of temperature changes on the magnetisation of the rods (magnetic needles), although the very first yearbooks did not report the temperature correction. This issue concerns the measurements of the variations of the horizontal intensity with a bifilar instrument (see the next section for some details on this device). The temperature correction coefficients for the first bifilar instrument in Prague, which was in operation until 1845, were calculated retrospectively only later. A brief description of the instruments, an overview of the measurement procedure and a discussion of the temperature corrections for the bifilar device are given in the paper by Hejda et al. (2021a).

Kreil points out the importance of performing variation measurements for magnetic and meteorological phenomena, as far as possible, with a time step $1\ \mathrm{h}$. Declination, horizontal intensity, inclination and the period of oscillation of the inclination needle were recorded in variational magnetic observations and presented in *Beobachtungen* in table forms. As pointed out, the variability of individual magnetic elements over time is different. This was taken into account in the observation time schedule. The first two elements, i.e. declination and horizontal intensity, often change quite significantly from minute to minute, and therefore their observations were always made in the same second. In case of inclination, the changes are less pronounced, and therefore it was enough to make the observation at the same minute. The variability of the inclination needle oscillation period over time, from which it was possible to infer changes in the total field, was considered even smaller and therefore required less precise observation times.

Detailed records of the variational magnetic observations are provided in the yearbooks under heading “Register der Variations Beobachtungen”. The hourly values of magnetic elements in original scale units are given here in tabular form for each day.

Furthermore, under heading “Resultate der Variations Beobachtungen” an overview of the processed and modified data is provided together with their recalculation from scaled units to degrees. The tables show the monthly averages of the hourly

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

values of measured data. Kreil tried to investigate how the declination changes during the year depended on particular seasons and also admitted the possibility of the Moon phases influence.

The remaining important parts of the yearbooks were organised as follows. Information on absolute measurements used to be placed in the introductory pages of individual volumes. Magnetic storms were either recorded within sections on regular observations, or separate sections were devoted to them. The term-day observations were typically reported in the section entitled "Magnetische Termins-Beobachtungen".

3 The first bifilar magnetometer in Prague

In 1832, Carl Friedrich Gauss developed the first method for measuring the magnetic field (Gauss, 1832), which is nowadays known as the Gauss's absolute method (e.g., Van Baak, 2003). Contemporary physicists are still familiar with this method because, simultaneously with introducing it, Gauss also established his physical unit to express the intensity of the magnetic field by means of a system of three basic units: millimetre, milligram and second (Garland, 1979).

Subsequently, in 1837, Gauss presented another method that he developed for monitoring changes in the horizontal intensity of the geomagnetic field (Gauss, 1838; Garland, 1979). The new method was important for the study of geomagnetic activity as the horizontal intensity has proved to be the key quantity for observing magnetic storms. For instance, the modern, widely used disturbance storm time (Dst) index is determined from observations of the horizontal intensity (e.g., Mayaud, 1980). The instrument used in this new method was called a bifilar magnetometer, or simply a bifilar. Unlike Gauss's absolute method, the bifilar is a little-known device today. Therefore, here we shortly introduce the principle of operation of this device.

The basic part of the bifilar is a magnetised rod (or "needle") hanging on a pair of long fibres which run close together and keep the needle in a horizontal plane (Fig. 1). By rotating the swivel mount from which the fibres hang, it is possible to achieve that the torsion of the pair of fibres brings the needle into a position perpendicular to the magnetic meridian. Let us imagine that the initial position of the needle and fibres was such that the needle pointed with its north end to the magnetic south (i.e. towards the magnetic pole in the Northern Hemisphere) and its south end pointed to the magnetic north (i.e. towards the magnetic pole in the Southern Hemisphere). Let us also assume that the fibres were in such a position that their torque acting on the needle was zero. Then it was necessary to have turned the swivel mount more than a right angle to bring the needle in a perpendicular direction; it was necessary to have turned the console by an angle of $90° + \Theta$ (Fig. 2). In this position, the mount was locked and the instrument was thus prepared to observe relative changes in the horizontal intensity of the geomagnetic field, that means the ratio dB_H/B_H.

When there was a change in horizontal intensity, the needle changed its direction slightly; in the horizontal plane, a deviation by a small angle $d\varphi$ could be observed (Fig. 3). There is a direct proportion between the relative change in horizontal intensity and the angle $d\varphi$ (Garland, 1979):

$$\frac{dB_H}{B_H} = \cot(\Theta)\, d\varphi . \quad (1)$$

The direct proportionality described above is actually the main idea on which the bifilar device operates. To observe these small angular changes, a scale was placed at a certain distance from the instrument (typically several metres), which the

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

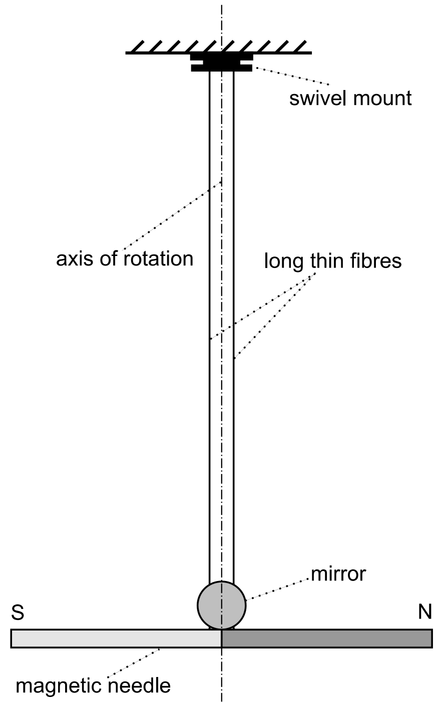

Figure 1. Simplified sketch of a bifilar device (side view).

observer observed in a reticle telescope in a mirror mounted on a needle. Equation (1) can thus be rewritten into the form

$$\frac{dB_H}{B_H} = k\,dn\,, \tag{2}$$

where k is a constant and dn is the number of divisions of the scale. The proportionality constant $\cot(\Theta)$, and from it also the constant k, can be determined by the procedure which we describe later.

In 1839, just two years after Gauss's invention of the bifilar magnetometer, Karl Kreil also installed such a device at the Clementinum Observatory in Prague. In the first volume of *Beobachtungen* (Kreil, 1841), which reported on geomagnetic observations, some interesting data about this apparatus can be found. Magnetized rod – huge magnetic needle – weighed $m = 2780$ g. The fibres on which it hung were so long that, to install the device, the ceiling of the room had to be cut through, and the device hanged on the roof beams; the suspending had a length $h = 4.8$ m.

The first adjustment of the instrument was carried out on 31 May 1839. By the adjustment, it was determined what change in the horizontal intensity corresponds to the change by one division on the scale. The procedure used by the observers is remarkable in that no further (or so-called absolute) measurements were necessary to determine the scale value. Because we have not come across a description of this procedure anywhere in modern literature, we devote a few paragraphs to it.

We reconstructed the procedure for obtaining the scale value (Kreil, 1841, p. 23) as follows: In the first step, the mount of the hanging was rotated so that the northern magnetic end of the needle pointed to the magnetic south (i.e. towards the magnetic

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

History of Geo- and Space Sciences
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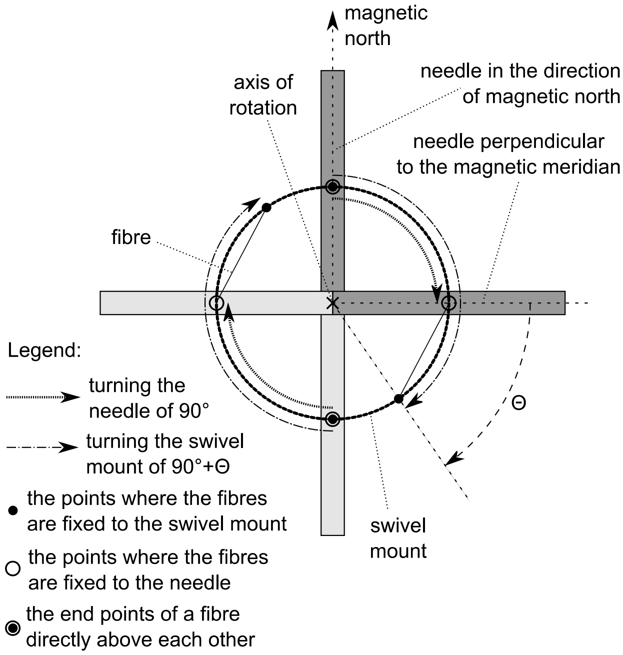

Figure 2. Setting the bifilar device to the working position (top view). First, the north end of the magnetic needle points to magnetic north. The fibres on which the needle hangs do not exert any torque on the needle. (If the distance between the fibres is the same throughout the height of the device, the fibres are exactly vertical.) Then the swivel mount is rotated until the magnetic needle gets to the perpendicular direction. In this position, the swivel mount is fixed and the instrument is ready to observe changes in the magnetic field.

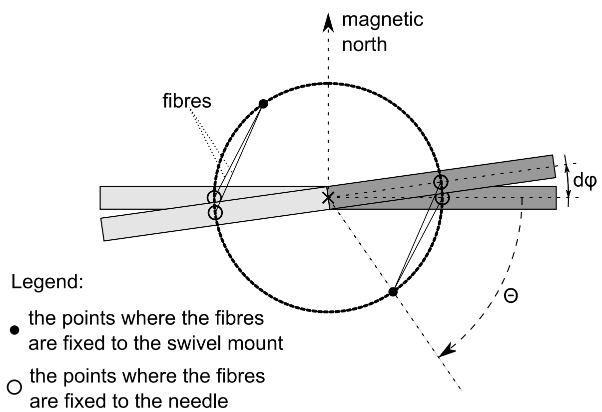

Figure 3. Changing the position of the needle by a small angle $d\varphi$ when the geomagnetic field increases (viewing from above). Otherwise, if the magnetic field weakens, the deflection $d\varphi$ is in the opposite direction.

pole in the Northern Hemisphere), the longitudinal axis of the needle still lying in the horizontal plane. In this position, the torque of the pair of fibres was zero. The needle was then slightly deviated from this balanced direction by the observer and

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

released (the longitudinal axis remaining in the horizontal plane). The released needle was heading to its original position by the sum of two torques: from the pair of fibres and from the horizontal intensity. The result was an oscillating movement, the period of which was

$$T_1 = 2\pi\sqrt{\frac{J}{\gamma + MB_H}} = 2\pi\sqrt{\frac{J}{\gamma\,(1+\sin(\Theta))}}\,, \tag{3}$$

where we used the equation for the balance of the torques that would apply in the position of the needle perpendicular to the magnetic meridian

$$MB_H = \gamma\,\sin(\Theta)\,. \tag{4}$$

The new quantities in Eqs. (3) and (4) are as follows: J is the moment of inertia of the needle with respect to the axis of rotation, M is the magnetic moment of the needle and γ represents the torque coefficient for the pair of fibres, which according to (Garland, 1979) can be expressed as

$$\gamma = mg\frac{ab}{h}\,, \tag{5}$$

where a and b mean the distance of the fibres from each other at the top and bottom of the hanging, respectively, and g is the gravity of the Earth (a net acceleration from the gravitation and centrifugal forces). Kreil measured the period $T_1 = 24.03$ s.

In the second step, the observers repeated the measurement in the inverted position; both the mount of the hanging and the needle were rotated 180°. In such a position, the torsion of the fibres is zero, but with a small deviation from this position, the torque from the pair of fibres is greater than the torque from the horizontal intensity. Therefore, even in this case, there is an oscillating movement of the needle. However, in Eq. (3) the sum of $\gamma + MB_H$ must be replaced by the difference $\gamma - MB_H$. Thus, we get the period of the oscillations in the inverted position

$$T_2 = 2\pi\sqrt{\frac{J}{\gamma - MB_H}} = 2\pi\sqrt{\frac{J}{\gamma\,(1-\sin(\Theta))}}\,. \tag{6}$$

Kreil measured the period $T_2 = 88.15$ s.

If we exclude the ratio J/γ from the pair of Eqs. (3) and (6), we get a useful relation

$$\Theta = \arcsin\frac{T_2^2 - T_1^2}{T_2^2 + T_1^2} = 59.503°, \tag{7}$$

by means of which we can express the coefficient of proportionality in Eq. (1). We thus obtain the following relation:

$$\frac{dB_H}{B_H} = 0.58897\,d\varphi\,. \tag{8}$$

From simple geometric considerations and from the known distance between the mirror and the scale, Kreil determined the constant k in Eq. (1); he found that one scale interval corresponded to an angular deviation $18{,}5757''$. This corresponds to a relative change in horizontal intensity $\frac{1}{18855}$.

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

By the way, from the above-mentioned value of $18,5757''$ and the distance of the mirror from the scale (the value was $5.552\ \mathrm{m}$) we can easily find out a detail about the device, namely that the distances between the marks on the scale were half a millimetre.

However, there was also one minor problem, which slightly complicated the operation of this undeniably elegant and straightforwardly simple apparatus. It proved necessary to take into account that the magnetisation of the needle was not constant. This problem is also known with much more modern magnetometers that use a magnetised needle, such as the QHM (Wienert, 1970), which was a common device until the 1990s. The magnetisation of a permanent magnet can change (decrease or grow) with a change in temperature, or it can lessen when the magnet is hit during an inattentive manipulation or accident, when the ferromagnetic material in some magnetic domains changes from an ordered to a random orientation.

Karl Kreil was aware of the problem of declining magnetic strength of the needle. On 1 August 1840, i.e. more than a year after the first set up of the bifilar at Clementinum, the fibre tore during handling of the device. This happened in the middle of the calibration measurements, by which Kreil wanted to determine the current value of the scale value and compare it with the value found in May 1839.

Using incomplete data from the interrupted measurements, Kreil managed to estimate that at the time before fibre rupture the scale value was $\frac{1}{17230}$. In our opinion, we must admit a certain inaccuracy in this provisional value, because in addition to the incomplete data on which Kreil relied, two other factors may have contributed to the inaccuracy: (1) the difference in room temperatures when performing calibration measurements in 1839 and 1840, (2) the change in the magnetisation of the needle by impact when the needle fell down during the accident.

Let us take a closer look at the temperature in the room during the measurements. For 1 August 1840, the source (Kreil, 1842, p. XI) gives four room temperature values: 17.3 °R; 17.3 °R; 17.0 °R; 17.2 °R (i.e. 21.6 °C; 21.6 °C; 21.2 °C; 21.5 °C – the average of these values being 21.5 °C). However, to our knowledge, the room temperature for 31 May 1839 was not recorded anywhere. We must therefore get an idea of the temperature conditions in the measuring room on the basis of the outdoor temperatures, which are available. The assumption that the room was located in the building of the Clementinum astronomical observatory with relatively massive walls must be taken into account.

In the spring and early summer, the inner walls of the unheated room were still warming up. On the contrary, the walls were already warmed up before the beginning of August. We can get some idea of the indoor temperatures on the base of data on outdoor temperatures recorded by the Clementinum observatory. Such data are available in the database that is accessible on the website of the Czech Hydrometeorological Institute (https://www.chmi.cz/historicka-data/pocasi/praha-klementinum#).

Checking the above-mentioned database one can see that the outdoor daily mean temperature during the May calibration measurement in 1839 was two degrees higher than during the calibration measurement in August 1840. Namely, the temperatures were 18.1 °C and 16.0 °C, respectively. However, this might be misleading information. As the measurements were probably performed during the day, and we believe that most likely during the morning, the outdoor temperature on the day of the measurement itself is not very important; the current outdoor temperature did not have time to significantly influence the temperature of the inner building walls. Actually, in the days preceding the measurement days, the temperatures in 1839 were much lower than in 1840. Going back from 1 to 30 days before the days of the calibrations, the averages of the outdoor

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

daily mean temperatures were 1 °C to 5 °C higher for 1840 than for 1839. It is therefore reasonable to assume that during the calibration measurements in 1840 the room air was warmer than during the measurements in 1839. Even if the magnetisation of the needle were not weakened by the gradual decrease of the magnetic force, the magnetisation would be weaker in the measurements of 1 August 1840 due to the temperature difference itself.

Kreil (1841, p. 24) mentioned that “[when the thread tore and the needle fell] the box to which the mirror measure was screwed ruptured”. With such a blow, the magnetised rod could lose some of its magnetisation. From the calibration measurements of 1 August 1840 thus Kreil perhaps found considerably less magnetisation compared to the one the needle had before the tore of the fibre.

Despite these considerations about the possible inaccuracy of Kreil’s determination of the decrease in magnetic force in the needle, it is nevertheless reasonable to assume that from May 1839 to the end of July 1840, the magnetisation of the needle really weakened; whether this has happened only slowly and gradually, or even some sudden changes have occurred, cannot be said with certainty.

For a new, stronger fibre, Kreil then determined a scale value equal to $\frac{1}{17770}$ of the total horizontal intensity. Rounded to two significant digits, the average between $\frac{1}{18855}$ and $\frac{1}{17230}$ is equal to this value for the new, stronger fibre. Thus, when Kreil was replacing the fibre, he set up the apparatus so that there was no substantial discontinuity and the observations in the scale divisions were well connected at the critical time around 1 August 1840. That implies, that using the same scale value for the period before August 1840 as after August 1840 (that is, the value set by Kreil for the new fibres), we commit only an acceptable inaccuracy.

The bifilar device, which Karl Kreil installed in mid-1839, operated in the Clementinum observatory until the end of 1845. From 1 January of the following year, the old device was replaced by a new one (Hejda et al., 2021a). It worked on exactly the same principle, but was probably much smaller than its predecessor. We assume that this new device was in operation until 1904.

4 The first magnetic storm observed at Clementinum

Only about a month after the beginning of systematic geomagnetic observations at Clementinum, the local observers recorded an interesting intense magnetic storm. The event began suddenly on 3 September 1839 in the evening and went on to be very strong also on the next day. The recorded course of magnetic declination, horizontal intensity and inclination (Kreil, 1842, p. 55) is a valuable study material which, even in the current state of relatively advanced knowledge of the topic, can still significantly contribute to a better understanding of the mechanisms of such extreme geomagnetic disturbances. Such extreme phenomena are rare, and we have only a few comparable events to study available in the modern space era and the digital age.

Raw data from the yearbook for magnetic declination and horizontal intensity, which were provided in divisions of the scales of the instruments, were converted to angular and physical units as described in (Hejda et al., 2021a, 2022). For this particular magnetic storm, the converted data are accessible in online database https://doi.org/10.1594/PANGAEA.936848, see (Hejda et al., 2021b), and are shown in Fig. 4. In addition, the course of magnetic inclination is shown here with the data obtained by

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

conversion of the raw inclination data using angular units (Kreil, 1842, p. 55); those observations having been carried out by means of inclinatorium with a magnetised needle as long as 81.6 cm (Kreil, 1841, p. 25). An analysis of this storm, which was published in (Hejda et al., 2021a), pointed to two sharp short-term decreases in horizontal intensity on 4 September 1839 in the early morning hours. They were interpreted as possibly caused by the substorm electrojet or some other electric currents in the auroral oval. Three arguments substantiated the claim that these sharp variations could be two consecutive magnetic substorms generated by a substorm electojet, or might be caused by some other electric currents closely related to the auroral oval: (1) the profile of the course for these disorders: these were very rapid variations similar to those typical of regions with the presence of the auroral oval, (2) the time of their occurrence: they occurred at night, after conversion to the local magnetic time they occurred at 01.39 h and 04.59 h, respectively and (3) occurrence of a significant aurora at the time of the geomagnetic disorder: there is a written record of the aurora observation on 3 September 1839 at Ashurst in West Sussex, England (Snow, 1842, p. 15).

All three of these arguments strongly suggest that during 3-4 September 1839 the auroral oval was expanded to middle geographic and geomagnetic latitudes (and perhaps even more towards the equator), in contrast to its usual position in areas near the Arctic Circle. This is a remarkable phenomenon that contributes to the confirmation that at least some of the strongest magnetic storms, even in the middle latitudes, can be caused by the same mechanism as strong magnetic disturbances in the high latitudes (e.g., Cid et al., 2015; Valach et al., 2019; Hejda et al., 2021a). A similar conclusion was reached by Valach et al. (2019) during a study of another magnetic storm observed at Clementinum, which occurred on 17 November 1848.

5 The first magnetic survey in Bohemia

The worldwide network of magnetic observatories organised by Göttingen Magnetic Union was aimed at improving the knowledge of the distribution of the magnetic field over the Earth in general. Kreil realised that there are many questions that can only be answered from the observations made within a dense network on small territory. These include, e.g., the connection between the magnetic force and the nature of the earth's crust, the influence that different types of mountains may exert on the magnetic force or the dependence of the strength of the magnetic force on the altitude of the place of observation.

Kreil discussed the idea of organising magnetic survey on the Bohemian territory among the members of the Royal Bohemian Society of Sciences and the Society supported him not only verbally but also financially. This allowed him to improve the instrumentation, especially to buy the Lamont's non-magnetic theodolite suitable for the measurements of the magnetic parameters D, H and I at field stations. The instrumentation further included a thermometer, as the measurement of magnetic intensity is temperature dependent, a barometer for estimating altitude, astronomical theodolite for estimating longitude and latitude as well as a chronometer. Since the chronometer showed a daily deviation of more than 10 s in the observatory's quiescent environment tests, it was assumed that in field conditions these deviations would be much greater. Therefore, Kreil used the astronomical theodolite also to accurately determine the time according to the Sun and the stars.

It is worth noting how diverse physical units were used at that time. Longitudes were measured from Ferro, however, in some tables also longitudes from Greenwich were given, the difference being $17° 39' 37''$. Temperature was given in Réaumur's

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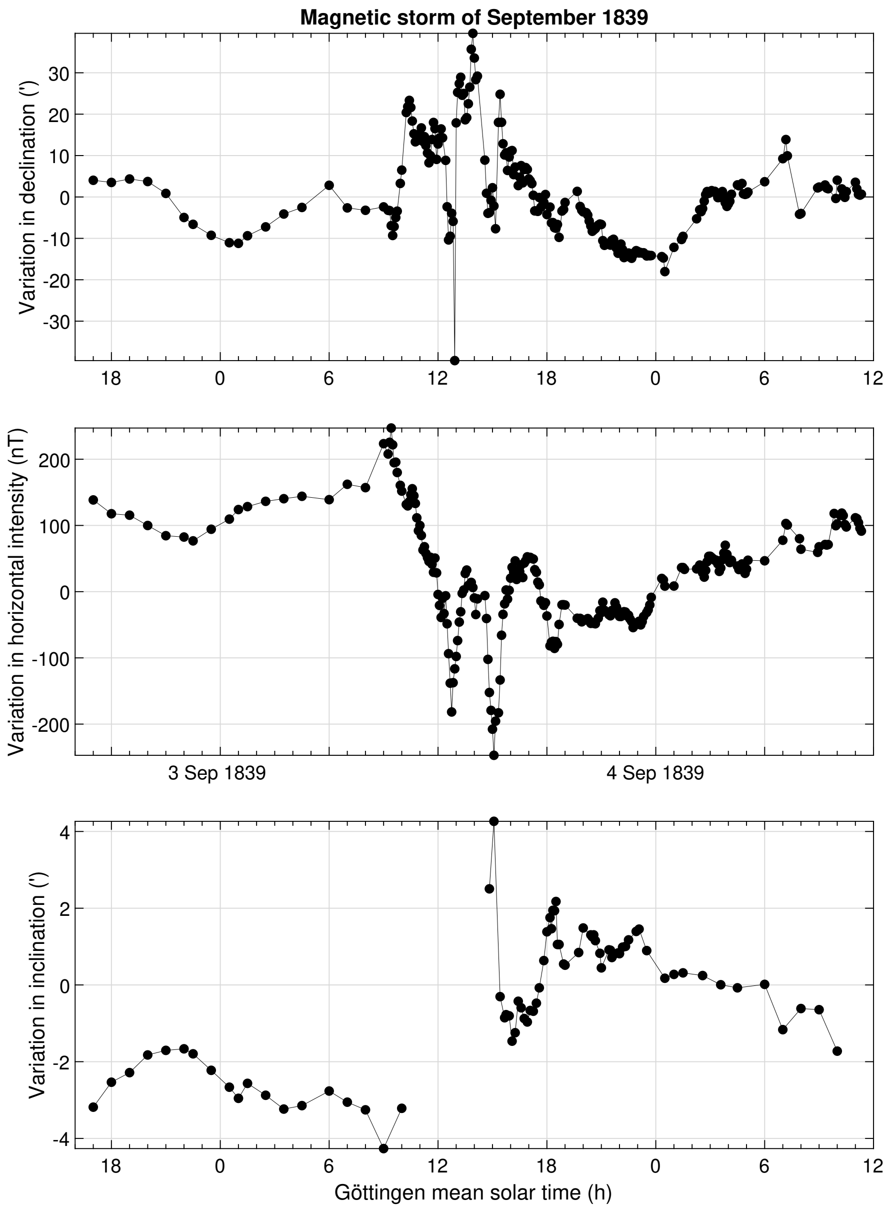

Figure 4. The first magnetic storm recorded in the Clementinum Observatory in Prague on 3-4 September 1839 (Hejda et al., 2021a, b). The course of magnetic declination, horizontal intensity and magnetic inclination is shown. For the records of declination and inclination, conversion from divisions of the instrument scale obtained from the yearbook (Kreil, 1842) to angular units was performed. Despite the visible gap in the inclination record, it is indicated here that a slight change in inclination during the main phase of a magnetic storm was feasible to be observed at that time.

degrees, barometer readings in Paris lines (2.255891 mm) and altitude in Toisen ($\sim$1.95 m). Intensity of the magnetic field was measured in units based on millimetre, milligram and second (equal to 10^{-5} T), introduced by Gauss and used in the frame of

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the Göttingen Magnetic Union. However, for consistency with papers and maps based on imperial units, the recalculation to those was added to the summary table of results.

The first magnetic survey in Bohemia, the western part of the Czech Crown, was started in 1843 (Kreil, 1847). The observations were scheduled for two years. In 1843, Kreil visited 9 sites in East and South Bohemia, and in 1844, 13 sites in North and West Bohemia. Although the original plan was fulfilled in the autumn of 1844, there was a need to repeat some measurements, for example, due to unfavourable weather conditions or excessive rush in the previous measurement. Therefore, in 1845, Kreil made repeated measurements at four points and added one new point. The measurements in 1845 had one more purpose. The Imperial Court approved Kreil's project for measurements throughout the Austrian monarchy and released funds to purchase new instruments. It was a good opportunity to test some of them.

The whole issue also had its human side. For each planned observation site, a contact person had to be found in advance to help with the selection of a suitable site and to allow measurements to be made there. Among them were nobles, higher school officials, clergy, or senior city officials. Therefore, each observation report in Kreil (1847) begins with a thank-you to these individuals and with a detailed description of the spot where the observation took place. It is followed by complete report on magnetic and geodetic measurements and closed by local geology.

The reports on observations at individual sites are followed by the summary of data analysis and processing. The data were reduced to the epoch 1845.0 by means of variation observations at Clementinum Observatory. Results were presented in the form of tables and maps of contour lines of individual components. Fig. 5 shows contour maps for magnetic declination, inclination and horizontal intensity. The contours for both the figures were computed from the original data by the Matlab software. Kreil's geomagnetic survey revealed the most important features of the geomagnetic field distribution in the Bohemia, which, from the viewpoint of our modern knowledge, reflect the existence of the main magnetic field, generated in the liquid Earth's core by magnetohydrodynamic processes, as well as local geomagnetic anomalies, which originate in the crustal magnetic rocks. The main features on the maps coincide well with the latest geomagnetic surveys (Hejda et al., 2012).

Over the next ten years, Kreil, with the help of Fritsch, made magnetic measurements in other parts of the Austrian monarchy, other countries in Southeast Europe and on the coast of Asia Minor. The resulting maps, reduced to the 1950.0 epoch, were published in Kreil (1862).

6 Conclusions

In the paper, we mentioned the events, some technical details about the observation instruments, and the observation records, which we consider to be crucial for the beginnings of geomagnetic field measurement at the Clementinum observatory in Prague. We showed that Karl Kreil was a key figure in these events. We draw attention to the fact that systematic regular observations of the magnitude of the magnetic field began in Prague already in 1839, that is, two years after Gauss invented the bifilar device and five years after the same Gauss had introduced the physical unit for the magnetic field. This ranks Clementinum among the world's leading workplaces that have significantly contributed to the development of geomagnetism.

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Preprint. Discussion started: 31 January 2023

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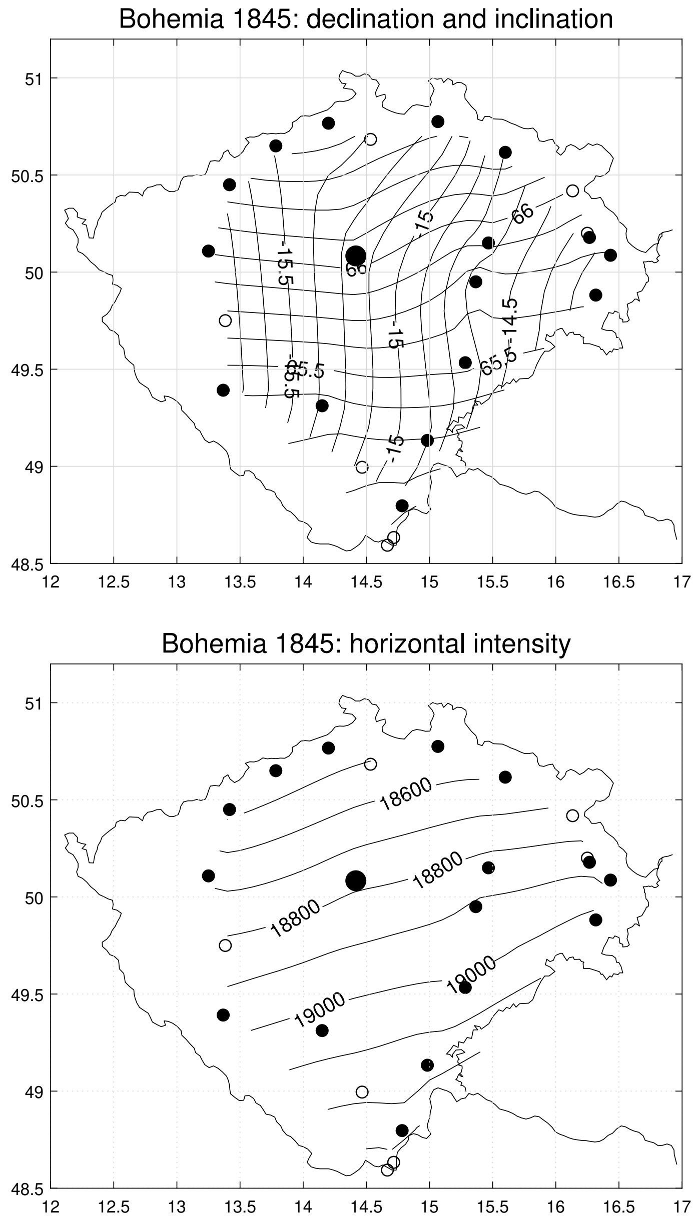

Figure 5. The contour maps for the magnetic declination (nearly vertical contours with values between -14.25° and -15.75°; the minus sign shows that the declination was western that time), the inclination (nearly horizontal contours with values between 65.125° and 66.375°) and the horizontal intensity (nearly horizontal contours with values between 18,500 nT in the south and 19,300 nT in the north). The contours are based on the original Kreil's data. The observation locations are shown as circles (the empty symbols denote points without measurements of inclinations.)

https://doi.org/10.5194/hgss-2022-13
Preprint. Discussion started: 31 January 2023

The bifilar device, which was in operation at Clementinum at the beginning of geomagnetic observations, made it possible to record several interesting magnetic storms, for example the above-mentioned event from 3-4 September 1839. Such old events represent unique material for the study of phenomena that are part of today's dynamically developing area called space weather. It shows that delving into old annals can bring a benefit even for the most modern contemporary science.

Mapping the distribution of the geomagnetic field, on the other hand, represents another aspect of research on the Earth's body, in which regular geomagnetic surveys continue to these days.

Author contributions. PH authored most of the introductory historical content of the manuscript in Sects. 1 and 2, and also wrote the section on the first magnetic survey in Bohemia (Sect. 5). FV prepared the passage about the bifilar magnetometer (Sect. 3). MR put together the part on the first recorded magnetic storm (Sect. 4). The authors participated equally in the final editing of the manuscript.

Competing interests. The authors declare that they have no conflict of interests.

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