

Karl von Lindener's sunspot observations during 1800–1827: Another long-term dataset for the Dalton Minimum

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Received 15 March 2023 / Accepted 7 September 2023

Abstract—On a centennial timescale, solar activity oscillates quasi-periodically and also tends to occasionally get into a low-activity period. The Dalton Minimum (circa 1790s–1820s) was one of such low-activity periods that had been captured in telescopic sunspot observations. However, it has been challenging to analyse the Dalton Minimum, as contemporary source records remained mostly unpublished and almost inaccessible to the scientific community. Recent studies have established reliable datasets for sunspot group number, sunspot number, and sunspot positions. This study further analyzes independent Silesian sunspot observations from 1800 to 1827 in a manuscript from the Library of Wrocław University (Ms AKC.1985/15) and complements it with the metadata for the observer: Karl Christian Reinhold von Lindener. We identified 547 days of sunspot observations in these records and derived the sunspot group number, individual sunspot number, and sunspot positions between 1800 and 1827. The results of this study have significantly revised von Lindener's sunspot group number, which was previously known for only 517 days in scientific databases, and removed contamination from general descriptions. Using our results, we extended investigations into individual sunspot counts and derived their positions. In our analysis, we locate von Lindener's sunspot positions in both solar hemispheres and contrast the Dalton Minimum with the Maunder Minimum, adding further independent credits to the previous results for Derflinger's and Prantner's datasets. Sunspot positions are also slightly biased towards the northern solar hemisphere in early Solar Cycle 6 (1812–1813). The high-latitude sunspot positions indicate the onset of Solar Cycle 7 as early as June 1822.

Keywords: Dalton Minimum / Solar cycles / Sunspot number / Solar activity / Space climate

1 Introduction

Telescopic sunspot monitoring dates back centuries and is used as a basis for discussions on long-term solar variability, multiple solar cycles, and background solar-dynamo activity (Charbonneau, 2020; Clette et al., 2014; Hathaway, 2015; Muñoz-Jaramillo & Vaquero, 2019; Arlt & Vaquero, 2020). Solar activity also varies on time scales longer than the regular Schwabe cycles (i.e., the 11-year activity cycle), with some cycles being greater than others. From time to time, the sun

undergoes comparatively more quiet periods (hereafter, “low-activity periods”) with diminished or nearly ceased solar activity over a longer period of time (like the Maunder Minimum or other grand minima) or just a couple of cycles (like the Dalton Minimum or other secular minima) (Brehm et al., 2021; Silverman & Hayakawa, 2021; Usoskin et al., 2021a). Thus far, these telescopic observations have detected two low-activity periods, the Maunder Minimum (MM) in circa 1645–1715 and the Dalton Minimum (DM) in circa 1790s–1820s (Eddy, 1976; Siscoe, 1980; Soon & Yaskell, 2003; Usoskin et al., 2015; Vaquero et al., 2015a; Hayakawa et al., 2020b; Hayakawa et al., 2021a; Usoskin, 2023). These periods allow us to develop a deeper understanding of the background physics of long-term

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solar activity. In addition, proxy reconstructions using cosmogenic isotope data indicate similar low-activity periods in a millennial timescale (Usoskin et al., 2016; Brehm et al., 2021; Silverman & Hayakawa, 2021; Usoskin et al., 2021b; Kudsk et al., 2022; Usoskin, 2023). These low-activity periods are unique among the instrumental sunspot observations and are occasionally used as references for similar periods detected in the cosmogenic isotope records (Usoskin et al., 2007, 2021b; Brehm et al., 2021).

As such, the MM (1645–1715) and the DM (1790s–1820s) have served as unique references for the low-activity periods and require archival investigation for contemporary observational records (Muñoz-Jaramillo & Vaquero, 2019; Usoskin, 2023). In particular, the MM has been considered a grand minimum with a distinct state of solar-dynamo activity based on highly suppressed solar cycles, weakened solar magnetic fields, extremely asymmetric distribution of sunspot appearances, and apparent loss of significant solar coronal streamers (Eddy, 1976; Ribes & Nesme-Ribes, 1993; Riley et al., 2015; Vaquero et al., 2015a; Usoskin et al., 2015; Hayakawa et al., 2021b, 2021c; Usoskin, 2023). In contrast, the DM has been considered shorter and shallower but has been less studied owing to significant data scarcity, with large scatters in the existing cycle reconstructions and poor data accessibility of contemporary sunspot positions (Muñoz-Jaramillo & Vaquero, 2019; Clette et al., 2023).

Recent studies have conducted intensive analyses of original sunspot records in the past (e.g. Vaquero et al., 2016 (hereafter V16); Svalgaard, 2017). These analyses have significantly revised estimates of past solar cycle reconstructions (Clette et al., 2014, 2023; Clette & Lefèvre, 2016; Svalgaard & Schatten, 2016; Usoskin et al., 2016, Usoskin et al., 2021a; Muñoz-Jaramillo & Vaquero, 2019) from what was previously known in the scientific community (Hoyt & Schatten, 1998 (hereafter HS98)). These efforts allow us to significantly improve our understanding of solar irradiance before the instrumental measurements (Tapping & Morgan, 2017; Criscuoli et al., 2018; Chatzistergos et al., 2019, 2020; Lean et al., 2020; Clette, 2021). Among such global efforts, long-term records of historical sunspot observers have played significant roles in these revisions, as exemplified by those of Johann Staudach (Arlt, 2009; Svalgaard, 2017), Heinrich Schwabe (Arlt et al., 2013; Senthamizh Pavaai et al., 2015), Hisako Koyama (Hayakawa et al., 2020b), Locarno Observatory (Clette et al., 2016; Cortesi et al., 2016), Greenwich Observatory (Willis et al., 2013), Madrid Observatory (Aparicio et al., 2014), and Mt. Wilson Observatory (Pevtsov et al., 2019).

Despite these recent efforts, the DM was located in a gap between two prominent long-term observers' data series (i.e. Staudach and Schwabe). Most contemporary observations covered only relatively short periods and remained unpublished, except for Wolf's preliminary tabulations. As reviewed in Clette et al. (2023), these difficulties have led to significant discrepancies in recent reconstructions of sunspot numbers and group numbers around the DM (Clette & Lefèvre, 2016; Svalgaard & Schatten, 2016; Usoskin et al., 2016, 2021b; Chatzistergos et al., 2017; Velasco Herrera et al., 2022).

In this regard, recent archival investigations have steadily improved our understanding of solar activity around the DM based on contemporary observations since V16. Recent

studies have added several short-term observers overlooked in the existing databases (Denig & McVaugh, 2017; Hayakawa et al., 2018; Carrasco et al., 2018). Furthermore, recent studies have examined original manuscripts from several long-term observers' records around the DM, especially those of Thaddäus Derfflinger in 1802–1824 (Hayakawa et al., 2020a), Stefan Prantner in 1802–1844 (Hayakawa et al., 2021a), Cornelis Tevel in 1816–1836 (Carrasco, 2022), and Honoré Flaugergues in 1782–1830 (Illarionov & Arlt, 2023). These results significantly improved the sunspot group number and confirmed sunspot distributions in both hemispheres during DM (as a secular minimum), in contrast to the MM (as a grand minimum). These contrasts have been independently supported by contemporary eclipse records that had shown significant coronal streamers in the DM compared to those in the MM without significant coronal streamers (Hayakawa et al., 2020c, 2021c).

However, several long-term sunspot observations during the DM have not yet been analysed in detail. Among them, a forgotten long-term observer known as “B.A. Lindener” observed sunspots from 1800 to 1827 (HS98). The scientific community first got knowledge of this observer through HS98 as “Lindener, B.A., 1800–1827. Manuscripts. University Library Archives, Wroław [sic.], Poland”, with only the sunspot group number having been incorporated into scientific databases (HS98 and V16). Their bibliographic description does not allow us to immediately identify the source record. Wroław is most probably a mistake of Wrocław. “B.A. Lindener” was almost unknown as an astronomer to the scientific community.

Such records require us to analyse their original manuscripts both in terms of sunspot group numbers and sunspot positions. This is because recent studies have revealed significant differences in historical and modern methods of group counting (e.g. Svalgaard, 2017). In addition, they have revealed contaminations through general descriptions and solar altitude observations (e.g. V16; Carrasco et al., 2019; Hayakawa et al., 2020a), which have significantly influenced the existing reconstructions (Clette et al., 2014; c.f., HS98). Furthermore, Lindener's name was known wrongly: not “B.A. Lindener”, as referred to in HS98 but “Karl C.R. von Lindener” (Von Priesdorff, 1937, p. 139), and his background has been virtually unknown to the scientific community (HS98). Therefore, this article locates and re-examines von Lindener's original records, details the observer and his observational instruments, and reconstructs the time series of his sunspot group numbers and sunspot positions.

2 Karl von Lindener and his observations

The name “Lindener” occasionally appears as “General-Major von Lindener” in Bode's *Berliner Astronomisches Jahrbuch* (e.g. Bode, 1809, 1819) and ‘General von Lindener’ in his sunspot manuscript of the Library of Wrocław University (MS Akc.1985/15). One of his correspondences located him at Glatz of Silesia (currently Kłodzko in Poland) in 1819 (Bode, 1819, p. 228). Indeed, a biographical reference to Prussian generals shows his name not as “B.A. Lindener” as in HS98 and V16 but as Karl Christian Reinhold von Lindener (Von Priesdorff, 1937, p. 139).

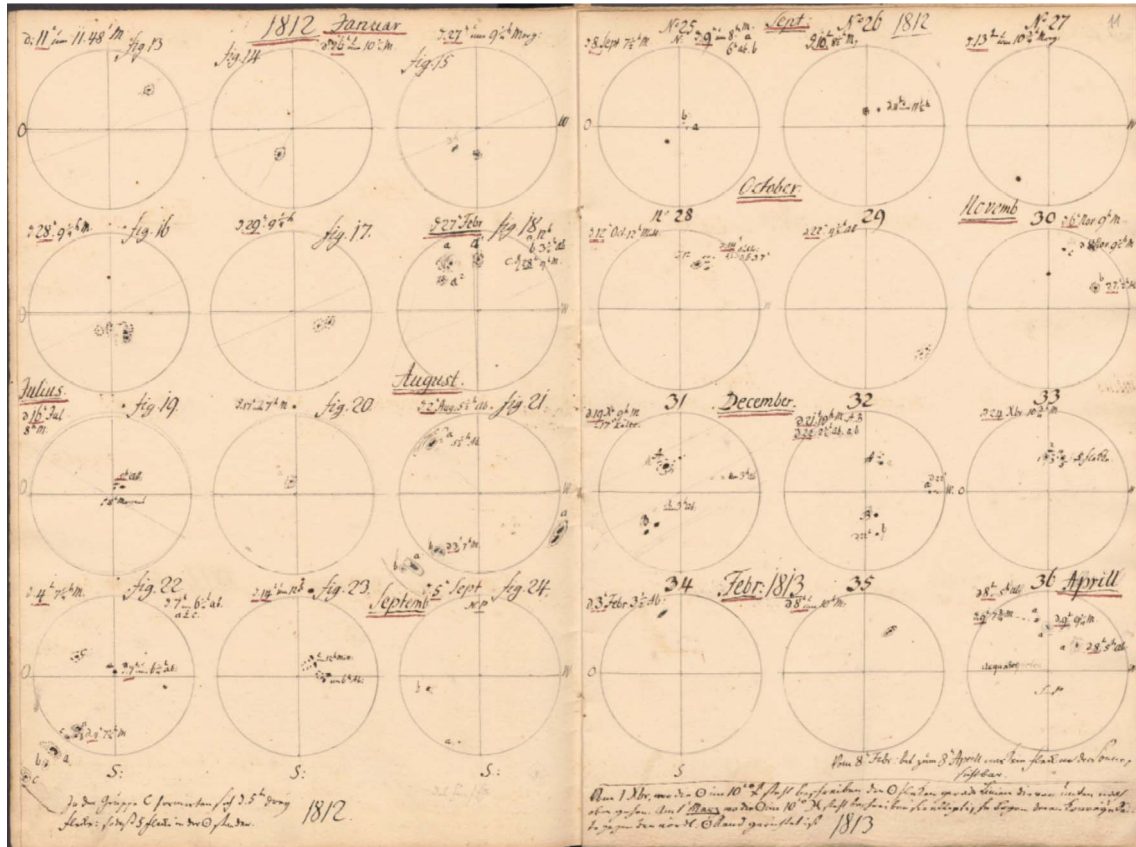


Figure 1. Examples of Karl von Lindener's sunspot observations in his manuscript (the Library of Wrocław University MS Akc.1985/15, ff. 10b–11a) provided by the Library of Wrocław University.

According to this biographical reference, Lindener was born in 1742 in East Prussia and passed away on 15 May 1828, in Glatz. He started his military career in engineering corps on 4 November 1767, and worked for Silesian fortresses, such as Breslau. His family name was honoured as “von” Lindener after he was ennobled in 1772. The First Coalition War was fought in 1792. In the early 1800s, he was based in Breslau and engaged in wars against the French army. On 20 May 1803, he was promoted to a major general and became a brigadier of Silesian fortresses. In 1806, he became a commander of the Breslau Fortress but had to surrender to the French army. After release, he was caught on 31 March 1808, and sentenced to perpetual imprisonment at Glatz Fort on 19 March 1811. This was due to his failure in Napoleon's invasion in 1806. He was pardoned in March 1814 and obtained a monthly pension of 25 thalers. He died on 15 March 1828, at Glatz (Von Priesdorff, 1937, p. 139).

Furthermore, von Lindener engaged in astronomical research in addition to his military duties. He had once recalled his sunspot observations in “a letter written by General-Major von Lindener from Glatz on Aug. 6th”, published in Bode's *Jahrbuch* with the ephemerides for 1822 (Bode, 1819). In this letter, he explains his observations as follows: “I observed the sun as often as weather conditions allowed since 1800, still in my 77th year, twice to thrice a day with my 2 1/2 f. Ramsden's achromatic telescope of 25 or 75 times enlargement and a composite of light brown and light blue flat glass, which makes

the image of the sun appear white. I put a cross thread in the telescope, and show in every square [or quadrant] all, even the smallest noticeable sunspots with visually estimated shapes and positions” (Bode, 1819, p. 228). The letter indicates that he used Ramsden's Achromatic for eyepiece observations with two magnifications ($\times 25$ and $\times 75$), two glasses as filters, and micrometres a few times a day. The telescope's focal length is difficult to convert into a modern unit of measurement. The focal length may be 72 cm (Silesian feet), 76 cm (British feet), or 79 cm (Prussian feet), depending upon which definition of feet von Lindener used (see Aldefeld, 1838). Since his early observations, he seems to have relied on the same instruments, or at least similar ones.

Apart from the fragmentary information in his correspondences, most of von Lindener's observations have remained unpublished. Our close inspection identified his observational records with MS Akc.1985/15 at the Library of Wrocław University. The manuscript title is translated as “Figures of sunspot observations in the years from 1800 to 1806 and from 1811 to 1824, and 26, 27 of General von Lindener: Belonging to the manuscript: On sunspot and comet observations (*Figuren zu den Sonnen Flecken Beobachtungen in den Jahren von 1800 bis 1806, u.[nd] von 1811 bis 1824 u.[nd] 26, 27. vom General von Lindener Zum M[anu]scripte: Über Sonnen flecken u.[nd] Kometen Beobachtungen gehörig*)”. According to the title of this manuscript, another (forgotten) manuscript should have been produced for his observations of sunspots and comets.

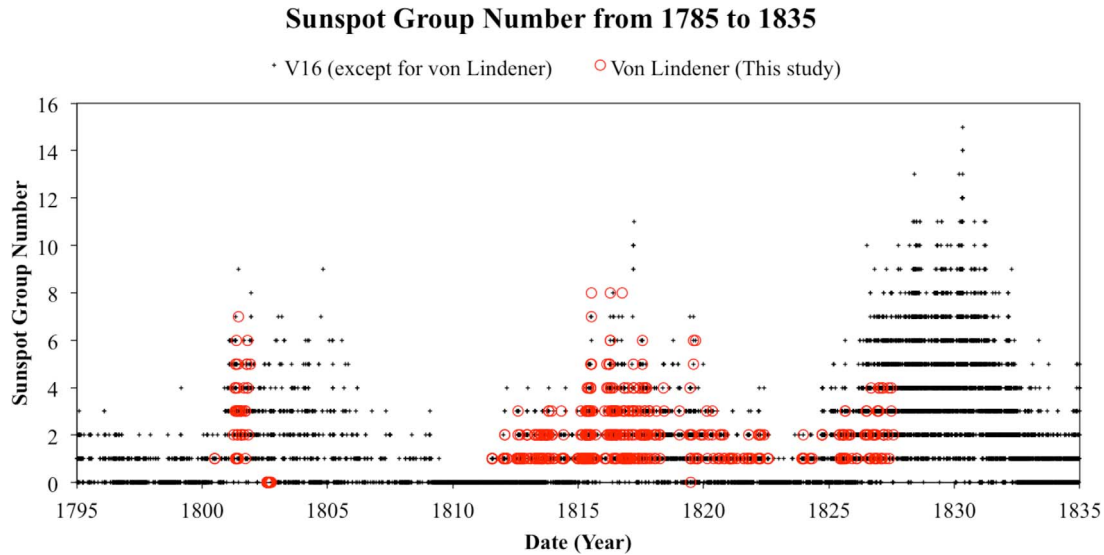


Figure 2. Comparison of von Lindener’s sunspot group numbers with the V16 database except for von Lindener’s dataset.

At the time of our research, we were not able to locate such a manuscript in the manuscript collections of the Library of Wrocław University.

Figure 1 shows examples of his sunspot drawings. Here, he may have described the umbral and penumbral regions. He also composited sunspot groups on the same solar disks over several days. For a few days, he also tracked the same groups, especially in composite drawings. Furthermore, he occasionally provided close-up drawings of specific sunspot groups with a higher magnification (probably $\times 75$) in addition to his regular sunspot drawings at a normal magnification (probably $\times 25$).

As can be inferred from the title, his manuscript is separated into two segments: his early observations from 1800 to 1806 (ff. 1a–5b) and his late observations from 1811 to 1827 (ff. 10a–35a). Apparently, his manuscript exhibited a relatively large data gap between these two parts. Moreover, the early part of his work only partially recorded his observations of sunspots (1800–1802). However, his observational engagements at Schweidnitz in Silesia (currently Świdnica in Poland) had been confirmed up to 1806 in his correspondence with Bode (1809, p. 90). This hiatus was probably a result of the War of the Fourth Coalition (1806–1807) when von Lindener was captured by the French army and afterward imprisoned in Prussia for “lifelong confinement in Glatz Fort” (Von Priesdorff, 1937, p. 139). This manuscript summarizes his early observations in 1800–1802. This manuscript also contains 68 blank solar disks, while their majority is without explicit dates (ff. 5a–6b). The indication is consistent with the manuscript title, which indicates the existence of another manuscript, lost or buried in archives, relating to observations of sunspots and comets. Consequently, we believe that the summary of his early observations has been incompletely incorporated into this summary.

Von Lindener described his observational site as Glatz in his original manuscript; however, it was occasionally referred to as Schweidnitz from 1800 to 1806 (Bode, 1804, p. 263; Bode, 1809, p. 89). Fortunately, von Lindener had enough time to engage in astronomy while imprisoned at Glatz Fort in 1811. Despite being pardoned in 1814, he appears to have spent his

final years at Glatz with his “monthly pension of 25 thalers”. Therefore, his observational sites are located around Schweidnitz (current Świdnica: N50°51′, E16°29′) in his early observations (1800–1802) and Glatz (current Kłodzko: N50°26′, E16°39′) in his late observations (1811–1827).

3 The sunspot groups recorded in von Lindener’s observations

We have identified 547 days of sunspot observations that were included in his summary manuscript (MS Akc.1985/15) and his correspondence with Bode, apart from his close-up sketches for specific sunspot groups. Using the Waldmeier classification (see Kiepenheuer, 1953), we counted the sunspot groups in his records (Hayakawa et al., 2023) and compared them with the V16 database (Fig. 2) and contemporary long-term observers (Fig. 3). Most part of the data were derived from his summary manuscript, except for two days of data from his textual correspondence with Bode (1819, p. 228). Our analysis removed 31 days with generic zeros in March 1813 but increased von Lindener’s dataset to 547 days, in contrast to the knowledge of scientific databases (519 days in HS98 and V16).

The generic zero values in March 1813 in the existing dataset (HS98; V16) are most likely based on von Lindener’s footnote on spotless days. In this case, von Lindener stated: “from 8 February to 8 April, there was no visible spot on the sun” (MS Akc.1985/15, f. 11a; see lower right of Fig. 1). Von Lindener himself included solar disks with sunspots on 8 February and 8 April 1813. On their basis, we had to revise the spotless interval from 1–31 March to 9 February–7 April 1813. However, it is unclear exactly when von Lindener monitored the solar disk during this period. Therefore, these generic descriptions have significantly suppressed existing reconstructions compared to reality (Clette et al., 2014; V16). Silesian weather conditions during this season prevent this

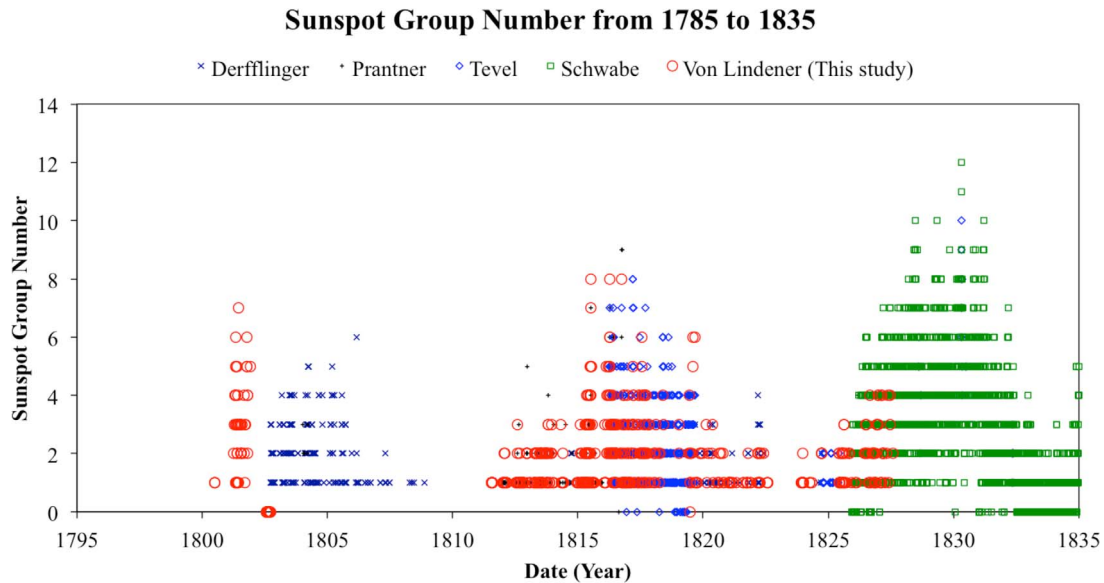


Figure 3. Von Lindener’s sunspot group numbers in comparison with contemporary long-term observers: Derfflinger (Hayakawa et al., 2020a), Prantner (Hayakawa et al., 2021a), Tevel (Carrasco, 2022), and Schwabe (V16).

interval from being completely sunny. Therefore, it is highly unrealistic that von Lindener viewed the solar disk every day during this interval. In 1813, von Lindener observed for 47 days, excluding the period from February to April. Thus, his monthly observation days for this year amount to 4.7 days. In the period between 9 February and 7 April 1813, von Lindener cannot be expected to be extremely diligent and cover the entire period. Consequently, we removed the general zeros in this interval from our dataset.

Additionally, caveats should be noted regarding the empty solar disks in 1802, which spanned 18 days (see Fig. 4). Although HS98 (and hence V16 too) interpreted them as active days, we have not found datable solar drawings with sunspots in this interval. Therefore, we had to revise them to spotless days. Although sunspots were active around 1802, neither Derfflinger nor Flaugergues reported them during this period (Hayakawa et al., 2020a; Illarionov & Arlt, 2023). However, we can also accommodate another scenario in which von Lindener depicted empty disks for his observation days but eventually failed to fill these solar disks for an undocumented reason. Moreover, he depicted empty solar disks without dates on the following folia (MS Akc.1985/15, ff. 5a–6b), and sunspots were actively observed in 1813 (e.g. Hayakawa et al., 2020b). Von Lindener’s faint sketches of faculae on 31 July, 1 August, and 5 August challenge this interpretation, although they appear strangely at the same location. The spotless day scenario contradicts the average solar activity in 1802. Unfortunately, von Lindener’s observing days during this period do not coincide with those of other observers, which leaves us incapable of determining which scenario to pursue. Therefore, these empty disks should be treated cautiously and might need to be omitted from quantitative discussions.

As a result, Figure 5 shows von Lindener’s yearly sunspot group number and compares this data series with those of three long-term observers around the DM: Derfflinger

(Hayakawa et al., 2020b) Prantner (Hayakawa et al., 2021a), and Tevel (Carrasco, 2022), except for 1816–1818, where Derfflinger’s data appear significantly lower than those of von Lindener and Tevel. According to this comparison, von Lindener’s time series is mostly consistent with those of Derfflinger, Prantner, and Tevel during Solar Cycle 6 (August 1810–May 1823; see Hathaway, 2015). Von Lindener’s early deviations in 1813–1814 may need to be corrected. Since von Lindener only provided a general description of spotless days occurring between 9 February and 7 April, 1813, we should consider our current estimate omitting this period to be somewhat exaggerated compared to the reality. The local deviations between 1817 and 1819 coincide among those observed by von Lindener and Derfflinger. This trend seems more consistent with the reconstructions of Clette & Lefèvre (2016), Usoskin et al. (2016), and Chatzistergos et al. (2017) rather than that of Svalgaard & Schatten (2016).

However, it is not straightforward to compare von Lindener’s time series with others in Solar Cycles 5 and 7 (April 1798–August 1810; May 1823–November 1833; see Tab. 2 of Hathaway (2015)). This is partial because von Lindener had a different observational site before his hiatus for a decade and may therefore have practiced different observational procedures.

In Solar Cycle 5, von Lindener’s data showed a sharp spike in 1801 and “spotless days” in 1802, whereas Derfflinger showed considerable sunspot groups in 1802. This result may be related to von Lindener’s failure to fill the blank solar disk in 1802. If this interpretation is correct, we must be cautious when referring to his records from 1802. According to von Lindener, Solar Cycle 5 exhibited a marginally higher amplitude than Solar Cycle 6, although there is a single data point from 1801 that supports this interpretation. This is consistent with Derfflinger’s time series (see Hayakawa et al., 2020b). It indicates the centre of the DM during Solar Cycle 6.

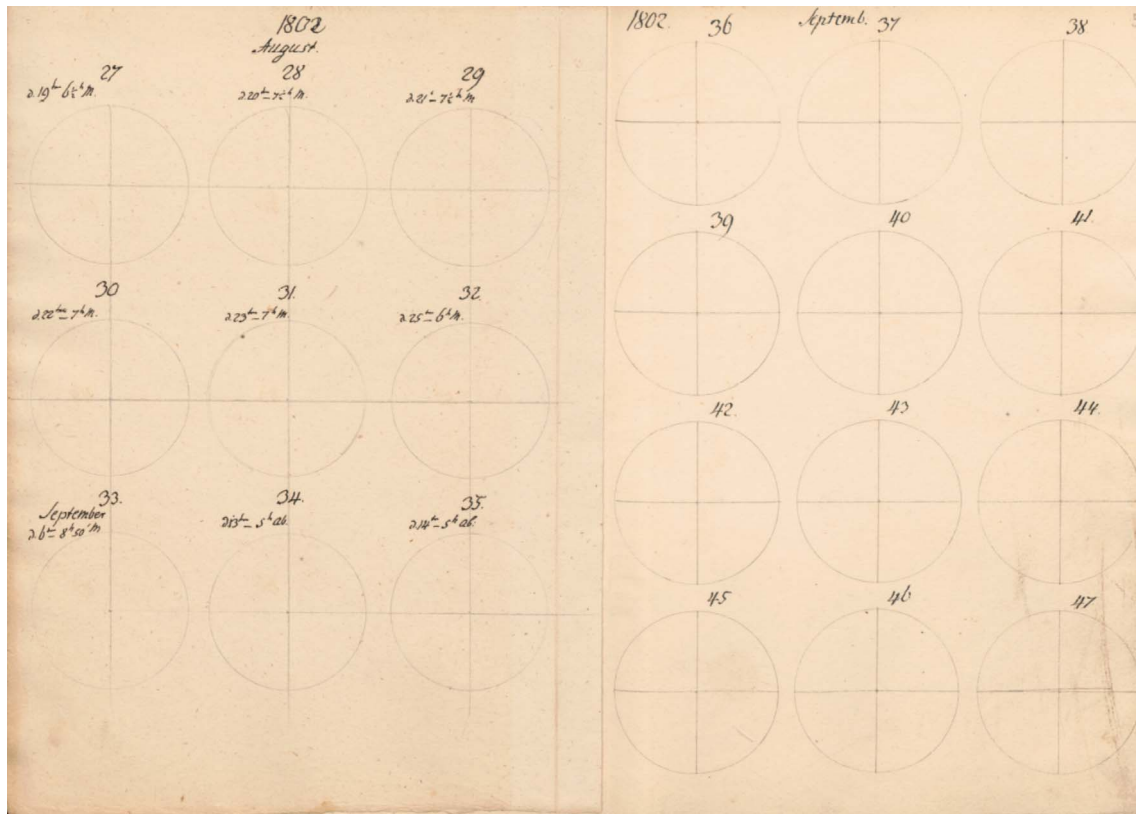


Figure 4. Examples of von Lindener's empty solar disks with or without date (MS Akc.1985/15, ff. 4b–5a) courtesy of the Library of Wrocław University. Von Lindener showed the diagram number above each solar disk, whereas they are different from the date of the observations.

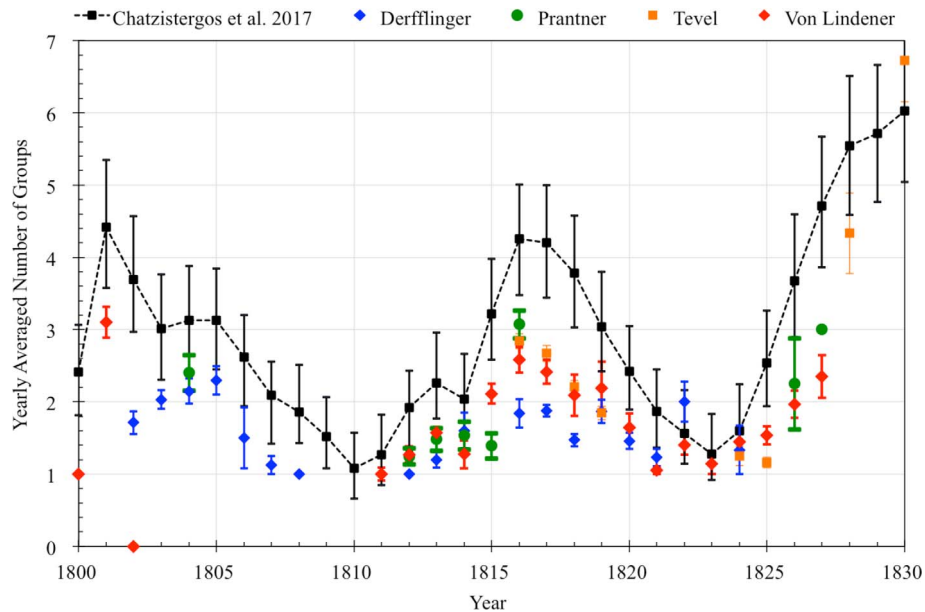


Figure 5. Yearly sunspot group number of von Lindener (red diamonds), Derfflinger in his summary manuscript (blue circles: Hayakawa et al., 2020b), Prantner (blue diamonds: Hayakawa et al., 2021a), and Tevel (orange squares: Carrasco, 2022). For reference, these data are compared with the annual sunspot group number of Chatzistergos et al. (2017), which has been regarded as “the most recommendable version for further analysis” in Petrovay (2020, p. 11). Accordingly, we have calculated the error margins for the individual data series in a standard error, whereas we have derived the error margins of Appendix B in Chatzistergos et al. (2017).

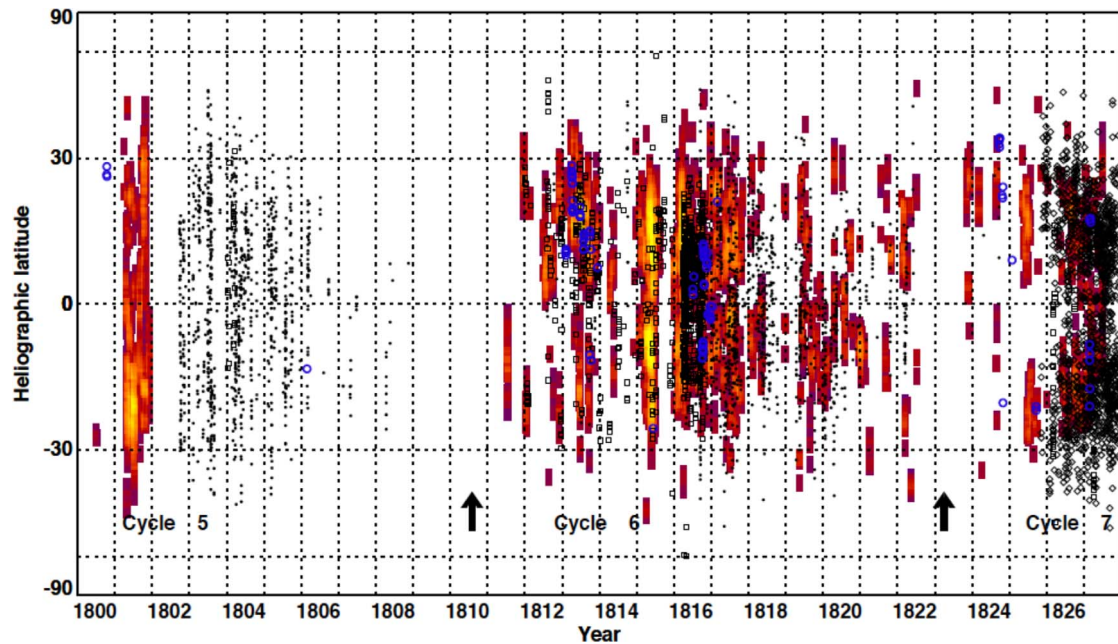


Figure 6. Von Lindener’s sunspot positions in comparison with those of Derfflinger (black dots: Hayakawa et al., 2020a), Prantner (black squares; Hayakawa et al., 2021a), Flaugergues (blue circles; Illarionov & Arlt, 2023), and Schwabe (black diamonds: Senthamizh Pavai et al., 2015). For von Lindener’s data, brighter and darker colours indicate denser and scarcer data concentrations of the sunspot positions.

For Solar Cycle 7, von Lindener chronologically overlapped with Tevel during the ascending phase (Fig. 2). Tevel’s data display a sharper ascending curve of the sunspot group number, even though both show the ascending phase smoothly. This does not fit well with von Lindener’s data. This interval occurred immediately before von Lindener’s death in 1828, when he was 83–85 years old. Therefore, it would not be surprising even if von Lindener’s visual acuity had already started to deteriorate in Solar Cycle 7.

4 Sunspot positions

We confirm sufficient quality in von Lindener’s drawings of the solar disk to determine the locations of all individual sunspots. The drawings include a basic coordinate system consisting of at least two pencil lines. Comparing the sunspot paths across the disk in the morning and evening hours, it is evident that there is a substantial difference in the position and angle of the sunspots. This occurs if the telescope is mounted horizontally, and the horizontal and vertical pencil lines are parallel to the horizon and perpendicular to the zenith, respectively.

Therefore, to obtain the sunspot positions, one option is based on the transformation of the horizontal coordinate system into an equatorial coordinate system and further conversion into heliographic coordinates. The latter conversion employs an ephemeris of how the solar rotation axis was positioned concerning the Earth’s rotation axis, i.e. the equatorial coordinate system. We used the ephemeris computed by the JPL Horizons system (<https://ssd.jpl.nasa.gov/horizons/>), which provides us with the sun’s north-pole direction concerning the celestial north pole as well as the heliographic coordinates of the centre of the visible disk.

Another option is to use the motion of spots across the solar disk to determine the position angles of the drawings. Theoretically, if at least one spot is visible for a minimum of two days, Bayesian inference can be used to determine the position angles and, thus, the heliographic coordinates of the spot. We used the same method described in Section 2.2 of Arlt et al. (2013). In practice, however, a single spot often fits with low residuals but leads to unlikely results concerning the spot’s latitude and the observational method employed by von Lindener (as evident from the typical orientations of other drawings given the time of day). Finding two spots in different groups seen on at least two days provided more plausible results. When only one sunspot group was available, we preferred to use the time of day for calculating the position angle.

Occasionally, both methods led to implausible spot positions, especially when only one spot was available on consecutive days. Afterwards, we manually adjusted the position angle of the solar disk to match the latitudes of the spots on adjacent days. This was done regardless of the longitudinal shift of the spots from one day to the next; in other words, the match would require an incorrect rotation rate of the sun. It differs from the Bayesian method, which considers two-dimensional coordinates in the drawing and does not give preference to latitudes or longitudes. We performed manual matches only if no other method yielded reasonable results. It is also important to clarify some spots did not allow us to derive positions owing to a lack of the required data.

Figure 6 shows the heliographic latitude of the sunspot positions obtained from von Lindener’s sunspot drawings. We can observe the beginning of Solar Cycle 5, the fair coverage of Solar Cycle 6, and the first half of Solar Cycle 7. The positions were compared with those obtained by Derfflinger (Hayakawa et al., 2020b) and Prantner (Hayakawa et al., 2021a) and the

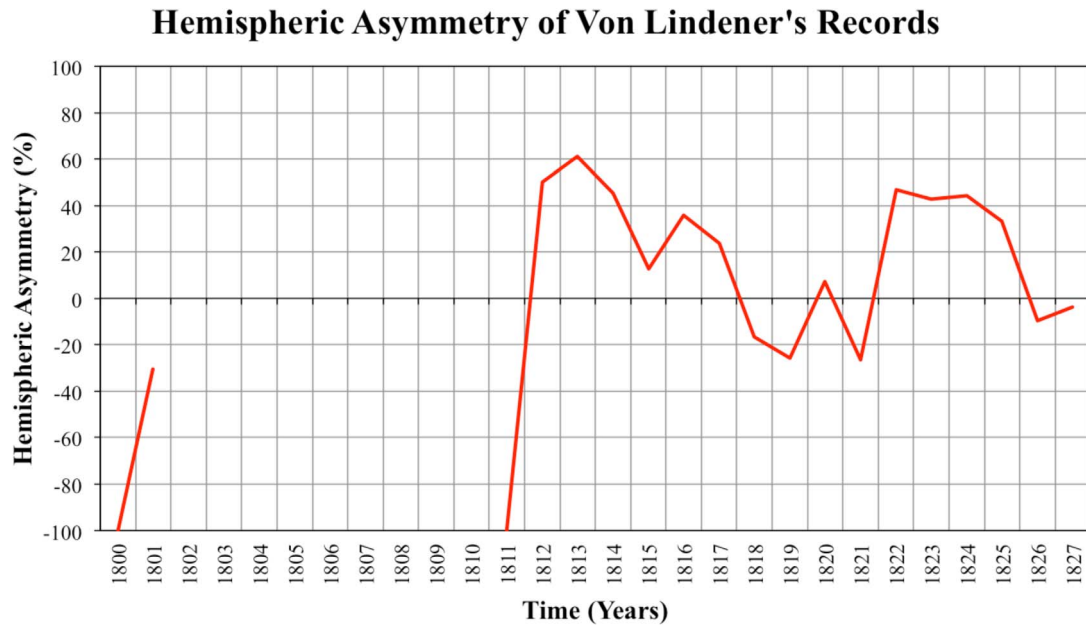


Figure 7. Hemispheric asymmetry index ($HA = (R_{NH} - R_{SH}) / (R_{NH} + R_{SH})$) for von Lindener's observations, based on the sunspot positions (Fig. 6).

group positions from Schwabe (Senthamizh Pavai et al., 2015). Figure 6 confirms von Lindener's sunspots in both solar hemispheres, following other contemporary sunspot observers' data (Hayakawa et al., 2020b, 2021a; Illarionov and Arlt, 2023). This result contrasts the Dalton Minimum with the Maunder Minimum (Ribes & Nesme-Ribes, 1993), unlike some claims that classify both of them as the same solar-activity categories (Zolotova & Ponyavin, 2015). Additionally, Figure 6 illustrates the relative concentration of sunspot positions in the Northern Solar Hemisphere during the ascending phase of Solar Cycle 6 (1812–1813). We have also tentatively derived a hemispheric asymmetry index ($HA = (R_{NH} - R_{SH}) / (R_{NH} + R_{SH})$) for von Lindener's observations, as shown in Figure 7. Figure 7 also confirms more sunspot groups in the northern solar hemisphere over Solar Cycle 6. This trend is consistent with the butterfly diagrams reconstructed from manuscripts of Prantner and Flaugergues (Hayakawa et al., 2021a; Illarionov & Arlt, 2023) and contrasted with those of the Maunder Minimum (Ribes & Nesme-Ribes, 1993; Vaquero et al., 2015b; Hayakawa et al., 2021b, 2021c).

We found two groups far from the solar equator on 3 June 1822 (at $\approx -40^\circ$), and 30 July 1822 (at $\approx +47^\circ$). Due to the absence of adjacent days, we were unable to generate secondary information regarding either the latitudes of the groups or the position angles of the spots. Therefore, the locations of the spots remain uncertain. We observed a second group on 3 June that was also observed by Derfflinger on 4 June between $+1^\circ$ and $+17^\circ$ in heliographic latitude (again, the exact position is unknown). By adjusting the second group observed by von Lindener to the location derived from Derfflinger, the group at $\sim -40^\circ$, not observed by Derfflinger, remains slightly south of -30° . This is unusual for spots at the end of a cycle. Thus, the two above incidences on 3 June and 30 July may represent the first spot occurrences of Solar Cycle 7 in 1822. Figure 6 shows that expected latitudinal migration during a cycle is less evident

in von Lindener's sunspot positions than in Derfflinger and Schwabe's sunspot positions (Arlt et al., 2013; Hayakawa et al., 2020a).

5 Summary and discussions

In this article, we present an overview of von Lindener's observations and analyse his sunspot records. We identified the observer as Karl Christian Reinhold von Lindener. We located his observational sites as Schweidnitz (current Świdnica: $N50^\circ 51'$, $E16^\circ 29'$) or its neighbourhood for his early observations (1800–1802) and Glatz (current Kłodzko: $N50^\circ 26'$, $E16^\circ 39'$) for his late observations (1811–1827). Furthermore, we identified his main telescope as a 79-cm Ramsden's achromatic telescope with magnifications of $\times 25$ or $\times 75$ and two filter glasses. His personal history explains the comparatively long hiatus between his early observations a slate observations with his military engagements and imprisonment as a consequence of the War of the Fourth Coalition.

We identified his manuscript as MS Akc.1985/15 at the Library of Wrocław University (Fig. 1) and acquired two reports in his correspondence to Bode (1819, p. 228). These records can be used to document von Lindener's instrumentation, recount sunspot groups, count individual sunspots, and reconstruct the time series of his sunspot group number. We need to cast caveats on dated empty sunspot drawings in 1802 and general descriptions of spotless days from 9 February to 7 April 1813 (Figs. 2 and 3). Von Lindener's records have enabled us to identify 547 days of sunspot observations with caveats on empty solar disks in 1802, omitting these unreliable records for possible spotless days. This reconstruction has shown a consistent trend with Derfflinger and Prantner's time series for Solar Cycle 6, with a caveat in his time series in 1802, and requires further reference data for the ascending phase of Solar Cycle 7 (Fig. 4).

Von Lindener's manuscript also allowed us to derive sunspot positions from 1800 to 1801 and from 1811 to 1827 (Fig. 5). The reported sunspots were located in both solar hemispheres, mostly within a latitudinal interval of -40° to 40° . These data allow us to locate the onset of Solar Cycle 7 around June–July 1822 owing to the occurrence of the first high-latitude sunspots.

The DM has shown significant differences against the MM due to the presence of sunspots in both solar hemispheres and apparent solar cycles in both sunspot group numbers and sunspot positions in the DM. These results also allow us to show reasonable consistency among the long-term sunspot observers' data series, namely those of von Lindener, Derfflinger, Prantner, Tevel, and Flaugergues, in terms of the sunspot group number (Figs. 2 and 4) and reasonable agreement in terms of sunspot positions (Fig. 6). Further inter-comparisons and inter-calibrations are needed for the long-term sunspot observers' data series around the DM so that the data can be bridged to sunspot records around Staudach and Schwabe's data series in 1749–1799 and 1825–1867, allowing us to derive solar activity in the DM more quantitatively.

Data accessibility

Karl Christian Reinhold von Lindener's original manuscript is accessible in the Library of Wrocław University as MS Akc.1985/15. See Hayakawa et al. (2023) in <https://doi.org/10.18999/2007775> and https://nagoya.repo.nii.ac.jp/record/2007775/files/von_lindener_sgn_ver2.txt for von Lindener's sunspot group number and individual sunspot number.

Acknowledgements. We thank the Library of Wrocław University for permissions on research and reproductions of von Lindener's manuscript. HH thanks Yuichiro Hayashi for his advice on the references of Prussian generals. HH thanks Agnieszka Gil-Świdarska, Lidia van Driel, and Stanislav Gunar for their help in identifying this manuscript. HH thanks Arkadiusz Berlicki for his helpful discussions on interpretations of von Lindener's manuscript. This research was conducted under the financial support of JSPS Grant-in-Aids JP15H05812, JP20K20918, JP20H05643, JP21K13957, JP20KK0072, JP21H01124, JP21H04492, and JP22K02956. HH has been part funded by JSPS Overseas Challenge Program for Young Researchers, the ISEE director's leadership fund for FYs 2021–2023, Young Leader Cultivation (YLC) programme of Nagoya University, Tokai Pathways to Global Excellence (Nagoya University) of the Strategic Professional Development Program for Young Researchers (MEXT), and the young researcher units for the advancement of new and undeveloped fields, Institute for Advanced Research, Nagoya University of the Program for Promoting the Enhancement of Research Universities. HH acknowledges the International Space Science Institute and the supported International Teams #417 (Recalibration of the Sunspot Number Series), #510 (SEESUP Solar Extreme Events: Setting Up a Paradigm), and #475 (Modeling Space Weather And Total Solar Irradiance Over The Past Century). The editor thanks two anonymous reviewers for their assistance in evaluating this paper.

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Cite this article as: Hayakawa H, Arlt R, Iju T & Besser BP 2024. Karl von Lindener’s sunspot observations during 1800–1827: Another long-term dataset for the Dalton Minimum. *J. Space Weather Space Clim.* **13**, 33. <https://doi.org/10.1051/swsc/2023023>.