Christian Horrebow’s Sunspot Observations – II.
Construction of a Record of Sunspot Positions

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Abstract The number of spots on the surface of the Sun is one of the best tracers of solar variability we have. The sunspot number is not only known to change in phase with the 11-year solar cycles, but also to show variability on longer time scales. It is however, not only the sunspot number that changes in connection with solar variability. The location of the spots on the solar surface is also known to change in phase with the 11-year solar cycle. This has traditionally been visualised in the so-called butterfly diagram, but this is only well constrained form the beginning of the 19th century. This is unfortunately, as knowledge about the butterfly diagram could aid our understanding of the variability and the Sun–Earth connection.

As part of a larger review of the work done on sunspots by the Danish astronomer Christian Horrebow, we here present a reanalysis of Christian Horrebow’s notebooks covering the years 1761 and 1764–1777. These notebooks have been analysed in at least three earlier studies by Thiele (1859, Astronomische Nachrichten 50, 257), d’Arrest (published in Wolf, 1873, Astronomische Mitteilungen der Eidgenössischen Sternwarte Zurich 4, 77) and Hoyt and Schatten (1995, Solar Phys. 160, 387). In this article, we construct a complete record of sunspot positions covering the years 1761 and 1764–1777. The resulting butterfly diagram shows the characteristic structure known from observations in the 19th century.
and 20th century. We do see some indications of equatorial sunspots in the observations we have from Cycle 1. However, in Cycle 2, which has much better coverage, we do not see such indications.

1. Introduction

Christian Pedersen Horrebow was director of the Royal Danish Observatory at Rundetårn in Copenhagen (55°40′53.00″N, 12°34′32.99″E) from 1753 until his death in 1776. In Jørgensen et al. (2019) (Paper I) we present a biography and the complete bibliography of Christian Horrebow. We also present English translations of 11 of Christian Horrebow’s publications in Dansk Historisk Almanak and one in Skrifter som udi Københavnske Selvskab af Lærdoms og Videnskabers Elsker.

Based on these publications we argue that Christian Horrebow was more productive than previously given credit for with detailed observations being performed over more than a decade under his leadership. Already in 1775 Christian Horrebow thus suggested that the Sun repeats itself with respect to the number and size of spots after a certain number of years, i.e. that the Sun is cyclic. We suggest that the reason why Christian Horrebow’s finding has not attracted more attention is due to the tarnished reputation he earned due to the unfortunate affair with the 1761 Venus transit and because Christian Horrebow published his findings in Danish.

A similar phenomenon is seen with the discovery of the butterfly diagram or Spoerer’s law, which is generally credited to Richard Carrington. Malapert however, noted the jump from near-equator to high-latitude sports at the cycle transition already in 1620 (Neuhäuser and Neuhäuser, 2016).

Here, we continue and analyse the observing notebooks made under Christian Horrebow. These notebooks have previously been analysed by Thiele (1859), d’Arrest (published in Wolf, 1873) and Hoyt and Schatten (1995), who also constructed their individual sunspot record based on them.

Christian Horrebow made his sunspot observations at a time of which we have very few other records of sunspot observations (Hoyt and Schatten, 1998a,b; Clette and Lefèvre, 2016; Svalgaard and Schatten, 2016). In fact the solar disc drawings by German astronomer Johann Caspar Staudacher, which covers the period from 1749 to 1799, appear to be the only observations covering this period. Additionally, the observations are from a period where the different reconstructions of solar activity disagree significantly (Clette and Lefèvre, 2016).

Another particular thing about the solar cycles in the last part of the 18th century is that they deviated significantly from the mean period length of 11.0 ± 1.2 year (Hathaway, 2015) as Cycles 3 and 4 were only 9.0 and 9.3 years, respectively, while Cycle 4, with 13.6 years, is the longest cycle on record. There is however, evidence that suggests that Cycle 4 was indeed two cycles (Usoskin et al., 2009; Karoff et al., 2015). This would bring the mean cycle length closer to 10 years.

Though it could be argued that it would be appropriate to make yet another sunspot reconstruction based on Christian Horrebow’s notebooks, this is not the aim of this study. Instead we want to construct a record of the sunspot positions
based on Christian Horrebow’s notebooks. From our analysis in Paper I and our
analysis of the notebooks, it is clear that such a record can be constructed based
on them. Such a record would clearly aid our understanding of the evolution of
the solar cycle and the solar dynamo as it would allow us to make a butterfly
diagram, measure the strength of the surface differential rotation and measure
the sunspot group tilt angles. All, important ingredients in understanding the
evolution of the solar cycle and in making dynamo models.

A reconstruction of the butterfly diagram in the 18th century has been pro-
duced by Arlt (2009) (see also Arlt, 2008) based on the drawings by Staudacher.
This reconstruction suggests that equatorial sunspots were common in the 18th
century, in between the Maunder and Dalton minima, especially in Cycles 0
and 1. This phenomenon has however, rarely been observed since the Dalton
minimum. Equatorial sunspots suggest the presence of a dynamo mode that is
symmetric around the equator (Arlt, 2009). Though Arlt (2009) argued that
the equatorial sunspots are not related to the quality of the observations, the
finding is of such an importance that it called for an independent test. In other
words, do Christian Horrebow’s observations confirm the presence of equatorial
sunspots in Cycle 1 and if so, have they disappeared in Cycle 2?

This article is arranged as follows. In Section 1 we provide a general in-
troduction to Christian Horrebow and the important questions related to his
work. In Section 2 we provide a more specific introduction to the notebooks.
An analysis of the notebooks is presented in Section 3. The reconstruction of
sunspot positions is given in Section 4 and a butterfly diagram is presented in
Section 5. A discussion of our findings can be found in Section 6 and concluding
remarks in Section 7.

2. The Notebooks

The sunspot observations from Rundetårn were documented in 36 handwritten
notebooks. The observations by Christian Horrebow and his assistants for the
year 1761 and 1764–1777 can be found in books 1–21. It is likely that the
notebooks containing observations from before 1761 and observations for the
years 1762 and 1763 were lost in the bombardment of Copenhagen in 1807.
Observations from the solar eclipse in 1787 can be found in book 24 and ob-
servations from 1806 can be found in book 30. Books 22-23 and 25-29 do not
contain any sunspot observations. The notebooks can be separated into two
different categories: observations protocols and fair-copies. Here books, 8, 10,
12, 14, 16, and 19 fall in the category of fair-copies and there rest are protocols.
Nearly all the text is in Latin, except for some technical comments in book 4
and 30, which are in Danish.

The quality of the drawings varies a lot, sometimes they appear as real draw-
ings of high quality with detailed distinction between umbrae and penumbræ
and sometimes they appear more as sketches supporting the tables. In general
the drawings do appear as supporting material for the tables and the positions
provided in the tables seem much more reliable than the positions provided in
the drawings.
From time to time the notebooks contain detailed drawings of houses, woods and fields often made with the instrument *Rota Meridiana*. These are likely made in order to test if the instrument has changes since the previous year.

In general, the fair-copies are systematised in a way, which suggests that these books have another purpose than the protocols. The fair-copies do also not contain a single drawing. All, expect one of the fair-copies contain the same tables as in the protocols. Book 18, which is a protocol, ends however, very strangely on 30 June 1776, even though the notebook contains a lot of blank pages hereafter. Here book 19, which is a fair-copy can be used, as it contains the entire year 1776. The sudden end of book 18 could indicate that the notebook was in fact mainly written by Christian Horrebow, as he died on 15 September 1776 though Leivog was still the most common observer after July 1775 (see Paper I).

Apart from the sunspot observations the notebooks contain stellar observations and solar observations for correcting the time. The purpose of the stellar observations was mainly to obtain a list of fixed stars that could be used for determining parallaxes. The solar observations for correcting the time, were conducted with *Machina Äquatorea* symmetrically before and after mid-day.

The main instrument for sunspot observations was *Machina Äquatorea* (see Paper I for a detailed description of this instrument). Observations with this instrument however, first started in 1767 (book 4). In the earlier years *Rota Meridiana* and *Quadrans* were the most used instruments and the one called *Machina Parallactica* was used a few times. The first part of book 4 contains a number of descriptions, often in Danish, of adjustment to *Machina Äquatorea* and it is clear that a lot of effort was put into improving the observations. None of the later books contain a similar description of adjustments to the instruments and so it appears that the adjustments were successful and the obtained precision satisfactory. The last description of such an adjustment is from 25 September 1767. The observations with *Machina Äquatorea* continued until 1777.

The observations conducted from 1767 to 1777 with *Machina Äquatorea* all contain a table with two columns and a drawing. As in the articles in the *Dansk Historisk Almanak* the tables describing the observations performed with *Machina Äquatorea* contain a horizontal axis with positions in hours, minutes, and seconds and a vertical axis with positions in screw turns. The positions were recorded as described in Paper 1. All observations contain measurements of the diameter of the Sun in both directions. In the vertical direction this can be used to transform the screw turns into hour angles.

The first notebooks only contain simple drawings, which seem more to play the role of illustrating the content in the tables than actually illustrating what goes on the Sun. This changes from 1770 (book 7) with the inauguration of the *Telescopium Gregorianum 2’*. It appears that this telescope was only used for making drawings and not for producing the content in the tables. The drawings produced with *Telescopium Gregorianum 2’* are however, of a much higher quality than the drawings made with *Machina Äquatorea* and they often contain clear distinctions between umbra and penumbra.

It is clear that the observations were not only performed by Christian Horrebow, but also, or mainly, by a number of assistants. It is likely that Christian
Horrebow wrote the articles in *Dansk Historisk Almanak* (see Paper I for this discussion).

### 3. Analysis of the Notebooks

The aim of the analysis of the notebooks is to produce a sunspot record containing the heliographic coordinates of the spots. From these records we will construct a butterfly diagram and in future publications we plan to analyse differential rotation and sunspot tilt angles. The aim of the analysis is not to construct the most reliable record of the sunspot number as this would demand going carefully through all the handwritten Latin comments in the notebooks.
We have not provided a record of sunspot groups in the notebooks, only of the individual sunspots. While reading the notebooks, it was not clear to us, how the sunspot groups could be counted in an objective way. We do however, speculate that the heliographic coordinates can be used, in an objective and transparent way, to calculate the number of sunspot groups. If fact, such a method could be a side product of measuring the sunspot tilt angles. We have however, not tested if this is possible.

We have also not been able to estimate the sizes of sunspots. Most of the spots in the drawings are just point sources that do not allow the area to be measured. Though some drawings do, as these are more realistic, using them for measuring sizes of sunspots would likely be highly biased to larger spots, as they would attract more attention and therefore the observers would been much more inclined to make a realistic drawing of a larger spot, than of a small one.

In order to construct a sunspot record containing heliographic coordinates, we reanalysed Book 1–21.

Book 24 and 30 were omitted as observations were performed under the supervision of Thomas Bugge and not Christian Horrebow and as these observations are rather detached from the other ones and of a lower quality.

Some of Book 1, 2 and 3 only include one coordinate in the tables and no drawings. As we cannot directly calculate heliographic coordinates based on this, the observations have also been omitted (an inference of the positions similar to Neuhauser, Arlt and Richter (2018) goes beyond the scope of this study). We do, however, note that the information in notebook 1, 2, and 3 is clearly good enough for calculation of the sunspot number, only the heliographic coordinates are a problem.

A number of tests with following spots on different days have shown us that the information in the tables is more reliable than the information in the drawings. Therefore, whenever informations are available in the tables we use them. It does however, happens that more spots are provided in the drawings than in the tables. We therefore want to include the information in the drawings whenever it is not available in the tables. For this we made a small program which would overlay the spots in the tables on the images of the drawings. The image size and rotation could be adjusted to align the spots from the tables with the spots in the drawings. When this was done, it was possible to mark, in the images of the drawings, the positions of spots, which are not present in the tables; those positions would then be provided in the same coordinate system as in the tables – except for a few cases where the tables were made from the top and not the bottom limb.

The task of aligning the tables and the drawings was not trivial as the match was not perfect. We expect that this is due to the drawings being illustrations of the tables rather than realistic drawings of the Sun.

A complete table with all the processed results for all sunspots, including heliographic coordinates, can be found in the electronic supplementary material. An example of some of the information in the table can be found in Table 2.
Table 2. Example of sunspot position reconstruction. The complete table with additional information is available as electronic supplementary material. RM stands for Rota Meridiana.

| Date       | Image | Longitude | Latitude | Instrument |
|------------|-------|-----------|----------|------------|
| 1761 05 05 10 57 | 6980b | 8.8       | 7.2      | RM         |
| 1761 05 05 10 57 | 6980b | 3.3       | 1.1      | RM         |
| 1761 05 05 10 57 | 6980b | 352.6     | 19.8     | RM         |
| 1761 05 05 10 57 | 6980b | 283.0     | -9.6     | RM         |
| 1761 05 05 10 57 | 6980b | 255.5     | 0.4      | RM         |
| 1761 05 05 10 57 | 6980b | 251.7     | -2.1     | RM         |
| 1761 05 05 10 57 | 6980b | 237.1     | -4.3     | RM         |
| 1761 05 08 10 56 | 6984  | 322.3     | 42.7     | RM         |
| 1761 05 08 10 56 | 6984  | 311.9     | 42.4     | RM         |
| 1761 05 08 10 56 | 6984  | 308.6     | 39.1     | RM         |
| 1761 05 08 10 56 | 6984  | 307.4     | 43.8     | RM         |
| 1761 05 08 10 56 | 6984  | 300.3     | 24.6     | RM         |
| 1761 05 08 10 56 | 6984  | 287.2     | -12.0    | RM         |
| 1761 05 08 10 56 | 6984  | 261.2     | -7.5     | RM         |
| 1761 05 08 10 56 | 6984  | 257.2     | -7.2     | RM         |
| 1761 05 08 10 56 | 6984  | 222.8     | 25.0     | RM         |
| 1761 05 08 10 56 | 6984  | 221.5     | 24.6     | RM         |
| 1761 05 08 10 56 | 6984  | 220.9     | 22.5     | RM         |
| 1761 05 08 10 56 | 6984  | 218.2     | 23.1     | RM         |
| 1761 05 08 10 56 | 6984  | 240.6     | -8.5     | RM         |
| 1761 05 08 10 56 | 6984  | 215.8     | 20.7     | RM         |
| 1761 05 08 10 56 | 6984  | 205.2     | 25.1     | RM         |
| 1761 05 08 10 56 | 6984  | 231.1     | -3.7     | RM         |
| 1761 05 08 10 56 | 6984  | 220.8     | -12.9    | RM         |
| 1761 05 08 10 56 | 6984  | 195.2     | -12.2    | RM         |

4. The Sunspot Number Series

We have used the information in Table 2 to calculate a sunspot number. This was done just by calculating the number of spots present at any day where observations were undertaken. In order to be able to make a fair comparison to other records, we have added days, where it is stated in the notebooks that observations were made, but no sunspots were seen. We have however, not included sunspot observations where we cannot obtain complete heliographic coordinates directly.

The sunspot number as a function of time is provided in Figure 1. The observations clearly show the indication of a solar cycles with a maximum in 1770. We have compared this sunspot record to three other records based on the observations by Christian Horrebow. The different records do not show perfect
agreement, which is, at least partly, due to the fact that they do not measure the same thing. Hoyt and Schatten (1995) reconstructed only the number of sunspot groups, whereas d’Arrest and Thiele (1859) reconstructed both sunspot groups and individual sunspots. Even though d’Arrest and Thiele (1859) measured the same quantity, groups, their reconstructions do also not show perfect agreement.

The first comparison is made with the record compiled by Hoyt and Schatten (1995) based on the original notebooks, i.e. that same material used in this
Figure 3. Sunspot record compiled by Thiele (1859). The solid line represents the monthly mean.

study. The sunspot number is calculated as the group sunspot number (Hoyt and Schatten, 1998b), however some differences can be expected between this and other records (see Figure 2). For this study we used the daily measurements that were available at the ftp server given in Hoyt and Schatten (1998b). Unfortunately, the link to the ftp server has not been active for some years. The measurements can now be found at the webpage of the National Geophysical Data Center.

The second record containing sunspot monthly means was compiled by Thorvald Nicolai Thiele (Thiele, 1859) (see Figure 3) and the third record was compiled by Heinrich Louis d’Arrest and published by Wolf (1873) (see Figure 4).

It appears that d’Arrest was not only the doctoral thesis supervisor of Thiele. Thiele also succeed d’Arrest in 1875 as professor at Copenhagen University and as director of the observatory. A position d’Arrest had held since 1857 (Pedersen and Schneider, 2018). Therefore, when Thiele published his record in 1859 as an astronomy student, he must have been one of the first students of d’Arrest. When d’Arrest later sent his record to Wolf in 1873, only two years before he died and Thiele took over his position, he must surely have known about Thiele’s record and considered his record as an improvement. It is not clear why d’Arrest’s records only contain sunspot observations from 1767 to 1776, but we speculate that this was done only to include the superior observations made with Machina Äquatorea.

The records by both Thiele (1859) and d’Arrest gives both the number of sunspot groups and the number of individual sunspots. We have calculated the

\[ \text{http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-indices/sunspot-numbers/group/} \]
Figure 4. Sunspot record compiled by d’Arrest. The solid line represents the monthly mean.

The sunspot number can be formulated as:

\[ R = (10g + s), \quad (1) \]

where \( R \) is the sunspot number, \( g \) is the number of sunspot groups, and \( s \) is the number of individual sunspots.

Caution should be taken when comparing the different sunspot reconstructions, as they were clearly not made using the same assumptions. Especially, definitions of what is an individual sunspot and what is a sunspot group changes between observers. Here it appears that Thiele (1859) has a larger likelihood of calling something a sunspot group than d’Arrest had (Hoyt and Schatten, 1995). Also, Hoyt and Schatten (1995) have only provided records of sunspot groups, whereas we have only provided records of individual sunspots. We have however, tried to compare the four different reconstructions. This has been done by binning the four reconstructions to the same monthly grid. This allowed us to both calculate the correlation between the different reconstructions and to plot the different reconstructions as a function of each other (Figures 5–10). In general, it is seen that the correlations are close to or above 0.9 between all reconstructions. The correlation between d’Arrest and Thiele (1859) (Figure 10) is even above 0.95, which is not surprising given the close connection between the two.

As expected the correlation analysis shows agreement, though not perfect, between the different reconstructions. We are not able to identify, based on the correlation analysis, if one of the reconstructions is better than the other. Our reconstruction will however, be the first one that will also provide sunspot positions.
5. Butterfly Diagram

In order to construct a butterfly diagram we need to transform the measured sunspot positions into heliographic coordinates. From the drawings, it is seen that the spots move from right to left over time, which suggests that the sunspot drawings are rotated 180 degrees with respect to the positions in the tables. There is however, no mention of any rotation of the images in the notebooks. By
Figure 7. Correlation between the sunspot reconstruction in this work and the reconstruction by Thiele (1859).

Figure 8. Correlation between the sunspot reconstruction by Hoyt and Schatten (1995) and the reconstruction by d’Arrest.

Comparing the drawings with the positions in the tables, it is seen that the time of the leftmost spot is recorded first so the western limb is situated on the left. Before each vertical measurement, it is written from which limb, top or bottom, the vertical distance of spots is measured. The positions in the tables agree well with the alignment of limbs in the drawings. Hence, the western limb of the Sun is situated on the left whereas the eastern limb is situated on the right and the bottom limb is the northern limb. All sunspot drawings seem to have this
orientation, except for a few drawings from July and November 1761 that are rotated by 180° compared to the positions provided in the tables.

The sunspot observing times are given in local sidereal time. We checked the observing times by calculating the solar elevation angles for the corresponding times and found that the times of 35 observations were incorrect as they showed solar elevation angles of less than 0°. Most of these incorrect times referred to the times around midnight, that is why it is likely that these errors are due to...

Figure 9. Correlation between the sunspot reconstruction by (Hoyt and Schatten, 1995) and the reconstruction by Thiele (1859).

Figure 10. Correlation between the sunspot reconstruction by d’Arrest and the reconstruction by Thiele (1859).
confusion between a 12 h and 24 h time system. We thus added 12 h to these 35 observations and recalculated the solar elevation angle. Now, all observations of the Sun were above the horizon. Figure 11 shows the local hour angle, which is the right ascension subtracted from the local sidereal time, for the sidereal observing times of the eastern limb of the solar disc. The red boxes in the plot correspond to the observing times, which showed negative solar elevation angle before the addition of 12 h, and the green boxes correspond to the corrected sidereal times of observation with an addition of 12 h. The gray area in the plot corresponds to the time between sunset and sunrise. Hence, from Figure 11, it can be seen that the times of observation fall within the period of the Sun being above the horizon after the correction to the sidereal times. The corrected sidereal times are further used for calculation of heliographic coordinates of sunspots.

![Figure 11](https://ssd.jpl.nasa.gov/horizons.cgi)

**Figure 11.** The local hour angles for the sidereal times when the eastern limb of the Sun was observed. The gray region in the plot refers to the time between sunset and sunrise. The red boxes and green boxes refer to the sidereal times before and after the addition of 12 h to the sidereal observing times of the eastern limb, respectively, while the yellow crosses refer to the unaltered readings from the observation.

The horizontal positions of sunspots are given in units of local sidereal time i.e., the time between the observations of the western limb and the spot in minutes and seconds and the vertical distance of sunspots, either from the lower or the upper limb, are given in screw turns of the instrument used. For the vertical measurements made with Machina Æquatorea and Machina Parallactican, the distance of the spots is always measured from the bottom limb. For Quadrante and Rota Meridiana, the distance of spots can be measured from either the top or the bottom limb. The orientation is, however, always given at the top of the vertical position readings. The horizontal and vertical diameters of the Sun are also given in the notebooks, either as transit times between passage of western and eastern limbs of the Sun or as screw turns. These diameters can be used to convert the horizontal and vertical sunspot positions from local sidereal time and screw turns into x and y coordinates of the spots. From the JPL HORIZONS ephemeris generator[^2] we obtain ephemeris providing, the tip of the celestial equator and the tilt of the line of sight of the Sun’s center in 6 h intervals at the geographical coordinates of Copenhagen observatory. From these ephemeris, we calculate the tip and the tilt for the times corresponding to the centre of the solar disc. The tilt of the solar disc is an important parameter in the calculation.

[^2]: https://ssd.jpl.nasa.gov/horizons.cgi
of latitudes of the sunspots, which are obtained from the vertical coordinates of the sunspots. The times at which vertical readings were measured are not given in the notebooks. However, in the observation description (Section 5.1 in Paper I), it is mentioned that the horizontal coordinates of the sunspots were measured first and then the vertical coordinates, and so the nearest known time of eastern limb passage is considered for the calculation of the tilt. The heliographic grids with the obtained tilts and tips of the Sun are imposed on the x- and y-coordinates of sunspots, and then the heliographic latitudes and the distances from the central meridian of the solar disc are obtained. The longitudes of the solar disc centre, corresponding to the sidereal times of disc centre, are obtained from the ephemeris and then the heliographic longitudes of sunspots are calculated using the longitudes of the solar disc centre and the central meridian distances of sunspots.

![Figure 12. Top panel: Butterfly diagram obtained from Christian Horrebow’s observations for the solar cycles 1–3. Bottom panel: comparison to the butterfly diagram obtained from Staudacher’s observations. The dashed lines denote the times of minima for solar cycles 2 and 3, which are taken from the “Average” column of the cycle timings by Hathaway (2015).](image)

Some of the numbers in the tables are follow by a comment: ”.”, ”−”, ”v” and ”d”. This is also the case for the tables in Horrebow’s printet articles. In Translation of Christian Horrebow’s writings in Dansk Historisk Almanak 1770 it is explained that ”.” means that one-fourth should be added to the number, ”−” means add one-half and ”v” means that one-fourth should be subtracted. ”d” on the other hand means that the number is uncertain. We have not applied these corrections to the numbers. The main reason for this is that the correction can be hard to read, especially the difference between ”.” and ”−”. Also, a correction
of half a second corresponds to less than half a degree in heliographic coordinates at solar disc center, which is far below the precision for these observations.

We obtained unique positions of 6648 spots from the notebooks for 1020 days during the years 1761, 1767–1777. Some days include more than one observation and in total we therefore have 1171 observations. The heliographic coordinates of sunspots are obtained for 6622 spots, whereas the remaining 26 spots lay outside the solar disc and so the heliographic coordinates could not be measured. Figure 12 shows the butterfly diagram calculated based on Christian Horrebow’s sunspot observations. This is also compared to the butterfly diagram calculated based on Staudacher’s sunspot observations. If there are more than one observation of a sunspot in a day, then the average of heliographic latitudes of a sunspot is used for the butterfly diagram which reduces the total number of sunspots from 6622 to 6170. The calculation of the average latitude of a sunspot is possible as the data contains label for each spot. Figure 12 shows the butterfly diagram obtained from 6170 spots of Horrebow data which covers a year during the maximum phase of solar cycle 1, full solar Cycle 2 except around a year in the beginning, and the beginning of Solar Cycle 3.

6. Discussion

The reanalysis of Horrebow’s notebooks have shown us that sunspot positions and not just sunspot numbers can be extracted from the observations. The fact that we see very few sunspots on or near the solar equator during Cycle 2 indicates that sunspot positions have a reasonable precision.

In general our result supports the conclusion by Arlt (2009), based on observations by Staudacher, that Cycle 0 and 1 contained a significant number of sunspots on or near the solar equator, while Cycle 2, 3, and 4 did not, though this is mainly based on the observations in 1761. Our measurements do therefore not contradict the suggestion by Arlt (2009) of the presence of a dynamo mode that is symmetric around the equator between the Maunder and Dalton minima. Future studies of i.e. tilt angles will allow us to test this hypothesis even further.

The aim of this study has not been to reconstruct the most reliable sunspot number record and in comparison with other sunspot number reconstructions, ours does not also stand out. In fact one can argue that our reconstruction is less reliable as we do not reconstruct the group sunspot number. We do, however, speculate that the sunspot positions can be used to calculate a group sunspot number in an objective and transparent way. Such a procedure would have the advantage that it could provide not only the group sunspot number, but also the tilt angles of the sunspot groups. The tilt angles of the sunspot groups have lately received renewed attention with the growing interest in flux transport dynamo models (see i.e. Dikpati and Charbonneau, 1999). We have earlier used similar historic observations to reconstruct tilt angles of sunspot groups (Senthamizh Pavai et al., 2015, 2016; Arlt et al., 2016) and intend to do the same for the Horrebow observations in a forthcoming paper (Senthamizh Pavai in preparation).
7. Conclusion

In this article we present a reanalysis of the sunspot observations by Christian Horrebow covering the period 1761 and 1764–1777. Contrary to an earlier analysis of Christian Horrebow’s observations we also reconstruct the sunspot positions, which allows us to calculate a butterfly diagram covering the maximum phase of Cycle 1, full Cycle 2 except around a year in the beginning, and the beginning of Cycle 3. The butterfly diagram is in agreement with similar observations by Staudacher (Arlt, 2009) that Cycle 0 and 1 did contain sunspot on or near the solar equator, while Cycles 2, 3 and 4 did not.

This article is the second one in our series on Christian Horrebow’s observations of the Sun. Paper I contains a biography and a complete bibliography of Christian Horrebow and we expect a forthcoming article that will present tilt angles of the sunspot groups observed by Christian Horrebow (Senthamizh Pavai in preparation).

In connection with this paper, a version of Horrebow’s notebooks is made available as electronic supplementary material.

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