On the Use of Naked-eye Sunspot Observations during the Maunder Minimum

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Abstract

Naked-eye sunspot observations (NESOs) have been recorded for the past two millennia, approximately. These kinds of records were made around the world, mainly in Asian civilizations, and they are compiled in several catalogs. In this work, we analyze solar activity on days of the 19th century when NESOs were recorded. We found that only more than five sunspot groups were recorded in 39% of days corresponding to these NESO events. Furthermore, regarding the largest groups observed on days when NESOs were reported, we show that the uncorrected areas of these groups were below 200 millionths of solar disk (msd) in 32% of total cases, while it is 12.9% for areas between 200 and 499 msd. Thus, NESO records do not necessarily imply high solar activity and big sunspot groups. Therefore, these results contradict the interpretations of recent works that, using the same N ESO set, suggest the solar activity level during the Maunder Minimum is still an open question. NESO records support the Maunder Minimum as a very low solar activity period.

Unified Astronomy Thesaurus concepts: Sunspots (1653); Solar activity (1475); Maunder minimum (1015)

1. Introduction

Sunspots can be observed with the naked eye under certain conditions of visibility (Schaefer 1993). Naked-eye sunspot observations (NESOs) constitute a heritage of enormous interest for the history of astronomy and the study of the physical conditions of the Sun during the past 20 centuries (Vaquero & Vázquez 2009). In recent decades, several researchers have made a great effort to understand the advantages and limitations of this type of record. Thus, several studies have concluded that historical, social, and meteorological factors clearly affect the record frequency of these observations (Hameed & Gong 1991; Chen et al. 2020).

Most NESOs were made by Asian civilizations such as China, Korea, and Japan (Kimematsu 1970; Tamazawa et al. 2017), although there are also western and other records around the world (Willis & Stephenson 2001; Vaquero & Gallego 2002). We can note that many observations made by Asian astronomers were carried out during sunsets in order to try to detect the first quarter of the Moon that regulated the calendar. There are around 300 known NESOs preserved in historical documents and collected in different catalogs (Wittmann & Xu 1987; Yau & Stephenson 1988). This observation set has been used in different studies of solar activity. For example, Vaquero et al. (2002) presented an annual series of NESOs for the period 165–1918 AD showing a 250 yr cycle, and Lee et al. (2004) studied the sunspot and auroral cycle from Korean records corresponding to the period of the 11th–18th centuries. For a recent review, see Section 2 in Arlt & Vaquero (2020).

In a benchmark article, Eddy (1976) established that the level of solar activity in the period 1645–1715 was very low. This period was called Maunder Minimum (MM). Cullen (1980) questioned the low level of solar activity during the MM using NESOs from oriental chronicles. Clark & Stephenson (1980) strongly criticized this result and, months later, a thorough study of the seasonal variability of NESO was published (Willis et al. 1980) concluding that oriental sunspot records likely provide circumstantial evidence of solar activity. A few years later, Xu & Jiang (1982) used the argument of the existence of NESOs in this period recorded in local Chinese histories to refute the existence of the MM, but this idea was quickly rebutted by Eddy (1982).

History repeats itself again, and some works in the recent past used NESOs recorded during the MM to suggest high solar activity in this period (Ogurtsov et al. 2003; Zolotova & Ponyavin 2015). Recently, Wang & Li (2020) have studied the sizes of NESOs recorded in the period 1819–1918 from the sunspot number index. Extrapolating the statistical results to the 12 NESOs recorded during the MM in Yau & Stephenson (1988), these authors concluded that at least 8 of those 12 NESOs should be identified as large sunspots and 4 as giant. Based on that argument, Wang & Li (2020) suggest that the solar activity level during the MM is still an open question.

In this work, we analyze the number of groups and the sizes of the largest groups observed on days when NESOs were recorded in the 19th century as in Wang & Li (2020). Data used in our analysis are presented in Section 2. The analysis and discussion of these data are given in Section 3, and Section 4 includes the main conclusions of this work. According to our analysis, the very low level of solar activity during MM cannot be questioned using our current knowledge of NESOs.

2. Data

There are 31 NESOs recorded between 1819 and 1885 according to Wang & Li (2020). Table 1 includes some information on these NESOs of the 19th century. We note that some of them seem to be the same sunspots observed in close days. One example of this fact could be the NESOs recorded on 1873 February 23 and 24. In this case, we can group all NESOs in 27 different “events.”

We have consulted several documentary sources in order to obtain the data presented in Table 1. Thus, we have extracted useful information from the observations by Tevel (1819), Schwabe (1829–1865), Secchi (1872), the Ogyalla and...
Table 1
Information on Solar Activity on Days when NESOs Were Recorded for the Period 1819–1885

| Year | Month | Day | Groups | Observer |
|------|-------|-----|--------|----------|
| 1819 | 9     | 3   | 3      | T*       |
| 1829 | 4     | 24  | 7      | S*       |
| 1829 | 4     | 27  | 8      | S        |
| 1839 | 8     | 14  | 5      | S        |
| 1848 | 5     | 9   | 6      | S        |
| 1851 | 12    | 25  | 8      | S*       |
| 1852 | 1     | 19  | 5      | S*       |
| 1852 | 3     | 22  | 5      | S        |
| 1852 | 4     | 2   | 8      | S        |
| 1852 | 12    | 29  | 6      | S        |
| 1853 | 2     | 22  | 4      | S*       |
| 1853 | 5     | 11  | 2      | S        |
| 1853 | 5     | 17  | 3      | S        |
| 1853 | 6     | 21  | 3      | S        |
| 1853 | 8     | 19  | 3      | S        |
| 1855 | 1     | 20  | 2      | S        |
| 1856 | 2     | 8   | 2      | S*       |
| 1856 | 9     | 13  | 1      | S        |
| 1860 | 12    | 4   | 10     | S        |
| 1861 | 3     | 30  | 9      | S        |
| 1861 | 11    | 24  | 5      | S        |
| 1863 | 3     | 19  | 2      | S*       |
| 1863 | 4     | 2   | 3      | S        |
| 1865 | 4     | 9   | 1      | S        |
| 1865 | 7     | 18  | 2      | S        |
| 1872 | 2     | 3   | 8      | SC       |
| 1873 | 2     | 23  | 8      | O*       |
| 1873 | 2     | 24  | 8      | O*       |
| 1874 | 12    | 9   | 3      | GPR      |
| 1883 | 12    | 26  | 10     | O and H  |
| 1885 | 7     | 5   | 4      | O and H  |

Note. Year, month, and day are represented in the first three columns, number of groups observed in that day (or the closest day) are reported in the fourth column, and the astronomer/observatory responsible for the observations (“T” refers to Tevel, “S” to Schwabe, “SC” to Secchi, “O” to Oggyalla Observatory, “GPR” to Royal Greenwich Observatory, and “H” to Haynald Observatory) is indicated in the sixth column. The asterisk symbol “*” depicts when there are no available records in a day when NESOs were recorded and then information corresponding to the closest day is provided.

Haynald Observatories in Hungary (1872–1885), and the Royal Greenwich Observatory (1874–1885). We highlight the sunspot observations analyzed in this work that were made by outstanding observers of that time, and therefore we can consider they are of good quality. We could not find information for the following dates: 1819 September 3, 1829 April 24, 1851 December 25, 1852 January 19, 1856 February 8, 1863 March 19, and 1873 February 23–24. Instead, we provide information corresponding to the closest dates available for these dates, that is, 1819 September 4, 1829 April 23, 1851 December 22, 1852 January 18, 1856 February 9, 1863 March 20, and 1873 February 19.

3. Analysis and Discussion on NESOs Recorded for the Period 1819–1885

We have analyzed the number of groups recorded for those days corresponding to NESOs included in Wang & Li (2020) during the period 1819–1885. Figure 1 depicts the number of cases (purple) and different events (green) as a function of the number of groups observed on dates when NESOs were recorded. The highest values in the number of groups recorded regarding the number of individual cases are when three and eight sunspot groups were observed, while it is three sunspot groups taking into account different events. Regarding different events, the second highest value is when eight sunspot groups were recorded. Furthermore, only around 39% of NSEO cases are recorded when the number of sunspot groups is higher than five and 42% when less than four groups were observed. If we consider the number of different events for the period 1819–1885, the results are very similar: around 37% of NESO events occurred when more than five groups were recorded and 63% when the number of groups observed was five or fewer (41% when three or fewer groups were recorded). Thus, this first analysis shows that NSEO records do not imply that solar activity on days when these NESOs were reported was high.

We have also calculated the sizes of the largest groups recorded on days when NESOs were reported during the period 1819–1885. Full spot areas (umbra and penumbra) were measured by using Sunspot, software created to calculate the sunspot positions and areas (Galaviz et al. 2020). We note that (i) Schwabe’s drawings corresponding to 1829 April 23 and 27 do not present penumbral areas (Arlt et al. 2013), (ii) area values corresponding to the largest groups recorded on 1874 December 9, 1883 December 26, and 1885 July 5 were taken from http://fenyi.solarobs.csfk.mta.hu/en/databases/GPR/, and (iii) no sunspot drawing could be found corresponding to 1872 February 3 or on close dates, and therefore areas were not calculated for that day. In order to analyze the area in NSEO records, we used the uncorrected areas by foreshortening, which are more suitable to their study. Some works (Schaefer 1993; Vaquero & Vázquez 2009; Usoskin et al. 2015) affirm no sunspots smaller than around 500 millionths of solar disk (msd) can be observed by the naked eye, and any sunspot greater than around 1000 msd is observable. However, Neuhäuser et al. (2020) show that a good naked-eye sunspot observer under determined atmospheric conditions could even detect sunspots with areas below around 150 msd. In our study, 3.2% of areas of the largest groups recorded on days when NESOs were reported were below 200 msd, 12.9% between 200 and 499, 35.5% between 501 and 1000, and 48.4% above 1000 msd. This means that NESOs were generally recorded on days when the area of the largest group was big, but a significant percentage was recorded when areas were small (16.1% for groups smaller than 500 msd). An example of this fact can be seen in Figure 2 where it is represented by the sunspot drawing made by Schwabe on 1856 September 13 (date when one NSEO was recorded) with only a small sunspot group. Therefore, NSEO records also do not necessarily imply big spots. We acknowledge the difficulties of obtaining area measurements from historical sunspot drawings. For example, Schwabe draw sunspots into circles of about 5 cm diameter. Thus, pores would need to have diameters of 0.04–0.1 mm and given the width of a pencil tip, at least small spots could be overestimated in the drawings (Senthamizh Pavai et al. 2015). We note that measurements calculated by Senthamizh Pavai et al. (2015) were not used in this work because only umbral areas, and not full spot areas, are provided. Moreover, the typically exaggerated spot sizes in drawings provide us upper limits and the real areas, which were seen by the naked eye, are even smaller.
Wang & Li (2020) suggested that 8 of the 12 NESOs recorded during the MM in Yau & Stephenson (1988) could be large sunspots and four giant sunspots, and therefore the level of solar activity for this period requires wider investigations. However, they are actually an argument for low solar activity because there are very few NESOs during the core and the end of the MM. A. D. Wittmann (1992, personal communication) and Xu et al. (2000) compiled more complete NESO catalogs based on the sunspot data published by Wittmann & Xu (1987) and Yau & Stephenson (1988). For example, A. D. Wittmann (1992, personal communication) provides 15 NESO records during the MM, three more cases than Yau & Stephenson (1647 July 28, 1660 May 22, and 1659 June 12) and Xu et al. (2000) one more additional NESO record on 1661 July 5. Furthermore, regarding the number of independent NESO events (as explained previously) recorded from 1600, A. D.
Wittmann (1992, personal communication) and Xu et al. (2000) recorded respectively: four and three independent NESO events during the decade of the 1600s, six in both cases in the 1610s, nine and eight both in the 1620s and the 1630s, four and five in the 1640s, four in both cases in the 1650s, five and six in the 1660s, zero in both cases in the 1670s, and one in both cases in the 1680s (Figure 3). Moreover, A. D. Wittmann (1992, personal communication) provides zero independent NESO events in the 1690s, one in the 1700s, and zero in the 1710s. In particular, if we consider the period 1667–1708, i.e., 42 yr (almost all the MM), only one NESO is included in A. D. Wittmann (1992, personal communication). This fact is outstanding, and there is no similar example during the telescopic era regarding the same data set by A. D. Wittmann (1992, personal communication) from 1600 to 1992. In addition, we highlight that a new study of Asian dust-storm activity (Chen et al. 2020) provides new arguments to understand the “high” number of NESOs during the first years of the MM. Obviously, a high activity of Asian dust storms implies higher probability of NESOs because the atmospheric aerosol acts as a natural filter and enlarges the time windows suitable for this kind of observation. The results obtained by Chen et al. (2020) shows a high Asian dust-storm activity when some sunspots were observed at the onset of the MM. Moreover, the number of NESO records during the 18th century was also low, although slightly higher than that in the MM. The main reason for this fact is probably that this century matches with a minimum in the number of dust storms in Asia (Chen et al. 2020), where the vast majority of NESO records were recorded. Then, a greater increase in the NESO records can be seen in the 19th century. We highlight that the peak of NESO records in the 1840s, 1850s, and 1860s is because of a significant increase in the number of NESO records made in western civilizations with respect to other decades: 18 records in the 1840s, 13 in the 1850s, and 9 in the 1860s.

We also show an example when one NESO was recorded just before the MM and only small groups were on the Sun. This is the case corresponding to 1643 July 2 when one NESO was recorded: “Within the Sun there was a black vapor shaped like a flying bird” (Yau & Stephenson 1988). However, the sunspot observation made by Hevelius (Hevelius 1647; Carrasco et al. 2019) shows two small sunspot groups for that date (Figure 4): the biggest around 300 msd (next to the western limb) and the other around below 200 msd. We also found some examples of possible inconsistencies between the telescopic observations and NESO catalogs at the beginning of the MM. According to Xu (1983), included in A. D. Wittmann (1992, personal communication) and Xu et al. (2000), “On the Sun there was a black light shimmering” on 1659 June 12 and “Black vapor on the Sun” was recorded on 1660 May 22, both from China. We found sunspot observations recorded by Hevelius on days close to these dates (Carrasco et al. 2015). Hevelius made observations on 1659 June 6 and 13 and on 1660 May 21 and 27 reporting no sunspots were on the Sun for these dates. Furthermore, according to the sunspot group database (Hoyt & Schatten 1998; Vaquero et al. 2016), Picard recorded one group from 1660 May 7 to 19 and then zero groups on 1660 May 20. If the observations really refer to sunspots, these could have been very small short-living groups only. Therefore, moderate or high solar activity seems unlikely in those days, as does the appearance of great sunspots on the solar disk.

4. Conclusions

Wang & Li (2020) analyzed NESO records made during the period 1819–1885. Extrapolating their analysis for that period to the MM, they suggest that 8 of 12 NESOs recorded during the MM should be identified as large sunspots and 4 as giant. Wang & Li (2020) point out this fact implies that the solar activity level for the MM is still an open question despite the fact that the reconstructions based on telescopic observations show otherwise (Muñoz-Jaramillo & Vaquero 2019).

In this work, we have studied solar activity on dates corresponding to the NESO data set analyzed by Wang & Li (2020). We found that 42% of NESO records analyzed in this work were recorded on days when less than four groups were observed on the Sun and only around 39% of cases when the number of sunspot groups is higher than five. Moreover, 3.2% of the uncorrected areas of the largest groups recorded on days when NESOs reported were below 200 msd and 12.9% between 200 and 499 msd. Therefore, we conclude that NESO records do not necessarily imply high solar activity or big sunspot groups. We note that even very low solar activity does not necessarily imply small spots (see, e.g., Neuhäuser et al.
We also highlight that Usoskin et al. (2015) analyzed the NESOs recorded by Schwabe for the period 1825–1867 showing that around 25% of these NESOs were reported for the years when the group sunspot number was below 20 and about 20% of NESOs by Schwabe were reported on days with only one group on the Sun. Thus, our results agree with those obtained by Usoskin et al. (2015) and NESO records should not be used in a simple way as an indicator of solar activity.

Regarding the MM, there is only one NESO record from 1667 to 1708 (42 yr, almost all the MM). This argument could be used to show the low solar activity during the MM because there is no other similar case in the telescopic era. Furthermore, we have shown other example just before the MM from Hevelius’ drawing in one day (1643 July 3) when a NESO was recorded and low solar activity and only small groups were recorded. We also found some examples of possible inconsistencies between the telescopic observations and NESO records at the beginning of the MM. NESO were recorded on 1659 June 12 and 1660 May 22 from China. However, Hevelius recorded that no sunspots were observed on the Sun on 6 and 1659 June 13 and on 21 and 1660 May 27 and Picard recorded one group from 7 to 1660 May 19 and then zero groups on 1660 May 20. Thus, high solar activity and big groups seems unlikely for these days.

Therefore, our conclusions disagree with the claim by Wang & Li (2020) that the NESO indicate higher activity during the MM than usually adopted. It is also important to understand the limitations of the NESO records. Historical and meteorological factor can influence clearly this record. For example, Hameed & Gong (1991) indicated that the annual number of NESO correlates badly with 14C from 1620 probably due to historical reasons (during this epoch local historical sources were used). The role of Asian dust-storm activity can be other key factor to understanding the NESO record because a higher number of dust storms, such as in Chen et al. (2020) for the MM, implies a higher probability of NESOs. Moreover, spot size measurements in historical drawings often lead to overestimated areas. If the true areas were smaller, the fraction of small spots seen by the naked eye will be even higher. Thus, we want to emphasize that, although NESO records provide interesting information about solar activity in the past, the correct interpretation of this kind of record must be made with caution and care, taking into account the remarkable historical, sociological, and climatological characteristics that also affect NESO records.

Figure 4. Sunspot drawing recorded by Hevelius in 1643 June–July. The sunspots recorded on 1643 July 2 are indicated by two green squares (Source: Hevelius 1647, courtesy of the Library of the Astronomical Observatory of the Spanish Navy).
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The authors declare that they have no conflicts of interest. All authors contributed to the study conception and design. The first draft of the manuscript was compiled by V.M.S. Carrasco and J.M. Vaquero and all authors read and approved the final manuscript.

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