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Rediscovering the observations of solar prominences from 1906 to 1957 recorded at the Madrid Astronomical Observatory

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Abstract – The Madrid Astronomical Observatory implemented a solar observation program from 1876 to 1986. In addition to sunspots, the observers at this observatory recorded other solar features such as prominences. In this work, we have consulted the documentary sources of the Madrid Astronomical Observatory (the information is not digitally available), digitized the records of the observers on the annual number of prominences, and constructed a homogeneous series of the total and hemispheric annual number of prominences with heights of 25″ and more for the period 1906–1957. To evaluate the quality of the data and assess their potential, we have compared the Madrid prominence series with the number of prominences recorded by the Astronomical Observatory of the University of Coimbra and other time series such as the sunspot number index, solar radio flux at 10.7 cm, and sunspot areas. We have also analyzed the hemispheric prominence numbers and the asymmetry index. We obtained the strongest correlation between Madrid and Coimbra prominence series ($r = 0.7$), whereas the correlations between the Madrid prominence series and the other solar activity time series are similar ($r \approx 0.6$). In addition, we found that the correlation coefficient between the Madrid prominence series and the sunspot number is lower than that from the Coimbra prominence series and the sunspot number. We suggest that these differences are a consequence of the way prominences were counted in the Madrid Astronomical Observatory.

Keywords: Sunspots / Prominences / Solar activity / Historical records / Madrid Astronomical Observatory

1 Introduction

Prominences are structures in the solar atmosphere appearing like arcs on or above the solar limb (Parenti, 2014). The first prominence observations were made during solar eclipses. For example, during the eclipse of 1860, the observations performed in Spain by Warren de la Rue from Rivabellosa, and by Angelo Secchi and José Monserrat from Desierto de las Palmas (using even photography) confirmed that prominences are a solar feature and their origin is not in the Moon or optic effects (de la Rue, 1862; Secchi, 1875; Foukal, 2004). Since then, spectroscopy started to develop and the first systematic observations of prominences were recorded at astronomical observatories (Bocchino, 1933; McIntosh, 1979; Makarov & Sivaraman, 1986; Rusin et al., 1988; Chatterjee et al., 2020; Carrasco et al., 2021; see also the chapter 4 of the monograph by Vaquero and Vázquez, 2009). One of these observatories where prominences were observed was the Madrid Astronomical Observatory.

The Madrid Astronomical Observatory carried out a solar observation program from 1876 to 1986 spanning from the last part of Solar Cycle 11 to the first months of Solar Cycle 22 (Ruiz-Castell, 2008; Aparicio et al., 2014). Sunspots were mainly recorded in this period at the observatory although there are some gaps in the observation series. Moreover, several sunspot catalogs were published by the observatory: the Aguilar catalog covering observations from 1914 to 1920 (Lefèvre et al., 2016), the Carrasco catalog including records for the period 1931–1933 (Aparicio et al., 2022a), and the "modern" catalog with observations for 1952–1986 (Aparicio et al., 2018). In addition to the sunspot observations, other solar features of the Sun were observed at the Madrid Astronomical Observatory such as prominences and chromospheric faculae (flocculi)

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(López Arroyo, 2004). In particular, observations of solar prominences were recorded in this observatory during the 20th century and summarized in annual tables for the period 1906–1957 (Jiménez Landi, 1913; Gullón, 1950; López Arroyo, 2004).

This work is the first step to exploring the prominent observations made at the Madrid Astronomical Observatory. In Section 2, we present the Madrid prominence observations, the instruments used, the responsible observers, and the retrieved data. We include an explanation and an analysis of the homogenized series we have constructed in Section 3 and the main conclusions of this work in Section 4.

2 The Madrid prominence series

2.1 Madrid prominence observations

Solar prominence observations were performed at the Madrid Astronomical Observatory for the period 1906–1957. Daily observations and summaries including annual data on different parameters that characterize the solar prominences were published in yearbooks and bulletins of the observatory (see Appendix). We note that there is no digital version of the prominence data recorded at the Madrid Astronomical Observatory.

In addition to the daily number of prominences, measurements of the base, height, and intensity (the latter from 1908 onwards) of the prominences were recorded. From 1907 onward, a specific drawing was made for each prominence (López Arroyo, 2004). Note that only a few examples of the drawings of the prominences recorded in Madrid were published in the yearbooks and bulletins. Figure 1 shows one of these examples including a prominence observed at the Madrid Astronomical Observatory on 11 September 1935.

Since it is not possible to have an actual idea of a prominence only from its base, height, and intensity, the International Astronomical Union agreed that the projected area of the prominences should also be recorded (Gullón, 1950). Thus, this parameter was also systematically measured from 1925 onward at the Madrid Astronomical Observatory. Since the projected areas of the prominences were not recorded in Madrid before 1925, Jiménez Landi (1925) measured it from the original observations for the period 1910–1920. Note that no observations were performed for the period 1921–1924 due to unfavorable circumstances, as mentioned by Gullón (1950). The observations continued until November 1936, when they stopped due to the Spanish Civil War (1936–1939). Then, they were performed in Valencia during the period 1937–1938 and resumed in Madrid in September 1939. The last interruption, due to a reconstruction of the pavilion of the observation tower, spanned 1942 and part of 1943. Finally, the prominence observations continued until 1957.

2.2 Instrumentation

The instrument used to carry out the first prominence observations was a Grubb spectroscope composed of four 60° prisms and two semi-prims with a configuration that produced a scattering equivalent to that obtained with ten prisms (Jiménez Landi, 1913). The spectroscope was mounted on a Grubb equatorial telescope with a 20 cm aperture and 3 m focal length. In 1925, the spectroscope was substituted by one of the Zeiss brand. In 1936, the Zeiss spectroscope was moved to Valencia and was mounted on a Zeiss equatorial telescope with a 15 cm aperture and 2.2 m focal length. In September 1939, the instrument was returned to Madrid to resume the observations at the Madrid Astronomical Observatory.

2.3 Observers

Several astronomers were responsible for the prominence observation program. It was started by Francisco Íñiguez in February 1906. From 1907 to 1921, Pedro Jiménez Landi was in charge of the observations. After that, the observations were interrupted until 1925. Then, they were resumed by Pedro Jiménez Landi. Upon his retirement in 1932, he was substituted by Enrique Gullón. During the stage in Valencia (from the end of 1936–1938), Rafael Carrasco and Mariano Martín Lorón performed the prominence observations. Finally, in 1954, Manuel López Arroyo assisted Enrique Gullón (Gullón and López Arroyo, 1955).

2.4 Data

In this work, two documentary sources including data on prominences observed at the Madrid Astronomical Observatory have been used: (1) yearbooks and bulletins of the observatory (see Appendix) and (2) the Madrid prominence series by Gullón (1950). We remind that prominence drawings were made by the observers of the Madrid Astronomical Observatory. However, they have not been considered for this work because, inter alia, only a few examples are available in the publications of the observatory. As a future task, it would be of interest to locate (and later digitize) all these original prominence drawings made in Madrid.

2.4.1 Yearbooks and bulletins (1906–1957)

The total and hemispheric prominence observations performed at the Madrid Astronomical Observatory for the period 1906–1957 were published in yearbooks and volumes of bulletins of the observatory (see Appendix). Daily records and summaries with monthly and annual values were shown in tables in those documentary sources available only in the printed version. We have extracted and combined the records from all those sources to build the annual prominence number series recorded in Madrid in digital format. Table 1 lists the total and hemispheric number of prominences per year included in the summary tables published by the Madrid Astronomical Observatory in the yearbooks and bulletins for the period 1906–1957.

We emphasize that the annual number of prominences in Table 1 does not constitute a homogeneous series because: (1) in 13 of the 47 years (1906–1910, 1918–1920, 1925, 1928, 1930, 1932 and 1938), not all the prominences observed at the Madrid Astronomical Observatory were taken into account for these statistics (some eruptive prominences and other type of prominences named "clouds" by the observers, due to their shapes as clouds, were not considered in this case) (Aguilar, 1910), (2) the number of observation days differs much from year to year, and (3) the methodology of prominence counting was different over the time since prominences of any height were only counted from 1906 to 1911, those with heights

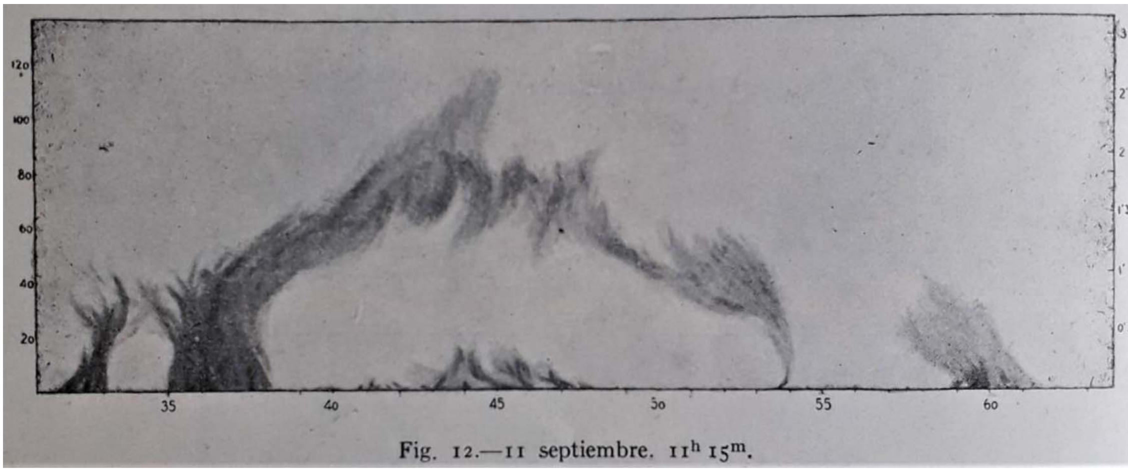

Figure 1. Solar prominence observed at the Madrid Astronomical Observatory on 11 September 1935. The heliographic latitude is shown along the abscissa, the height of the prominence in units of thousands of kilometers, and arcmin and arcsec are shown at left and right ordinates, respectively [Source: Gullón, 1936].

Table 1. Prominence data per year published in the yearbooks and bulletins of the Madrid Astronomical Observatory for the period 1906–1957. The columns represent: (i) the year of the observations, (ii) the number of observation days in the corresponding year, (iii) the number of prominences observed in the corresponding year, and frequency of the (iv) total, (v) north, and (vi) south number of prominences (that is, the total, north, and south number of prominences divided by the number of observation days).

Year	Days	*N*	ft	fn	fs	Year	Days	*N*	ft	fn	fs
1906	153	954	6.24	3.72	2.48	1934	85	297	3.49	1.61	1.88
1907	131	1084	8.27	4.11	4.16	1935	256	1243	4.86	2.20	2.68
1908	194	1857	9.57	4.50	5.07	1936	169	1097	6.49	3.37	3.22
1909	214	1789	8.36	4.27	4.09	1937	184	1178	6.40	3.13	3.27
1910	198	1143	5.77	2.71	3.06	1938	94	318	3.38	2.15	1.35
1911	160	545	3.41	1.01	2.40	1939	40	186	4.65	2.76	1.91
1912	174	353	2.03	0.60	1.43	1940	54	259	4.80	2.09	2.70
1913	153	300	1.97	0.78	1.19	1941	102	347	3.40	1.91	1.49
1914	163	502	3.08	1.30	1.78	–	–	–	–	–	–
1915	114	586	5.14	2.61	2.53	1943	24	81	3.37	1.13	2.25
1916	146	969	6.29	3.47	2.82	1944	184	580	3.15	1.53	1.62
1917	113	876	7.75	4.08	3.67	1945	147	711	4.84	2.14	2.70
1918	116	670	5.78	2.33	3.45	1946	98	724	7.4	3.7	3.8
1919	139	640	4.60	2.52	2.08	1947	94	756	8.0	4.3	4.0
1920	109	437	4.01	1.69	2.32	1948	122	1020	8.4	4.1	4.7
–	–	–	–	–	–	1949	130	967	7.4	4.4	3.4
1925	62	379	6.10	3.74	2.36	1950	115	609	5.3	3.0	2.4
1926	88	564	6.41	3.62	2.78	1951	163	762	4.7	2.3	2.5
1927	106	573	5.41	2.98	2.43	1952	155	540	3.5	1.9	1.7
1928	102	568	5.57	2.68	2.89	1953	204	561	2.8	1.4	1.3
1929	74	316	4.27	1.69	2.58	1954	257	593	2.3	1.3	1.0
1930	122	397	3.25	1.71	1.54	1955	177	616	3.5	2.1	1.4
1931	143	502	3.51	1.78	1.73	1956	221	925	4.2	2.4	1.8
1932	153	451	2.95	1.76	1.19	1957	34	124	3.6	2.1	1.5
1933	136	364	2.68	1.63	1.05	–	–	–	–	–	–

below 30″ were not counted in 1913 and 1915–1920, the prominences counted during the period 1925–1930 were selected according to their importance in terms of area, regardless of their heights (no specific area criterium is provided in the documentary sources to know how the observers chose the prominences), and only prominences with heights of 25″ and more were taken into account in the years 1912, 1914 and from 1931.

We note that the value of the total frequency (ft) shown in Table 1 is not equal to the sum of the values of the frequency for the northern (fn) and southern (fs) hemispheres in some years (1906, 1926, 1935, 1936, 1938, 1940, 1943, 1946–1953). This can be due to typos in the summary tables published by the observatory or the way to round values of frequencies by the observers.

Table 2. Data of the homogenized series of the annual number of prominences with heights of 25″ and more of the Madrid Astronomical Observatory obtained in this work for the period 1906–1957. The columns represent: (i) the year of the observations, (ii) the number of observation days in the corresponding year, (iii) the number of prominences observed in the corresponding year, and frequency of the (iv) total, (v) north, and (vi) south number of prominences (that is, the total, north, and south number of prominences divided by the number of observation days).

Year	Days	*N*	ft	fn	fs	Year	Days	*N*	ft	fn	fs
1906	152	635	4.18	2.45	1.72	1934	85	297	3.49	1.61	1.88
1907	138	742	5.38	2.74	2.64	1935	256	1243	4.86	2.20	2.68
1908	194	1090	5.62	2.50	3.12	1936	169	1097	6.49	3.37	3.22
1909	218	1028	4.72	2.37	2.35	1937	184	1178	6.40	3.13	3.27
1910	200	697	3.48	1.56	1.92	1938	100	347	3.47	2.20	1.39
1911	156	248	1.59	0.47	1.12	1939	40	186	4.65	2.76	1.91
1912	174	353	2.03	0.60	1.43	1940	54	259	4.80	2.09	2.70
1913	153	382	2.50	0.97	1.53	1941	102	347	3.40	1.91	1.49
1914	163	501	3.07	1.31	1.77	–	–	–	–	–	–
1915	114	756	6.63	3.35	3.28	1943	24	81	3.37	1.13	2.25
1916	146	1254	8.59	4.57	4.02	1944	184	580	3.15	1.53	1.62
1917	113	1115	9.96	5.28	4.68	1945	147	711	4.84	2.14	2.70
1918	117	882	7.54	4.00	3.54	1946	98	724	7.39	3.67	3.81
1919	137	838	6.12	3.43	2.69	1947	94	756	8.04	4.30	4.00
1920	107	565	5.28	2.36	2.92	1948	122	1020	8.36	4.11	4.68
–	–	–	–	–	–	1949	130	967	7.44	4.40	3.35
1925	62	462	7.45	4.50	2.95	1950	115	609	5.3	3.0	2.4
1926	88	674	7.86	4.49	3.37	1951	163	762	4.7	2.3	2.5
1927	106	715	6.75	3.70	3.05	1952	155	540	3.5	1.9	1.7
1928	102	716	7.02	3.36	3.66	1953	204	561	2.8	1.4	1.3
1929	74	364	4.92	1.90	3.02	1954	257	593	2.3	1.3	1.0
1930	122	445	3.65	1.88	1.77	1955	177	616	3.5	2.1	1.4
1931	143	502	3.51	1.78	1.73	1956	221	925	4.2	2.4	1.8
1932	153	451	2.95	1.76	1.19	1957	34	124	3.6	2.1	1.5
1933	136	370	2.72	1.66	1.06	–	–	–	–	–	–

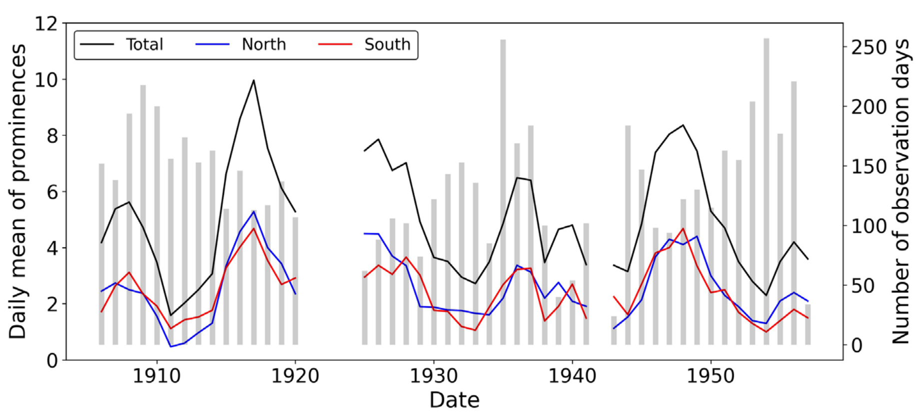

Figure 2. Daily mean of the number of prominences recorded at the Madrid Astronomical Observatory for the period 1906–1957. The total, north, and south number are represented by black, blue, and red lines, respectively. The annual number of observation days is depicted by gray bars.

2.4.2 Gullón prominence series (1906–1949)

The annual number of prominences considered by Gullón (1950) was slightly larger than that recorded in the summary tables published in the yearbooks and bulletins of the Madrid Astronomical Observatory (Table 1) in a few years (1906–1910, 1918–1920, 1925, 1928, 1930, 1933, and 1938). This is because Gullón (1950) took into account all prominences recorded in the original observations without discarding eruptive and "cloud" prominences. We note that information on how many eruptive/cloud prominences were ignored is not included in the documentary sources.

On the other hand, prominences considering any height were only listed at the Madrid Astronomical Observatory from 1906 to 1911. While in 34 of the 47 years of the observational period, astronomers of this observatory recorded prominences with heights of 25″ and more. To construct an annual homogenized prominence number series of prominences with heights of

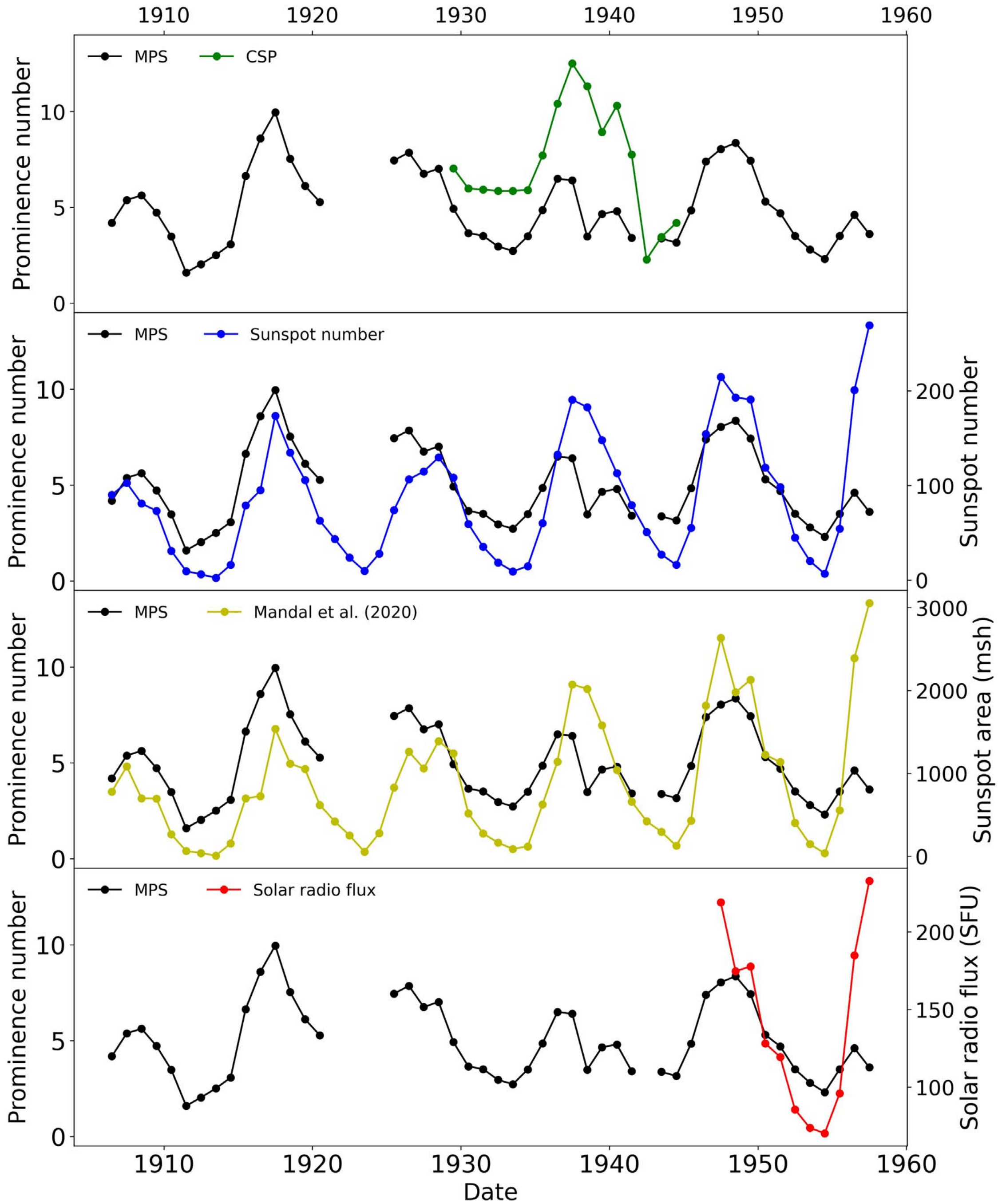

Figure 3. Comparison between the daily mean of the number of prominences recorded at the Madrid Astronomical Observatory for the period 1906–1957 (black) and, from top to bottom, the number of prominences recorded at the Astronomical Observatory of the University of Coimbra for the period 1929–1944 (dark green), the sunspot number for the period 1906–1957 (blue), the sunspot area by Mandal et al. (2020) for the period 1906–1957 (yellow), and the solar radio flux at 10.7 cm for the period 1947–1957 (red).

25″ and more, Gullón applied some corrections to the number of prominences recorded in Madrid for the period 1906–1949 in those years when prominences with heights between 25″ and 30″ were not recorded (Gullón, 1950). For it, Gullón calculated the average percentage of prominences with heights between 25″ and 30″ with respect to the number of prominences of 25″ and more for the years 1906–1912, 1931–1933, 1935–1936, 1941, and 1944–1949 obtaining 22.7%. Then, Gullón took into account this percentage in the years when only prominences with heights of 30″ and more were recorded to calculate the total number of prominences that would have been recorded if the observation threshold had been 25″ instead of 30″. This annual series by Gullón (1950) contains 25,578 prominences of which 23,789 are from direct observations and 1789 are extrapolated. Note that the Gullón series was only available in the printed version.

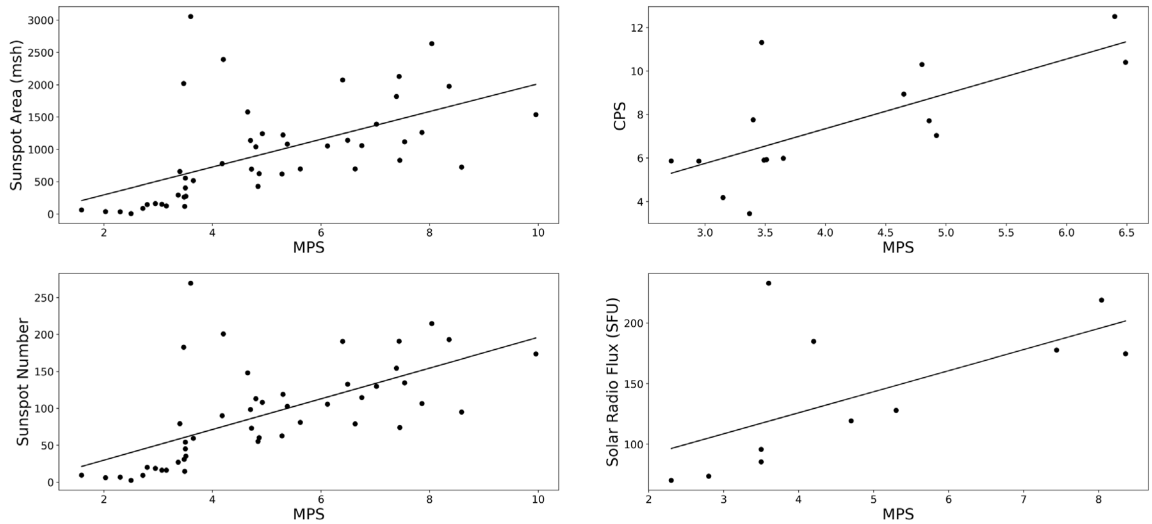

Figure 4. Comparison between the Madrid annual prominence series (MPS) and (top-left panel) the sunspot area series by Mandal et al. (2020), (top-right panel) daily mean of the prominences number recorded at the Astronomical Observatory of the University of Coimbra by Carrasco & Vaquero (2022), (bottom-left panel) the sunspot number index (version 2) and (bottom-right panel) solar radio flux at 10.7 cm. Black lines depict the best linear fit between the datasets.

3 Data homogenization and comparison to other activity indices

3.1 Homogenization of the Madrid prominence number series

We have constructed a homogenized series of total and hemispheric annual prominence numbers from Madrid data for the period 1906–1957 using the values for prominences with heights of 25″ and more by Gullón (1950) for the period 1906–1949 and those recorded in the yearbooks and bulletins of the observatory for the period 1950–1957, which followed the methodology by Gullón (1950). This homogenized series of the total and hemispheric annual number of prominences with heights of 25″ and more recorded at the Madrid Astronomical Observatory for the period 1906–1957 is included in Table 2 (the digitized version is available as Supplementary Material of this work).

The total number of observation days for the period 1906–1957 was 6383. This represents a temporal coverage of 37.0% discarding the years 1921–1924 and 1942 when no observations were made at the observatory. Thus, the annual mean of the number of observation days is around 136. The number of observation days as well as the daily mean of the total and hemispheric number of the homogenized series of prominences observed at the Madrid Astronomical Observatory are shown in Figure 2. Note that the sum of the number of prominences with heights of 25″ and more of the Madrid homogenized series (column "N" in Table 2) is 30308 of which 28,519 were observed and 1789 were calculated by Gullón (1950) applying the corrections indicated above. In addition, the sum of the values of the frequency for the northern (fn in Table 2) and southern (fs) hemisphere is not equal to the total frequency (ft) in some years (1906, 1914, 1935–1936, 1938–1940, 1943, 1946–1953). As in Table 1, this can be due to typos in the summary tables published by the observatory or the way to round the values of the frequencies by the observers. Also, there is a change in the way to present the values by the Madrid Astronomical Observatory since values corresponding to the observations for the period 1906–1949 were provided with two decimals and from 1950 with only one decimal.

Table 3. Correlation coefficients between the homogenized series of the Madrid prominence number presented in this work and Coimbra prominence series, sunspot number, sunspot area, and solar radio flux at 10.7 cm.

Comparison	r and p-value
MPS vs CPS	r = 0.71, p-value = 0.003
MPS vs S_N	r = 0.62, p-value < 0.001
MPS vs SA	r = 0.56, p-value < 0.001
MPS vs SRF	r = 0.62, p-value = 0.04

One can see that the homogenized series of the Madrid prominence number (MPS) follows the 11-yr solar cycle (Fig. 2). The strongest solar cycle according to the MPS for the period 1906–1957 is Solar Cycle 15 (maximum in 1917) with a daily mean in the number of prominences around 10 and the weakest one is Solar Cycle 14 (maximum in 1908) with around 6. Note that the strongest cycle for that period according to the sunspot number was Solar Cycle 18 and the weakest one was Solar Cycle 14 (this in agreement with the Madrid prominence number series).

The temporal homogeneity of the MPS for the period 1906–1957 has been evaluated using the Standard Normal Homogeneity Test (Alexandersson, 1986). This test is useful to detect inhomogeneities in the series, which could appear because of, for example, changes in the instruments used to observe or the way to count, in this case, prominences. According to this test, the annual series of the total number of prominences and the total, north, and south frequencies are homogeneous at a 95% significant level.

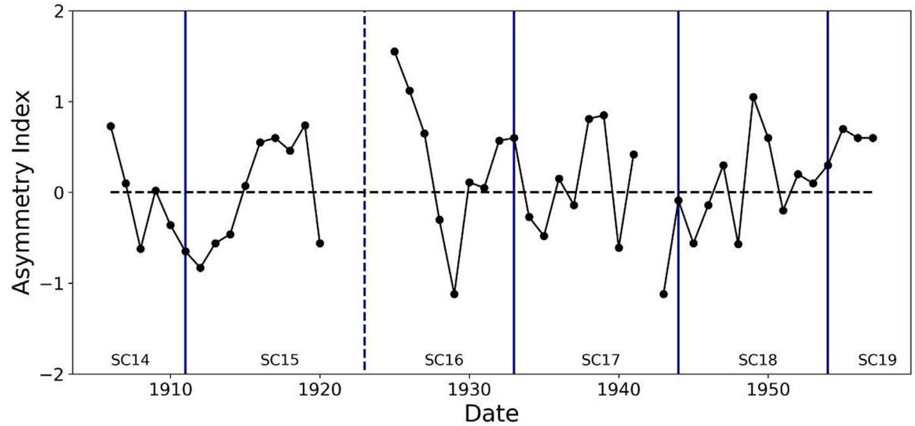

Figure 5. Annual asymmetry index calculated from hemispheric prominence observations carried out at the Madrid Astronomical Observatory from 1906 to 1957. Dashed horizontal line represents a value of the index equal to zero. Vertical solid lines depict the minima of solar cycle according to the Madrid prominence series and the vertical dashed line is the minima of Solar Cycle 16 according to the sunspot number index. Solar cycle numbers are indicated above the abscissa.

3.2 Comparison with other indices of solar activity

We compared the annual MPS with other indicators of solar activity. First, we show the comparison between MPS and the prominence series computed by Carrasco & Vaquero (2022) from the observations made at the Astronomical Observatory of the University of Coimbra (CPS) for the period 1929–1944 (Fig. 3).

We note some differences in the solar cycle behavior between Madrid and Coimbra series. The number of prominences recorded in Coimbra is significantly larger than that in MPS. Moreover, the minimum of Solar Cycle 17 was one year later in MPS (1933) with respect to CPS (1932), the maximum of that cycle was one year before (1936 in MPS), and the minimum of Solar Cycle 18 could be two years later (it was in 1942 according to CPS, whereas it was in 1944 in MPS although we note that there is no data in MPS in 1942).

The best linear fit between MPS and CPS is (Fig. 4): CPS = (1.6 ± 0.4) · MPS + (0.9 ± 1.9), with $r = 0.71$ and p-value = 0.003. Furthermore, the correlation coefficient between the annual values of the sunspot number index and the CPS for the period 1929–1944 is $r = 0.86$ with p-value < 0.001, whereas it is $r = 0.70$ and p-value = 0.003 between the sunspot number and MPS regarding that same observation period of Coimbra.

We suggest that the differences between both series may be due to the way to count prominences in both observatories. The annual MPS only includes prominences with heights of 25″ and more while all prominences were counted in CPS regardless of their height. Part of the discrepancy may be due to the fact that the annual calculations shown in Figure 3 for each prominence series were not made using common observation days in both observatories. In our future work, we will search for, digitize and analyze the daily observations of prominences of the Madrid Astronomical Observatory to try to understand these differences.

We also compared the annual MPS with other indicators of solar activity (Figs. 3 and 4). For example, the best linear fit between MPS and the annual sunspot number (version 2, S_N) provided by the Sunspot Index and Long-term Solar Observations (SILSO, sidc.be/silso) is: S_N = (21 ± 4) · MPS + (−10 ± 21), with $r = 0.62$ and p-value < 0.001. In relation to the dates of maxima and minima, the maximum of Solar Cycle 15 and the minima of Solar Cycles 17, 18, and 19 occurred in the same years in MPS and the sunspot number. However, the maxima of Solar Cycles 14 and 18 in the MPS were one year after those in S_N, the maxima of Solar Cycles 17 and 19 were one year earlier in the MPS and the minimum of Solar Cycle 15 and the maximum of Solar Cycle 16 were two years earlier in the MPS. Note also that the number of observation days of prominences in Madrid in 1957 (year of maximum of Solar Cycle 19 according to the sunspot number) was only 34. Taking into account this low value and the fact that, due to repair works on the dome where the telescope was located, the observations of prominences were not evenly distributed throughout the year 1957 (Gullón and López Arroyo, 1958), the observations may not represent accurately solar activity in the aforementioned year.

We have also compared the MPS with the solar radio flux at 10.7 cm (SRF), extracted from the website https://lasp.colorado.edu/lisird/data/noaa_radio_flux/), for the period 1947–1957 (Tapping, 2013), and the sunspot area series (SA) published by Mandal et al. (2020) for the period 1906–1957 (Figs. 3 and 4). The best linear fits between these datasets are: (i) SRF = (17 ± 7) · MPS + (60 ± 38), with $r = 0.62$ and p-value = 0.04, and (ii) SA = (211 ± 47) · MPS + (−114 ± 250), with $r = 0.56$ and p-value < 0.001. Thus, the stronger correlation in these comparisons is found between MPS and CPS, whereas the correlation between MPS and the sunspot number, sunspot area, and the solar radio flux at 10.7 cm is similar (Table 3).

We computed the asymmetry index following the definition used in recent works such as Veronig et al. (2021) and Aparicio et al. (2022b): $\Delta = P_n - P_s$, where Δ is the absolute asymmetry, P_n and P_s is the number of the prominences observed in the northern and southern hemisphere according to the MPS. This index is represented in Figure 5.

One can see that the southern hemisphere was dominant in the declining phase of Solar Cycle 14 (−0.13) and in Solar

Cycle 15 (−0.64), whereas the northern hemisphere dominated in Solar Cycles 16 (2.63), 17 (0.21), 18 (0.69), and the rising phase of 19 (2.20). Note that the previous values in parentheses are the sum of the annual values of the asymmetry index in each solar cycle. We note that Aparicio et al. (2022b) also concluded that the sunspot numbers in the northern hemisphere were dominant in Solar Cycles 17, 18, and 19. Furthermore, the maximum value of the northern hemisphere according to the daily mean of the prominence number was larger than that of the southern hemisphere in Solar Cycles 15–17, whereas it is the opposite in Solar Cycles 14, 18, and 19.

4 Conclusions

This work is the first step in the study of the prominence observations performed at the Madrid Astronomical Observatory. Here, we present a digitized version of a homogenized series of the total and hemispheric annual number of prominences with heights of 25″ and more, which covers the period 1906–1957. The values were extracted from documentary sources in printed versions, i.e., the yearbooks and bulletins of the observatory and Gullón (1950), corrections were applied in some years of the period 1906–1938, and the homogeneity of the series was checked. This digitized version is available as Supplementary Material for this work.

We have made an analysis of this annual series explaining, in addition, the methodology and instruments used to carry out the prominence observations at the Madrid Astronomical Observatory. We have clarified that the methodology to count prominences in Madrid changed over time.

We have compared the MPS with sunspot number values provided by SILSO, the solar radio flux at 10.7 cm, the sunspot area series by Mandal et al. (2020), and the prominence series by Carrasco and Vaquero (2022) from the Astronomical Observatory of the University of Coimbra. The highest correlation was found between the prominence series of Madrid and Coimbra (r = 0.71). However, we found that the correlation coefficient between the MPS and the sunspot number is significantly lower than those between the sunspot number and the other solar activity time series. In particular, the correlation coefficient between Coimbra series (1929–1944) and the sunspot number is r = 0.86 (it is r = 0.7 between Madrid and the sunspot number when the Coimbra study period is considered). These differences, as well as those detected in the time of maxima and minima between the different series, may be due to the way the prominences were counted in Madrid since only prominences with heights of 25″ and more were considered. Our analysis of the asymmetry index from the MPS showed that the southern hemisphere was dominant in the last part of Solar Cycle 14 and Solar Cycle 15, and the northern hemisphere dominated from Solar Cycle 16 to the rising phase of 19, when MPS finished.

This work is a continuation of our efforts to analyze solar activity using observations carried out at the Madrid Astronomical Observatory. Studies reconstructing the total and hemispheric sunspot number series from Madrid data (1876–1986) and analyzing and providing machine-readable versions of different sunspot catalogs recorded at this observatory have already been published. In the future, more data from solar prominences and other solar features observed at the Madrid Astronomical Observatory shall be made available.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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Supplementary Material

The supplementary material of this article is available at https://www.swsc-journal.org/10.1051/swsc/2023003/olm.

References

Aguilar M. 1910. Protuberancias solares. *Anuario del Observatorio Astronómico de Madrid para el año 1910*.

Alexandersson H. 1986. A homogeneity test applied to precipitation data. *J Climatol* **6**: 661. https://doi.org/10.1002/joc.3370060607.

Aparicio AJP, Vaquero JM, Carrasco VMS, Gallego MC. 2014. Sunspot numbers and areas from the Madrid Astronomical Observatory (1876–1986). *Sol Phys* **289**: 4335. https://doi.org/10.1007/s11207-014-0567-x.

Aparicio AJP, Lefèvre L, Gallego MC, Vaquero JM, Clette F, Bravo-Paredes N, Galaviz P, Bautista ML. 2018. A sunspot catalog for the period 1952–1986 from observations made at the Madrid Astronomical Observatory. *Sol Phys* **293**: 164. https://doi.org/10.1007/s11207-018-1387-1.

Aparicio AJP, Carrasco VMS, Gallego MC, Vaquero JM. 2022a. A sunspot catalog by Rafael Carrasco at the Madrid Astronomical Observatory for the period 1931–1933. *Sol Phys* **297**: 58. https://doi.org/10.1007/s11207-022-01992-9.

Aparicio AJP, Carrasco VMS, Gallego MC, Vaquero JM. 2022b. Hemispheric sunspot number from Madrid Astronomical Observatory for the period 1935–1986. *ApJ* **931**: 52. https://doi.org/10.3847/1538-4357/ac5dc6.

Bocchino G. 1933. Migrazione delle protuberanze durante il ciclo undecennale dell'attività solare. *Osservazioni e memorie dell'Osservatorio astrofisico di Arcetri* **51**: 5.

Carrasco VMS, Nogales JM, Vaquero JM, Chatzistergos T, Ermolli I. 2021. A note on the sunspot and prominence records made by Angelo Secchi during the period 1871–1875. *J Space Weather Space Clim* **11**: 51. https://doi.org/10.1051/swsc/2021033.

Carrasco VMS, Vaquero JM. 2022. A catalog of faculae, prominences, and filaments for the period 1929–1944 from the astronomical observatory of the University of Coimbra. *ApJS* **262**: 44. https://doi.org/10.3847/1538-4365/ac85dd.

Chatterjee S, Hegde M, Banerjee D, Ravindra B, McIntosh SW. 2020. Time-latitude distribution of prominences for 10 solar cycles: a study using Kodaikanal, Meudon, and Kanzelhohe data. *Earth Space Sci* **7**: e2019EA000666. https://doi.org/10.1029/2019EA000666.

Foukal PV. 2004. Solar Astrophysics, 2nd rev. ed., Wiley-VCH, Weinheim.

Gullón E. 1936. Protuberancias notables. *Boletín Astronómico del Observatorio de Madrid* **2(6)**: 84.

Gullón E. 1950. Treinta y nueve años de observaciones de protuberancias solares. In: *XIII Congreso Luso-Espanhol para o Progresso das Ciências*, Associação Portuguesa para o Progresso das Ciências, Lisboa.

Gullón E, López Arroyo M. 1955. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1954. *Boletín Astronómico del Observatorio de Madrid* **IV(8)**: 1.

Gullón E, López Arroyo M. 1958. Protuberancias solares. Resumen de las observaciones realizadas en Madrid durante el año 1957. *Boletín Astronómico del Observatorio de Madrid* **V(3)**: 1.

Jiménez Landi P. 1913. Protuberancias solares. Estudios hechos sobre las observadas en el Observatorio de Madrid de 1907 a 1912. *Anuario del Observatorio Astronómico de Madrid para 1914*, 295.

Jiménez Landi P. 1925. Estudio de la actividad solar deducido de la "profil-área, de las protuberancias observadas en Madrid desde 1910 a 1920. *Anuario del Observatorio Astronómico de Madrid para 1926*, 337.

Lefèvre L, Aparicio AJP, Gallego MC, Vaquero JM. 2016. An early sunspot catalog by Miguel Aguilar for the period 1914–1920. *Sol Phys* **291**: 2609. https://doi.org/10.1007/s11207-016-0905-2.

López Arroyo M. 2004. *El Real Observatorio Astronómico de Madrid (1785–1975)*, Dirección General del Instituto Geográfico Nacional, Madrid.

Makarov VI, Sivaraman KR. 1986. On the epochs of polarity reversals of the polar magnetic field of the sun during 1870–1982. *Bull Astron Soc India* **14**: 163.

Makarov, VI, Sivaraman, KR. 1986. On the epochs of polarity reversals of the polar magnetic field of the sun during 1870–1982, Bull Astron Soc India, 14: 163.

Mandal S, Krivova NA, Solanki SK, Sinha N, Banerjee D. 2020. Sunspot area catalog revisited: daily cross-calibrated areas since 1874. *A&A* **640**: A78. https://doi.org/10.1051/0004-6361/202037547.

McIntosh PS. 1979. *Annotated atlas of H-alpha synoptic charts*, World Data Center A for Solar Terrestrial Physics, NOAA.

Parenti S. 2014. Solar Prominences: Observations. *Living Rev Sol Phys* **11**: 1. https://doi.org/10.12942/lrsp-2014-1.

de la Rue W. 1862. *On the total solar eclipse July 18th, 1860, observed at Rivabellosa near Miranda de Ebro in Spain*, Taylor and Francis, London.

Ruiz-Castell P. 2008. *Astronomy and astrophysics in Spain (1850–1914)*, Cambridge Scholars, Newcastle.

Rusin V, Rybanský M, Dermendjiev V, Stavrev KY. 1988. Catalogue of solar prominences (1967–1986). *Contrib Astron Obs Skaln Pleso* **17**: 63.

Secchi AP. 1875. *Le Soleil*, Gauthier-Villars, Paris.

Tapping KF. 2013. The 10.7 cm solar radio flux (F10.7). *Space Weather* **11**: 394. https://doi.org/10.1002/swe.20064.

Vaquero JM, Vázquez M. 2009. *The sun recorded through history: scientific data extracted from historical documents*. Springer, New York.

Appendix

Bibliographic references containing the original data of the Madrid Astronomical Observatory for the period 1906–1957:

Íñiguez F. 1907. Protuberancias solares observadas en el año 1906. *Anuario del Observatorio Astronómico de Madrid para 1908*, 329.

Jiménez P. 1908. Protuberancias solares observadas en el año 1907. *Anuario del Observatorio Astronómico de Madrid para 1909*, 311.

Jiménez P. 1909. Protuberancias solares observadas en el año 1908. *Anuario del Observatorio Astronómico de Madrid para 1910*, 329.

Jiménez P. 1910. Protuberancias solares observadas en el año 1909. *Anuario del Observatorio Astronómico de Madrid para 1911*, 467.

Jiménez P. 1911. Protuberancias solares observadas en el año 1910. *Anuario del Observatorio Astronómico de Madrid para 1912*, 319.

Jiménez P. 1912. Protuberancias solares observadas en el año 1911. *Anuario del Observatorio Astronómico de Madrid para 1913*, 503.

Jiménez P. 1913. Protuberancias solares observadas en el año 1912. *Anuario del Observatorio Astronómico de Madrid para 1914*, 389.

Jiménez P. 1914. Protuberancias solares observadas en el año 1913. *Anuario del Observatorio Astronómico de Madrid para 1915*, 495.

Jiménez P. 1915. Protuberancias solares observadas en el año 1914. *Anuario del Observatorio Astronómico de Madrid para 1916*, 433.

Jiménez P. 1916. Protuberancias solares observadas en el año 1915. *Anuario del Observatorio Astronómico de Madrid para 1917*, 537.

Jiménez P. 1917. Protuberancias solares observadas en el año 1916. *Anuario del Observatorio Astronómico de Madrid para 1918*, 527.

Jiménez P. 1918. Protuberancias solares observadas en el año 1917. *Anuario del Observatorio Astronómico de Madrid para 1919*, 539.

Jiménez P. 1919. Protuberancias solares observadas en el año 1918. *Anuario del Observatorio Astronómico de Madrid para 1920*, 481.

Jiménez P. 1920. Protuberancias solares observadas en el año 1919. *Anuario del Observatorio Astronómico de Madrid para 1921*, 383.

Jiménez P. 1921. Protuberancias solares observadas en el año 1920. *Anuario del Observatorio Astronómico de Madrid para 1922*, 467.

Jiménez P. 1926. Protuberancias solares observadas en el año 1925. *Anuario del Observatorio Astronómico de Madrid para 1927*, 493.

Jiménez P. 1927. Protuberancias solares observadas en el año 1926. *Anuario del Observatorio Astronómico de Madrid para 1928*, 497.

Jiménez P. 1928. Protuberancias solares observadas en el año 1927. *Anuario del Observatorio Astronómico de Madrid para 1929*, 439.

Jiménez P. 1929. Protuberancias solares observadas en el año 1928. *Anuario del Observatorio Astronómico de Madrid para 1930*, 545.

Jiménez P. 1930. Protuberancias solares observadas en el año 1929. *Anuario del Observatorio Astronómico de Madrid para 1931*, 419.

Jiménez P. 1931. Protuberancias solares observadas en el año 1930. *Anuario del Observatorio Astronómico de Madrid para 1932*, 499.

Jiménez P. 1932. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1931. *Boletín Astronómico del Observatorio de Madrid* **I**(7): 1.

Jiménez P. 1933. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1932. *Boletín Astronómico del Observatorio de Madrid* **I**(14): 1.

Jiménez P. 1934. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1933. *Boletín Astronómico del Observatorio de Madrid* **I**(20): 1.

Jiménez P, Gullón E. 1935. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1934. *Boletín Astronómico del Observatorio de Madrid* **II**(3): 1.

Gullón E. 1936. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1935. *Boletín Astronómico del Observatorio de Madrid* **II**(6): 1.

Gullón E. 1941. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1936. *Boletín Astronómico del Observatorio de Madrid* **II**(7): 1.

Carrasco R, Martín Lorón M. 1942. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1937. *Boletín Astronómico del Observatorio de Madrid* **II**(8): 1.

Carrasco R, Martín Lorón M. 1943. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1938. *Boletín Astronómico del Observatorio de Madrid* **II**(10): 1.

Gullón E. 1944. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1939. *Boletín Astronómico del Observatorio de Madrid* **III**(1): 1.

Gullón E. 1944. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1940. *Boletín Astronómico del Observatorio de Madrid* **III**(1): 17.

Gullón E. 1944. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1941. *Boletín Astronómico del Observatorio de Madrid* **III**(2): 1.

Gullón E. 1946. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1943. *Boletín Astronómico del Observatorio de Madrid* **III**(6): 1.

Gullón E. 1946. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1944. *Boletín Astronómico del Observatorio de Madrid* **III**(6): 9.

Gullón E. 1947. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1945. *Boletín Astronómico del Observatorio de Madrid* **III**(7): 1.

Gullón E. 1948. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1946. *Boletín Astronómico del Observatorio de Madrid* **III**(8): 1.

Gullón E. 1949. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1947. *Boletín Astronómico del Observatorio de Madrid* **IV**(1): 1.

Gullón E. 1950. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1948. *Boletín Astronómico del Observatorio de Madrid* **IV**(2): 1.

Gullón E. 1950. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1949. *Boletín Astronómico del Observatorio de Madrid* **IV**(3): 73.

Gullón E. 1950. Treinta y nueve años de observaciones de protuberancias solares. In: *XIII Congreso Luso-Espanhol para o Progresso das Ciências*, Associação Portuguesa para o Progresso das Ciências, Lisboa.

Gullón E. 1951. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1950. *Boletín Astronómico del Observatorio de Madrid* **IV**(4): 1.

Gullón E. 1952. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1951. *Boletín Astronómico del Observatorio de Madrid* **IV**(5): 1.

Gullón E. 1953. Protuberancias solares. Resumen de las observaciones realizadas en el año 1952. *Boletín Astronómico del Observatorio de Madrid* **IV**(6): 3.

Gullón E. 1954. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1953. *Boletín Astronómico del Observatorio de Madrid* **IV**(7): 5.

Gullón E, López Arroyo M. 1955. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1954. *Boletín Astronómico del Observatorio de Madrid* **IV**(8): 1.

Gullón E, López Arroyo M. 1956. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1955. *Boletín Astronómico del Observatorio de Madrid* **V**(1): 1.

Gullón E, López Arroyo M. 1957. Protuberancias solares. Resumen de las observaciones realizadas durante el año 1956. *Boletín Astronómico del Observatorio de Madrid* **V**(2): 1.

Gullón E, López Arroyo M. 1958. Protuberancias solares. Resumen de las observaciones realizadas en Madrid durante el año 1957. *Boletín Astronómico del Observatorio de Madrid* **V**(3): 1.

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