



A Sunspot Catalog by Rafael Carrasco at the Madrid Astronomical Observatory for the Period 1931 – 1933

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Abstract

A sunspot catalog was published by the Madrid Astronomical Observatory from sunspot observations made by Rafael Carrasco and his assistants for the period November 1931–December 1933. We have digitized this catalog and carried out a quality control to detect inconsistencies. We present a machine-readable version of this sunspot catalog together with an erratum list. Moreover, we compared the Madrid sunspot number and area with other reference series. We found that sunspots in the northern hemisphere were predominant during this period, confirming previous studies. We have also analyzed the group morphological typologies registered in the catalog and show a butterfly diagram drawn with this new information. A comparison with the sunspot catalog by the Royal Greenwich Observatory shows that almost all the groups included in the Carrasco’s catalog are also present in the aforementioned catalog.

Keywords Sun: general · Sun: activity · Sun: sunspots

1. Introduction

Observations of sunspots made over the last four centuries are fundamental elements for the study of solar activity evolution (Clette et al., 2014; Arlt and Vaquero, 2020). In particular, long-term sunspot observation programs have been carried out in scientific institutions in the past (Lefèvre and Clette, 2014), especially from the late 19th century to nowadays (Muñoz-Jaramillo and Vaquero, 2019). In addition to the sunspot counting, other parameters such as the sunspot area and heliographic coordinates of individual sunspots or groups were also

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recorded in those programs. Thus, many observatories have published sunspot catalogs containing all this information. These catalogs are key to better understanding long-term solar activity (Usoskin, 2017).

Lefèvre and Clette (2014) showed that only a limited number of sunspot catalogs are available in digital version. Moreover, these authors pointed out that there is a limited temporal overlap between the catalogs and a mismatch in contents and conventions. There is an increasing interest in the recovery and analysis of sunspot catalogs because of the valuable information on different solar parameters they contain. For that reason, some catalogs published by different astronomical observatories have been recently digitized and analyzed. For example, Baranyi, Győri, and Ludmány (2016) described the main characteristics of the available observations edited by the Debrecen Heliophysical Observatory from various catalogs. Mandal et al. (2017) and Ravindra et al. (2020) present the total and hemispheric sunspot number and area series from the digitization of the observations made at the Kodaikanal Observatory during the last century. Willis et al. (2013a, 2013b) and Erwin et al. (2013) analyzed the errors included in the sunspot catalog of the Royal Greenwich Observatory (RGO) for the period 1876–1976. Sunspot catalogs are also available digitally from sunspot observations made at the different observatories of the USSR, compiled by Pulkovo Observatory for the period 1932–1991 (Nagovitsyn et al., 2008) and from observations at the Kislovodsk Mountain Astronomical Station of the Central Astronomical Observatory in Pulkovo operating since 1948 (Muñoz-Jaramillo et al., 2015; Tlatov et al., 2019). Recently, Carrasco et al. (2021) recovered and analyzed the sunspot catalog published by the Stonyhurst College Observatory (1921–1935).

Several historical sunspot catalogs published by observatories in the Iberian Peninsula have been recovered in the last decade. Carrasco et al. (2014) published a machine-readable version of the sunspot catalog published by the Valencia Astronomical Observatory for the period 1920–1928. Also, Curto et al. (2016) presented the data included in the historical heliophysical series collected at the Ebro Observatory, and de Paula and Curto (2020) studied several characteristics of solar activity just using the sunspot catalog. Carrasco et al. (2018) digitized and analyzed the historical sunspot catalog made by the Astronomical Observatory of the Coimbra University for 1929–1941. Two sunspot catalogs have been published from sunspot records made at the Madrid Astronomical Observatory (Aparicio et al., 2014). On the one hand, Lefèvre et al. (2016) digitized and analyzed the “Aguilar” catalog which includes sunspot observations made at the Madrid Astronomical Observatory for the period 1914–1920. On the other hand, Aparicio et al. (2018) retrieved and studied the so-called Madrid “modern” sunspot catalog published by this observatory from records made between 1952 and 1986.

Despite these recent efforts to recover sunspot catalogs, more work remains to be done in order to solve the weakness pointed out by Lefèvre and Clette (2014). Thus, this work continues with the recovery of historical sunspot observations made at scientific institutions, in particular at the Madrid Astronomical Observatory. We digitize and analyze the sunspot catalog published by this observatory for the period 1931–1933. We present the catalog in Section 2. An analysis of the catalog and a comparison with other data sources are shown in Section 3. Finally, we expose the main conclusions of this work in Section 4.

2. The Madrid Sunspot Catalog for 1931 – 1933

The Madrid Astronomical observatory observed sunspot in four periods: i) 1868–1896, ii) 1906–1923, iii) 1931–1933, and iv) 1935–1986. Aparicio et al. (2014) found daily records

for the first and fourth periods. However, we have retrieved a sunspot catalog published during the third period (November 1931–December 1933) including daily observations. These were carried out by Rafael Carrasco, assisted by Miguel Aguilar Stuyck until mid-1932 and then by Marcelo Santaló Sors until May 1933. The telescope used was the same as in the previous stage of the observatory (Aparicio et al., 2014): a Steinheil equatorial telescope (aperture of 12 cm and focal length of 1.85 m) with a Zeiss photoheliograph.

Rafael Carrasco (1901–1981) was an important Spanish astronomer who became director of the Madrid Observatory after a process of imprisonment and purge by Franco's dictatorial regime. Some biographical notes about him have been published by Vaquero (2015). Miguel Aguilar Stuyck (1901–1950) was the son of fellow astronomer Miguel Aguilar Cuadrado (1869–1925) and Marcelo Santaló Sors (1905–?) was an astronomer who had to go into exile in Mexico after the Spanish Civil War (1936–1939). More notes on the historical context of this catalog can be found in López Arroyo (2004) and Ruiz-Castell (2008, 2010).

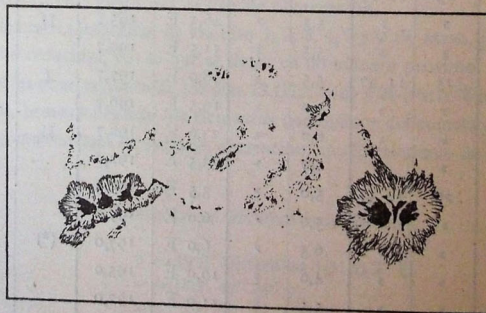
The sunspot catalog includes the following information: i) number of photographic plate, ii) number assigned to the observed spot, iii) date and time (UT) of the observation, iv) latitude, and v) longitude (according to the central meridian and Carrington longitude) of the sunspot in degrees, vi) type of group according to Cortie's (1901) classification to which the spots are associated, vii) ratio between the distance of the spot to the center of the disk and the solar radius, and viii) area of the sunspot in millionths of the solar hemisphere. Figure 1 shows an example page of the publication of this catalog. A machine-readable version of this catalog is available as supplementary material as well as on the website of the Historical Archive of Sunspot Observations (<http://haso.unex.es>).

The total number of observation days included in this catalog is 531. This represents an observational coverage equal to 67 % with respect to all days for the period November 1931–December 1933. There are some cases with more than one observation per day. This occurs on 21, 22, 24, and 25 November and 1 December 1931, and 26 and 27 February 1932. Unlike the "Aguilar" catalog corresponding to the period 1914–1920 (Lefèvre et al., 2016), this one includes spotless days. Information on the time of the observation was provided for the spotless days corresponding to the period November 1931–July 1933, whereas only a list of spotless days without additional details was indicated in the documentary source until the end of 1933.

We stress that not all sunspots observed by the astronomers of the Madrid Astronomical Observatory were recorded in this catalog. One example of this fact can be seen on 27 April 1932. For this date, only six sunspots were recorded although much more sunspots were recorded in a drawing made by Gullón for that day (see the drawing in Figure 1). Unfortunately, we have not found any information on the criteria that the observers followed to select the recorded sunspots. Furthermore, there are two different observation sets for the period 6–23 February 1933 in the original documentary source. The second observation set includes corrections made by the observers with respect to the first set. We only include in our digital version of the catalog the corrected observations corresponding to the second observation set. Occasionally, only one area and/or a p/R value (defined as the ratio between the distance of the spot to the center of the disk and the solar radius) is provided for a set of two spots. In the case of the areas, this means that the value provided in the documentary source is the sum of the areas of the two spots. This actually occurs on 26 and 27 April and on 17 and 19–24 May 1932. To identify these cases in the digital catalog, we added the symbol "***" followed to those area and p/R values involved. In addition, sometimes data for p/R and sunspot areas were not provided. Examples of this can be found on 31 January and 10 February 1933. Missing data are represented by "-9999" in our digital version. Note that spotless days are represented by the value of 0 in the "SPOT_CODE" column.

Número de la placa.	Número del grupo o mancha.	FECHA		LATITUD		LONGITUD		Tipo.	$\frac{\rho}{R}$	Superficie manchada en millonésimas.
		Febrero 1932.		Boreal.	Austral.	Referida al meridiano central.	Referida al primer meridiano.			
		Día.	Hora.							
»	161	»	h m	o	o	o	o		0,256	107
96	162	27	10 42	5,0	»	11,5 W	201,4		274	177
»	163	»	»	4,5	»	8,5 W	198,4		282	62
»	164	»	»	5,5	»	6,5 W	196,4	(*)	227	13
»	165	»	»	6,5	»	6,5 W	196,4		251	11
»	166	»	»	4,0	»	4,0 W	193,9		196	115
»	167	»	»	6,0	»	3,0 W	193,9		227	152
»	168	»	»	15,0	»	82,0 E	107,9		985	74
97	169	27	15 46	5,0	»	14,0 W	201,1		313	170
»	170	»	»	4,5	»	12,0 W	199,1		282	29
»	171	»	»	5,5	»	9,0 W	196,1	(*)	258	26
»	172	»	»	6,5	»	8,5 W	195,6		282	19
»	173	»	»	4,0	»	6,0 W	193,1		235	77
»	174	»	»	6,0	»	5,5 W	192,6		215	92
»	175	»	»	14,5	»	80,0 E	107,1	IV _a	977	98
98	176	29	15 48	4,5	»	41,0 W	201,8	IV _e	657	191
»	177	»	»	4,0	»	32,0 W	192,8		547	18
»	178	»	»	6,0	»	32,0 W	192,8	II _c	541	100
»	179	»	»	13,0	»	49,5 E	111,3		805	252
»	180	»	»	14,0	»	59,0 E	101,8		883	77

(*) Véanse los dibujos de estos grupos, publicados en el núm. 3 de este BOLETÍN



Grupo de manchas solares, del 27 de Abril a las 12 h. y 47 m.
Observación y dibujo de E. Gullón Senespleda.

Figure 1 An example page of the sunspot catalog published by the Madrid Astronomical Observatory for the period 1931 – 1933 (source: Carrasco and Aguilar Stuyck, 1932, I(5), p. 6).

Although all the sunspots of the catalog in the documentary source contain information about the typology of their groups, our digital version contains this typology only for the first spot recorded of each group, in order to identify more clearly the different groups for

each day. For example, if we analyze the heliographic coordinates of the spots recorded on 24 June 1932, we can see that one group was recorded with one spot and one group with three spots. Then, in our digital version, we indicate the typology “IVa” for the sunspot of the group with only one spot, the typology “IVd” for the first spot (4° north, 8.5° west) recorded of the other group and “-9999” for the other two spots of that group.

We have carried out a quality control to search for inconsistencies in the Madrid sunspot catalog. First, we checked that all the values were logical. For example, the latitudes and longitudes must range between 0° and 90° both for north and south. According to the typologies, we verified that they were consistent with the Cortie classification. For example, there is no type “IVf” because that class is not included in the Cortie classification, or one group composed by several spots cannot be classified such as “IVc”, because this type corresponds to isolated spots. Moreover, we have compared our calculations of the monthly number of observations and the monthly mean of the number of groups and the sunspot area with those published in the summary table of the original documentary source (see [Appendix](#)). Thus, we detected some inconsistencies in the original catalog: two cases (spots 340 and 353) are related to problems with latitudes and longitudes and there are 18 cases where the types of the groups disagree with the Cortie classification. A list including these inconsistencies is available in our digital version of the catalog (they are mentioned but not corrected).

3. Analysis and Discussion

3.1. Group and Sunspot Number

The number of sunspot groups recorded by astronomers at the Madrid Astronomical Observatory for the periods 1876–1896 and 1935–1986 are included in the most updated group number database by Vaquero et al. (2016). However, the number of groups recorded by Rafael Carrasco in the catalog published for 1931–1933 is not included, as well as those recorded by Aguilar in his sunspot catalog for 1914–1920 (Lefèvre et al., 2016). In the present work, we have counted the number of groups recorded in the catalog by Rafael Carrasco according to the distribution of the heliographic coordinates of the sunspots. Thus, the number of groups recorded at the Madrid Astronomical Observatory for this period can be also incorporated in future versions of the sunspot group number database to complete the group number series from the Madrid Astronomical Observatory. Figure 2 represents the number of groups observed at the Madrid Astronomical Observatory for the period 1876–1986.

We have also computed the sunspot number from the Madrid data (MSN) as $MSN = 10G + S$, where G and S are the number of groups and individual sunspots, respectively. Note that not all individual sunspots observed at the observatory were recorded in the Carrasco catalog, as explained previously. Figure 3 shows the monthly sunspot number values calculated from the Madrid data compared with the sunspot number (version 2, S_N) provided by the Sunspot Index and Long-term Solar Observations (SILSO, <https://www.bis.sidc.be/silso>) for the period 1931–1933. One can see that the values of S_N are always larger than those computed from the Carrasco catalog. The best linear fit between both daily datasets is: $MSN = (1.81 \pm 0.04) + (2.3 \pm 0.5) S_N$, with $r = 0.89$ and p -value < 0.001 , where r is the correlation coefficient and p is the probability that the null hypothesis is true. Moreover, we also obtained the ratio between the mean monthly values from SILSO and the mean monthly values from Carrasco computed taking the same observation days. It is equal to 2.15, which

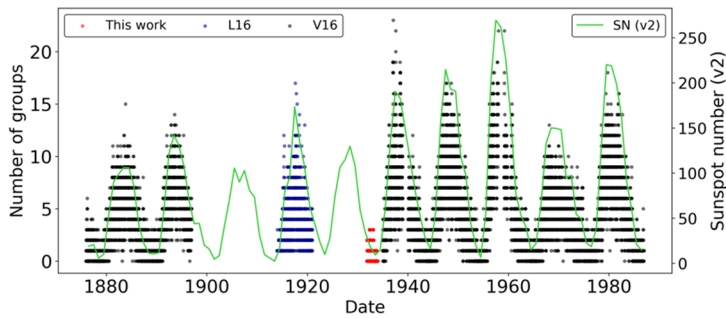


Figure 2 Number of groups recorded at the Madrid Astronomical Observatory. The sunspot counts presented in this work are depicted by red dots, the ones made by Lefèvre et al. (2016) by blue dots, and those included in Vaquero et al. (2016) by black dots. Annual sunspot number (version 2, <https://wwwbis.sidc.be/silso>) is represented by the green line.

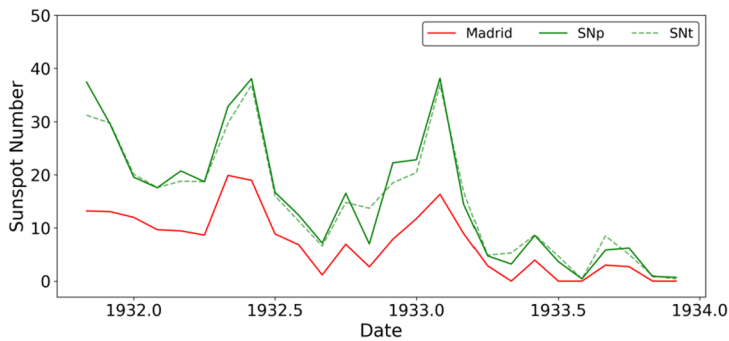


Figure 3 Comparison between the monthly sunspot number values computed from the Madrid sunspot observations for the period November 1931–December 1933 (red line) and those from the sunspot number (version 2) calculated using all daily records (green dashed line, SNT) and only the common observation days with the Madrid data (green continuous line, SNp).

is lower than that computed by Lefèvre et al. (2016) from the Aguilar catalog (2.45) despite the fact that Carrasco used the same equipment as Aguilar. We note that Carrasco observed during the last part of Solar Cycle 16, whereas Aguilar observed almost the entire Solar Cycle 15. For example, if we consider the first two years of Aguilar’s observation (1914 and 1915, just after the solar minimum of Solar Cycle 15), which have a closer solar activity level than those recorded by Carrasco, that ratio is 1.84. Therefore, this ratio depends on the different stages of the solar cycle when sunspot observations are made.

3.2. Sunspot Area

In the present work, a monthly area series was computed from the daily sunspot observations included in the Carrasco catalog from November 1931 to December 1933. This series, together with that obtained by Aparicio et al. (2014) from a table of monthly data recorded at the Madrid Astronomical Observatory, and that of Mandal et al. (2020), who constructed a daily calibrated area series since 1874 out of data from different observatories, are represented in Figure 4.



Figure 4 Monthly sunspot area series from November 1931 to December 1933 according to this work (red line), Aparicio et al. (2014) (purple, A14), both from Madrid sunspot observations, and Mandal et al. (2020) using all daily records (green dashed line, M20t) and only the common observation days with Madrid data (green continuous line, M20p).

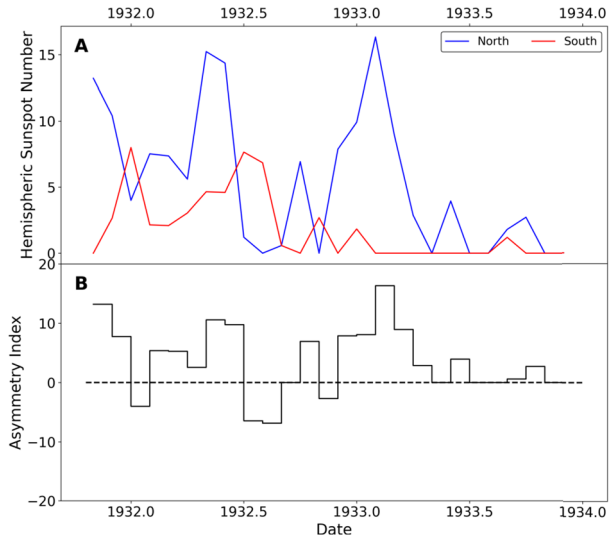
There are three small differences between the area series of this work and that published by Aparicio et al. (2014) for the studied period. The first one is related to days when two observations were recorded for the same day. We only take the first observation recorded on these days to carry out the calculations, whereas Aparicio et al. (2014) considered all observations, regardless of whether there were one or two records per day. Thus, we calculate the daily mean area value for each month and Aparicio et al. (2014) calculated the mean area value per observation for each month. Second, there is an error in the summary table of monthly mean values of the original documentary source for November 1932. The observers made a mistake in counting the number of days with an actual observation. Consequently, this error affects the daily mean area value for that month. Aparicio et al. (2014) took the area values from that summary table. In the present work, we recalculated the area to obtain the correct value for the daily mean area. Third, the monthly mean sunspot area for February 1933 in our work was computed using the observation set corrected mentioned in Section 2, whereas Aparicio et al. (2014) took those values from calculations by observers at the Madrid Observatory published in the summary table from the original sources (we have found that the observers used the non-corrected observation set).

We compare our results with the area series published by Mandal et al. (2020). The best linear fit between both daily datasets is: $MSA = (0.87 \pm 0.01) + (21 \pm 4) SA$, with $r = 0.93$ and $p < 0.001$, where MSA and SA are the Madrid and Mandal et al. (2020) sunspot area series, respectively. If we calculate the ratio between the monthly mean from the area series by Mandal et al. (2020) and that from the Carrasco catalog using common observation days, we obtain a value equal to 2.17. It is similar to that found for the ratio between the monthly sunspot number by SILSO and the Carrasco catalog (2.15).

3.3. Hemispheric Observations

We computed the sunspot number for each hemisphere from the sunspot observations made in the Madrid Astronomical Observatory during the period 1931–1933. Figure 5 (top panel) depicts this hemispheric index. One can see that the sunspot number values in the northern hemisphere were generally larger than those in the southern one. We also calculated the asymmetry index following Temmer et al. (2006) and Aparicio et al. (2022) such as $\Delta = R_n - R_s$, where Δ is the absolute asymmetry, R_n is the Madrid north sunspot number and R_s is the Madrid south sunspot number. Figure 5 (bottom panel) shows the temporal evolution

Figure 5 (A) Madrid north (blue line) and south (red line) sunspot number computed from the sunspot catalog by the Madrid Astronomical Observatory for the period November 1931 – December 1933. (B) Monthly values of the asymmetry index calculated from hemispheric sunspot observations made at the Madrid Astronomical Observatory for the period previously indicated. The dashed line represents a value of the index equal to zero.



of the monthly values of this index. The northern hemisphere was predominant during the period 1931 – 1933 according to Madrid data. This result agrees with that found by Veronig et al. (2021), who published a hemispheric sunspot number series from 1874 to 2020.

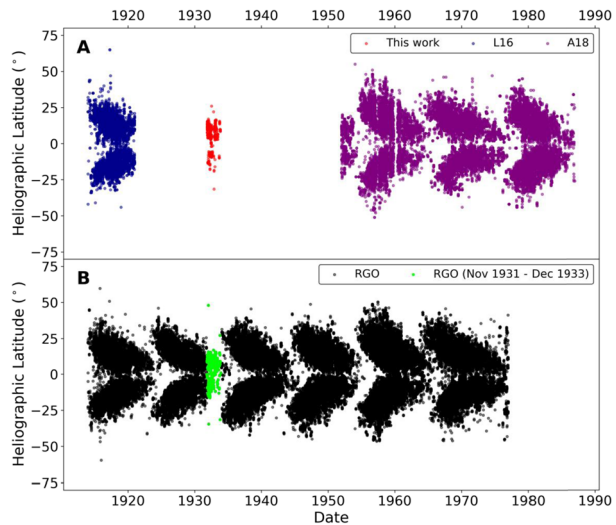
We depict the butterfly diagram from the heliographic latitudes of sunspots recorded at the Madrid Astronomical Observatory in Figure 6. Lefèvre et al. (2016) recovered the sunspot positions for Solar Cycle 15 and Aparicio et al. (2018) extended the butterfly diagram from the Madrid records including the last part of Solar Cycle 18 in addition to Solar Cycles 19, 20, and 21. We complete the Madrid butterfly diagram incorporating sunspot positions corresponding to the last years of the declining phase of Solar Cycle 16. In our case, most sunspots were observed below 20° both in the northern and southern hemisphere such as is to be expected just before a solar minimum. Moreover, the northern hemisphere is also predominant regarding the number of sunspots.

3.4. Group Typologies

Cortie (1901) defined a sunspot group classification based on the morphological shapes and patterns observed in sunspot groups recorded at the Stonyhurst College Observatory during the last part of the 19th century. The objective of Cortie (1901) was to describe the different phases of sunspot groups during their lifetime. Thus, he defined five different types of groups (I, II, III, IV, and V) with some subtypes within these types (IIa, IIb, IIc, IIIa, IIIb, IVa, IVb, IVc, IVd, and IVe). More details on the description of these classes as well as their physical meaning can be also found in Carrasco et al. (2015). Then, according to Cortie (1901), the normal evolution of sunspots consists of a first stage in which there are a few small, scattered dots (type I), which are later joined into two main sunspots (type II). Some small spots appear between these two spots (type III). The small spots disappear within a few days, followed by the disintegration of the pair of principal sunspots (type IV). This stage with a single round sunspot can last several solar rotations. Finally, the single spot gradually decreases in size and the cycle starts again. Irregular groups of large sunspots are classified into a special type (type V).

We have calculated the percentages of typologies assigned to sunspot groups recorded at the Madrid Astronomical Observatory for the period 1931 – 1933. For this purpose, we

Figure 6 Butterfly diagram from heliographic latitudes recorded at: (A) Madrid Astronomical Observatory according to this work (red dots), Lefèvre et al. (2016) (blue, L16) and Aparicio et al. (2018) (purple, A18). (B) The Royal Greenwich Observatory (black, RGO) with sunspot observations between November 1931 and December 1933 shown in green.



removed those inconsistencies found in the quality control of the catalog: i) type IVf for 26–30 November 1931, ii) type IIa on 1 May 1932, iii) type IIa on 21 and 22 June 1932, iv) type IVd for 25–28 June 1932, v) type IIIa on 3 July 1932, vi) type IVd on 7 February 1933, and vii) type IVc for 8–10 February 1933. Thus, the largest percentages are obtained for types IV (49.1%) and the lowest ones for types III (5.9%) and V (5.3%). The percentage for type I is 22.0%, whereas it is 17.7% for type II.

We expected to obtain the highest percentage in type I, since this group class is associated with the birth of sunspots. However, we find the highest percentage in type IV. A possible explanation for this fact is that sunspot groups can remain in type IV for up to several solar rotations, whereas they are in type I for only a few days. In contrast, type II, III, and V have the lowest percentages from Madrid data, as expected. For example, Carrasco et al. (2014), using Valencia sunspot observations (1920–1928), and Carrasco et al. (2021), using Stonyhurst sunspot observations (1921–1935), found the largest percentages for type I, followed by type IV. The lowest percentages for type II, III, and V agree by Carrasco et al. (2014, 2021), although we note that the percentage obtained in this work for type II is significantly higher than that from Carrasco et al. (2014, 2021). We speculate that the differences between our work and that by Carrasco et al. (2014, 2021) can be due to the different stages of the solar cycle when sunspot observations were carried out at these observatories (only the last part of the declining phase was recorded in our catalog).

3.5. Comparison with RGO

The sunspot catalog published by the RGO, based on observations between 1874 and 1976 (Willis et al., 2013a, 2013b; Erwin et al., 2013), is a reference for studying solar activity. Some works based on this catalog were, for instance, the butterfly diagram published by Maunder (1904), the model for the total solar irradiance developed by Hoyt and Eddy (1982), and the sunspot area series by Balmaceda et al. (2009) and Mandal et al. (2020).

We compare the Carrasco catalog with that from RGO. Data from RGO are available on the website: <https://solarscience.msfc.nasa.gov/greenwch.shtml>. First, since the RGO catalog contains group information, we convert the sunspot information from the Carrasco catalog into group information. For example, the heliographic latitude of the groups is the

Table 1 Comparison between the sunspot observations included in the Carrasco and RGO catalogs. See text for an explanation of the percentages in brackets.

	CARRASCO	RGO
Observation days [temporal coverage]	531 [67.0%]	455 [57.4%]
Common observation days	304 [38.4%]	
No observation at all	110 [13.9%]	
Total number of groups	342	793
Groups with correspondence in the other catalog	330 [96.5%]	391 [49.3%]

average of the latitudes of all sunspots in the same group. Then, we identify the groups recorded in both observatories by applying some specific constraints in latitude and longitude. Thus, a sunspot group recorded in the Carrasco catalog is considered the same as other included in the RGO catalog when the latitude and longitude of the RGO group are within the range $\pm 5^\circ$ and $\pm 15^\circ$ of the latitude and longitude, respectively, of the Carrasco group. These intervals were chosen following the methodology applied by Carrasco et al. (2014, 2018).

We found that the number of groups recorded in the Carrasco catalog with correspondence in the RGO is 330. This means 96.5% of all sunspot groups included in the Carrasco catalog. Moreover, 55 groups in the Carrasco catalog are associated with two or more groups in RGO. In the RGO case, 391 sunspot groups have a corresponding entry with some group in the Carrasco catalog, that is, 40.3% of all sunspot groups recorded in RGO during the period November 1931–December 1933. Regarding the calculations of the total number of groups, we considered that if the same group was observed in X days, it is counted X times (the same as in the Madrid data). It is worth mentioning that the temporal coverage of the Carrasco catalog is 67.0%, larger than that from RGO catalog (57.4%). In addition, the number of common observation days was 304, which is 38.4 % of the days for the period November 1931–December 1933, whereas no observations were carried out at any of these observatories for 110 days of that period (13.9%). Table 1 includes a summary of these results. The two main differences in the number of groups recorded in the above observatories are: i) the number of groups recorded by RGO when no observations were made in Madrid for the period November 1931–December 1933 was 324 (out of the total 793 groups recorded in RGO) and ii) RGO recorded significantly more small sunspot groups than Madrid on common observation days. In the latter case, RGO recorded 163 groups with areas lower than 50 millionths of the solar hemisphere, whereas Madrid only recorded 72 groups.

4. Conclusions

The Madrid Astronomical Observatory published a sunspot catalog for the period November 1931–December 1933. This catalog is based on the photographic sunspot observations made by Rafael Carrasco and his assistants using the same methodology as in the previous stage of the observatory (Aparicio et al., 2014). However, we found that not all sunspots observed by astronomers were included in the catalog. We present a machine-readable version of this catalog as supplementary material (Carrasco_catalog.csv). It can be also downloaded from the website of the Historical Archive of Sunspot Observations (<http://haso.unex.es>).

We detected some inconsistencies in the catalog after applying a quality control. A list of these inconsistencies is available together with the digital version of the catalog.

We calculated the sunspot number and area series from the Carrasco catalog. The first one was compared with the sunspot number (version 2) and the second one with the area series recently published by Mandal et al. (2020). The monthly values of the Madrid sunspot number are always lower than those of the sunspot number and the Madrid area series generally presents monthly values lower than those by Mandal et al. (2020). We also computed the Madrid hemispheric sunspot number and the asymmetry index. One can see from the analysis that the northern hemisphere was predominant for the studied period. This result agrees with that obtained by Veronig et al. (2021).

We present a butterfly diagram constructed with all the observations made in Madrid and collected in catalogs. Incorporating the heliographic latitudes of the Carrasco catalog, the Madrid butterfly diagram covers most of Solar Cycle 15, the final parts of the declining phases of Solar Cycle 16 and 18 and Solar Cycles 19, 20, and 21. The analysis of the group types recorded in the Carrasco catalog shows that the main difference with the typologies recorded in other catalogs, such as the Valencia and Stonyhurst sunspot catalogs, is that the predominant group type included in the Carrasco catalog is the sum of types IV, followed by type I, i.e. the opposite of the other catalogs. We speculate that this may be due to different stages of the solar cycle when the sunspot observations were carried out. Furthermore, we found that most of the groups recorded in the Carrasco catalog (96.5%) are also included in the RGO catalog, whereas only half of the groups recorded in the RGO catalog are in the Carrasco catalog. We also discovered that RGO recorded significantly more small sunspot groups than Madrid in common observation days. Comparison between the catalogs is of crucial importance if we want to have precise information on past solar activity. Furthermore, the recovery of these catalogs is essential to have data redundancy and to obtain good statistics and comparisons.

This article contributes to the recovery work of solar activity data from the sunspot observations made at the Madrid Astronomical Observatory from 1876 to 1986, i.e. from Solar Cycle 11 to 21. This work line was started with the analysis by Aparicio et al. (2014) of the sunspot observations made at the Madrid Astronomical Observatory and followed with the works made by Lefèvre et al. (2016) and Aparicio et al. (2018) on the Aguilar and the Madrid modern catalogs, respectively. There is still work to be done using sunspot observations from this observatory. Thus, in a future work, we will study the prominence observations made at this observatory during the first half of the 20th century.

Appendix

Bibliographic references containing the original data of the Madrid Astronomical Observatory:

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Data Availability The datasets generated in this work are available as supplementary material, also on the website <http://haso.unex.es> or from the corresponding author on reasonable request.

Declarations

Disclosure of Potential Conflicts of Interest The authors declare that they have no conflicts of interest.

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