



The Sunspot Drawing Collection of the National Solar Observatory at Sacramento Peak (1947–2004)

V.M.S. Carrasco^{1,2} · A.A. Pevtsov³ ·
J.M. Nogales⁴ · J.M. Vaquero^{2,5}

Received: 21 July 2020 / Accepted: 9 December 2020 / Published online: 5 January 2021
© The Author(s), under exclusive licence to Springer Nature B.V. part of Springer Nature 2021

Abstract A complete dataset of sunspot drawings recorded at Sacramento Peak Observatory (SPO) from late 1947 till mid-2004 has been digitized. We present the history of the observations and describe the data included in the drawings. We compare the sunspot number index calculated from the SPO data and the International Sunspot Number ($S_N v2$), and we find that both series exhibit a similar behavior. The ratio of two sunspot numbers is relatively constant at about 1.2–1.3 during 1955–1995, with larger variations present at the beginning of the time series. This work represents the first step for the publication of the SPO sunspot catalogue in digital format. More information, such as positions and areas of sunspots, will be included in the next versions in order to provide the space weather and climate community a more complete sunspot catalogue with good quality observations.

Keywords Solar cycle · Observations · Sunspots · Statistics

1. Introduction

Sunspot drawings represent the earliest and the longest record of direct observations of solar activity (Muñoz-Jaramillo and Vaquero, 2019). The earliest drawings were taken by Harriot, Galileo, Scheiner, Fabricius, and others four centuries ago (Arlt and Vaquero, 2020). Despite its simplicity, this proxy of solar activity continues to be used till present. The strength

✉ V.M.S. Carrasco
vmcarrasco@unex.es

A.A. Pevtsov
apectsov@nso.edu

¹ Departamento de Física, Universidad de Extremadura, 06006 Badajoz, Spain

² Instituto Universitario de Investigación del Agua, Cambio Climático y Sostenibilidad (IACYS), Universidad de Extremadura, 06006 Badajoz, Spain

³ National Solar Observatory, Boulder, CO 80303, USA

⁴ Departamento de Expresión Gráfica, Universidad de Extremadura, 06800 Mérida, Spain

⁵ Departamento de Física, Universidad de Extremadura, 06800 Mérida, Spain

of the sunspot number (SSN) time series is that today it represents essentially the same measure as 10, 100, or even 500 years ago. This allows to create a uniform time series representing the evolution of activity on our Sun during this time period independent of ever-changing technology (e.g. instruments and detectors, Clette et al., 2014). However, the sunspot number is a relative measure, depending on the characteristics of each observer (instrument, location, visual acuity, counting method, etc.), and the long-term observations from different sites are essential for detecting any non-solar trends.

Several professional observatories developed sunspot observation programs in the past. The reference in this kind of programs was the Royal Greenwich Observatory carrying out photographic sunspot observations from 1874 to 1976 (Willis et al., 2013a,b; Erwin et al., 2013). The extensive sunspot observation programs were also performed by several other observatories: (i) Mount Wilson began the daily sunspot drawings made at the 150-Foot Solar Tower on 4 January 1917 and continue till present (Pevtsov et al., 2019), (ii) Kodaikanal series includes digitized and calibrated white-light sunspot data from 1921 to 2011 (Mandal et al., 2017), (iii) Kanzelhohe, (iv) Kislovodsk, (v) Specola, and (vi) Debrecen started the sunspot records in 1943, 1948, 1957, and 1974, respectively (Pötzi et al., 2016; Muñoz-Jaramillo et al., 2015; Cortesi et al., 2016; Baranyi, Györi, and Ludmány, 2016), and (vi) sunspot observations were made from the early 20th century at the Iberian observatories in Valencia, Ebro, Madrid, and Coimbra (Carrasco et al., 2014; Curto et al., 2016; Lefèvre et al., 2016; Carrasco et al., 2018). These kinds of observations are preserved in archives and libraries of scientific institutions. However, only a limited number of historical sunspot catalogues are currently available in digital format. For that reason, this recovery task of historical sunspot catalogues should be continued in order to fill temporal gaps existing in the observations and to correct possible shortcomings in the sunspot data series (Casas and Vaquero, 2014; Lefèvre and Clette, 2014).

In this article, we present a newly digitized data set of sunspot numbers based on the observations from the SPO. The observations were conducted over 57 years including early years of the modern period of space exploration, by different observers and using different telescopes. The sunspot drawings of the Sacramento Peak program were used in training the early observers for the Solar Observing Optical Network (SOON), and it served as a basis for developing a semi-automated algorithm for a sunspot number time series from the Improved Solar Observing Optical Network (ISOON). Such a dataset may provide invaluable information about how the properties of a composite SSN time series may change as the new knowledge is acquired and the new technologies are introduced. In this article we describe the history of SPO observations and present their comparative analysis with other datasets from the same era.

2. Observations

The history of Sacrament Peak (Sac Peak) Observatory (SPO)—from its earliest establishment as part of the Cambridge Research Laboratories of the Office of Aerospace Research, United States Air Force, later transferred to the National Science Foundation (NSF) in 1976, and a more recent (2017) partial transfer of operations from the National Solar Observatory to the Sunspot Solar Observatory Consortium led by New Mexico State University—is full of fascinating facts, which the reader can find in several early publications (Bushnell, 1962; DeVorkin, 1983; Zirker, 1998; Ramsey, 2002; Liebowitz, 2002; CH2M HILL Inc., 2017). Here we briefly describe only the part of history relevant to sunspot drawings.



Figure 1 Aerial photograph of the National Solar Observatory at Sacramento Peak taken on 16 November 2002. The location of instruments that were used for the program of daily sunspot drawings are marked by white numbers: (1) the Grain Bin Dome, (2) the Hill Top Dome, and (3) the Evans Solar Facility. A white building with a protruding telescope tube to the left of the Hill Top Dome is the ISOON instrument, which was later relocated to Kirtland Air Force Base in Albuquerque, New Mexico. Photo courtesy of Kit Richards.

The daily drawings of sunspots at the future site of the SPO started in August 1947 as part of the site testing. The first observations were taken with a 5-inch refractor by Rudolph (Rudy) Cook (RHC initials on sunspot drawings) by tracing the projected image of the Sun. In December 1947, Cook was joined by Lee Davis (LD, the first drawing was taken on 13 December 1947), and about a year later, by Harry Ramsey (HER). The regular program at SPO began in early 1949 using instruments placed outside, in open air, with protective coverings. In 1950, the instruments were placed in a newly constructed Grain Bin Dome (No. 1 in Figure 1)—a modified small commercial silo purchased from the Sears-Roebuck catalog (Bushnell, 1962; Evans, 1967).

In early 1952, the observatory acquired a new 6-inch telescope (Bushnell, 1962), and starting from 5 May 1952, the daily sunspot drawings were taken with that instrument. On 11 May 1966, the instrument was moved from its original location at the Grain Bin Dome to the Hill Top Dome (No. 2 in Figure 1), where it remained till the end of the program of sunspot drawings in May 2004. Between 1966 and 1970, the drawings were made by the US Air Force (USAF) personnel trained for the Solar Observing Optical Network (SOON, Neidig et al., 1998). From 1 May 1990 through December 1994, each year there were extended periods when the coronal monitor telescope (CGS, 16-inch/40 cm aperture) at Evans Solar Facility (ESF, a.k.a. Big Dome, No. 3 in Figure 1) was used for the daily drawings. This was related to a shortage of the observing personnel during their vacation time. According to Lou Gilliam “more than likely” these observations were taken using the coronagraph with the occulting disk out and an auxiliary lens inserted. The solar disk size without the auxiliary lens was 3.8 inches. With the auxiliary lens inserted, the image went to six inches. The observers could also have used the coelostat at the ESF, but in this case, the largest disk

image size would have been slightly under 4 inches. The advantage to the coelostat would be less image rotation. There is more rotation on the coronagraph, but the drawings can be done fairly quickly using the auxiliary lens (Douglas Gilliam, 2020, private communication).

The decrease in funding and the change in priorities for the National Solar Observatory at Sac Peak resulted in scaling down the program of daily sunspot drawings and several other synoptic programs beginning 1993. In 2002, the decision was made to replace the manual sunspot drawings and the sunspot number determination by a semi-automatic routine using the white-light observations from a newly constructed Improved Solar Observing Optical Network (ISOON, Neidig et al., 1998; Balasubramaniam and Pevtsov, 2011) instrument at SPO. During 2002–2004, the simultaneous observations from the two instruments were used to establish a functional relation between the sunspot number derived using the ISOON observations and the classical Sac Peak drawings. The last drawing was taken on 11 May 2004 by Timothy (Tim) Henry (TWH). Additional details of comparison between the sunspot and group numbers derived using Sac Peak hand-drawings and ISOON observations can be found in Balasubramaniam and Henry (2016). Based on 10 years of observations, a good correlation ($\approx 95\%$) is obtained between ISOON-derived sunspot number with the International Sunspot Number ($S_N v2$, Balasubramaniam and Henry, 2016).

3. Sunspot Drawings

SPO used nine types of record cards to preserve sunspot observations (Figure 2). The early drawings contained only markings corresponding to sunspots, pores, and some facular regions, in addition to information such as date and time of the observation, observer's initials, photometer reading and description of the atmospheric conditions. From August 1948 another format of drawings was used, and after 3 September 1948, the observers began including information about the total number of groups (N_G), sunspots (N_S), and the sunspot number (SSN) computed as $SSN = 10 \times N_G + N_S$. No observer-specific scaling coefficient as in the traditional formula for the international sunspot number was used. Another drawing style was used in 1951, and it was again changed in January 1952, February 1952, March 1956, and January 1966. New information was provided in the drawings from March 1964, when the observer indicated specific information about groups recorded such as an SPO number assigned to each group, type of group according to Zurich classification and number of sunspots recorded in each group. Moreover, very few isolated drawings also include information on group positions and areas (see e.g. Figure 2, drawing 8).

The drawings may contain different notes, which we broadly classified into two categories. The first type, which represents a scientific value to the solar physics community may include location and size of solar features (e.g. sunspots, pores, and sometimes facular regions), name of the observer, date and time of observations, total number of sunspots and groups, together with the sunspot number computed by the observer, sky brightness, and atmospheric seeing. Figure 3 represents an example of a drawing recorded on 2 September 1959. That drawing corresponds to the observations with the maximum daily number of sunspots recorded at SPO, where 543 single sunspots and 20 groups were recorded. The sky conditions (240) indicate an extremely low level in sky brightness and the seeing pointed out by the observer was good or very good (3–5). Both enabled the observer to see the solar surface in great detail. In addition, some drawings may have markings and notes corresponding to other, non-solar phenomena which the observer may have noted during the observations or even personal notes (e.g. about the weather or somebody's birthday). These notes may

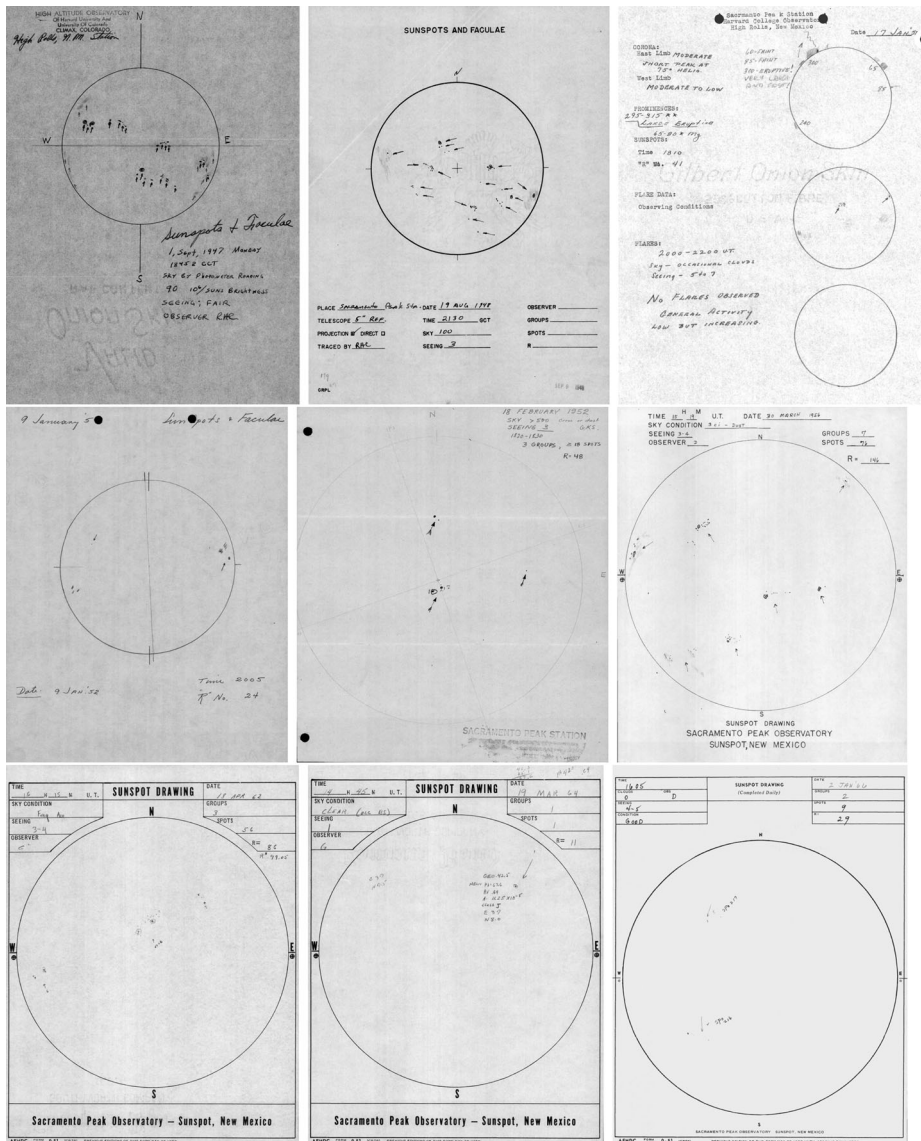


Figure 2 Different types of sunspot drawings used at SPO. These records were made on: (1) 1 September 1947, (2) 19 August 1948, (3) 17 January 1951, (4) 9 January 1952, (5) 18 February 1952, (6) 30 March 1956, (7) 18 April 1962, (8) 19 March 1964, and (9) 2 January 1966. Numbers correspond to panels from the top left to the bottom right. A better detail of the drawings can be appreciated by enlarging the figure.

have a value for historians and even general public interested in an early history of the SPO and its surrounding areas, and thus are included in the database.

As one example, the drawing taken on 17 October 1947 shows a dashed line drawn across the Sun accompanied by the following note: “Dotted line represents [the] path of [a] large round hazy object. It took about 5 min to cross Sun. There were no visible clouds in sky and no mice in scope. I tried to bring it to a sharper focus with projection eyepiece without much

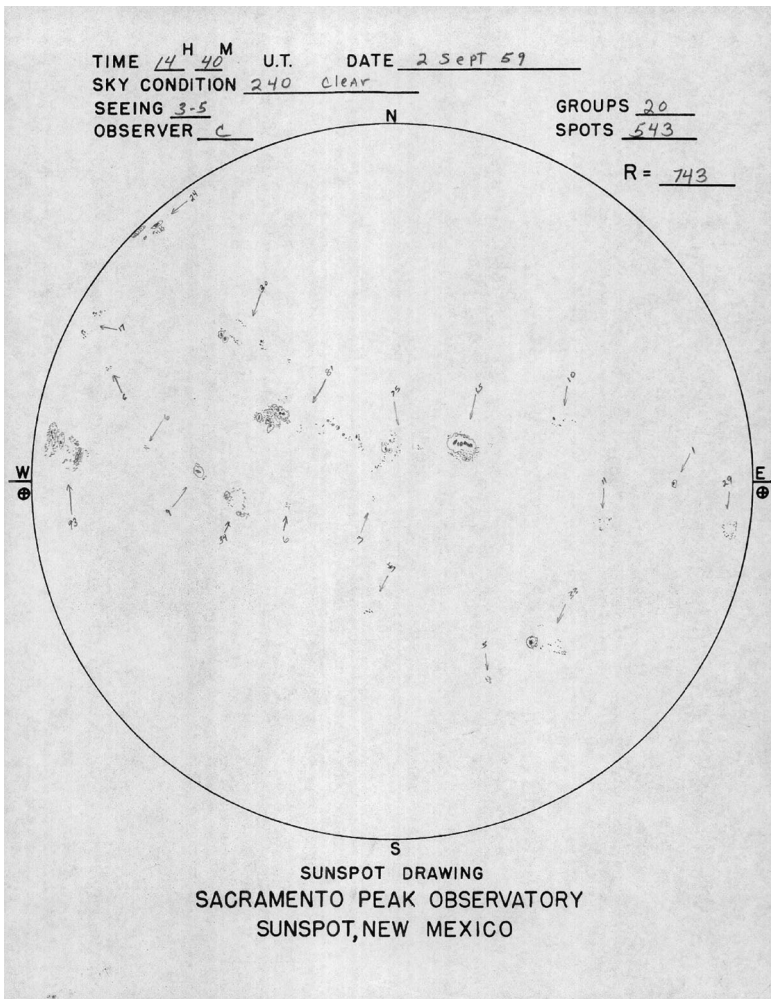


Figure 3 Sunspot drawing made at SPO on 2 September 1959.

luck. By the time I got the seeing eyepiece on it was gone—Do you have any idea what this was? Time 1630 Z”.

Based on the description, we think it could be a high-altitude balloon passing across the field of view of the telescope. The fuzziness of the object could be explained if the balloon was flying at low altitude above the telescope when it was detected. It could also be due to the semitransparent material of the balloon (polyethylene), which when viewed against a bright background (solar disk) would appear as being out of focus. During 1947, several stratospheric polyethylene balloons were launched from the nearby Alamogordo Army Air Field (after January 1948—the Holloman Air Force base, AFB) in the framework of the (then) top secret Project Mogul (carrying sensitive microphones for long-distance detection of sound waves generated by Soviet atomic bomb tests). In June–July 1947, one of the Mogul Project balloons crashed near Roswell, New Mexico giving rise of the well-publicized Roswell “UFO crash” conspiracy theory. However, the database of bal-

loon launches by StratoCat (<https://stratocat.com.ar/globos/1947e.htm>) does not show any launches on 17 October 1947. Based on the angular size of the object, and the time it took to cross the solar disk, it is reasonable to assume that what the observer at SPO refers to is likely a large weather balloon perhaps launched from the Holloman AFB. The weather balloons are not included in StratoCat database.

Between 13 April 1961 and 22 August 1962, in addition to a regular SSN, most drawings show an alternative, significantly larger sunspot number (R^*). Although we are not able to identify how R^* was computed, we note that the timing of this additional sunspot number coincides with the initial development of the so-called effective sunspot number (e.g. Chadwick, 1963) determined by fitting a model of the critical frequency (f_0) of the ionospheric F_2 layer to the observed f_0F_2 values (for a later review of work on this index, see Secan and Wilkinson, 1997).

In 2010, all sunspot drawings were digitized (scanned), and archived at NOAA database at <ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-imagery/photosphere/sunspot-drawings/sac-peak/>. During 2019–2020, the information from the scanned images of the drawings was extracted and tabulated by the authors of this article.

4. SPO Sunspot Catalogue

The results of our digitization project were used to create a machine-readable version of the information included in the daily sunspot drawings made at SPO. Due to difference in hand-writing, changes in the location, and format of information recorded on the drawings, we have digitized by hand some of it. The information provided in the machine-readable version is divided in the following columns:

- i) “Year”, “month”, and “day”: year, month, and day of the observation.
- ii) “Time_start” and “Time_end”: initial and final hour of the observation.
- iii) “Observer”: Initials of a person responsible of the observation.
- iv) “Clouds”: photometer reading for sky brightness in millionth of solar disk brightness. For a reference, the sky brightness > 500 does not permit observing the solar corona. The column labeled as Clouds gives the frequency, thickness, and types of clouds, where the acronyms mean the following: OC – occasional, FR – frequent, VF – very frequent, Cu – cumulus, Ac – alto-cumulus, Ci – cirrus. The thickness is 1 to 5, where 5 is complete obscuration. Entries of Fair, Clear, Fog, Blowing Snow (BS), and so forth, maybe found as well (e.g. see p. 69 in Carrigan and Oliver, 1967).
- v) “Seeing”: from 1 (very bad seeing) to 10 (very good seeing). The criteria for “seeing” were not well-defined, but rather taught as part of the initial training supplemented by the later experience. Note that values from 8 to 10 were only used before 1960 and values from 6 to 7 before 1970. From 1970, the scale used was from 1 to 5, although the seeing was equal to “5–6” one day in 2002 and another in 2003.
- vi) “Condition”: condition of the sky to observe (e.g. poor, bad, good, excellent).
- vii) “G”, “S”, and “R”: Number of groups, single sunspots recorded, and sunspot number computed, respectively.
- viii) From “Group_1” to “Group_22”: group codes are assigned which are composed of the number assigned to each group, their typology according to the Zurich classification and the number of single sunspots recorded in each group (e.g. “9999_D_12” means group “9999” is composed of 12 single sunspots and its typology according to the Zurich classification is “D”). “X” is indicated when no information is available.

- ix) “Notes”: this column includes comments made by the observers and explanation of corrections applied to the information included in the drawings.

Some drawings may provide fewer parameters, and the list of parameters changes throughout the lifetime of the observing program.

We have applied a quality control to the digitized data in order to identify mistakes in the information included in the original drawings. Errors have been corrected in cases when, for example, the number of single sunspots and groups provided in the counting box is not equal to that recorded in the drawings, some values of the sunspot number index were miscalculated and wrong group codes were provided because of misprints or different groups have the same group code. The corrections applied in the machine-readable version are explained in the “Notes” column indicating as well what the original values were in the drawings. However, some errors, mainly in the group code assigned to the groups, may still remain, and thus, a deeper analysis of the dataset is needed. Explanations about some errors that were identified but not corrected are also provided in the “Notes” column.

The number of observations made at SPO between 1 September 1947 and 11 May 2004 is 15480 in 15382 different observation days. This means a temporal coverage equal to 74.8 % and an average of 273 observation days per year. We highlight that more than 300 observation days per year were recorded in 29 years during the period covered by the dataset. There are 98 days with multiple drawings. Some of the multiple drawings were made on the days, when initially no sunspot activity was observed. In some cases, the last drawing may show a single pore, which would disappear by the next day. While the overall statistics of such cases is not great, it may be relevant for understanding the properties of the sunspot number index near cycle minimum. Figure 4 (top panel) shows the yearly temporal coverage calculated according to SPO data. The observation period spans more than five solar cycles, from the maximum of Solar Cycle 18 to the end of Solar Cycle 23. Furthermore, Figure 4 (bottom panel) shows a comparison between the yearly sunspot number index from SPO and the reference yearly sunspot number index ($S_N v2$) provided by the Sunspot Index and the Long-term Solar Observations (<http://sidc.oma.be/silso/>). Note that the yearly values from SPO were calculated from daily data. Maxima and minima of solar activity are located in the same year in both series except for the maxima of Solar Cycles 19, 21, and 23 which occurred one year later in the three cases according to SPO with respect to the reference sunspot number. Typically, the SPO sunspot number is smaller than $S_N v2$, except for the rising phase of Solar Cycle 20, when the two series match each other quite well. We note that this period coincides with the training of USAF SOON personnel (see, Section 2) although it could be just a coincidence. We have also calculated the ratio between yearly values from the reference sunspot number and SPO (black dashed line in Figure 4, bottom panel). In the first years, the ratio decreased from 2.2 until 1.0 in 1954. Then, it ranged between 0.9 and 1.4 from 1955 till 1990 when the ratio reached 1.5. Since 1990, the value ranged between 1.2 and 1.7. The trend in SSN and the SSN ratio observed during the first 4–5 years can be due to several causes. One of them is the observers’ learning curve; as far as we know, the same telescope was used until 1952 (Section 2), but the new observers were introduced to the task of taking daily sunspot drawings. Other reasons that contribute to this trend can be the successive changes of observers and of projection diameter of the drawings. We think that this first part of the SPO series should be treated as multiple stations, different from the “standard” station of SPO. Moreover, the standard deviation of the ratio is rather uniform and there are not significant changes between maxima and minima of solar activity. This is a striking fact because the ratio should be affected by larger deviations in the minima than in the maxima, when values of sunspot number are much larger (Dudok de Wit, Lefèvre, and Clette, 2016). However, we note that the relative error of the ratio shows a solar cycle

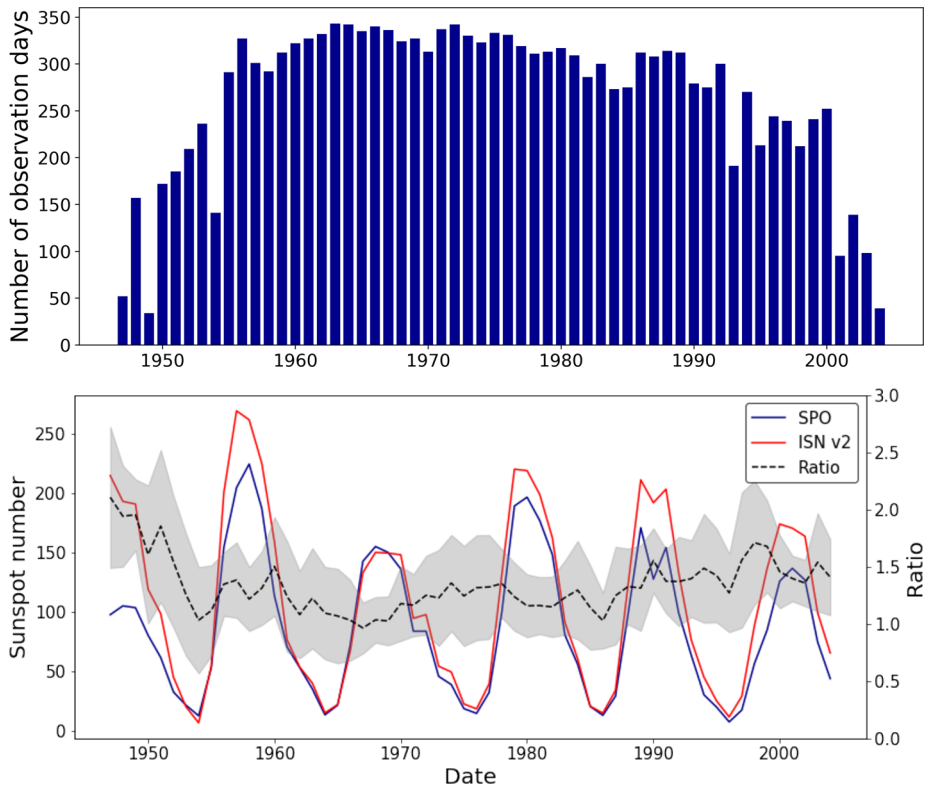


Figure 4 (top panel) Number of observation days recorded at SPO for the period 1947–2004. (bottom panel) Comparison between yearly $S_N v2$ (www.sidc.be/silso/) (red curve) and the yearly sunspot number index computed from SPO drawings (blue curve). The black dashed line depicts the ratio between both series and gray shadow represents its standard deviation.

dependency. The number of observation days steadily increases (Figure 4) till mid-1950s, and then it stays at a high level till about mid-1990s, when the first cuts to the program were made. A minimum in ratio of SPO and $S_N v2$ maybe a combination of the learning curve and the minimum in sunspot activity, when a small difference in the observed sunspot number could result in a relatively large difference in ratio. By the beginning of 1955, the SPO SSN had stabilized, and the observations were taken more regularly as is evident from the total number of observation days (Figure 4). Between 1990–1994, due to the observers' schedule, there were extended periods of time when the sunspot drawings were made operating the coronal monitor (Section 2). Despite the larger aperture telescope, the ratio of SPO SSN and $S_N v2$ does not show a systematic deviation from the mean ratio. Based on this catalogue, a future work could be to investigate how fluctuations in the ratio change according to different observers. As the program of sunspot drawings was ramping down, the number of observation days shows a sharp decline beginning 2001.

5. Future Work

The long time coverage (57 years), well-documented observing conditions and the observer names make the Sac Peak sunspot drawing series a unique dataset for studying the effects

of objective and subjective parameters on the determination of the sunspot number. The datasets span the period of modern space exploration, which, at least in principle, allows for making a connection between sunspot properties and modern measures pertinent to space weather. In the first step of this work, we have presented valuable information recorded in the SPO drawings such as the daily number of single sunspots and groups, values of sunspot number index, conditions of the sky for the observation, and observers responsible of each record. However, more information can be obtained from these drawings. As future work, positions and areas of the groups recorded should be calculated. We note that this information is included in several drawings made in 1964 and in one drawing made in 1965 and other in 1966. In this way, a more complete sunspot catalogue would be available. This could facilitate other studies such as the longitudinal/latitudinal emergence of active regions and the population of various group types as a function of activity level.

Some mistakes have been solved in this first version of the SPO sunspot catalogues as explained previously. However, others remain to be tackled in next versions. For example, there are no group codes for groups recorded between 1947 and 1964 and group codes could be assigned for those groups to complete the catalogue. Furthermore, many groups, especially from 1995, do not have group code and it should be completed according to group codes assigned to other groups recorded in those dates. There are also several examples where the number of groups was not recorded in a particular day though it was recorded for the previous and subsequent days. This fact should be revised case by case. Thus, these issues and others that may arise in the future will be analyzed in upcoming versions.

There are also important parameters recorded in the SPO drawings such as the atmospheric seeing, condition of the sky, photometer readings for the sky brightness, and the names of the observers responsible for each record. These parameters could be used, for example, to investigate if there is any systematic trend with time in sunspot number index from the same observer. Moreover, another issue to be analyzed could be how the seeing and atmospheric conditions affect the sunspot number index.

6. Conclusions

SPO carried out a sunspot observation program from August 1947 to May 2004 spanning from the maximum of Solar Cycle 18 till the end of Solar Cycle 23. Drawings were recorded in more than 15000 observation days during this period with a temporal coverage of around 75% regarding all the observation days. We created a machine-readable version including the information of these drawings which can be accessed via <https://doi.org/10.25668/9x5p-6d86> and Historical Archive of Sunspot Observations (<http://haso.unex.es/>). We note that several mistakes were detected and corrected. Explanations about corrections applied to the catalogue are provided in the machine-readable version.

A comparison between sunspot number computed from SPO observations and the $S_N v2$ shows that both series have a similar behavior. Regarding maxima and minima of solar cycles, we have only found differences for maxima of Solar Cycles 19, 21, and 23, when they occurred one year later according to sunspot observations made at SPO. Moreover, these drawings could be useful to study, for example, space weather events. Figure 5 shows sunspot drawings recorded at SPO when some extreme space weather events occurred such as those in 1967, 1989 (Quebec solar storm), and 2003 (Halloween solar storm).

The Sac Peak sunspot drawing series has several interesting aspects that deserve a detailed study. While this time series is associated with the professional observatory, many

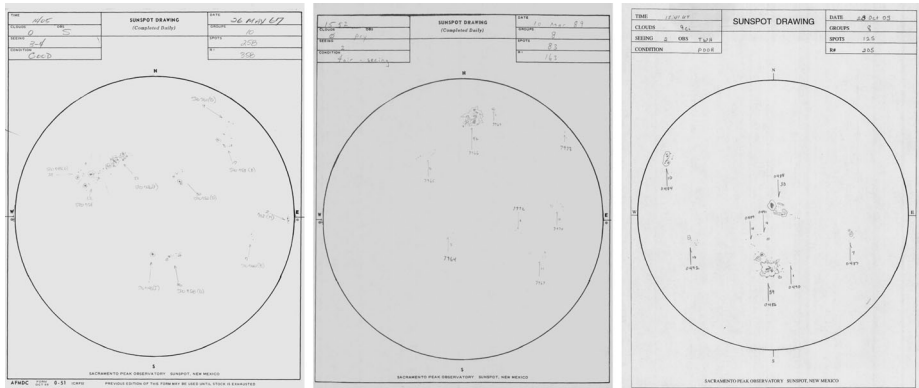


Figure 5 Sunspot drawings recorded at SPO on 26 May 1967, 10 March 1989, and 28 October 2003 when extreme space weather events occurred.

observers were not trained scientists. Due to its location (remote area of a sparsely populated state) and the time of the observatory creation (shortly after World War II), some of the earlier observers even included local ranchers, who were hired by the observatory first as the supporting staff (e.g. William (Bill) Davis, the owner of the Davis Ranch for those familiar with the area). Some observers were graduate students and some were scientists with formal university Ph.D. training. The program was also used for personnel training for USAF SOON network. Recording the time periods and the names of different observers allow to investigate any subjective trends (e.g. learning curves), and their effect on a composite sunspot number. Due to emphasis on coronal observations in the early days of the Sac Peak observatory, the drawings contain important information about the sky brightness, which could be used to investigate the effect of atmospheric scattered light on sunspot visibility.

As future work, we propose the determination of sunspot positions and areas. Moreover, in order to complete the sunspot catalogue for SPO, groups codes should be assigned to groups with no code and those problems detected and explained in previous sections must be analyzed case by case. Future investigations on how atmospheric conditions and observations made by the same observer over time affect the sunspot number index will be carried out using the SPO dataset. Thus, the recovering task of historical sunspot catalogues allows us to study past space weather and climate, and it will help us make better forecasts of future solar activity and space weather events.

Acknowledgements The authors acknowledge the international team on Recalibration of the Sunspot Number Series supported by the International Space Science Institute (ISSI), Bern, Switzerland. This research was supported by the Economy and Infrastructure Counselling of the Junta of Extremadura through project IB16127 and grants GR18097 (cofinanced by the European Regional Development Fund) and by the Ministerio de Economía y Competitividad of the Spanish Government (CGL2017-87917-P). Sac Peak drawings were digitized by NOAA's (former) National Geophysical Data Center (NGDC) and AAP. AAP acknowledges fruitful conversation with Kim Streater about his experience as a Sac Peak observer, and the help by Lou Gilliam and Douglas Gilliam with identifying the names of many observers (their initials on drawings are shown in parentheses): Bryan Armstrong (BDA), George Austin (GMA), Harley Baird (HB), Ed Bergstrom (ENB, EHB), Bill Breedlove (WOB), Todd Brown (DTB), Don Carson (DC), Roger Carson (RC), Eddy Coleman (JEC), Roy Colter (RLC), Rudolph Cook (RHC), John Cornett (JLC), Harry Crawford (HC), Bill Davis (B, BD), Lee Davis (LD), William Davis (W), Howard DeMastus (HD, D, HLD), Joe Elrod (JKE), Lou Gilliam (G, LBG, LG), Douglas Gilliam (DLG), Buzz Graves (BG, BEG), Frank Hegwer (H), Steve Hegwer (SLH), Tim Henry (TWH), Ellis Johansen (E, EEJ, EJ), Dick Mann (M), Frank Manigold (FEM), Patrick S. McIntosh (MC INTOSH), Gary Phyllis (GLP, GP), Harry Ramsey (HER), George Schnable (GSK, GS), Mike Smith (MTS), Arnold Starr (AUS), Rod Stover (S), Kim V. Streater (KVS), Steve

Tullis (SET, TULLIS), Bob Wade (W), Jim Warwick (JPW, WARWICK), Phil Young (PCY, PYC), and Dr. Ching-Sung Yu (Y, YU). We thank all observers for their dedication to the program of daily sunspot drawings at Sacramento Peak observatory. Data were acquired by the white-light patrol instrument operated by NSO/AURA/NSF.

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

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

- Arlt, R., Vaquero, J.M.: 2020, Historical sunspot records. *Living Rev. Solar Phys.* **17**, 1. DOI.
- Balasubramaniam, K.S., Henry, T.W.: 2016, Sunspot numbers from ISOON: a ten-year data analysis. *Solar Phys.* **291**, 3123. DOI. ADS.
- Balasubramaniam, K.S., Pevtsov, A.: 2011, Ground-based synoptic instrumentation for solar observations. In: *Solar Physics and Space Weather Instrumentation IV, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **8148**, 814809. DOI. ADS.
- Baranyi, T., Györi, L., Ludmány, A.: 2016, On-line tools for solar data compiled at the debrecen observatory and their extensions with the greenwich sunspot data. *Solar Phys.* **291**, 3081. DOI.
- Bushnell, D.: 1962, *The Sacramento Peak Observatory 1947-1962, OAR Report 5-History*, Historical Division, Office of Aerospace Research, Washington. National Solar Observatory archives
- Carrasco, V.M.S., Vaquero, J.M., Aparicio, A.J.P., Gallego, M.C.: 2014, Sunspot catalogue of the Valencia observatory (1920–1928). *Solar Phys.* **289**, 4351. DOI.
- Carrasco, V.M.S., Vaquero, J.M., Gallego, M.C., Lourenço, A., Barata, T., Fernandes, J.M.: 2018, Sunspot catalogue of the observatory of the University of Coimbra (1929 — 1941). *Solar Phys.* **293**, 153. DOI.
- Carrigan, A.L., Oliver, N.J. (eds.): 1967, *Geophysics and Space Data Bulletin* **4**, Air Force Research Laboratories, Office of Aerospace Research, United States Air Force, Washington. https://books.google.com/books/download/Geophysics_and_Space_Data_Bulletin.pdf?id=PuD5dvuoyEoC&output=pdf.
- Casas, R., Vaquero, J.M.: 2014, The sunspot catalogues of Carrington, Peters, and de la Rue: quality control and machine-readable versions. *Solar Phys.* **289**, 79. DOI.
- CH2M HILL Inc.: 2017, Proposed changes to Sacramento Peak observatory operations: historic properties assessment of effects. Technical report. https://www.nsf.gov/mps/ast/env_impact_reviews/sacpeak/section106/Historic_Properties_Assessment_of_Effects_Report.pdf.
- Chadwick, W.B.: 1963, Effective sunspot numbers, January 1961 through July 1962. *J. Res. Natl. Bur. Stand., D Radio Propag.* **67D**, 38. https://nvlpubs.nist.gov/nistpubs/jres/67D/jresv67Dn1p37_A1b.pdf.
- Clette, F., Svalgaard, L., Vaquero, J.M., Cliver, E.W.: 2014, Revisiting the sunspot number. *Space Sci. Rev.* **186**, 35. DOI.
- Cortesi, S., Cagnotti, M., Bianda, M., Ramelli, R., Manna, A.: 2016, Sunspot observations and counting at Specola Solare Ticinese in Locarno since 1957. *Solar Phys.* **291**, 3075. DOI.
- Curto, J.J., Solé, J.G., Genescà, M., Blanca, M.J., Vaquero, J.M.: 2016, Historical heliophysical series of the Ebro observatory. *Solar Phys.* **291**, 2587. DOI.
- DeVorkin, D.: 1983, In: *Interview of Walter Roberts on 1983 July 27, Niels Bohr Library & Archives*, American Institute of Physics, College Park. <https://www.aip.org/history-programs/niels-bohr-library/oral-histories/28418-2>.
- Dudok de Wit, T., Lefèvre, L., Clette, F.: 2016, Uncertainties in the sunspot numbers: estimation and implications. *Solar Phys.* **291**, 2709. DOI.
- Erwin, E.H., Coffey, H.E., Denig, W.F., Willis, D.M., Henwood, R., Wild, M.N.: 2013, The greenwich photo-heliographic results (1874 – 1976): initial corrections to the printed publications. *Solar Phys.* **288**, 157. DOI.
- Evans, J.W.: 1967, Sacramento peak observatory. *Solar Phys.* **1**, 157. DOI. ADS.
- Lefèvre, L., Aparicio, A.J.P., Gallego, M.C., Vaquero, J.M.: 2016, An early sunspot catalog by Miguel Aguilar for the period 1914 – 1920. *Solar Phys.* **291**, 2609. DOI.
- Lefèvre, L., Clette, F.: 2014, Survey and merging of sunspot catalogs. *Solar Phys.* **289**, 545. DOI.
- Liebowitz, R.P.: 2002, Donald Menzel and the creation of the Sacramento Peak observatory. *J. Hist. Astron.* **33**, 193. DOI. ADS.
- Mandal, S., Hedge, M., Samanta, T., Hazra, G., Banerjee, D., Ravindra, B.: 2017, Kodaikanal digitized white-light data archive (1921-2011): analysis of various solar cycle features. *Astron. Astrophys.* **601**, A106. DOI.

- Muñoz-Jaramillo, A., Senkpeil, R.R., Windmueller, J.C., Amouzou, E.C., Longcope, D.W., Tlatov, A.G., Nagovitsyn, Y.A., Pevtsov, A.A., Chapman, G.A., Cookson, A.M., Yeates, A.R., Watson, F.T., Balmaceda, L.A., DeLuca, E.E., Martens, P.C.H.: 2015, Small-scale and global dynamos and the area and flux distributions of active regions, sunspot groups, and sunspots: a multi-database study. *Astrophys. J.* **800**, 48. DOI. ADS.
- Muñoz-Jaramillo, A., Vaquero, J.M.: 2019, Visualization of the challenges and limitations of the long-term sunspot number record. *Nat. Astron.* **3**, 205. DOI.
- Neidig, D., Wiborg, P., Confer, M., Haas, B., Dunn, R., Balasubramaniam, K.S., Gullixson, C., Craig, D., Kaufman, M., Hull, W., McGraw, R., Henry, T., Rentschler, R., Keller, C., Jones, H., Coulter, R., Gregory, S., Schimming, R., Smaga, B.: 1998, The USAF improved solar observing optical network (ISOON) and its impact on solar synoptic data bases. In: Balasubramaniam, K.S., Harvey, J., Rabin, D. (eds.) *Synoptic Solar Physics, Astr. Soc. Pacific Conf. Ser.* **140**, 519. ADS.
- Pevtsov, A.A., Tlatova, K.A., Pevtsov, A.A., Heikkinen, E., Virtanen, I., Karachik, N.V., Bertello, L., Tlatov, A.G., Ulrich, R., Mursula, K.: 2019, Reconstructing solar magnetic fields from historical observations. V. Sunspot magnetic field measurements at Mount Wilson observatory. *Astron. Astrophys.* **628**, A103. DOI. ADS.
- Pötzi, W., Veronig, A.M., Temmer, M., Baumgartner, D.J., Freislich, H., Strutzmann, H.: 2016, 70 years of sunspot observations at the Kanzelhöhe observatory: systematic study of parameters affecting the derivation of the relative sunspot number. *Solar Phys.* **291**, 3103. DOI.
- Ramsey, J.: 2002, *New Mexico Sunspot: Sacramento Peak Observatory in the Beginning*, Essence Publishing, Belleville. ISBN 978-1-55306-484-8.
- Secan, J.A., Wilkinson, P.J.: 1997, Statistical studies of an effective sunspot number. *Radio Sci.* **32**, 1717. DOI. ADS.
- Willis, D.M., Henwood, R., Wild, M.N., Coffey, H.E., Denig, W.F., Erwin, E.H., Hoyt, D.V.: 2013a, The greenwich photo-heliographic results (1874 – 1976): procedures for checking and correcting the sunspot digital datasets. *Solar Phys.* **288**, 141. DOI.
- Willis, D.M., Coffey, H.E., Henwood, R., Erwin, E.H., Hoyt, D.V., Wild, M.N., Denig, W.F.: 2013b, The greenwich photo-heliographic results (1874 – 1976): summary of the observations, applications, datasets, definitions and errors. *Solar Phys.* **288**, 117. DOI.
- Zirker, J.B.: 1998, The Sacramento Peak observatory. *Solar Phys.* **182**, 1. DOI. ADS.