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Long-term variation of solar activity: recent progress

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Abstract

The concept of solar activity is a common term nowadays. However, it is not straightforwardly interpreted and it is ambiguously defined. A review of our knowledge of the long-term behavior of solar activity in the past is presented, as reconstructed using the indirect proxy method (millennial time scale) and the direct historical observations (secular time scale). The latest international efforts to obtain a series of sunspot numbers of the last four centuries are reviewed. Observations of sunspots during the Maunder minimum (1645–1715) are particularly interesting and they show the solar cycle during this period of Grand Minimum of solar activity.

1 Introduction

The long-term variability of the solar activity is studied with interest by the international scientific community, especially by solar physicists, geophysicists, and astrophysicists. The history of solar activity can be reconstructed from (i) proxies as the cosmogenic isotopes [23] and (ii) historical documents [26]. Although the study of solar activity over the last millennia is only possible with records of C^14 and Be^10, the final calibration of these series is performed using the Sunspot Number, that is obtained from historical documents (the ancient observations of sunspots made with telescopes from 1610). In fact, the sunspot counting is the longest current experiment in the history of science [17].

However, not only the ancient telescopic observations of sunspots can be used for the reconstruction of solar activity. Other documents also provide interesting facts about solar activity in the past. Figure 1 shows the different kinds of direct and indirect observations that are interesting for the reconstruction of the past solar activity.

In this work, I review the latest efforts of the scientific community in the field of the reconstruction of the solar activity during the last centuries using historical documents.

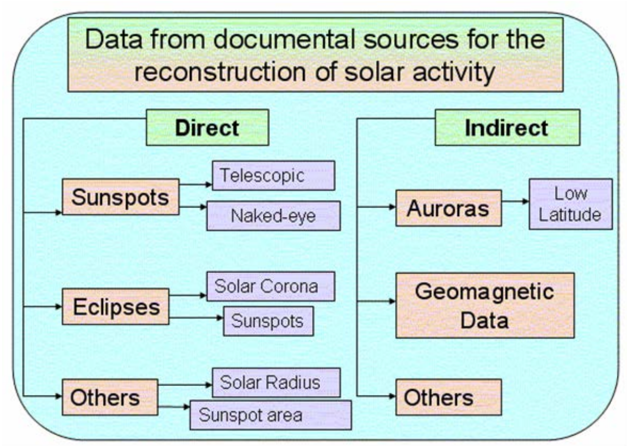


Figure 1: Data from documentary sources for the reconstruction of past solar activity.

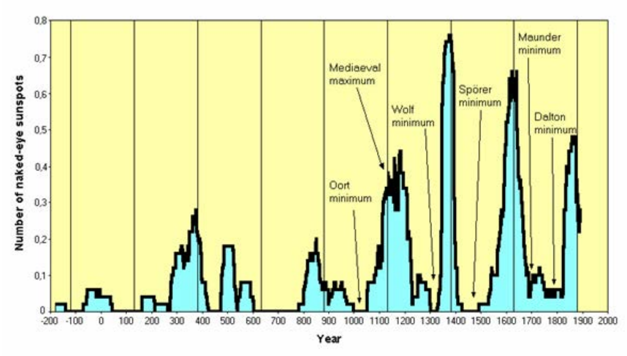


Figure 2: Number of naked-eye sunspot observation (50-year moving average) in the last 22 centuries (modified from [25]).

2 Naked-eye observations of sunspots

Sometimes, the atmosphere acts as a natural filter and great sunspots can be seen through the mist or smoke without the aid of telescopes (see Chapter 2 of Vaquero and Vzquez, 1999). Using historical records (especially from Oriental countries, mainly China, Japan and Korea), we can find the number of naked-eye observations of sunspots during the last 22 centuries at least [25]. Although this series of observations (Figure 2) is contaminated by sociological and climatic effects, the great events of the past solar activity can be clearly detected.

A possible link between the Medieval Climate Anomaly (MCA) and an anomalous solar activity during the twelfth and thirteenth centuries has been speculated (see, for example [11]). [27] have reconstructed the solar cycle length (average duration of 10.72 ± 0.20 years) during the MCA using observations of naked-eye sunspot and aurora sightings. They found that solar activity was probably not exceptionally intense. This result supports the view that internal variability of the coupled ocean-atmosphere system was the main driver of the MCA.

3 The "new" sunspot number

The well-known "relative sunspot number" was derived by Rudolf Wolf in the 19th century using the number of sunspot groups and the number of individual sunspots reported in modern and historical solar observations (Wolf, 1851, 1856). The original idea has been continuously updated forming the so-called "International Sunspot Number" [5]. However, [10] derived the "Group Sunspot Number" using only the number of sunspot groups. Figure 3a shows these series that agree only from 1885 approximately.

During the last years, some meetings have been held to understand the differences between these series. The main results of this effort are two new series: "Sunspot Number, S_N" and "Group Number, G_N" [7]. An important part of the discrepancies between the original series has been explained [6] and two new institutions have been created: SILSO (Sunspot Index and Long-term Solar Observations, World Data Center for the production, preservation and dissemination of the international sunspot number; www.sidc.be/silso/) and HASO (Historical Archive of Sunspot Observations; haso.unex.es).

Moreover, a Topical Issue of the journal Solar Physics on the sunspot number time series will be published in December 2016. It will include independently-proposed alternative SN time series and articles about the historical context, critical assessments, correlative analyses, and observational data related to the sunspot number time series.

The next step in the study of the past solar activity from a synoptic point of view is the recovery of the sunspot catalogues and collection of historical sunspot images (drawings and photographs) that are preserved in archives and libraries of several scientific institutions [12]. Several examples have been published in the last years from different institutions and associations as Madrid, Valencia, and Ebro observatories in Spain [13, 2, 9], Specola Solare Ticinese [8], Debrecen Observatory [1] and Kanzelhhe Observatory [18].

4 The solar radius since 1773

Sunspot Numbers can be derived from historical solar observations. Moreover, another important set of direct solar observations is related to measurements of the solar radius. A long series of measurements of the solar diameter during the past four centuries [20] is available but the apparent variations in solar radius differ depending on several factors including the instruments, methods used, the Earth's atmosphere in the case of ground-based observations, and even the observer, especially in historical observations. Thus, the recovery of historical solar-radius measurements is important [21, 16] because the long-term trend of the solar diameter is still an open and controversial issue.

Recently, [29] have recovered the measurements of the solar diameter made at the Royal Observatory of the Spanish Navy (today the Real Instituto y Observatorio de la Armada) almost continuously since its creation in 1753. During the last 250 years approximately, this observatory has monitored the solar diameter using different instruments: Mural Quadrant Manufactured by Bird (1773–1790), small and portable instruments (1801–1808), Meridian Telescope Manufactured by Jones (1833–1868), Meridian Circle Manufactured by Troughton

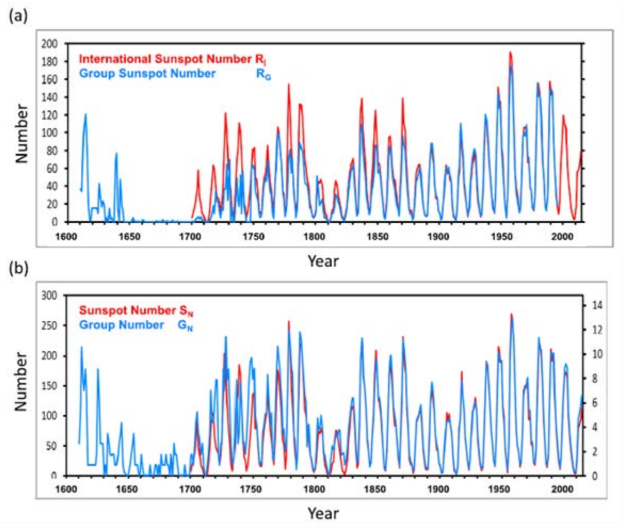


Figure 3: (a) The "old" Sunspot Numbers: International Sunspot Number (R_I) and Group Sunspot Number (R_G). (b) The "new" Sunspot Numbers: Sunspot Number (S_N) and Group Number (G_N) (modified from [7].

and Simms (1892–1930), and, finally a Danjon Astrolabe (1991–2006). If we stacked all that the documents that were consulted in the historical archive of this institution, the boxes of documentation would form a column approximately 15 m high. Figure 4 shows the annual data and no significant long-term trends were found. The average value for the solar semidiameter, with one standard deviation, calculated from these observations (after applying corrections for refraction and diffraction) is equal to $958.87'' \pm 1.77''$.

5 Great solar and geomagnetic storms

In the last year, two case studies of great solar and geomagnetic storms occurred in the first half of the 20th century have been published. Ribeiro et al. (2016) reviews the first space weather event that affected significantly a number of communication networks in the Iberian Peninsula using an account by the Director of the Spanish Meteorological Service and the historical observations of the geomagnetic field preserved in the archives of the Coimbra Observatory (Portugal) and the Royal Observatory of the Spanish Navy (Spain). The geomagnetic storm took place on 31 October 1903. This epoch correspond to the ascending phase of solar cycle 14, the lowest since the Dalton Minimum. The widespread problems that occurred in the telegraph communication network in Portugal and Spain are described. The telegraphic service was practically interrupted from 09h30 to 21h00 UT.

The geomagnetic measurements confirm the simultaneous occurrence of large geomagnetic disturbances. The magnetograms recorded in Coimbra have been recovered. In the Royal Observatory of the Spanish Navy, the instruments were saturated. However, the observers describe carefully the geomagnetic storm (Figure 5).

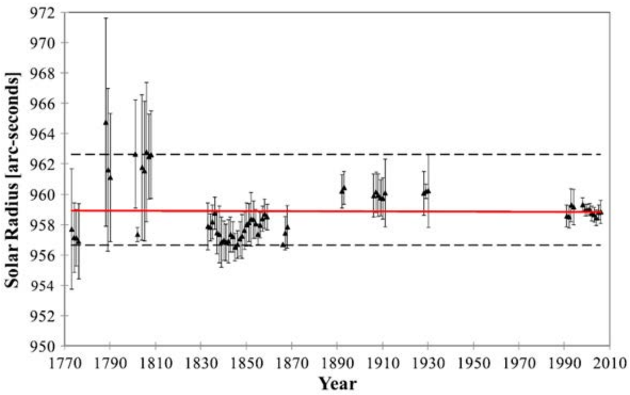


Figure 4: Annual averaged values of the measurements of the solar radius in arc-seconds with error bars (1σ) made at the Royal Observatory of the Spanish Navy in Spain during approximately the past 250 years. The heavy line shows the least-squares fit. The two horizontal dashed lines represent the interval 959.63”$\pm$3.00”.

The main conclusion of the work by Vaquero et al. (2016) is that under certain geomagnetic conditions large geomagnetically induced currents can occur in southern European countries.

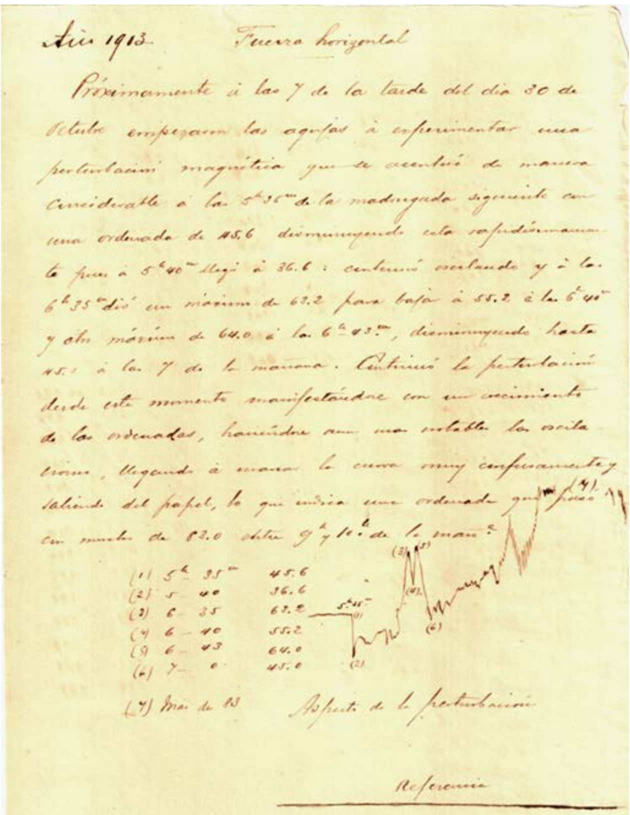
Another interesting case study was presented by [14]. On 18-19 September 1941, the Earth experienced a great magnetic storm. It arrived at an interesting moment in history because radio and electrical technology was emerging in the middle of a military conflict, the World War II. Different relevant effects are described as auroras or radio blackouts.

6 Maunder minimum: What’s up?

[30] have challenged the reality of the numbers of reported sunspots during the Maunder Minimum concluding that the Maunder Minimum was not a radical departure from normal solar behavior. Thus, [30] speculate that 11-yr peak sunspot counts ranged from 30 to 100 approximately during the core of the Maunder Minimum (rather than the 0.1 to 2.0 range inferred from Hoyt and Schatten, 1998). McCracken and Beer (2014) obtained an independent estimate of solar activity (using cosmogenic nuclide concentrations in ice cores) during the Maunder Minimum with highest values from 3.5 to 11 approximately. Some recent articles [3, 4, 22, 24, 28] estimate the maximum value of the sunspot number during the Maunder Minimum using original sources. These studies provide values around 10, in agreement with the cosmogenic nuclide studies (Figure 6).

7 Conclusion

The Sun controls our life and all the processes that occur in our Solar System and, especially for us, in our planet. Any information on the state of the Sun in past times would be



Año 1913 Fuerza horizontal

Próximamente á las 7 de la tarde del día 30 de Octubre empezaron las agujas á experimentar una perturbación magnética que se acentuó de manera considerable á las 5h 35m de la madrugada siguiente con una ordenada de 45.6 disminuyendo esta rapidísimamente pues á 5h 40m llegó á 36.6: continuó oscilando y á las 6h 35m dió un máximo de 63.2 para bajar á 55.2 á las 6h 40m y otro máximo de 64.0 á las 6h 43m, disminuyendo hasta 45.0 á las 7 de la mañana. Continuó la perturbación desde este momento manifestándose con un crecimiento de las ordenadas, haciéndose aun más notable las oscilaciones, llegando á marcar la curva muy confusamente y saliendo del papel, lo que indica una ordenada que pasó (7) con mucho de 83.0 entre 9h y 10h de la mañana.

(1)	5h 35m	45.6
(2)	5 – 40	36.6
(3)	6 – 35	63.2
(4)	6 – 40	55.2
(5)	6 – 43	64.0
(6)	7 – 0	45.0

(7) Más de 83

Aspecto de la perturbación

Referencia

Figure 5: Handwritten notes on the early stages of the storm of 31 October 1903 from the Royal Observatory of the Spanish Navy.

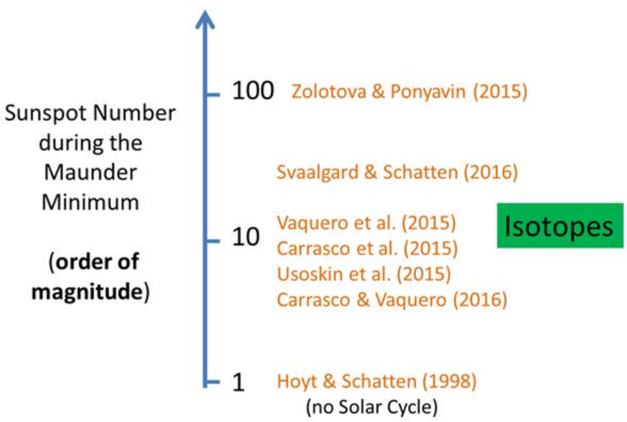


Figure 6: A sketch of the last results about the Sunspot Number during the Maunder minimum.

interesting because the Sun is not a laboratory experiment that can be controlled. Here, I have reviewed some efforts made in the last years in this direction. However, important and forgotten information about the state of the Sun in past times is still preserved in archives and libraries.

Acknowledgments

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