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Shedding Light from the Past: the Example of the Solar Records

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Abstract

Astronomy is a science grounded in observations rather than experiments. While all scientific disciplines can glean insights from their past, in the case of astronomy, this holds even greater significance. Any observation made in the past can be relevant in certain contexts. In this presentation, I will explore what solar and heliospheric physics can extract from past observations, with a special focus on the development of the Sunspot Number – arguably the most renowned temporal series in the history of science, crucial for understanding solar activity in the past. Nevertheless, solar astronomers and geophysicists can also obtain valuable insights from other resurrected observations: auroras, the solar corona during total eclipses, various observables (such as sunspot area, solar radius, or umbra/penumbra ratio), or geomagnetic measurements, to name some examples..

1 Introduction

Historical records present extraordinary opportunities and enormous challenges to scientists, even though traditionally science is not directly linked to history. In this sense, the case of geosciences is really significant. Archives and historical libraries hold series of information on earthquakes, volcanic eruptions, landslides, floods, droughts, auroras and many other phenomena of geophysical interest that deserve and should be studied by the scientific community (see, for example, Ambraseys, 1971, and Pyle and Barclay, 2020). Like geosciences, astronomy is another science that is especially related to observations rather than experiments and, therefore, historical documents should play a relevant role in some of its fields of research.

Figure 1 can be a paradigmatic example of the surprises that a scientist can find in historical documents. Malville (2008) proposed that the petroglyph in Figure 1, located on the south face of the so-called “Sun Stone” in Chaco Canyon, represents the solar corona observed by the Pueblo Indians during the solar eclipse of July 11, 1097. However, we all know that proving this hypothesis seems almost impossible. What would be possible is to falsify this hypothesis, since Figure 1 clearly shows a solar corona during a maximum of the 11-year solar cycle. The solar corona during a minimum of the cycle shows long equatorial coronal streamers, which do not appear in Figure 1. Can we know if the year 1097 was associated with a maximum or a minimum of activity?

Fortunately, Vaquero and Trigo (2012) identified the maxima of the solar cycles of the 11th and 12th centuries from historical observations of auroras and sunspots observed with the naked eye because they were interested in knowing the solar activity during the so-called Medieval Climate Anomaly (MCA). Malville and Vaquero (2014) showed that the hypothesis why the year 1097 is associated with a maximum solar activity cannot be falsified. Therefore, readers are possibly looking at Figure 1 for the first CME recorded in history more than a thousand years ago. And I think that is quite impressive.

Figure 1: The petroglyph on the south face of Piedra del Sol in Chaco Canyon may depict the solar corona observed during the total solar eclipse of July 11, 1097 CE.

In this text, I would like to highlight some lessons that we can learn from historical documents applied to solar and magnetospheric physics. First, I would like to review what we know about the Maunder minimum from historical documents. This minimum of solar activity that occurred in the second half of the 17th century is the great paradigm of terrestrial-solar physics. I will also briefly review the new version of the sunspot number and the next goals of our community regarding this famous time series. But sunspots are not the whole story. I will also review historical measurements of the solar radius, some of special interest to the Spanish community.

2 The Maunder Minimum

Today, we have many indices based on physical measurements to quantify solar activity. However, the different time series of these indices cover only a few tens of years. Activity reconstructions for millennia exist, thanks to measurements of cosmogenic isotopes such as

BE10 and C14 (Beer et al., 2012; Usoskin, 2017). In between these time scales, we have sunspot counts for the last 400 years, approximately.

In the isotope-based record, there is a very striking feature: the presence of periods of several decades with very low solar activity that have been called 'grand solar minima'. Only one of these periods has occurred in the last four centuries (which we can call the telescopic epoch). The Maunder Minimum (MM) was a period of very low solar activity that occurred in the 17th century (Eddy, 1976). Since this century also saw one of the coldest phases of the 'Little Ice Age' (LIA) and one of humanity's global crises (Parker, 2014), this episode in the recent history of solar activity has become the paradigm of Sun-Earth relations.

However, simple and linear relations do not usually occur in this field of science, and everything is often more complex. I would like to show the following anecdote that illustrates the complexity of the studies of the Sun-Earth relations. If one looks at any popular text on the MM, one can find images of paintings made by the famous artists of the time, full of snowy landscapes and frozen rivers. In particular, it is very easy to find the work titled 'The Hunters in the Snow' an oil-on-wood painting by Pieter Bruegel the Elder (Figure 2) that is preserved in the collection of the Kunsthistorisches Museum in Vienna, Austria. However, this painting was painted in 1565... a century before the MM occurred! What is very clear is that the LIA was a very irregular climatic event, which occurred over several centuries with different moments of intensity and in different places on Earth, that is, with great variability on temporal and spatial scales.

Figure 2: The Hunters in the Snow, an oil-on-wood painting by Pieter Bruegel the Elder.

Over the past 20 years, the literature on the MM has grown a lot and some facts are now firmly established:

(i) Low solar activity during the MM was real. The order of magnitude of the mean value of the "sunspot number" is 10 units. Scenarios with values of 1 unit (as in the reconstruction of Hoyt and Schatten, 1998) and 100 units (as proposed by Zolotova and Ponyavin, 2015) are ruled out.

(ii) The solar activity cycle did not disappear, although it was greatly attenuated. Following the solar activity reconstruction of Hoyt and Schatten (1998), solar dynamo modellers have tried to suppress the solar cycle to explain the MM. But we now know that the solar cycle was not suppressed. It was just attenuated to damped (Vaquero et al., 2015a).

(iii) There was a large hemispheric asymmetry during the MM. The early work of Ribes and Nesme (1993) already clearly showed this result, which has been confirmed by successive studies, leading to the completion of a butterfly diagram during the MM that clearly shows this asymmetry. The southern hemisphere was clearly the most active and the few sunspots that were observed were mainly located in this hemisphere (Vaquero et al., 2015b).

3 The new sunspot number(s): our next main goal

The sunspot number series, known as the longest-running scientific data series, is essential to understand the Sun's influence on Earth's climate and its impacts on our technology-dependent society. Since 2011, a dedicated effort has been underway to develop a community-vetted sunspot number series, with uncertainties quantified over the past 400 years. This improved data set aims to anchor long-term studies of solar variability, reaching back to the last glacial period, and to support climate models that examine the Earth's response to solar activity.

Efforts to reconstruct the sunspot number series have historically involved multiple approaches. One influential series was introduced by Hoyt and Schatten in 1998, which extended the sunspot record back to 1610 and created the first digital database. However, flaws in their methodology went unnoticed for over a decade, during which time the Hoyt and Schatten series gained widespread acceptance. For example, their methods for adjusting group counts were later found to be inconsistent, resulting in significant discrepancies. To avoid similar issues in future revisions, the ISSI (International Space Science Institute) Sunspot Team developed a new process involving teams of advocates, critics, and mediators to critically analyze each proposed series.

The path forward requires a multidisciplinary approach, combining observations, analysis, and statistical methods to reconstruct an accurate and reliable sunspot series. The ISSI Team emphasizes a probabilistic approach, which considers both observations and uncertainties. Their goal is to develop refined methodologies that can account for data scarcity in historical periods, potentially using composite methods to enhance accuracy. The creation of robust sunspot (SN) and group number (GN) series will allow for more reliable historical climate models and link modern sunspot data to ancient cosmogenic records.

In the coming years, the ISSI Team aims to finalize and validate a trusted sunspot reference series, providing a comprehensive view of solar activity over centuries. This series will offer the scientific community a foundation for studying the long-term evolution of solar behavior and its impact on Earth, with implications for future climate projections and understanding solar-driven climate variability before the modern telescope era (Clette et al., 2023).

4 Measurements of solar radius: from San Petronio (Italy) to San Fernando (Spain)

Although sunspot counting is a paradigmatic case of the kind of science that can be done from historical documents, other examples can be proposed. Here we review two examples of the use of ancient measurements of solar radius.

Tovar et al. (2021) analyzed solar diameter measurements taken at the Basilica of San Petronio (Bologna, Italy, Figure 3) from 1655–1736, aiming to determine any differences between measurements from the Maunder Minimum (MM) period (1655–1715) and the following years (1716–1736). Despite limited metadata and potential personal biases, using the same instrument and method allows for internal comparisons. Results from Tovar et al. (2021) show no statistically significant difference in solar diameter between these periods; the median and average differences are around 0.6", below the measurement accuracy. This finding contrasts with earlier studies suggesting major solar diameter changes during the MM. Since this dataset had not previously been analyzed, these findings provide valuable insights into the solar diameter's stability and contribute to ongoing scientific debate.

Figure 3: The Basilica of San Petronio in Bologna (Italy).

The Royal Observatory of the Spanish Navy (ROA) in San Fernando, founded in 1753, has conducted astronomical observations for over 260 years, including measurements of the solar radius. Through a detailed archival review, 7284 reliable solar radius observations from 1773 to 2006 were recovered, covering six observational stages (Vaquero et al., 2016). Instruments used include the Bird mural quadrant, Jones meridian telescope, Troughton and Simms meridian circle, and a modified Danjon solar astrolabe. Observations varied based on the equipment used, with the Troughton and Simms meridian circle providing the highest solar radius values. Some historical measurements were abnormally high, likely due to the instability of the Cádiz observatory building and the use of temporary or portable instruments. Despite these anomalies, a statistical analysis showed no significant long-term trend in the solar radius over the past 250 years, aligning with previous studies that suggest stable solar diameter since the mid-18th century. There was no observed correlation between solar radius changes and sunspot activity. After applying diffraction and refraction corrections, the mean solar radius calculated from ROA records from 1773 to 2006 was found to be 958.8 arcseconds, with a margin of error of ± 1.8 arcseconds. This dataset provides critical insight into solar stability over centuries, though further research is needed for records from the Maunder Minimum.

5 Final words

In this modest work, we have tried to show how historical documents related to the observation of the Sun have provided us with information of great interest to better understand both our Sun and the interactions between it and our planet. This idea of taking advantage of historical records to improve our understanding of physical phenomena can be extrapolated to all sciences in which real experiments cannot be carried out and we can only observe the phenomena, as usually occurs in astrophysics and Earth and space sciences. Perhaps the readers of this work will pay, from now on, some attention to these historical aspects that could be beneficial for their work and research.

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