“I am fairly skeptical about a new Maunder Minimum”

The influence of the Sun on the Earth's climate is a fascinating subject. Everyone understands that the sun is the main energy source for the climate system. However, the detection of clear variations of climatic parameters due to solar activity is very difficult because the climate system is extremely noisy. Therefore, time scales have a fundamental role in these studies.

“Solar Activity” is a rather vague term. Thanks to cosmogenic isotopes we have some “visions” of “solar activity” in recent millennia (Usoskin, 2013). The most striking of these “visions” of solar activity is that the Sun may be in a “normal” state, or in two states named grand solar maximum or minimum (Usoskin et al., 2014). Obviously, we think that if the Sun is in a state of grand maximum (minimum), then more (less) energy arrives on Earth and, therefore, the temperature of our atmosphere will increase (decrease). This simple idea agrees with the fact that the Little Ice Age coincided with the Maunder Minimum (MM) and the Medieval Climate Anomaly (MCA) coincided with the Solar Medieval Maximum. But in the end, things are a bit more complicated.

For example, My colleague Ricardo Trigo and I obtained recently a result that supports the view that internal variability of the coupled ocean-atmosphere system was the main driver of the Medieval Climate Anomaly and, therefore, solar activity had a minor role in this climatic episode. Note that new reconstructions of solar activity based on cosmogenic radionuclides do not sufficiently constrain the Total Solar Irradiance (TSI) range during the Medieval Climate Anomaly (see black lines in Figure 1). Therefore, we made other approximations of the problem. We reconstructed the average solar cycle length (SCL) during the Medieval Climate Anomaly using historical data from naked-eye sunspot observations and aurora sightings. We used information recorded in historical sources because they have a high time-resolution. We conclude that the average duration of the solar cycle was about 10.72 ± 0.20 years. This value for the solar cycle length corresponds to a solar activity that was probably not exceptionally intense, supporting the hypothesis that internal variability of the climatic system is the main driver of the Medieval Climate Anomaly.

These results are based on very old observations that were made without telescopes. Using these early historical data it is easier to detect solar maxima like the medieval maximum than solar minima like the Maunder Minimum. It is very difficult to detect solar minima using naked-eye sunspot observations and aurora sightings. Therefore, historical sunspot observations using astronomical telescopes are a key to understand the Maunder Minimum.

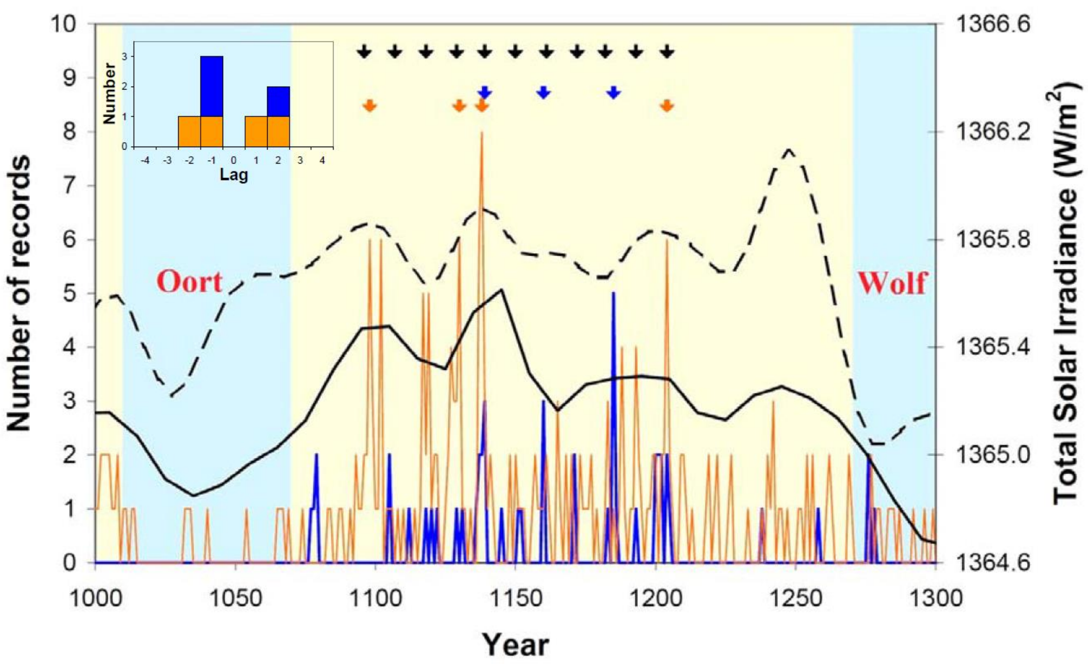

Figure 1. Different solar activity proxies during the period 1050–1300: TSI reconstructed by Steinhilber, Beer, and Fröhlich (2009) (dashed black line), TSI reconstructed by Vieira et al. (2011) (continuous black line), annual number of naked-eye observations of sunspots (Vaquero, Gallego, and García, 2002) (blue line), and annual number of auroral nights (Krivský and Pejml, 1988) (orange line). Black arrows are evenly spaced and correspond to the estimated maxima of solar cycle derived from Vaquero and Trigo (2012). Blue arrows correspond to estimated maxima of solar cycle using naked-eye observations the orange arrows are based on auroral nights sightings. Inset shows, using the same color code, a histogram of the delays (in years) between the fitted and estimated maxima of solar cycle. Oort and Wolf refers to two periods of lower solar activity.

Maunder Minimum

The classical reconstruction of solar activity based on the Wolf number started in 1700, 1749 and 1818 at annual, monthly and daily scales respectively (International Sunspot Number, ISN, see Clette, 2011). Therefore, it does not cover the Maunder Minimum. However a reconstruction by Hoyt and Schatten (the so-called Group Sunspot Number, GSN) published in 1998 starts in 1610 and, therefore, is an extremely useful tool to investigate the Maunder Minimum. The Group Sunspot Number is based only on the number of sunspot groups that are observed in the solar disc. However the International Sunspot Number is computed from the number of sunspot groups and the number of individual spots that are observed in the solar disc. GSN and ISN are pretty similar from approximately 1880 onwards. However they are very different in the 18th century and much of the 19th century. GSN values show a strong upward trend since the end of the Maunder Minimum up to now while values of ISN show no significant trend.

The Hoyt and Schatten series (GSN) is the best reconstruction of solar activity of the last four centuries available today. But we now also know there are some major problems with this series. All reconstructions of solar activity or the Total Solar Irradiance of the last centuries or millennia used this series, directly or indirectly, at some point in their derivation. Thus, the GSN is of great significance.

Unfortunately, Clette et al (2014), of which I am coauthor, has revealed several problems in the current GSN. The most important is that the reference series (obtained from the solar program at the Royal Greenwich Observatory, RGO, started in 1874) is not homogeneous in its early years. I presented Figure 2 in the 2nd Sunspot Number Workshop (Brussels, May 2012, see Cliver et al., 2013). This figure shows the ratio between the sunspot group counts of RGO and the main sunspot observers in the last quarter of the 19th century. All ratios present a positive trend. Therefore, sunspot counts by RGO are low in the first years of this Figure 2 and high in the last years in comparison with the rest of observers. Therefore, RGO counts are not homogeneous in these times. However, RGO was chosen by Hoyt and Schatten (1998) as the prime observer due to the prestigiousness of its solar program. This causes lower GSN values before 1880 because the calibration constant of the observers were adjusted using these first years and the error was propagated back.

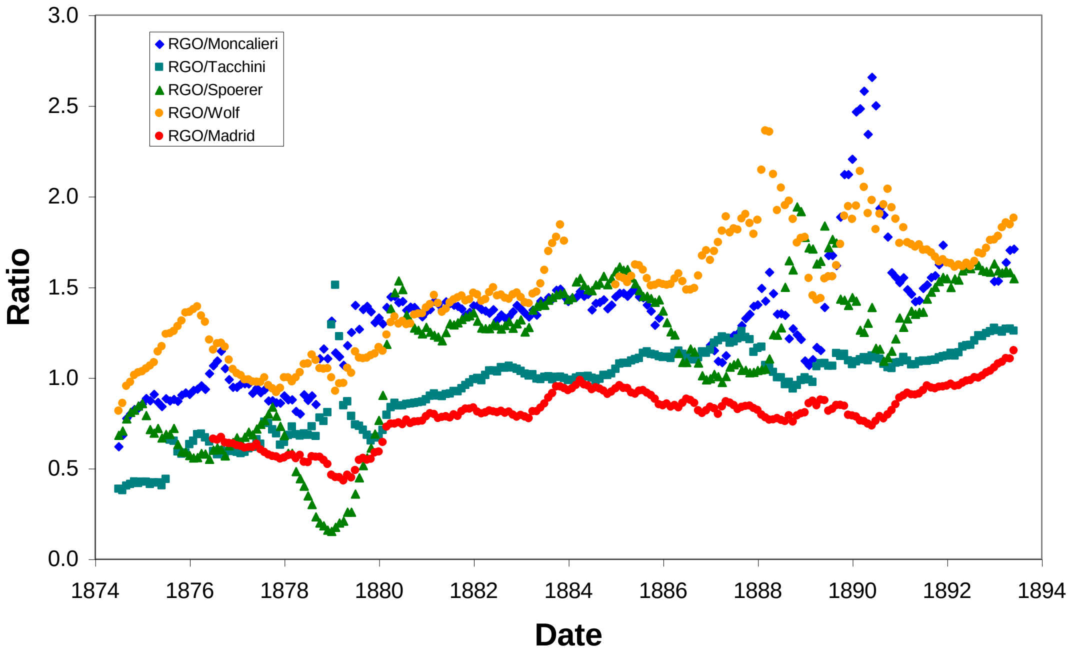

Figure 2. Smoothed ratio between the sunspot group counts of Royal Greenwich Observatory and the main sunspot observers in the last quarter of the 19th century.

Furthermore, Leussu et al. (2013) found the ISN series decreased by roughly 20% around 1848 comparing with the data from original sunspot drawings by Schwabe. However, it was not found by Clette et al (2014) using the data provided by Hoyt and Schatten (1998). According to Leussu et al (2013), this breakpoint around 1848 was caused by the change of the primary observer from Schwabe to Wolf and, probably, an inappropriate individual correction factor used for Schwabe in the ISN. Therefore, we must check both historical sources to detect exactly the origin of these discrepancies.

This leads directly to the controversy over the existence of the Modern Grand Maximum in the 20th century. The results obtained by Clette et al. (2014) suggest there could be no Grand Solar Maximum in the second part of the 20th century. Figure 3 shows the trends for different versions of the sunspot number. Only the GSN produced by Hoyt and Schatten (1998) has a significant trend, allowing a high solar activity in the 20th century in comparison with the other centuries.

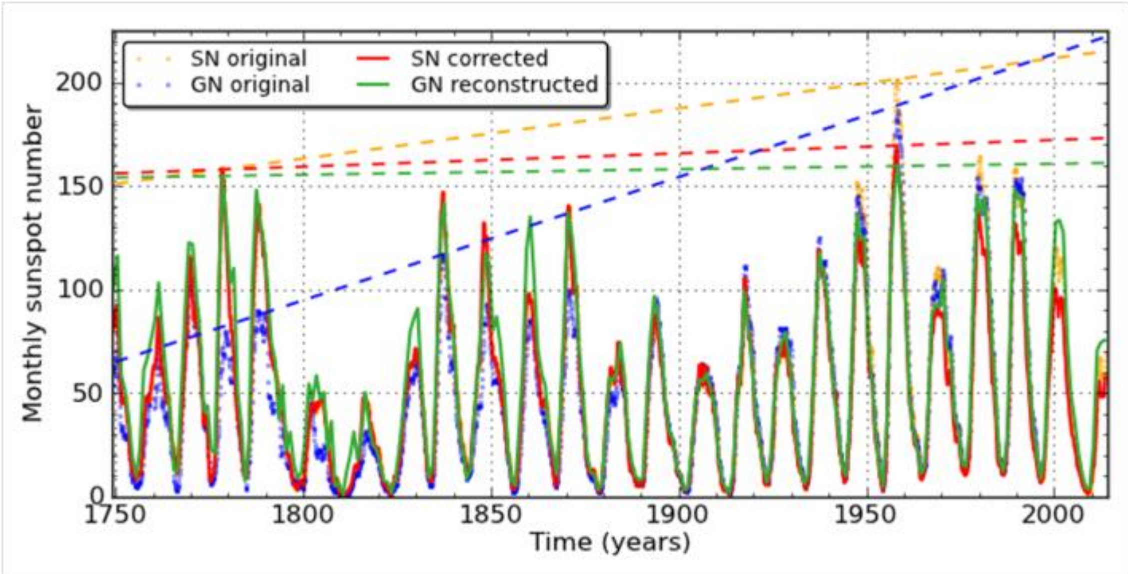

Figure 3. Trends different versions of the sunspot number: (yellow) ISN original, (blue) GSN original, (red) ISN corrected by Clette et al. (2014) and (green) GSN corrected by Clette et al. (2014).

In any case, note that the results presented by Clette et al. (2014) are preliminary and the authors indicate that “although recent cycles do not reach unprecedented amplitudes anymore, the repetition of five strong cycles over the last 60 years (cycles 17 to 22, with the exception of cycle 20) still marks a unique episode in the whole 400-year record” and they add that “this unique character is also illustrated when considering another sunspot byproduct, i.e. the number of spotless days over each sunspot cycle minimum”. Figure 4 shows the total number of spotless days from 1818 (red line). Unfortunately, we have no reliable data of this indicator for earlier years.

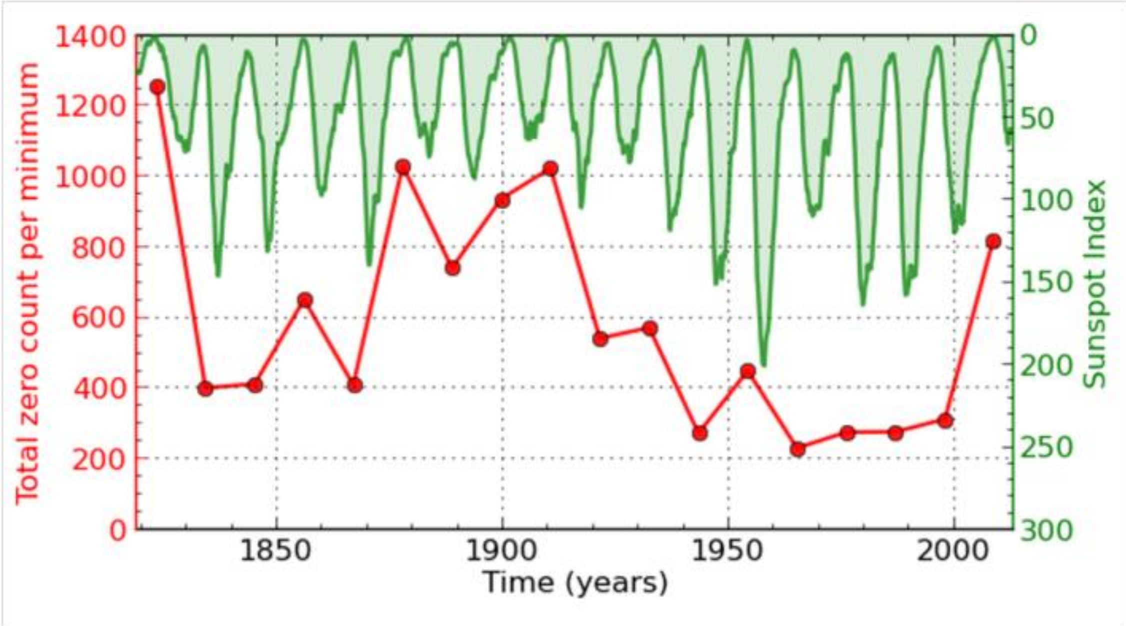

Figure 4. Cycle-to-cycle variation of the total number of spotless days from cycle 6 to 24, for which daily sunspot numbers are available (red curve). The ISN series is over-plotted with a reversed scale to highlight the strong anti-correlation between this indicator and the amplitude of the solar cycle.

My personal opinion is that we don't have a clear definition of Grand Episodes (Maxima and Minima), including the Maunder Minimum. Note in Figure 5 a new definition of the limits dates of the Maunder Minimum(Vaquero and Trigo, 2015) that illustrate the problem with the exact definitions of Grand Episodes. The common limits dates for the MM are 1645-1715, proposed by Eddy (1976). However, we have proposed a redefinition of the Maunder Minimum period with the core "Deep Maunder Minimum" spanning from 1645 to 1700 (that corresponds to the Grand Minimum state) and a wider "Extended Maunder Minimum" for the longer period 1618–1723 that includes the transition periods. The origin of this new "definition" was the discovery of sunspot observations made by G. Marcgraf in 1637. A new analysis of this data (and other revised historical observations) indicated a possibly gradual onset of the minimum with reduced activity starting two cycles earlier (Vaquero et al., 2011).

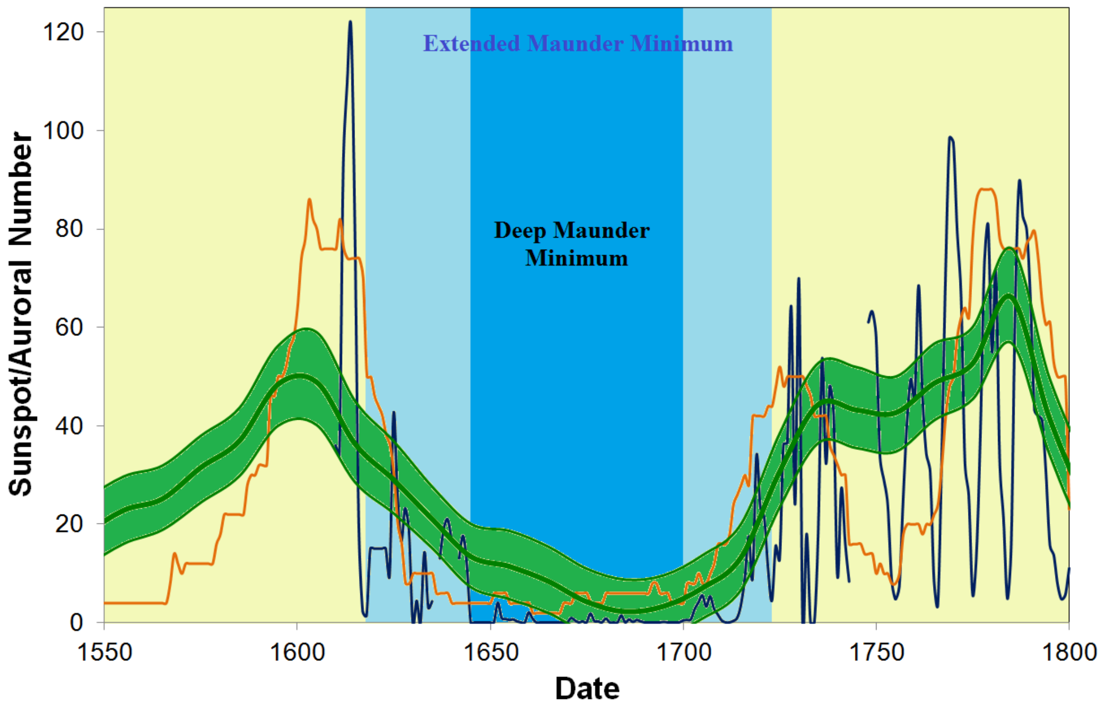

Figure 5. Solar activity indexes for the period 1550-1800: (green)decadal sunspot numbers, reconstructed by Usoskin et al. (2014), (orange) 25-year moving average of the number of aurorae observed from Hungary (Rethly and Berkes 1963), and (blue) Group Sunspot Number (Hoyt and Schatten 1998, Vaquero et al. 2011).

Certainly, understanding the Maunder Minimum is key for our understanding of a lot of things about the Sun and the climate of the Earth because it is a unique Grand Minimum observed using telescopes. However, our knowledge about it is quite limited. I would like to present one example. Figure 6 shows one slide of my presentation in the last Sunspot Workshop (Locarno, 2014). It shows a fragment of a table containing observations of the solar meridian altitude. Observations of the solar meridian altitude (the angle between the Sun and the horizon just when the Sun is crossing the meridian of a place) are relevant because Hoyt and Schatten (1998) used them to check if the Sun had been observed during the Maunder Minimum (see Vaquero and Gallego (2014) for details).

These observations (Figure 6) were made by Hevelius, one of the main sunspot observers during the Maunder Minimum. Note how, in this table, comments (in Latin) about sunspots are not exactly associated with the reported solar meridian altitude. Thus, Hoyt and Schatten (1998) computed "zero" sunspot numbers using all the observation in this table if no information on sunspot was available. Therefore, the number of days with "zero" sunspots is very large because there are few days with direct information about the presence/absence of sunspots.

Figure 6. A fragment of the table of solar meridian altitudes published by Hevelius in his Machinae Coelestis, showing records of sunspots during the Maunder Minimum. Comments about sunspots are not exactly associated with the reported solar meridian altitude.

I have computed the average sunspot number using only the direct information about sunspots that appear in this historical source. My results indicate an average value of GSN equal to 3 and 4 for the periods 1659-1661 and 1653-1663, respectively. In contrast, Hoyt and Schatten (1998) obtained values equal to 0.9 and 0.5 for the same periods. Therefore, the estimations of GSN from Hevelius' direct observations are 3-8 times higher than the values obtained by Hoyt and Schatten. Obviously, the values remain very low if we compare them with modern values (see Figure 3). But this result indicates that there are probably many erroneous values equal to zero in the database by Hoyt and Schatten (1998). And, our knowledge of the Maunder Minimum, based now on the original GSN series, is not correct in some important details.

In any case, with better or worse series of temperature and solar activity, today we have the best tools to explore the relationship between the Sun and the Earth's climate: Earth System Models. I hope that the next few years a lot of results will be published offering explanations of the mechanisms that produce local changes in the Earth's climate due to changes in solar activity, since some steps are being given. These models are the appropriate tools to explore the impact of a possible new "Maunder Minimum" in the 21th century.

I am in fact pretty skeptical about the possibility of a new great episode. I think we do not know enough about how the solar dynamo works and, therefore, it is not possible to offer predictions. In fact, the studies that suggest a Grand sunspot minimum are based on observational aspects and not on the physics of the Sun.

In any case, I can point out that we showed recently that the transition from a normal to a grand minimum state occurred gradually during the Maunder Minimum (Vaquero et al., 2011). Therefore, if a new Grand minimum occurs in this century, I expect that the transition will be gradual (not abrupt) again.

Some authors have begun to explore the impact of a possible solar grand minimum on the climate of the Earth (Feulner and Rahmstorf, 2010; Jones et al., 2012; Anet et al., 2013; Meehl et al., 2013). Early results suggest that this grand minimum will not stop global warming caused by CO2 and other greenhouse gases. However, locally, the signal of this possible Grand minimum could be more intense, for example, in the European winter (Barriopedro et al., 2008; Lockwood et al., 2010).

Biosketch

José Manuel Vaquero (Badajoz, Spain, 1973) is a physicist interested in the reconstruction of solar activity and Earth's climate during the last centuries from documentary sources. He is currently lecturer in Physics of the Earth (Centro Universitario de Mérida, University of Extremadura, Spain). Dr. Vaquero has published over 110 papers in peer-reviewed journals and a book (co-authored by Manuel Vázquez) entitled "The Sun Recorded Through History" (Springer, Astrophysics and Space Science Library, Vol. 361, 2009).

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