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Sunspot and Group Number: Recent advances from historical data

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Abstract. Due to its unique 400-year duration, the sunspot number is a central reference for understanding the long-term evolution of solar activity and its influence on the Earth environment and climate. Here, we outline current data recovery work. For the sunspot number, we find historical evidence of a disruption in the source observers occurring in 1947–48. For the sunpot group number, recent data confirm the clear southern predominance of sunspots during the Maunder Minimum, while the umbra-penumbra ratio is similar to other epochs. For the Dalton minimum, newly recovered historical observations confirm a higher activity level than in a true Grand Minimum.

Keywords. Sun: sunspots, Sun: photosphere, Sun: activity, methods: data analysis, history of astronomy

1. Introduction

For multiple applications, ranging from the physical modeling of the solar magnetic cycle to the evolution of the Earth climate, the sunspot number S_N defined by Wolf (1859) and the sunspot group number G_N introduced more recently by Hoyt & Schatten (1998) provide a unique multi-century record of the long-term evolution of the solar cycle. The homogeneity of those sunspot data series over several past centuries is of crucial importance, but poses difficult challenges.

Over recent years, this motivated new investigations, which led to the release of the first official revision of the S_N series (cf. SILSO Web site: http://www.sidc.be/silso). The associated key advances were published in a topical issue of Solar Physics (Clette *et al.* 2016a). While several methodological issues must still be verified and settled, future progress definitely depends on the production of complete and fully verified databases of historical sunspot observations. In the case of G_N, such a fully updated database of raw observations was recently produced (Vaquero *et al.* 2016). However, the period of the Maunder minimum still poses a challenge, given the sparsity of data and ambiguity of spotless reports. For S_N, instead of the current corrections to the original series, a full reconstruction is now envisioned from the original observations. In this case, the construction of an entirely new database is needed. Hereafter, we are outlining some of this ongoing data-recovery work.

2. Rebuilding a database for the Zurich sunspot number

Between the creation of the sunspot number in 1849 and the closing of the Zurich observatory in 1981, the daily sunspot number rested on fairly simple principles. By default, on most days, the daily S_N was the number from the primary observer at the Zurich reference station. On missing days (bad weather), sunspot counts from a network of auxiliary stations were used as a replacement. Consequently, most of the data sent by external stations were not effectively used to produce the original S_N values (Version 1). Moreover, as all Zurich observers were considered equivalent, no distinction was made between the primary observer (i.e. the successive directors) and the assistants.

So, a lot of information was ignored, but fortunately, those data can now be recovered, as the base observations were published in yearly tables in the collection of *Mittheilungen* of the Zurich Observatory. Over 2017–2018, we fully encoded those tables to rebuild the first sunspot number database in digital form. Before making it accessible to the scientific community, we are now conducting a full quality control. However, this thorough data recovery already revealed a few important facts:

• All input data were published only until 1919. Then, following a steep growth of the network after World War I, only a minor part of the data were still published thereafter, up to 1945, when no data tables were published anymore (Figure 1). All published data have now been entirely digitized, but although the Zurich Observatory mentioned in 1919 that the remaining unpublished data were archived and could be provided on request, those archives are missing and still need to be recovered.

• When M. Waldmeier became Director and primary observer in 1945, the former team of W. Brunner (previous Director) and assistant Brunner actually continued observing until 1947. Only starting in 1948, new assistants are recruited, but most of them appear only during short durations. None of them observed in parallel with the aforementioned long-term observers active before 1948. This thus marks a sharp and unprecedented break in the composition of the Zurich team.

• A similar synthesis of external contributing stations show that all stations that contributed before World War II progressively stopped between 1938 and 1945. During the war, a temporary network of local amateur observers was set up by the Zurich Observatory. However, none of those observers contributes for a long duration. Only after the war, Waldmeier re-creates a full worldwide network. However, there is almost no overlap between this new network and the one that was active before the war. This thus marks another disruption in the input data for the sunspot number series.

It turns out that a sharp 18% jump was found in the scale of the original sunspot number precisely in 1947 (Clette & Lefèvre 2016, Clette *et al.* 2014, Lockwood, Owens & Barnard 2014). So far, such a jump and its timing were difficult to explain. Indeed, the main cause of this inhomogeneity was a methodological change (Zurich internal counts weighted as a function of sunspot size) that was introduced progressively and much earlier by A. Wolfer (Friedli 2016, Svalgaard, Cagnotti, & Cortesi 2017). Now, by their temporal coincidence with this 1947–1948 jump, the two above discontinuities in the source data of the sunspot number provide strong historical evidence that the long-term chain of primary and auxiliary observers was broken at that moment, making possible a shift in the scale of the resulting sunspot numbers.

3. The Maunder minimum (1645–1715)

During the last years, some important advances have been made regarding the Maunder minimum after the controversy generated by the publication of two studies with mismatched results (Zolotova & Ponyavin 2015, Usoskin *et al.* 2015).

First, a digital version of sunspot latitude data from previous studies is available to the international community (Vaquero *et al.* 2015a). These data have confirmed the butterfly diagram for the Maunder minimum as well as the strong hemispheric asymmetry, with predominance of spots in the southern hemisphere (Figure 2). In addition, another study has confirmed the presence of the solar cycle during the Maunder minimum using

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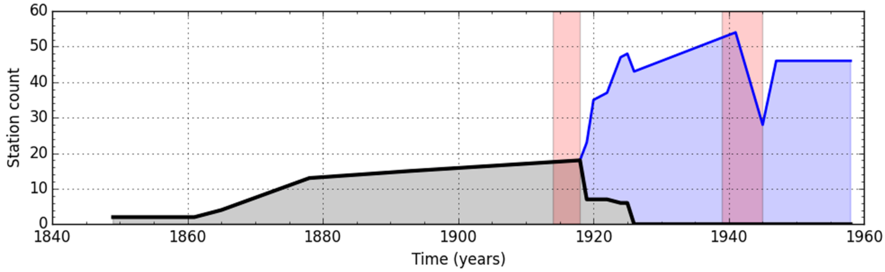

Figure 1. Evolution of the number of auxiliary stations contributing to the production of the Zurich sunspot number. From 1849 to 1919, all data were published in the Mittheilungen of the Zurich observatory and are now digitized (thick line), but thereafter, only part of them, when the network greatly expanded (thin line). So far, a large part of those more recent unpublished data has not been recovered. The vertical shaded bands mark the two World Wars, which had a clear influence on the sunspot observing network.

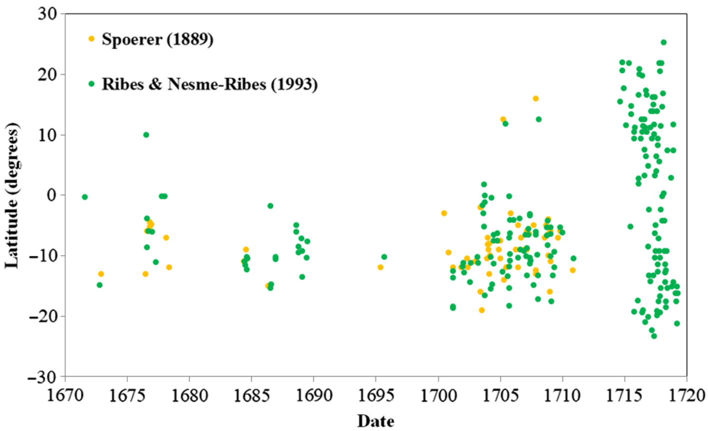

Figure 2. Butterfly diagram during the Maunder minimum using the data from Spoerer (orange circles) and Ribes and Nesme-Ribes (green circles).

subsets of observations from the Hoyt & Schatten (1998) database. These subsets were constructed using different quality criteria (Vaquero *et al.* 2015b). Several articles have appeared improving the Hoyt and Schatten database during the Maunder minimum (Carrasco *et al.* 2015, Carrasco & Vaquero 2016, Vaquero *et al.* 2016), and this effort to improve data availability continues (Neuhäuser *et al.* 2018).

Very recently, the umbra–penumbra area ratio during the Maunder minimum has been evaluated using 196 sunspot drawings published in scientific journals of that epoch (Carrasco *et al.* 2018a). They cover 48 different sunspots observed during the period 1660–1709. The mode value of the ratio obtained from the occurrence frequency distribution lies between 0.15 and 0.25, very similar to values found for other epochs.

4. The Dalton minimum (1793–1827)

Recent studies have confirmed that the Dalton minimum cannot be considered a Grand Minimum but a secular minimum (Vaquero *et al.* 2016, Ogurtsov 2018). Thus, for example, Vaquero *et al.* (2016) found that the expected value of active days for the Maunder minimum (9.94%) was significantly lower than for the Dalton Minimum (61.63%).

Several articles have been published recently adding new sunspot observations into the databases. Hayakawa *et al.* (2018) recovered a sunspot drawing made by Iwahashi Zenbei on 26 August 1793 and Denig & McVaugh (2017) analyzed a set of 25 drawings made by Jonathan Fisher in 1816 and 1817. Carrasco *et al.* (2018b) recovered the sunspot observations performed by Cassian Hallaschka in 1814 and 1816. These works have helped to improve our knowledge of solar activity for the Dalton minimum.

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