The International Sunspot Number revisited: from SIDC to SILSO

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Abstract:

With the advent of a new generation of dynamo models, the interest for long-term impacts of space weather and the current issues about climate change, the sunspot number (SSN) is now being used more than ever before as the multi-secular tracer of solar activity in a wide range of science studies. This has motivated new efforts to revisit, improve and expand this reference index of solar activity, which had been left largely untouched for many decades.

Here, we review the main advances achieved recently, both in the early historical part of this series but also in modern SSN values. Based on all new corrections identified in the SSN series by a collective work, the publication of a new revised SSN series is now planned for 2014, bringing the first thorough revision of the sunspot number series since the time of Rudolph Wolf.

In parallel to this major update of the main data series, we also entirely updated and reworked the operational production of the SSN and its quality control. For our users, this transition will materialize in the form of a new website, new data products as well as a new name for our World Data Center: SILSO, for "Sunspot Index and Long-term Solar Observations". We describe the new features of this new central portal serving the sunspot number to our growing community of scientific and non-scientific users.

Full revision of the historical SSN (1610-1980)

The Sunspot Number remains the only multi-secular tracer of solar activity. However, two primary series coexist. The main series that is still currently maintained is the International Sunspot Index, which has its roots in the Zürich sunspot number created by R.Wolf in 1849, and includes both the group count N_g and spot count N_s ($R_z = k\ (10\ N_g + N_s)$.

The second series is the **Group sunspot number** which only considers the group count (Hoyt & Schatten, 1998). It is often considered as the most reliable series before the mid-19th century (less sensitive to the visibility of small spots, includes more early data). However, it shows a large ~40% discrepancy before 1880 (Group Number lower than SSN).

Over the past 2 years, new joint efforts were undertaken to diagnose those discrepancies, in the framework of the **Sunspot Number Workshops**. A combination of parallel approaches was used:

- Exploitation of all available historical documents: inclusion of new observations not used by R.Wolf.
- Validation through parallel solar series (e.g. Greenwich photographic catalog, Mount Wilson CaII index, rY index)

Two main corrections have been identified:

•**The 1880 jump**: progressive trend over 1880-1905 (Fig. 1) attributable to a trend in the early Greenwich (RGO) photographic data (Willis et al. 2013a and b), which were used as the scaling reference for the Group sunspot number.

⇨ **Group number underestimated by ~40% before 1880**

•**The 1945 jump**: sharper jump attributable to the introduction of a weighting according to sunspot size in the Zürich counts (Svalgaard, 2012) around 1945 and still in use nowadays by the Specola Solare pilot station (Locarno, see Fig. 2).

⇨ **SSN overestimated by ~20% after 1945**

The effect of the corresponding corrections on the ratio between the SSN and Group Number is illustrated here, together with two smaller corrections also identified recently (Schwabe-Wolf jump in 1849, RGO-USAF/SOON jump in 1976, see Fig. 3).

With those corrections, the two series agree within the uncertainties from the early 19th century up to present. In both corrected series, **the earlier positive trend between the mid-19th century and the mid-20th century is strongly reduced** (Fig . 4)**.** The recent Grand Maximum (Usoskin, 2013) would thus not imply anymore particularly exceptional cycle amplitudes relative to previous centuries but only a tight repetition of strong cycles.

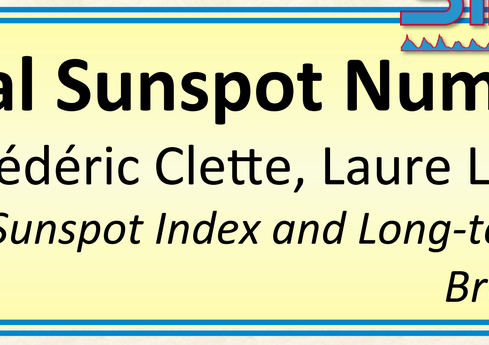


Fig1. Ratio of group counts from different observers with the RGO group count (1874–1894), showing a systematic upward trend of about 40%.

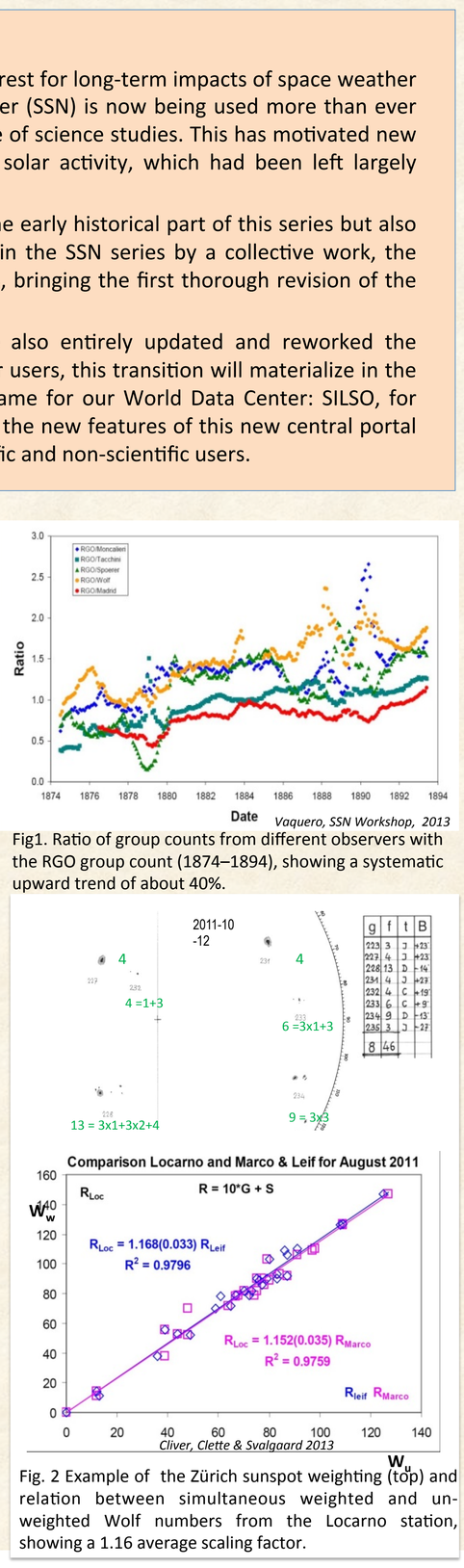


Fig. 2 Example of the Zürich sunspot weighting (top) and relation between simultaneous weighted and un-weighted Wolf numbers from the Locarno station, showing a 1.16 average scaling factor.

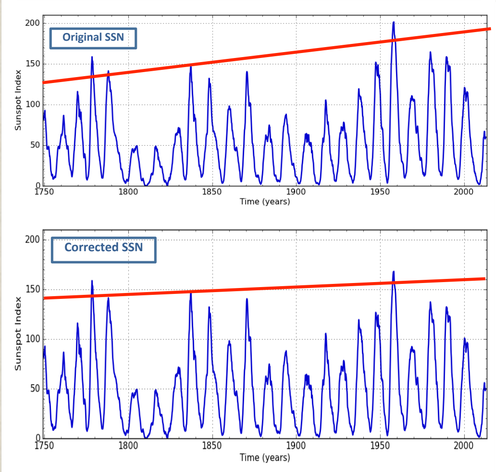


Fig. 4 The main corrections identified in the SSN series lead to a strong reduction of the rising trend between the 18th and 20th century.

Fig. 3 Ratio Ri/Rg (gaussian smoothing on 24 months, middle panel). In black, one sigma confidence intervals based on monthly standard deviations of the Group Sunspot Number given by Hoyt & Schatten (1998). In blue below, the number of days of observations per month (in %). The small upper right plot shows the ratio before corrections are applied. The lower left plot shows the series after applying all identified corrections.

The last 30 years: trends identified in the SIDC pilot station

When the World Data Center – « Sunspot Index » was transferred from Zürich to Brussels in 1981, three main changes were introduced:

•A new calculation method involving the whole observing network instead of a single primary observer (Zürich).

•A new pilot station: Specola Solare Locarno (associated to Zürich since 1955).

•The extension of the worldwide observing network (270 stations and 450000 observations since 1981; See network statistics in Fig. 5).

The new calculation consists of 4 steps (see diagram). This process allows to detect and reject abnormal daily values from any station, including the Locarno pilot station, leading to a lower dispersion of daily values. However, as all stations are scaled on a monthly basis to the reference counts of the pilot station, **the resulting statistical SSN tracks closely the Locarno Wolf number for time scales longer than a month**, which is demonstrated by the constant average ratio between those two quantities since 1981 (Fig. 6). This allowed a seamless Zürich-Brussels transition in 1981, avoiding an artificial scaling jump in the SSN series.

However, **by applying a global analysis of k personal coefficients for all SILSO stations, we find a varying trend over the last 32 years**. This analysis consisted in 3 steps:

•For each individual station, computation of the ratio between each daily Wolf number and the corresponding SSN value.

•For different subsets of stations, based on their duration and rms dispersion (quality), we compute the mean k coefficient.

•We finally check the linear correlation of individual stations with the resulting average k profiles (validation).

This analysis shows a **consistent « S » shaped drift, with an amplitude of ~20%,** relative to the common reference (SSN i.e. the Locarno station, see Fig. 7). By adding earlier data from the Zürich era (before 1980), we show that this trend started only in 1981, when Zürich terminated its observations and the Locarno station was alone to provide the scaling reference (Fig. 8). As the long-term scaling of the SSN was defined by Locarno since 1981, the detected trend can be entirely attributed to a drift of the Locarno station.

As the WDC – SILSO maintains a full database of all raw observations since 1981, this defect can be fully corrected. A corrected SSN series for the last 32 years will thus be entirely rebuilt in the coming months.

Data elimination: outliers at 2 σ_k
Monthly mean station k_s: first approximation (k_s, σ_k)

⇩

Daily average SSN R:
first approximation (R, σ_R)
W_{LO} data elimination at 1 σ_R

⇩

Data elimination: outliers at 1 σ_k
Monthly mean k: final (k_s, σ_k)

⇩

Iteration: elimination at 1 σ_R
Daily average SSN R_i: final value (R_i, σ_{Ri})

SSN calculation method

- Scaling: average monthly k relative to pilot station:
  $$k_s = (\sum_d W_{LO}(d)/W_s(d))/n_d$$
- Daily SSN: statistics over whole network: $$R_i = (\sum_s k_s \cdot W_s)/n_s$$
- Elimination of abnormal daily Locarno values

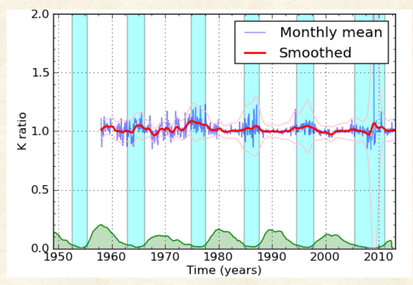


Fig. 6 Ratio between the Locarno raw Wolf numbers and the SSN. The flat ratio indicates that the SSN is closely tied to the Locarno average scale over long timescales .

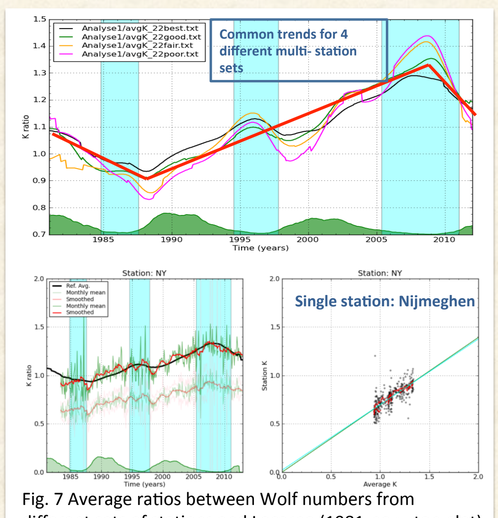


Fig. 7 Average ratios between Wolf numbers from different sets of stations and Locarno (1981-now, top plot). Equivalent plot for a single high-quality station (lower panels) showing a close match with the network average.

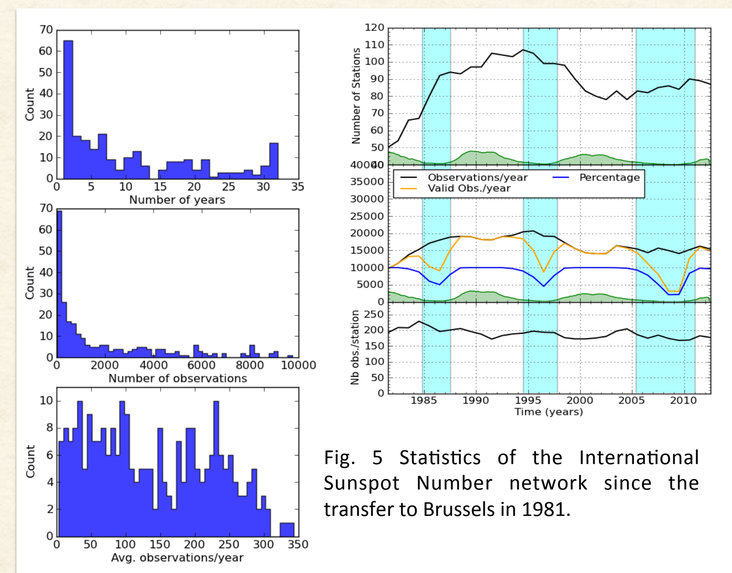


Fig. 5 Statistics of the International Sunspot Number network since the transfer to Brussels in 1981.

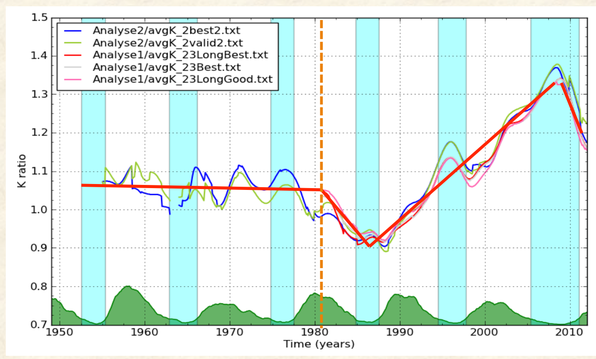
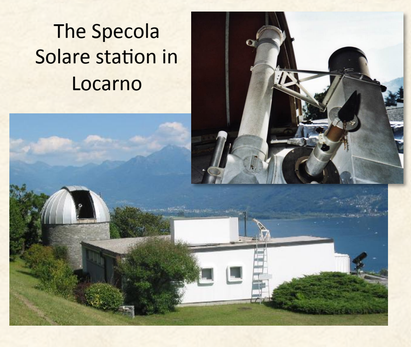


Fig. 8 Trend between different sets of stations and Locarno from 1950 to now. The identified Locarno drift starts when the Zürich Observatory ceased to be the primary station in 1981.

The Specola Solare station in Locarno



WDC – SILSO: new products and Web site

Over the past two years, a deep modernization of the sunspot index processing has been undertaken. (migration from old Fortran codes to Python). So far, this evolution remained largely invisible to our users.

On November 5, we just released an **entirely new Website** that is destined to become the central portal for accessing the sunspot number data and other long-term records of solar activity. As this marks a major transition and a new wider scope, we also decided to rename our World Data Center, which now becomes **SILSO for "Sunspot Index and Long-term Solar Observations".**

Over the past 15 years, the SIDC ("Solar Influences Data analysis Center") progressively encompassed a wider range of activities and projects and it now actually designates the entire Solar Physics team at the Royal Observatory of Belgium. In this very eclectic context, from now on, **SILSO gathers again all long-term services and research activities addressing the specific needs of our users interested primarily in the secular evolution of solar activity and Sun-Earth relations**. SILSO thus takes up and modernizes the initial role of the SIDC as "Sunspot Index Data Center" when it was created 32 years ago, under a new name and acronym.

While providing a more user-friendly access to our data files in their traditional format, our new site already includes **various new features**: improved data documentation, files in CSV format (for direct import in your favorite spreadsheet) and a FAQ section. We also implemented a dynamical plot of the near real-time Estimated sunspot number (EISN) fed every 5 minutes by our worldwide network, in addition to our monthly-cadenced products.

This new communication platform is destined to grow over the coming weeks and months. Our future plans include e.g. **new data and graphical products, SILSO network statistics, error bars on the sunspot numbers, extension of the group number series** and the upcoming end-to-end revision of the sunspot number series itself, resulting from the Sunspot Number Workshops.

The Sunspot Number Workshops

•Motivations:
- Full revision and validation of the SSN series
- Reconciling the SSN and the GN

No more ambiguity about which one is best and most reliable !

•3 past workshops: NSO, Sac. Peak (Sept. 2011), ROB, Brussels (May 2012), NSO-Tucson (Jan. 2013)

•Next and final workshops:
- **Specola Solare, Locarno May 2014**
- Boulder, USA, Fall 2014 ?

•Final output (2014):
- **Special journal issue gathering all results (~ 40 contributors)**
- **Release of a fully revised SSN series (WDC – SILSO, Brussels)**

http://ssnworkshop.wikia.com/wiki/Home

Conclusion and prospects

•The WDC « Sunspot » becomes SILSO with a new dedicated Website

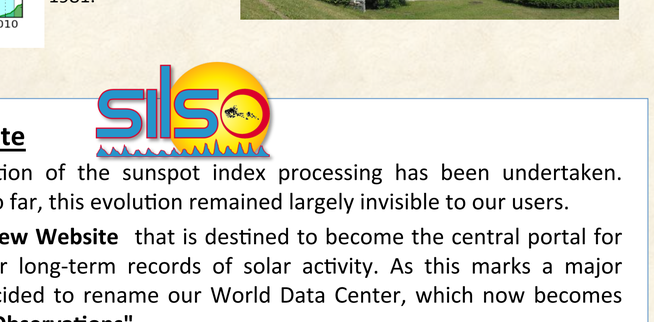
•Fully modernized SSN production and distribution of the international SSN

•Several large jumps or trends have now been diagnosed, both in the SSN series and in the group sunspot number

•First end-to-end revision of SSN series since R. Wolf: release scheduled for mid-2014

•Implications:
- SSN and group number will be reconciled back to ~1800, allowing a common treatment of the early part of the series back to 1610.
- The corrected series lead to a strong reduction of the upward trend in solar activity between the mid-19th century and mid 20th century, with possible implication on past solar activity and irradiance reconstructions.

http://sidc.be/silso



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