Improving the Sunspot Number and Group Number Series: How and When?

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Abstract

Efforts have been undertaken by the solar community since 2010 to revise both the Sunspot Number and the Group Number series (SN and GN). This led to a recalibration of the Sunspot Number (Clette & Lefèvre, 2016) and also to several revised Group Number reconstructions (e.g. Svalgaard & Schatten 2016, Chatzistergos et al. 2017, Usoskin et al. 2021). We present here our achievements since 2010, what progress has been made since, and our plans for the near future.

First, since the last revision of SN in 2015, significant progress has been made in recovering and digitizing historical datasets, notably including the Mittheilungen from the Zürich Observatory, but also a lot of different sources (see figure 3). These recovered records enabled new reconstructions of the SN series from 1816 to 1944 (Bhattacharya et al., 2021, 2023, 2024). Furthermore, in 2022, the WDC-SILSO team launched the FARSUN project, aiming to collect, harmonize, and centralize all available sunspot datasets into a single FAIR-compliant (Findable, Accessible, Interoperable, and Reusable) database hosted in Belgium (https://www.sidc.be/farsun).

Second, on the side of the modern production of the SN and GN series, the WDC-SILSO launched a project to modernize the day-to-day computation of the SN, and add the production, at the same frequency, of the GN (Belgian SUNRISE, https://www.sidc.be/sunrise).

In summary, in the near future, by mid-2027, a historical database centralizing all available sunspot data will be put into action, and will keep being updated as new data is digitized. By the same time, the production of the SN will be modernized and GN will be produced by the WDC-SILSO with the same frequency as SN. At this time, new major versions of SN and GN will be released with complete transparency as to their construction.

1) 2010–2019 Revisions & Corrections

Over the past 15 years (since 2010), the **Sunspot Workshops** and the **ISSI teams on the recalibration of the Sunspot Number** (https://www.issibern.ch/teams/sunspotnoser/) have reshaped how the community evaluates the Sunspot Number (SN) and Group Number (GN) series. The shared objective has been clear: deliver community-vetted, long-term, homogeneous solar-activity series—spanning more than 400 years—with quantified, time-dependent uncertainties that can anchor millennial reconstructions (e.g. from cosmogenic nuclides) and rigorously test Sun–Earth coupling models.

Recalibrations largely removed the discrepancies between the traditional **Sunspot Number (SN)** (see **Figure 1** for the differences between SNV1 and SNV2) and Hoyt–Schatten (1998; HoSc98) **Group Number (GN)**. These efforts prompted scrutiny of methods and, in response, several independent series were produced: a correction to SN by Lockwood, Owens & Barnard (2014–2016), GN reconstructions by Usoskin et al. (2016) and Chatzistergos et al. (2017), with further updates by Willamo et al. (2017) and Usoskin et al. (2021). As documented in the 2016 Solar Physics topical issue, the field thus arrived at multiple, methodologically distinct reconstructions that still diverge before ~1880—roughly bounded by Svalgaard & Schatten (2016) on one side and Hoyt and Schatten (1998) on the other—underscoring the need for transparent calibration chains and comparable uncertainty estimates **(Figure 2)**.

A major lesson has been that consensus cannot be rushed: the influence of the Hoyt & Schatten GN series (1998) persisted for years despite internal inconsistencies—e.g., near-equal scale factors for Wolf and Wolfer despite Wolfer's systematically higher group counts—highlighting the need for transparent methods, reproducible data flows, and early, critical scrutiny (Clette et al., 2023).

The reconstruction efforts advanced on several fronts. Scientifically, it tightened the historical chain of reference observers and clarified known scale breaks; statistically, it adopted explicit uncertainty modeling, encouraging a probabilistic view that never separates an observation from its error. The 2016 Solar Physics topical issue consolidated this with end-to-end recalibration principles, and the ISSI "triad" reviews (advocate–critic–mediator) institutionalized constructive challenge across competing series. Practically, the community converged on: (i) curated, digitized historical inputs; (ii) transparent calibration/scale-transfer procedures; (iii) uncertainty budgets that vary with epoch and data quality; and (iv) side-by-side publication of legacy and revised series to preserve provenance.

SN corrections

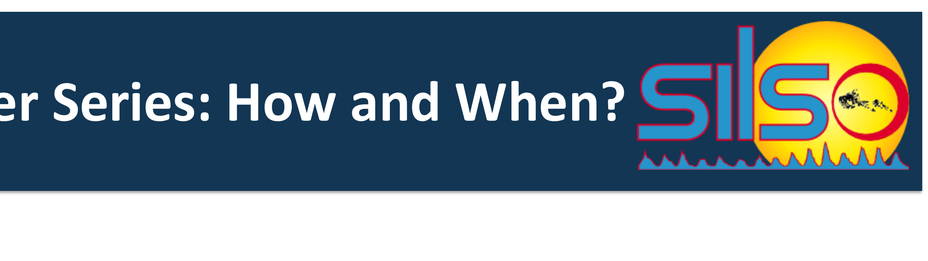


Figure 1. Corrections applied to SNV1 to obtain SNV2

GN reconstruction

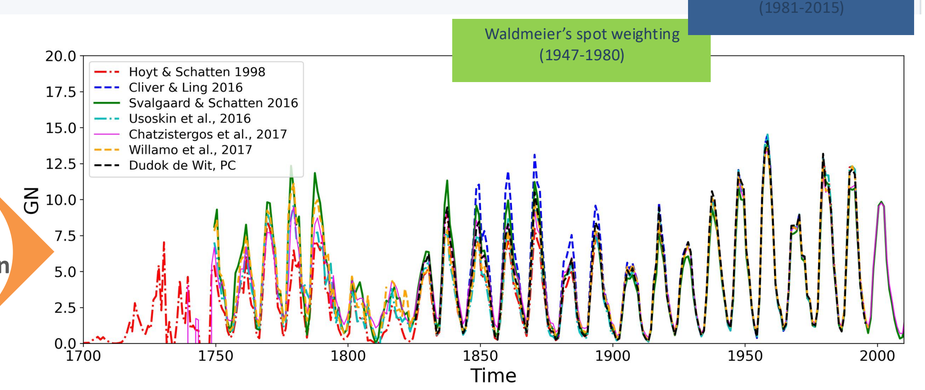
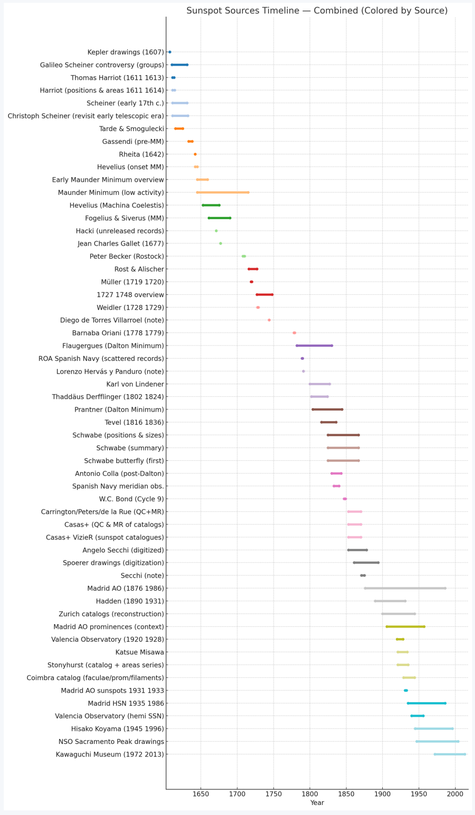


Figure 2. Different GN series published after the recalibration effort in 2016.

2) 2019 – 2025 Data & Methods



Between 2017 and 2019, to enable the reconstruction of the International Sunspot Number, WDC–SILSO digitized the *Mittheilungen* (the Zürich Observatory journals initiated by Rudolf Wolf), converting these primary sources into searchable, machine-readable datasets with improved metadata and provenance. In parallel, colleagues led major source-recovery efforts (e.g. Hisashi Hayakawa, Rainer Arlt, José M. Vaquero and Víctor M. S. Carrasco), they located, transcribed, and published numerous early telescopic sunspot records spanning from the early 1600s to the modern era (see **Figure 3**). Together, these initiatives expanded the historical observation base, enabling independent cross-checks of observers and epochs, strengthened scale-transfer and calibration analyses, and provided the foundation for more robust, uncertainty-quantified reconstructions of the long-term sunspot series.

Recovered data are being harmonized in a FAIR historical database within the FARSUN program, that also is adding a few key datasets (see the poster by Dr. Chandrashekar Kalugodu – QR CODE below). Legacy series such as Carrington's observations have been reprocessed (Bhattacharya et al., 2021), techniques developed for GN have been adapted to the SN (Bhattacharya et al., 2024**).**

Figure 3. Non exhaustive graphical representation of digitized sunspot data by the main teams between 2010 and 2025. All horizontal lines represent the period of the data that has been retrieved.

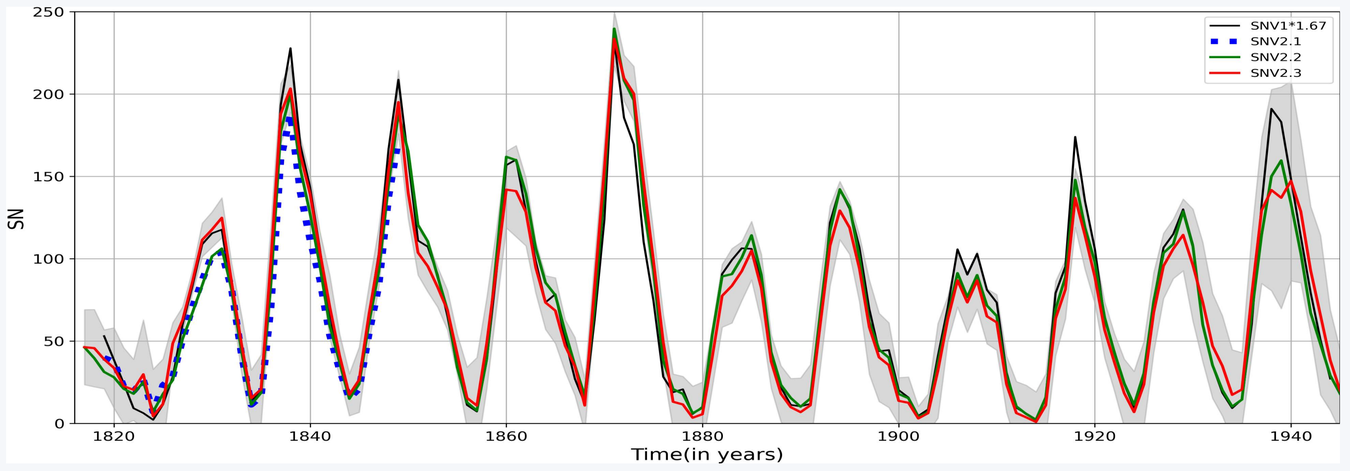


Figure 4. Annually averaged SN series for SNV1, SNV2.1 (Bhattacharya et al. 2023), SNV2.2 and SNV2.3 (Bhattacharya et al., 2024). The grey-shaded area represents the 1σ uncertainty of SNV2.3. We note that SNV1 has been multiplied by 1.67 to bring it to the same scale as the other series. The construction of SNV2.3 uses a new method (Chatzistergos et al. 2017) to compute the Sunspot Number from 1816.

Methodologically, this new reconstruction of the historical International Sunspot Number for 1816–1944, ties reference observers with explicit scale transfers and uncertainty tracking, in dialogue with previous multiple Group Number reconstructions (Svalgaard & Schatten, 2016; Chatzistergos et al., 2017; Usoskin et al., 2021).

In parallel, the SUNRISE initiative (from 2023) is modernizing operations: the daily SN production chain is being rebuilt for transparency, automation, and reproducibility, and a GN product will be generated at the same cadence. Together, these efforts deliver a better-documented, uncertainty-quantified solar-activity record suitable for long-term heliophysics, climate applications, and space-weather operations.

3) What's Next (to mid-2027)

Future (see Figure 5) :

A first draft version of the FARSUN database has been released to the community in March 2025, and a more definitive version will be delivered to the Sunspot Workshop team at the beginning of 2026. In 2026, we foresee an online community meeting focused on methods harmonization and a versioning policy for the International Sunspot Number (SN) and Group Number (GN). The 2026 Sunspot Workshop will stress-test calibration chains, scale transfers, and uncertainty propagation. In 2026-2027, we will deploy at ROB a FAIR, unified database that integrates historical sources and modern network observations with explicit provenance, machine-actionable metadata, and programmatic access. In 2027, the WDC–SILSO will commission a new production pipeline delivering daily SN and GN operations, with auditable processing and automated QA. Also in 2027, we will publish major versioned releases of SN and GN, each with complete provenance records, method documentation, and DOIs.

Deliverables :

- Public database, and documentation, schema descriptions, and example notebooks for reproducible access.
- Versioned releases and citation practice: side-by-side availability of legacy and new series; clear citation guidance and machine-readable landing pages (schema.org/DataSet).
- Reproducible methods and uncertainty budgets: open code, containerized workflows, and end-to-end uncertainty propagation with release notes and change-logs for the releases linked to SILSO production.

Collectively, these steps will provide a transparent, uncertainty-quantified reference for long-term solar variability, enabling robust cross-disciplinary reuse in heliophysics, space weather, and climate applications.

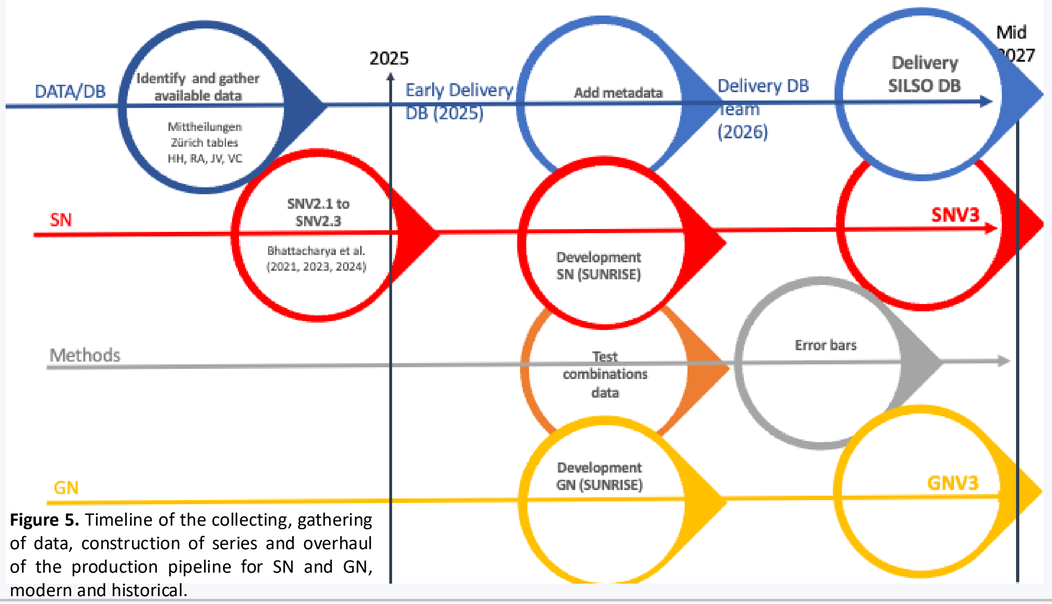


Figure 5. Timeline of the collecting, gathering of data, construction of series and overhaul of the production pipeline for SN and GN, modern and historical.

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