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The revised sunspot number

New properties and new data standards

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The 400-year sunspot record

- Only direct record of the evolution of the solar cycle over multiple centuries
- Longest scientific experiment still ongoing

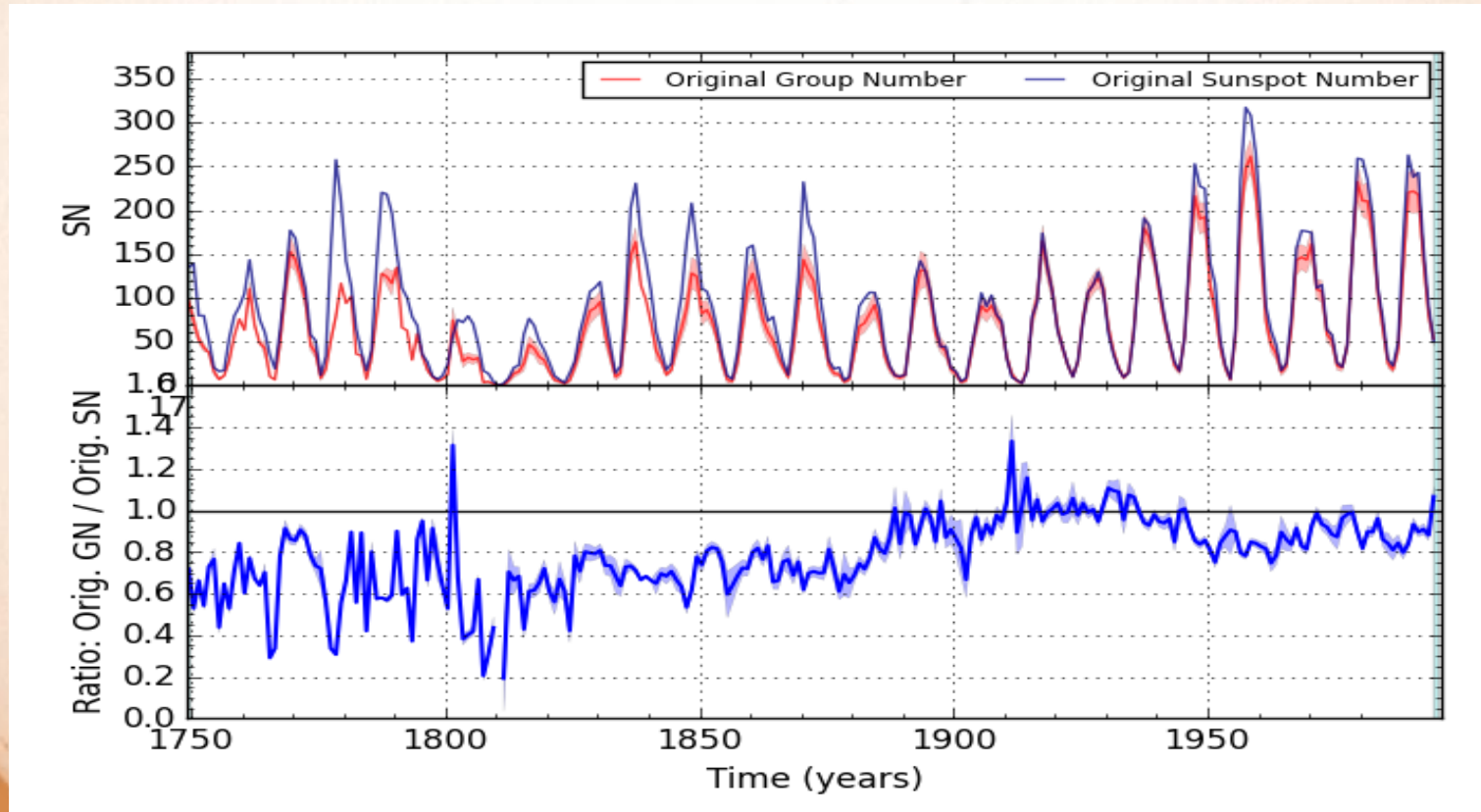
(B.Owens, Nature, March 2013)
- Multiple applications:
 - Solar dynamo modelling
 - Long-term irradiance reconstructions
 - Calibration of the cosmogenic isotopes (^{14}C , ^{10}Be)
 - Earth climate change
 - Infrastructure maintenance (pipelines, electrical power grid)
- > 100 scientific publications / year
- Part of public culture and astronomy education
 - > 150 000 Google hits on “sunspot number”:

A necessary revision

- No critical revision of the Sunspot Number series since its creation by R. Wolf in 1849
- Only alternate series: the **Group Number** (Hoyt & Schatten 1998)
- **Large discrepancies between the series (up to 40%)**

$$R = \frac{1}{N} \sum_i k_i (10Ng_i + Ns_i)$$

$$G_N = \frac{12.08}{N} \sum_i k_i Ng_i$$



A new impulse: Sunspot Number Workshops

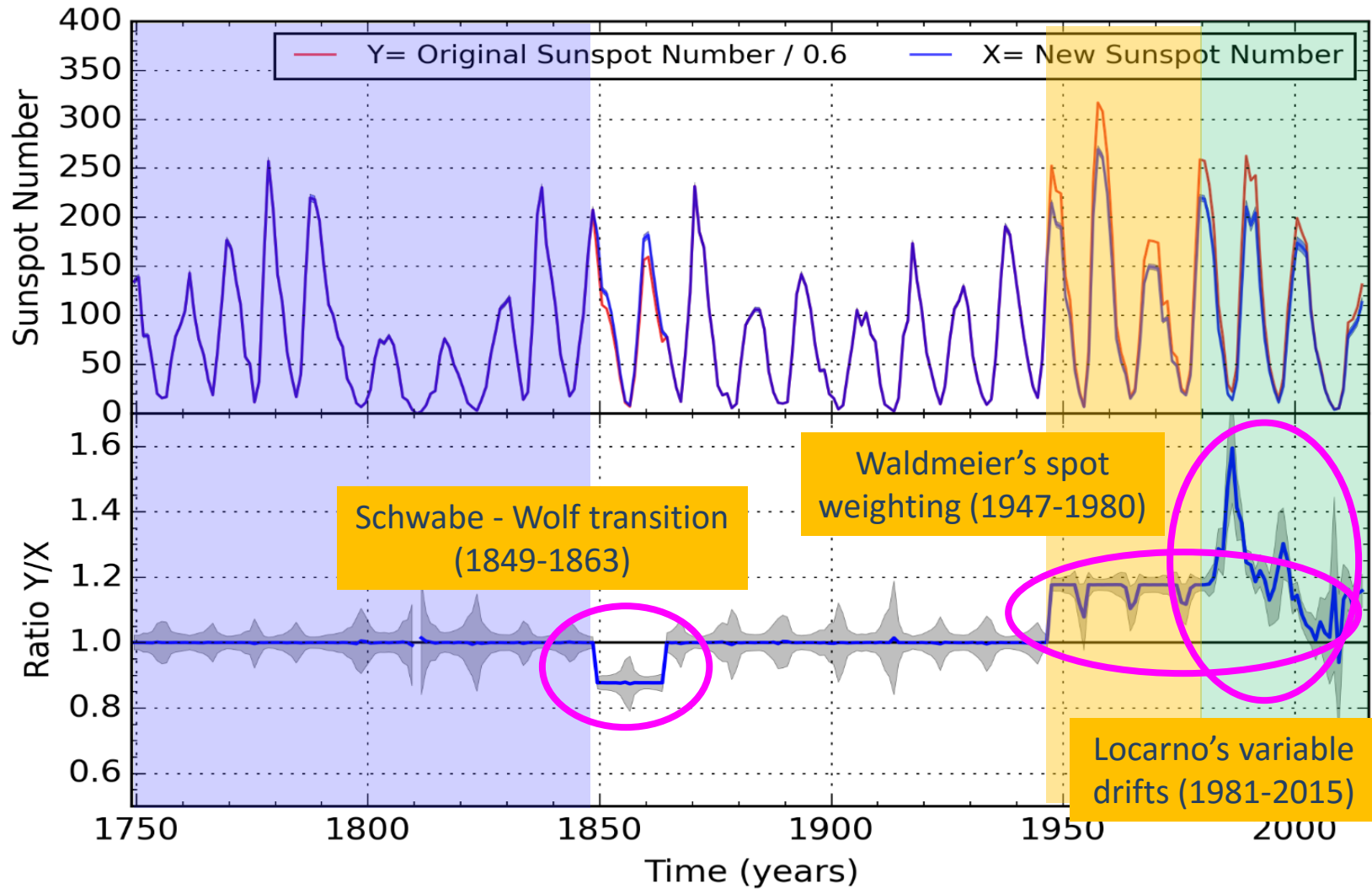
- Community effort started in Sept. 2011:
 - 4 Sunspot Number Workshops: Sac. Peak, Brussels, Tucson, Locarno
 - 50 participants



Synthesis in:

**Clette, F., Svalgaard, L., Vaquero, J.M., Cliver, E.W.: 2014,
Revisiting the Sunspot Number. A 400-Year Perspective on the Solar Cycle.
Space Science Reviews, 186, p. 35-103**

Sunspot Number corrections: overview



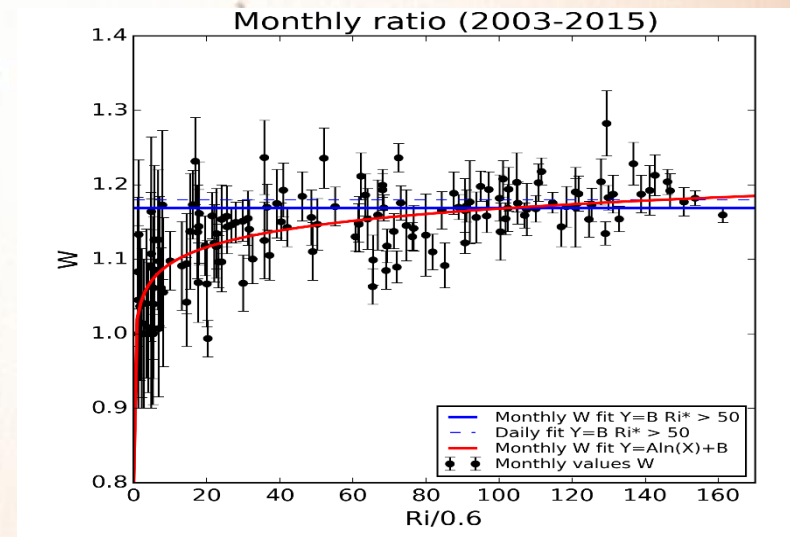
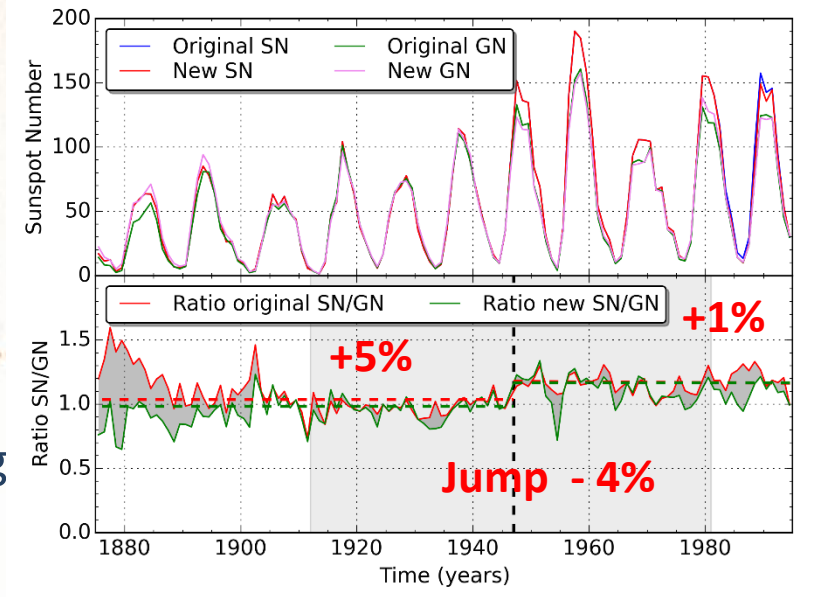
Waldmeier's weighted number (1947-1980)

- 1947: **new counting method: large spots counted as >1 (2 to 5) according to penumbral size**
- **Inflation factor range: 1.15 to 1.25**
- One low value: 1.126 (*Lockwood et al.2014*), but improper data:
 - Original series SN and GN containing other uncorrected biases (before 1915 and after 1980)

➡ **Corrected jump: 1.171**

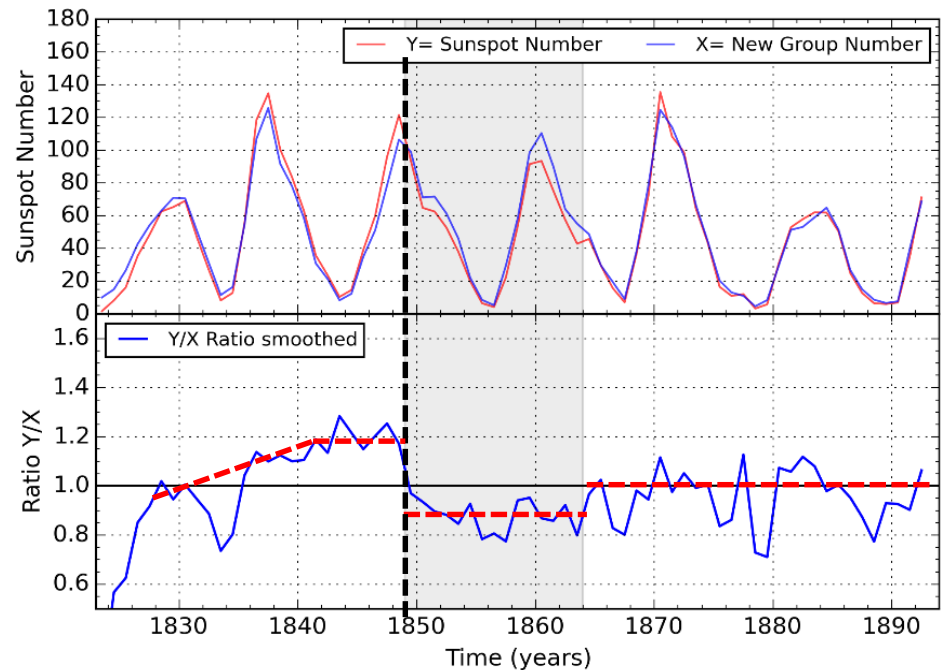
- Most robust determination: **double counts, weighted and standard, done at the Locarno station:**
 - Mean ratio in cycle 24: 1.165 +/- 0.035

➡ Existence of a maximum asymptotic mean value: **1.177 +/- 0.005**

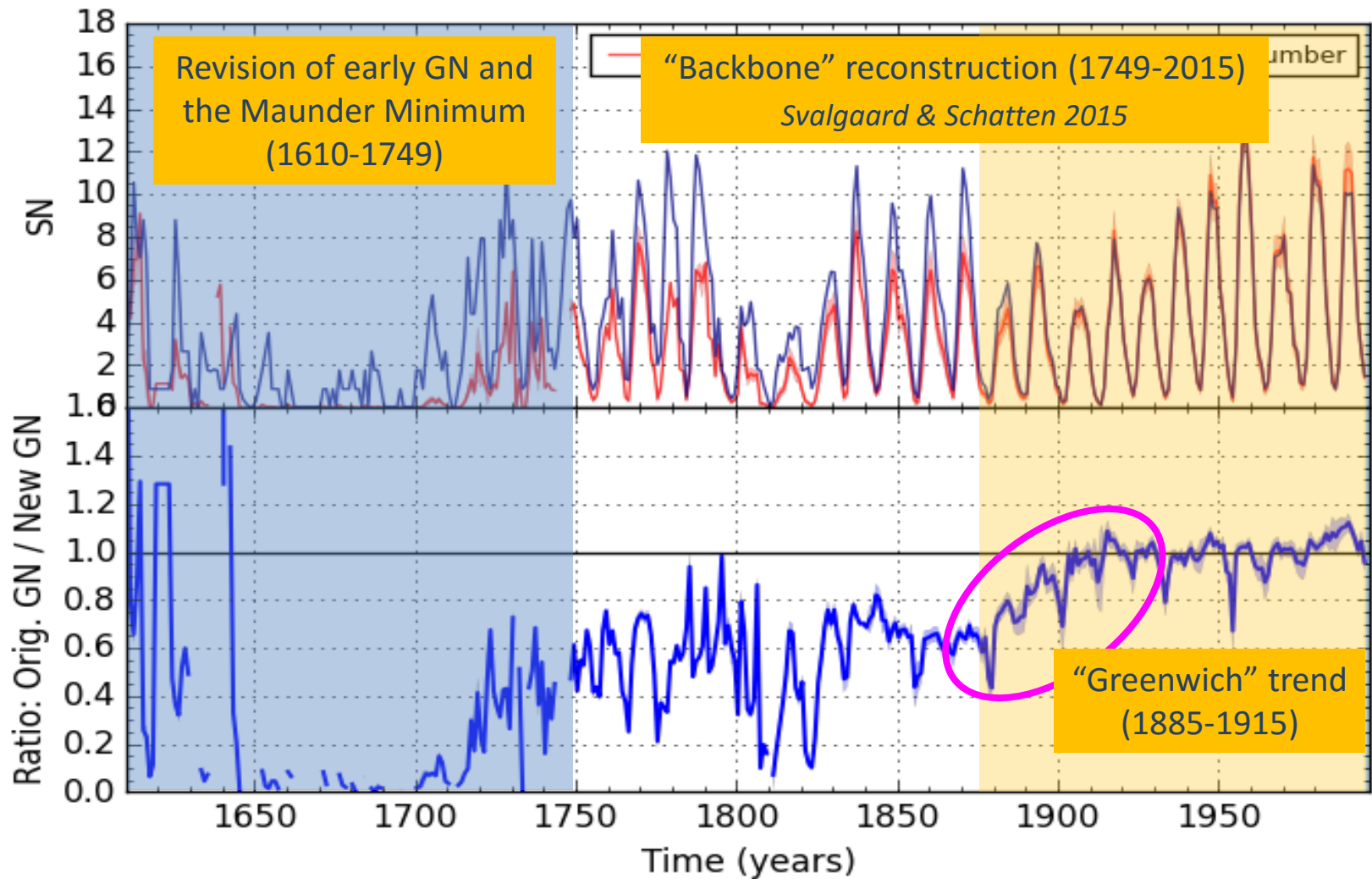


The Schwabe- Wolf transition (1849-1863)

- **1849: 20% downward jump** in the SN relative to the original Schwabe numbers (*Leussu et al. 2013*)
 - By comparison with the Group Number over a wider time interval:
 - Schwabe upward trend 1826-1840
 - **14% upward jump in 1864**
 - Combination of two causes:
 - Wolf initially mixed the raw Schwabe numbers with his own observations
 - Distinct markers only appear in published tables by 1863 (*Wolf 1863*)
 - Wolf mostly used a small portable travel telescope:
 - **New assistant using the standard 80mm Zürich refractor in July 1864** (*Opening of the Zürich Observatory, Wolf 1865*)
- ➡ Equal scale before 1826 and after 1863
- Time-limited correction: **SN increased by 1.14 (+/- 0.02) over 1849-1863**



Group Number correction: overview



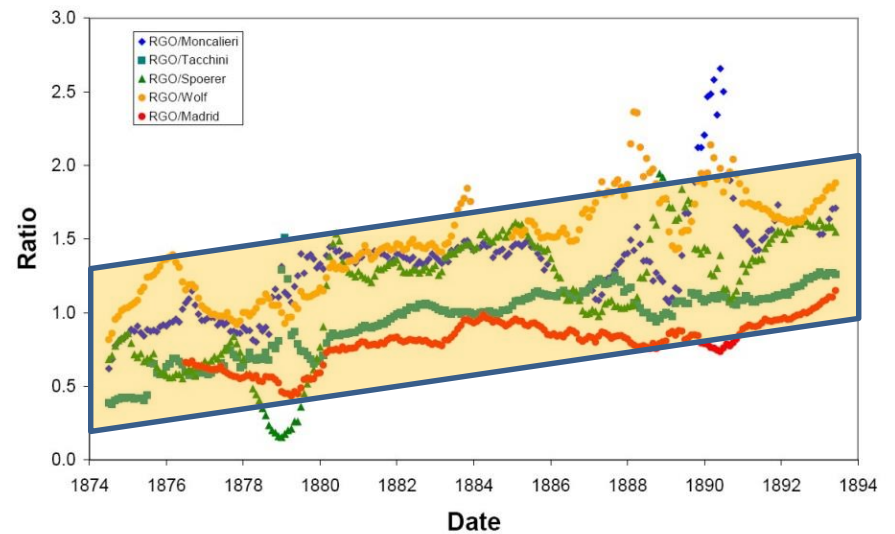
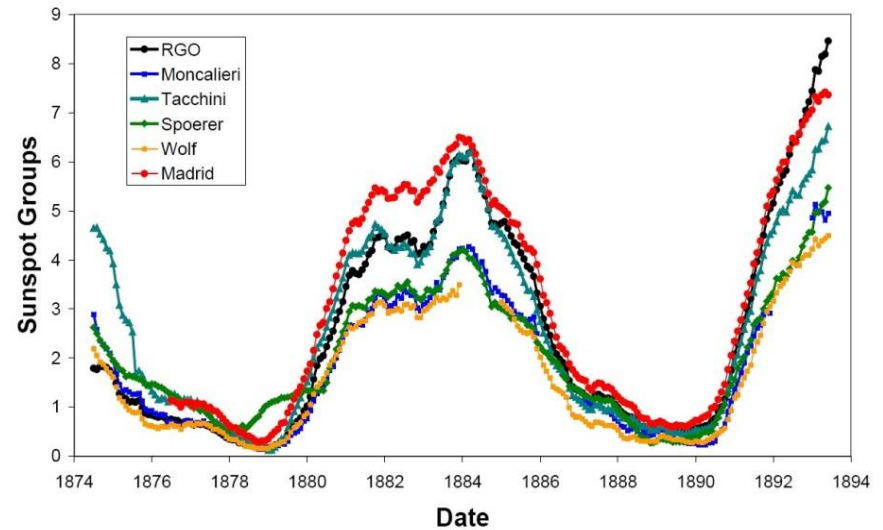
The 1880-1915 « Greenwich » trend (GN)

- Ratio of the RGO group count relative to parallel visual observers (*Svalgaard 2012, Vaquero 2013, Cliver & Ling 2015*)

➔ **Ratio increases by ~40% over 1880 – 1915**

- Indications of changes in the early RGO data set (*Willis et al, 2013*):
 - Photographic plate type
 - Measuring method

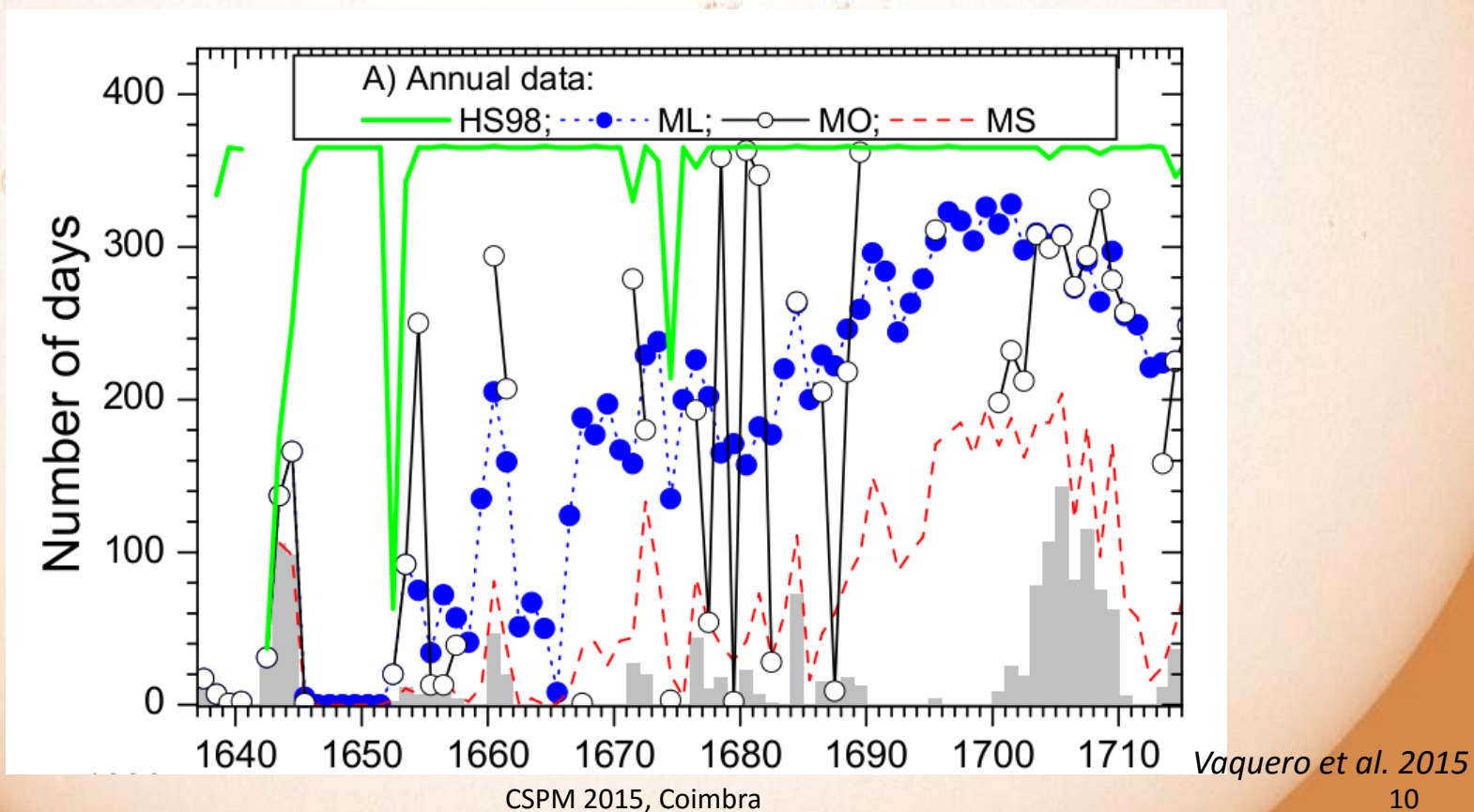
➔ **The new GN reconstruction only uses multiple visual observers, also over the entire 20th century (*Svalgaard & Schatten 2015, Cliver & Ling 2015*)**



Vaquero, SSN Workshop, 2013

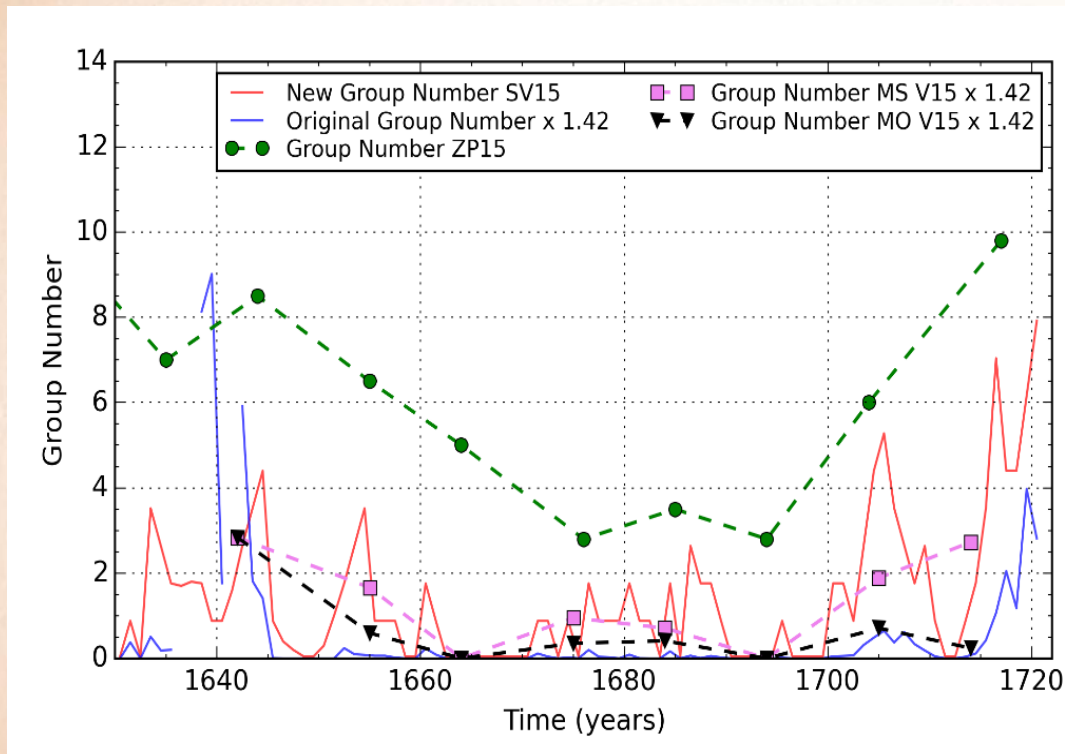
Revisiting the Maunder Minimum

- Elimination of many interpolated null GNs in meridian transit observations (*Vaquero & Gallego 2014, Clette et al. 2014, Vaquero et al. 2015 in press*):
- Reduction of the actual coverage from $\sim 100\%$ down to $\sim 60\%$



Revisiting the Maunder Minimum

- Recent revisions by several alternate approaches like the “active days” method (*Vaquero et al. 2015, Usoskin et al. 2015*)



Original Group Number

SV15: « Backbone », Svalgaard 2015
Sol.Phys.

ZP15: Zolotova & Ponyavin 2015

V15: Vaquero et al. 2015 A&Ap

MS « Strict » model;

MO: « Optimum » model

- High values proposed by Zolotova & Ponyavin (2015) are excluded (see poster S4.11 Usoskin et al.)

➔ Slight increase in the sunspot numbers during the MM:

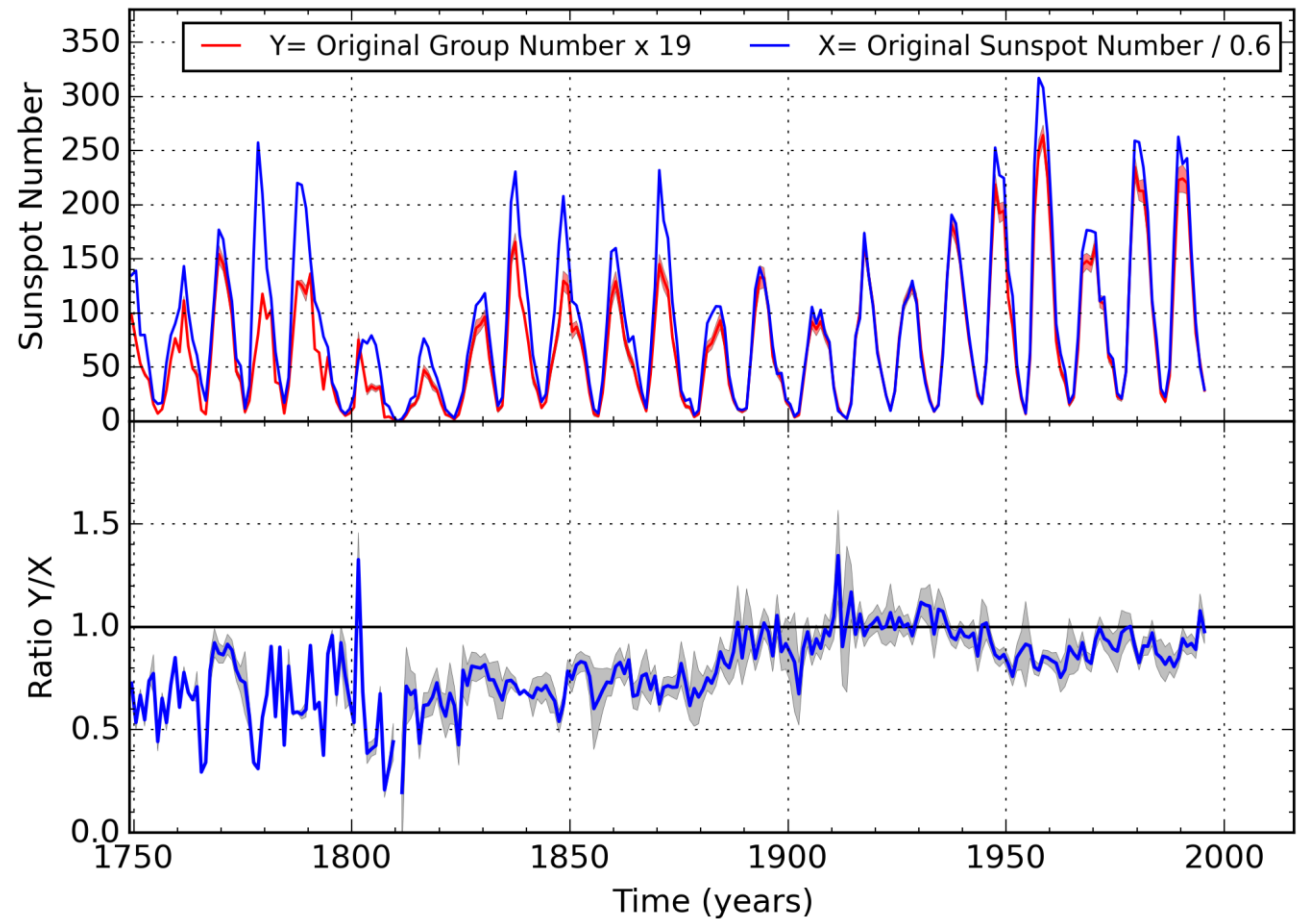
- Short 9-year solar cycles

Combining all corrections: matching SN and GN

Original
series:

SN / 0.6

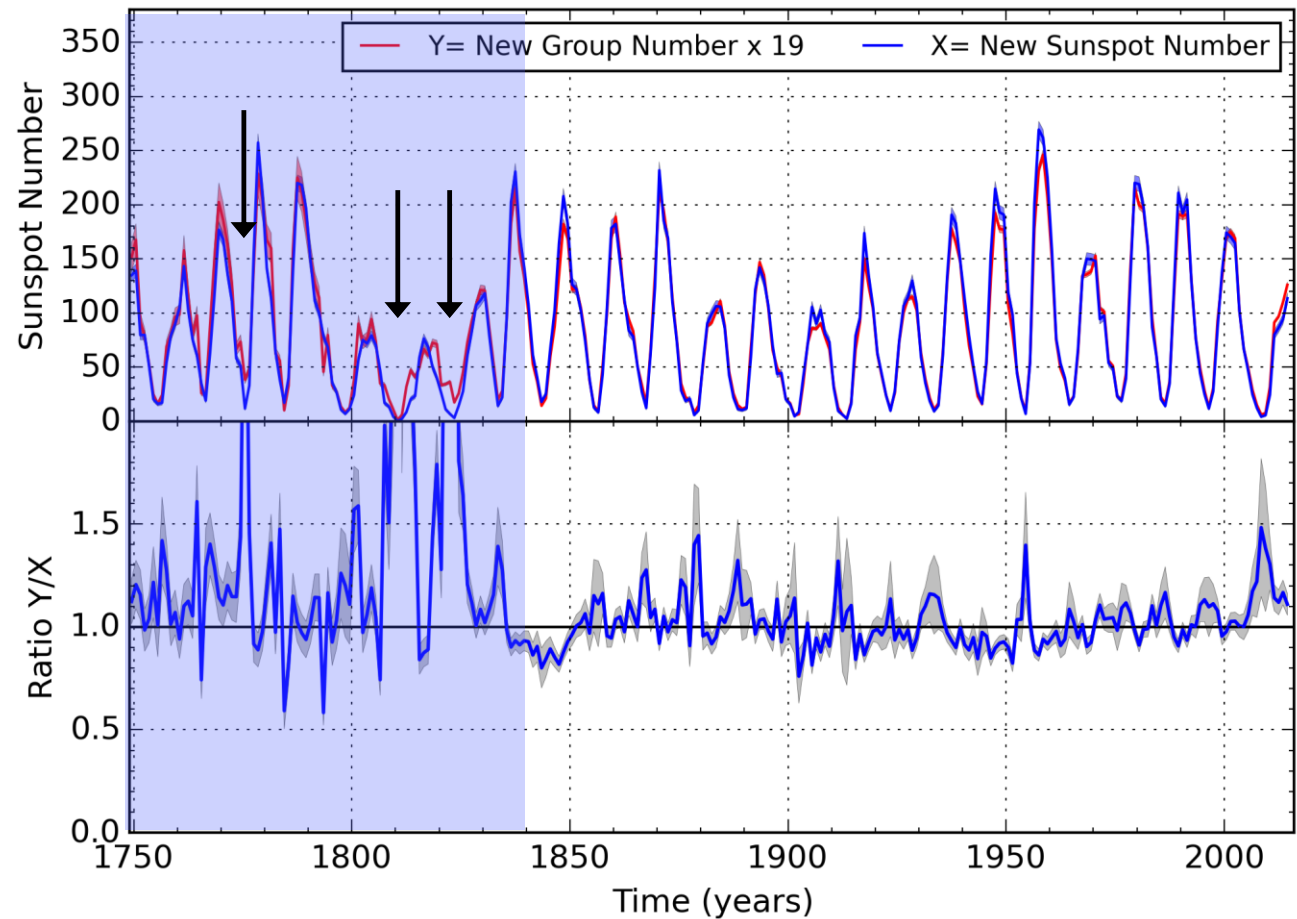
GN x 19.



Combining all corrections: matching SN and GN

Close agreement over the entire interval 1826-2015

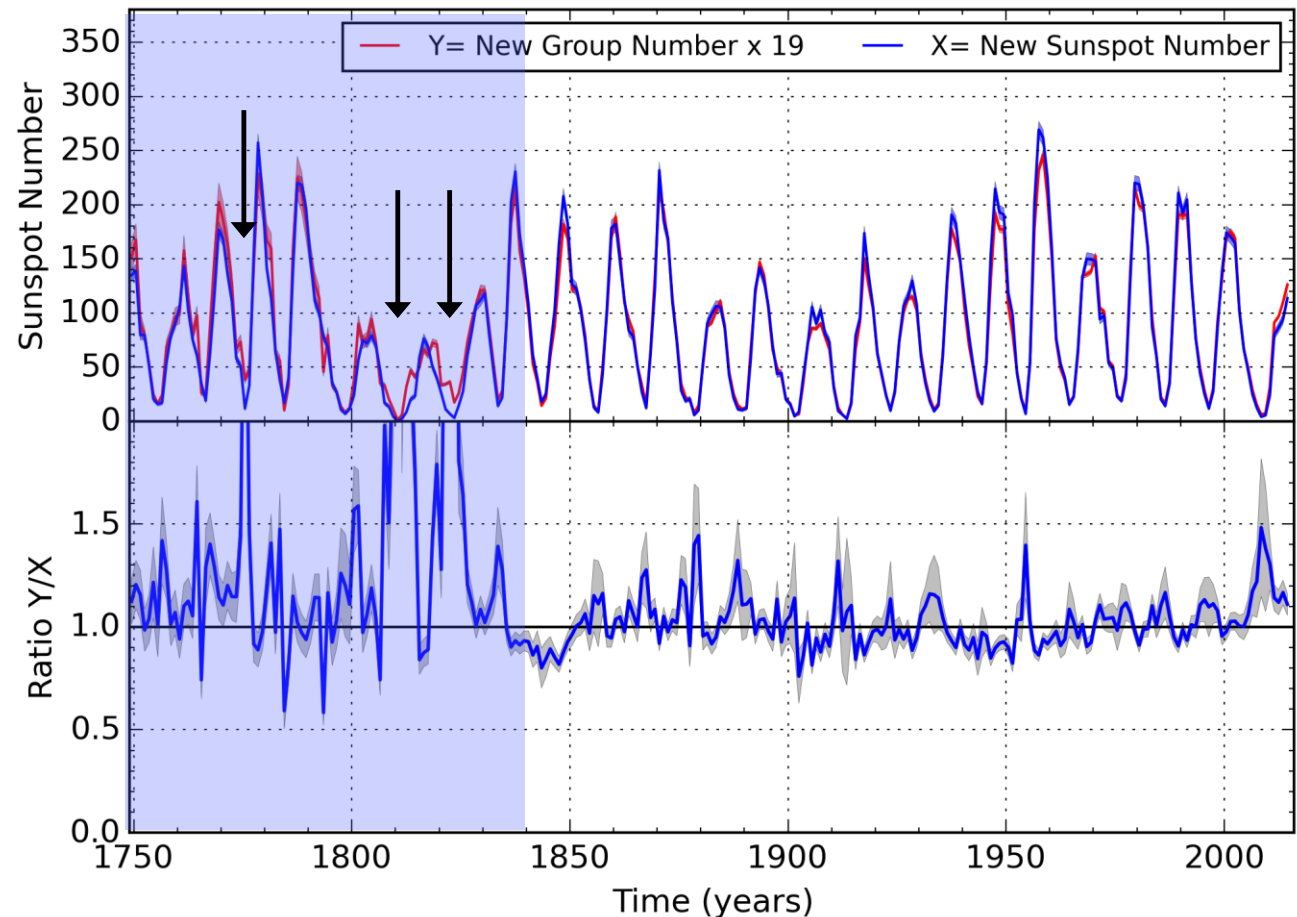
Still significant differences before 1826: more work is needed !



Combining all corrections: matching SN and GN

Close agreement over the entire interval 1826-2015

Still significant differences before 1826: more work is needed !

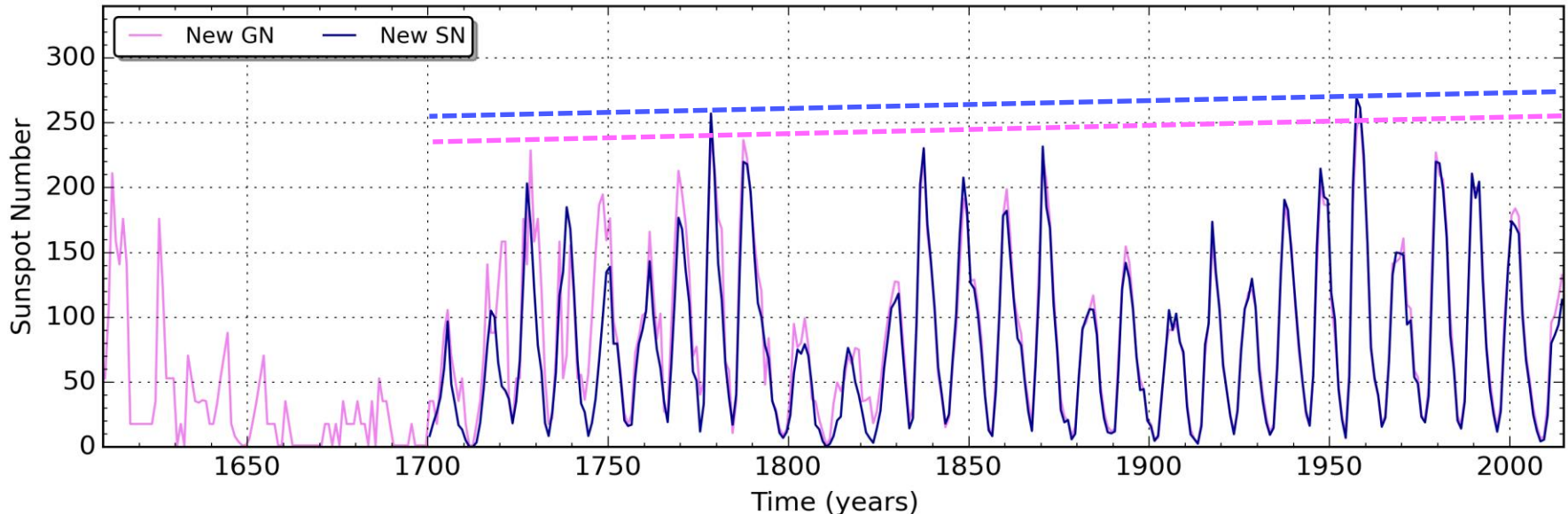


- **The improved agreement gives a strong confirmation of the validity of the corrections**

Uniform peak cycle amplitudes over last 3 centuries

- Original series: strong upward secular trend from the end of the Maunder Minimum to the mid 20th century (“Modern maximum”, *Solanki et al. 2004*, *Usoskin 2013*):
 - GN: + 40% / century (*red*) SN : + 15% / century (*green*)
- New SN and GN= similar **very weak upward trend** < 5 %/century (*blue, purple*)

➔ Soon after the Maunder Minimum , solar activity returned to high levels equivalent to recent cycles of the 20th century



Comparison with indirect indices of solar activity

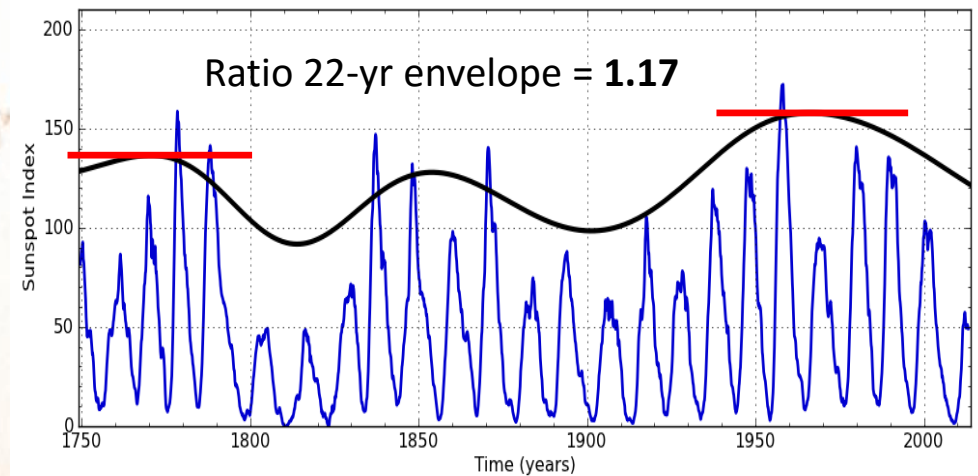
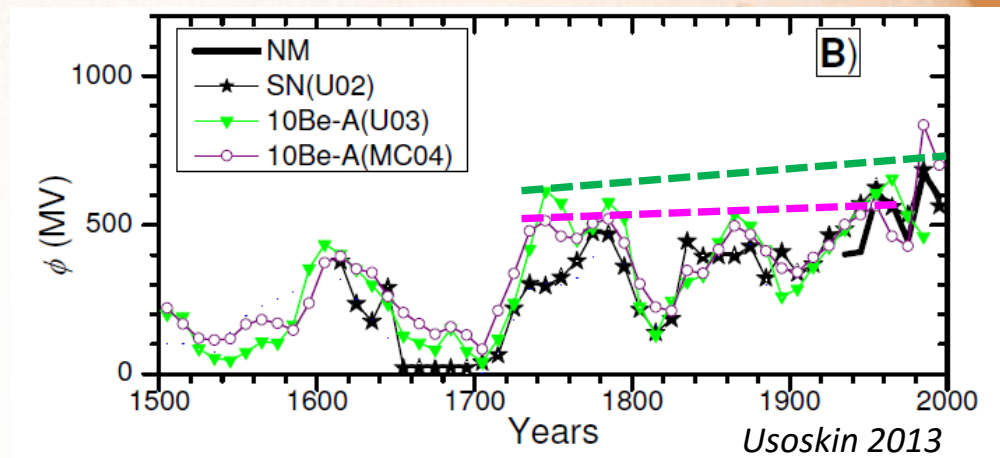
- **Cosmogenic isotopes (^{10}Be , ^{14}C):**

- contradictory results between different samples and models (modulation potential ϕ):
 - Upward trend (Usoskin et al. 2002, Solanki et al. 2004)
 - No trend (Muscheler 2007, Usoskin et al. 2015)
- Limitations: complex deposition processes, evolution of Earth magnetic field

- **Time integration of ϕ**
(20 to 40 years)

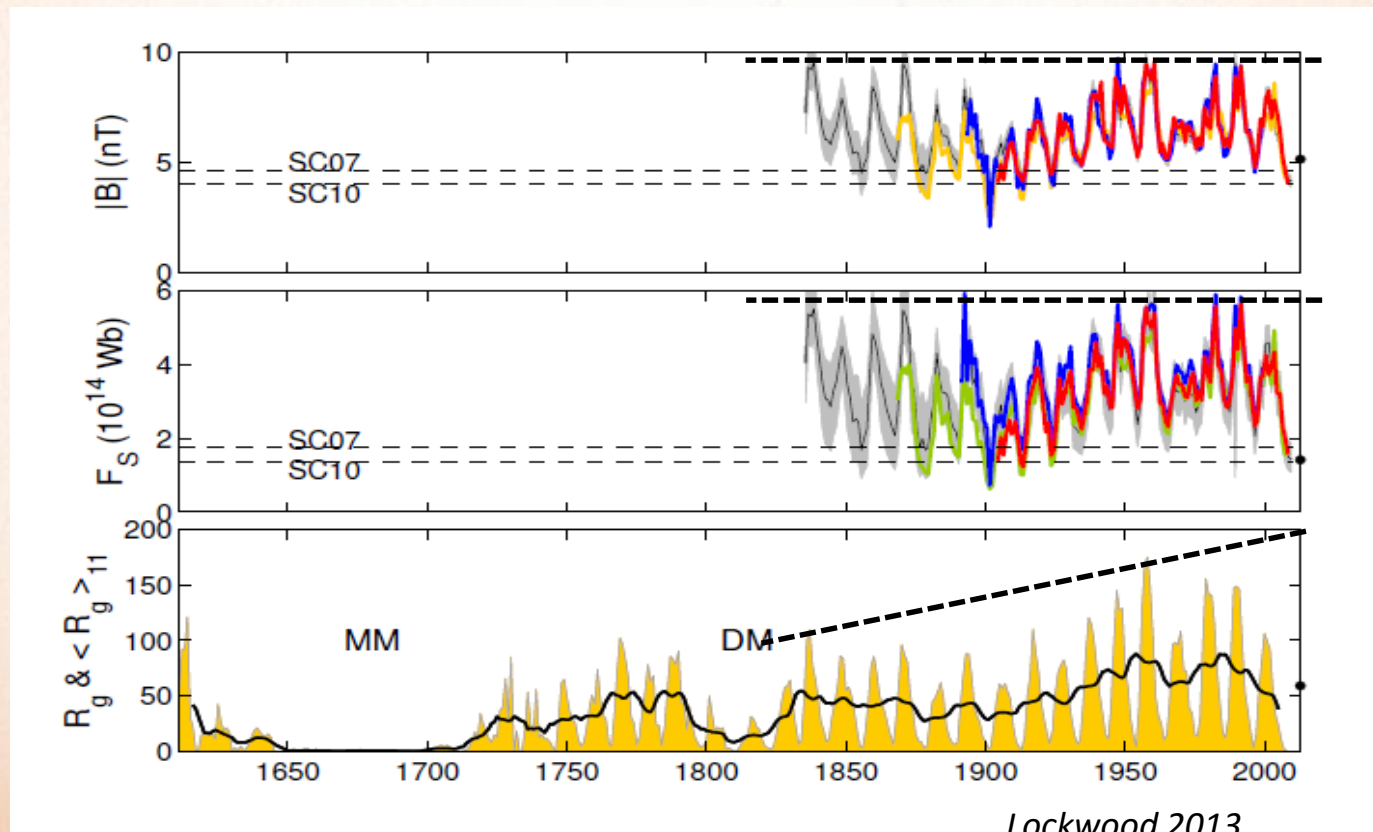
- Low-pass filtering of SN series (22 years):
- Upward trend but weaker

➔ The longer sequence of strong cycles in the 20th century gives a higher solar signal without stronger solar cycles



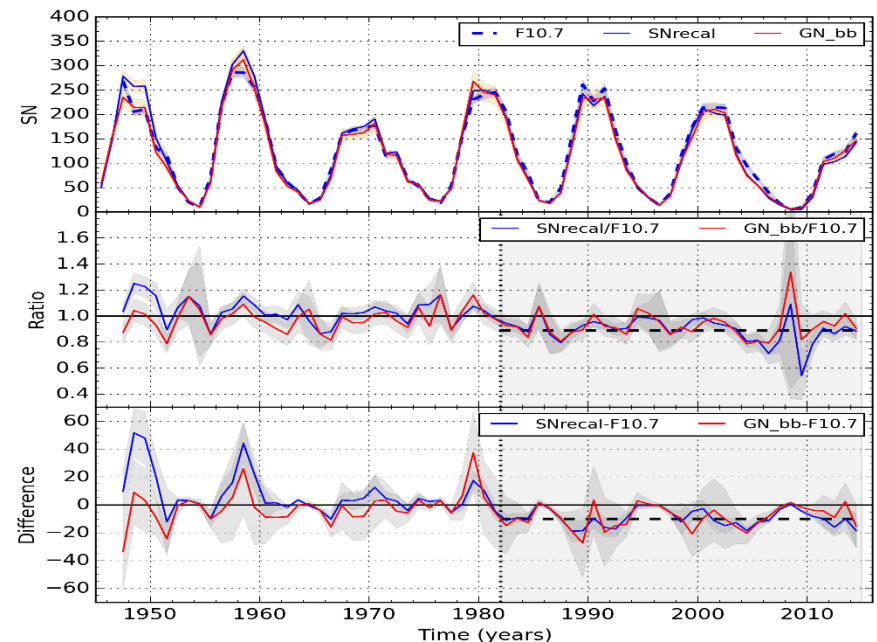
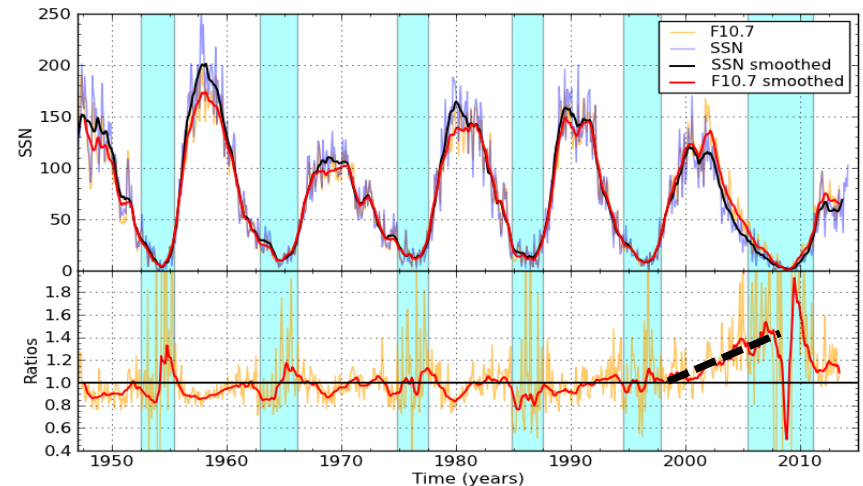
Comparison with indirect indices of solar activity

- Geomagnetic indices: reconstructed open magnetic flux over the last 180 years (*Lockwood et al, 2013*)
 - Recent reconstructions show identical cycle amplitudes between the mid-19th century and the 20th century



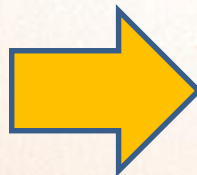
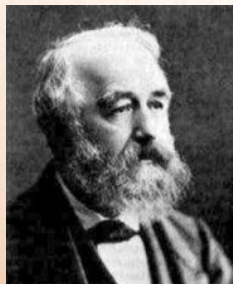
Better agreement with modern solar indices

- Original SN too low versus the $F_{10.7}$ radio flux after 2000 (*Svalgaard & Hudson 2010*, *Lukianova & Mursula 2011*, *Clette & Lefèvre 2012*)
- Using the reconstructed SN and the “backbone” GN over 1945-2015
 - no more anomaly after 2000
 - $F_{10.7}$ is too high by 10% after 1983 !



Upgraded data distribution and production

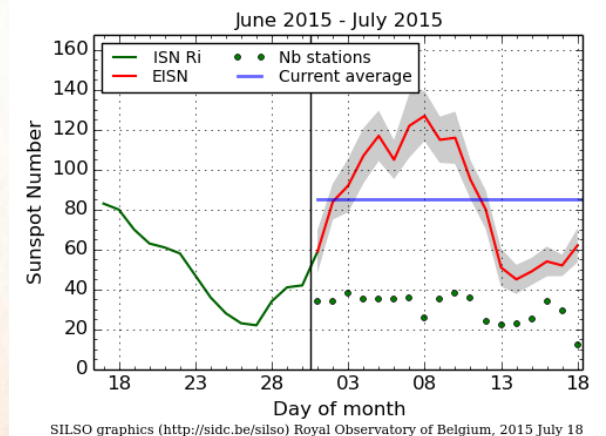
- New SILSO Web site (since early 2014)
- Operational transition to the new SN: **July 1st, 2015**
 - Adaptation of entire software for all SILSO products: **hemispheric numbers, daily estimated SN (EISN), 12-month predictions**
- Unchanged base method for the total SN but:
 - Pilot station: **Specola, Locarno un-weighted counts** (original Wolf formula)
 - New scale convention: **Zürich factor 0.6 set to 1.0**
 - New reference: **A. Wolfer (1893-1926)**



CSPM 2015, Coimbra

8/10/2015

The screenshot shows the SILSO website interface. At the top, there is a navigation menu with links for Home, Data, FAQ, Observers, News-Archive, Contact, and Subscribe. Below the menu, a banner reads "World Data Center for the production, preservation and dissemination of the international sunspot number". A prominent red box highlights the "Major change of data set on July 1st, 2015: key information". The main content area features a "Sunspot number series: latest update" section with a line graph showing the international sunspot number (Ri) from 2004 to 2015, comparing the old series (blue) and the new series (red). A "Transition to the new Sunspot Number successfully completed" announcement is displayed, detailing the process of uploading new archive files and updating the website. The page also includes a "Latest Sunspot Bulletin" section with a "Daily estimated sunspot number" and a "Latest USST observations (JOB, Brussels 17/01/2015)" section with a "Latest USST drawing" and "Latest USST image".



SILSO graphics (<http://sidc.be/silso>) Royal Observatory of Belgium, 2015 July 18

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New version management

- Objective: structured scheme for future additions and improvements to the SN series
- For each version:
 - Filenames with a **2-digit version number: Vn.i**
 - **n**: for each major change to the SN values
 - **i**: for minor changes (e.g. isolated typos) or side modifications (e.g. error estimates, file format).
 - Incremental documentation
- **New version = V2.0**
 - New symbol: S_N (and G_N)
- **“Archive” section:**
 - Past versions remain available
- Supervision:
 - Data distribution: **World data System (ICSU)**
 - Scientific: creation of an advisory committee (**IAU, Division E and B**)



The screenshot shows the website's navigation menu with 'Version Archive' selected. The main content area is titled 'Version Archive' and explains the versioning scheme. It lists 'VERSION 1.0' as the initial series and 'VERSION 2.0' as the new official series. Below the text, there are several data download options for different time periods and categories, each with buttons for 'TXT', 'CSV', 'PLOT', and 'INFO'. A 'VERSION 2.0' banner is visible at the bottom of the content area.

Home Data FAQ Observers News-Archive Contact Subscribe

Version Archive

This section contains past versions of the Sunspot Number data. Each version is uniquely identified by a 2-digit version number N.M, with:

- N: the primary number that changes for each new version where the sunspot numbers were collectively modified by any kind of correction.
- M: a second sub-version number is used to indicate secondary modifications that do not change the numbers themselves (e.g. new error estimates) or that involve only isolated modifications of the values (e.g. a typo found in a single daily value).

All files belonging to one version include the version number in the filename. Each version will be documented by a description of the incremental changes relative to the previous version and by associated files (scientific publications, links to relevant Web pages).

VERSION 1.0

This is the initial Sunspot Number series that was built without any subsequent modification by the Zürich Observatory, from R. Wolf in 1849 to M. Waldmeier in 1980, and by the Royal Observatory of Belgium since 1981 (WDC - SIDC, now SILSO).

For the first upgrade of the sunspot number to version 2.0, we first make available here the original files without modification (original filenames and same internal format), to leave time for our users to get used to the new data scheme. However, for global coherency, in a few months, those files will be converted to the same file format as version 2.0. As no documentation was ever attached to those files by our predecessors and because the scarce information is dispersed over many publications, the documentation of version 1.0 will be built progressively.

A recent synthesis of the construction of the original sunspot can be found in: Clette, F., Svalgaard, L., Vaquero, J.M., Cliver, E. W., "Revisiting the Sunspot Number. A 400-Year Perspective on the Solar Cycle", Space Science Reviews, Volume 186, Issue 1-4, pp. 35-103. (see initial section and the many references cited therein)

Different relevant presentations from F. Clette, T. Friedli, L. Svalgaard, R. Arlt and others can be found in the Wiki of the Sunspot Number Workshops: <http://sunspotworkshop.wikia.com/wiki/Home>

A thematic issue of the Solar Physics Journal is in preparation by mid 2015 and will gather many papers relevant to the V1.0 to V2.0 transition.

Total sunspot number

- Daily total sunspot number [1/1/1818 - now]
TXT1 TXT2 TXT3 CSV PLOT INFO
- Monthly mean total sunspot number (+ 13-month smoothed numbers [1/1/1749 - now])
TXT CSV PLOT INFO
- Yearly mean total sunspot number [1700 - now]
TXT CSV PLOT INFO

Daily Estimated Sunspot Number

TXT CSV PLOT INFO

Hemispheric sunspot numbers

- Daily total and North/South sunspot numbers (yearly files) [1/1/1992 - now]
TXT INFO
- Daily total and North/South sunspot numbers (single file) [1/1/1992 - now]
TXT CSV INFO
- Monthly mean North-South sunspot numbers [1/1/1992 - now]
TXT PLOT INFO

VERSION 2.0

This is the new official Sunspot Number series. The information concerning this new series can be found in the base Data section.

Data policy

The future

- Development of a **new operational method**
 - Implementation of a multi-station reference

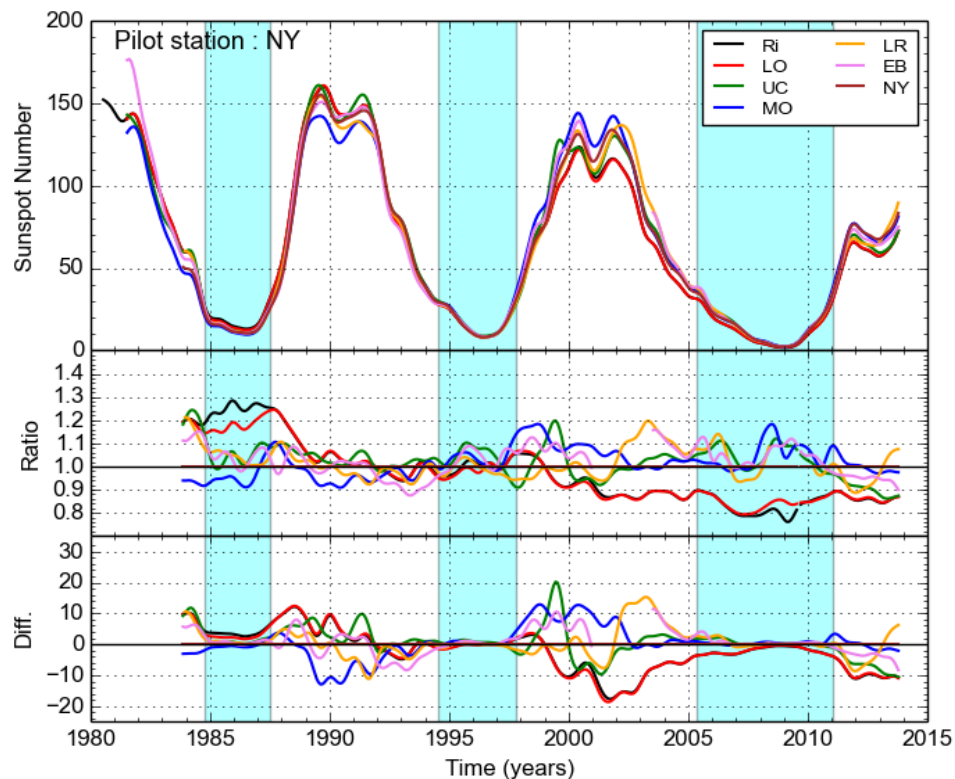
➔ Full re-calculation of the SN since 1981

- Routine production of the **Group Number**

- Application of more **advanced statistical methods:**

- sparse data with gaps and null values (ARMA, Bayesian regressions, multiscale decomposition, PCA)

➔ Revisiting Wolf's work on historical data 1700- 1849



Conclusions

- The new SN and GN now largely agree
- **From a static heritage to a living data series**
- Multiple implications:
 - Same levels of solar activity from Maunder Minimum to 21st century
 - Elimination of past discrepancies with modern solar indices
- ➔ **Opening new research paths**
- Renewed interest for the long-term sunspot record:
 - **Recent wave of new publications**
 - **Topical issue of Solar Physics (> 30 papers)**
- **Base for a new Sunspot Number production:**
 - open to future additions and improvements

For the latest information, please visit ...



WDC – SILSO Sunspot Index and Long-term Solar Observations

<http://sidc.be/silso>

Home Data FAQ Observers Contact

World Data Center for the production, preservation and dissemination of the international sunspot number

Menu

- Home
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Sunspot number series: latest update

International sunspot number R_t ; last 13 years and forecasts

Latest Sunspot Bulletin

Daily estimated sunspot number

03 November : 88
04 November : 91
05 November : 87
06 November : 98
07 November : 99

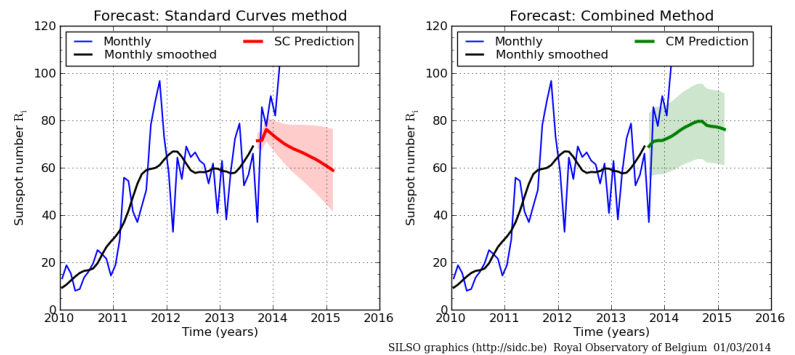
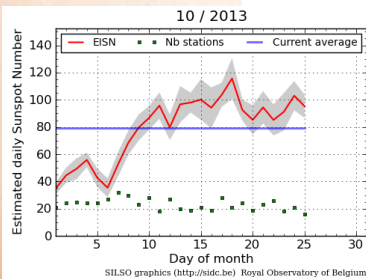
News

Welcome to the new central Web site for the International Sunspot Number !

We designed those new Web pages to offer you an easier access to the existing sunspot data and to the associated information. This new communication platform is destined to grow over the coming months and years, with new data and graphical products and new sections providing extra information about the World Data Center and its worldwide observing network. This initial version already features new items... more

Fri, 18 Oct 2013

Supported by:



Sunspot Workshops

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

Historical Archive of Sunspot Observations

<http://haso.unex.es/>