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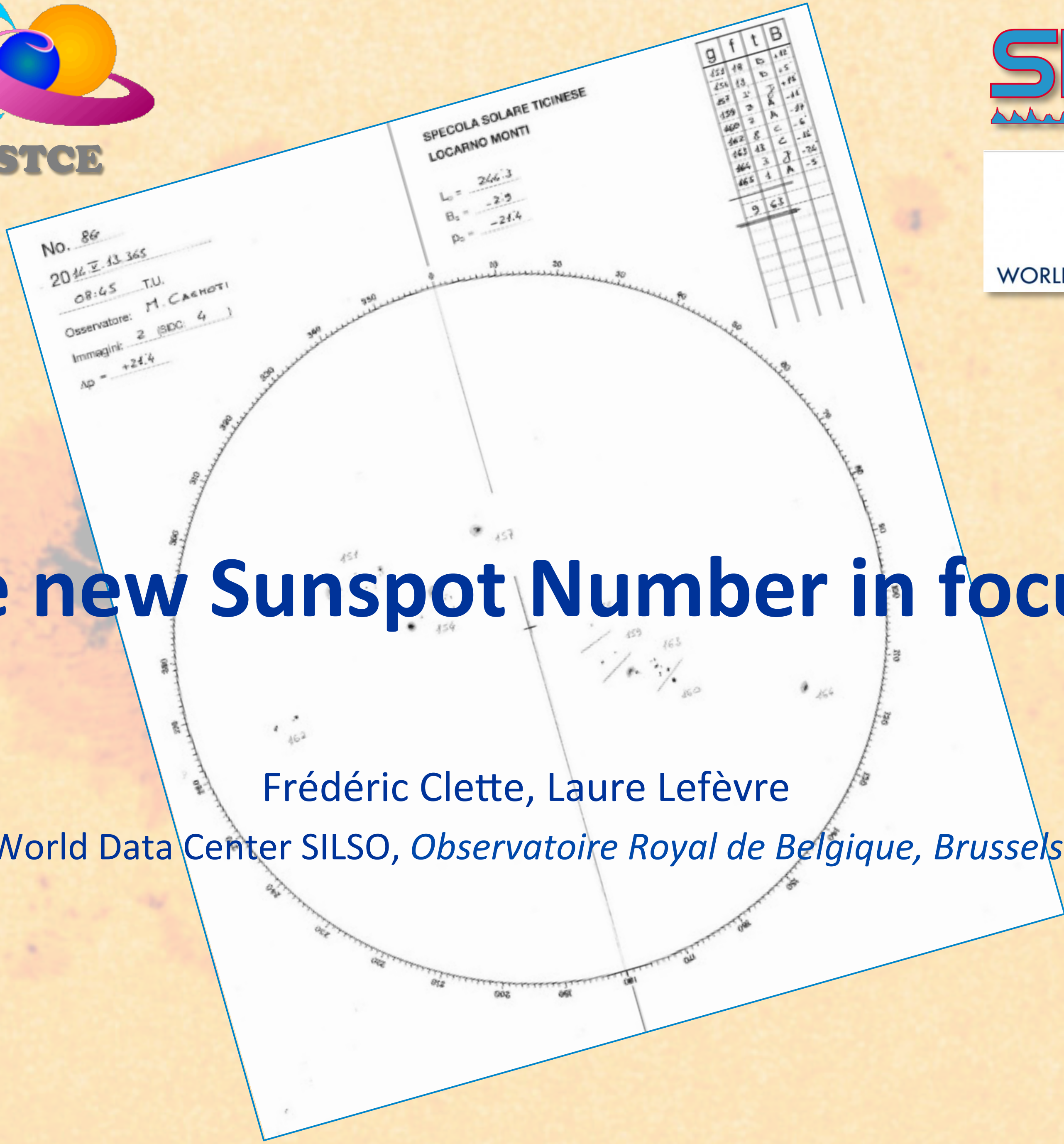


The new Sunspot Number in focus

Frédéric Clette, Laure Lefèvre

World Data Center SILSO, *Observatoire Royal de Belgique, Brussels*

ICSU WORLD DATA SYSTEM

Outline

A new series:

- A new starting point: sunspot number Version 2.0
- 3 main corrections:
    1. 1849 Wolf-Wolfer transition
    2. 1947 Waldmeier jump
    3. 1981-2015: Locarno drift
    - *Recent invalid corrections*
- A non-linear SN-GN relation

A new context:

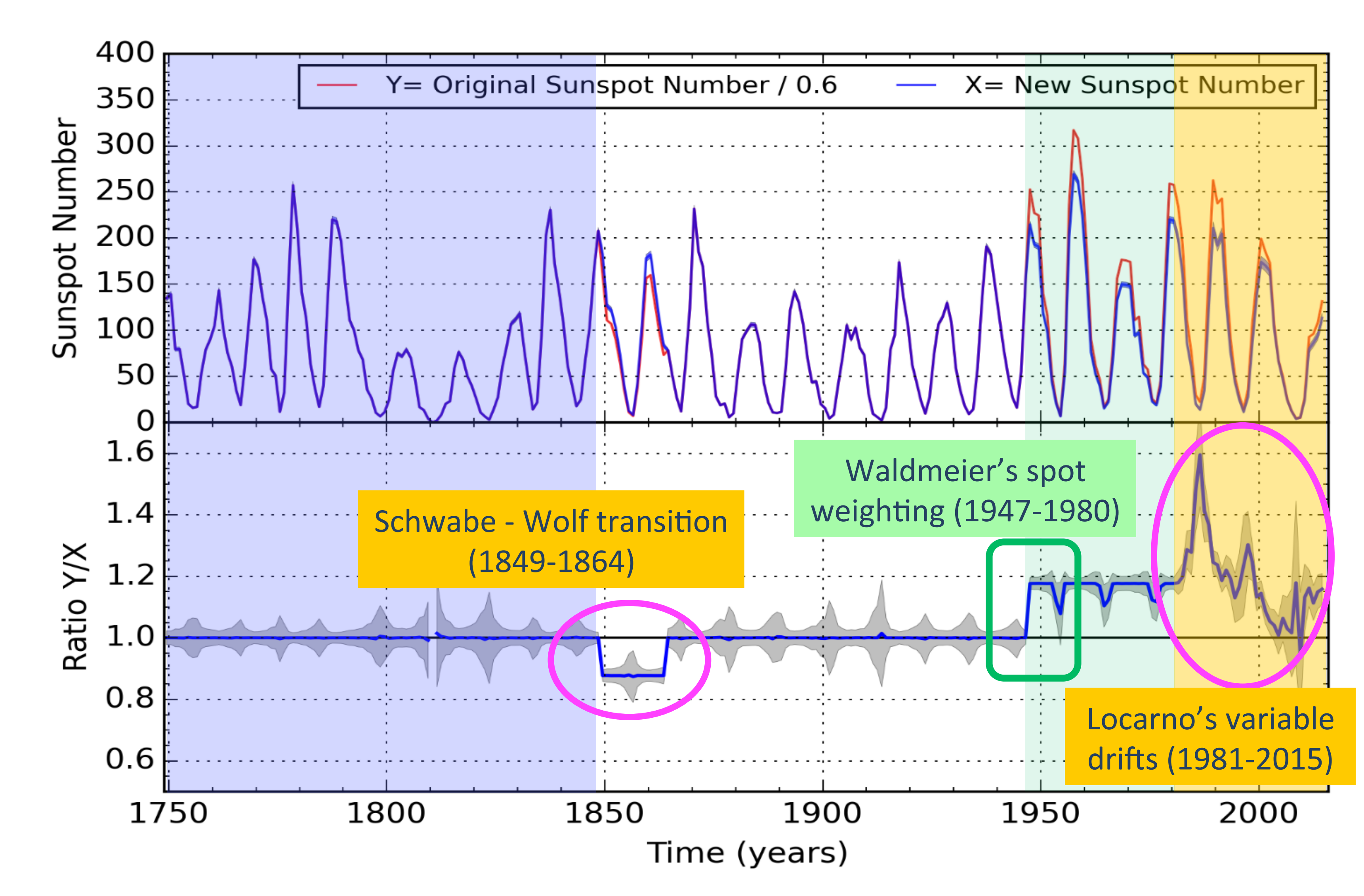
- Remaining issues and new objectives
- Recent wave of publications: lessons learned
- A new role for WDC- SILSO

A necessary revision: Sunspot Number Workshops

- 4 workshops (2011-2014): Sac. Peak, Brussels, Tucson, Locarno
- Multiple diagnosed problems in the SN and GN:
  - **Clette, F., Svalgaard, L., Vaquero, J.M., Cliver, E.W.: 2014, *Revisiting the Sunspot Number. A 400-Year Perspective on the Solar Cycle*. Space Sci. Rev. 186, 35-103**
  - **Solar Physics topical issue (2016): 35 papers**

- **Sunspot and Group numbers corrected independently**

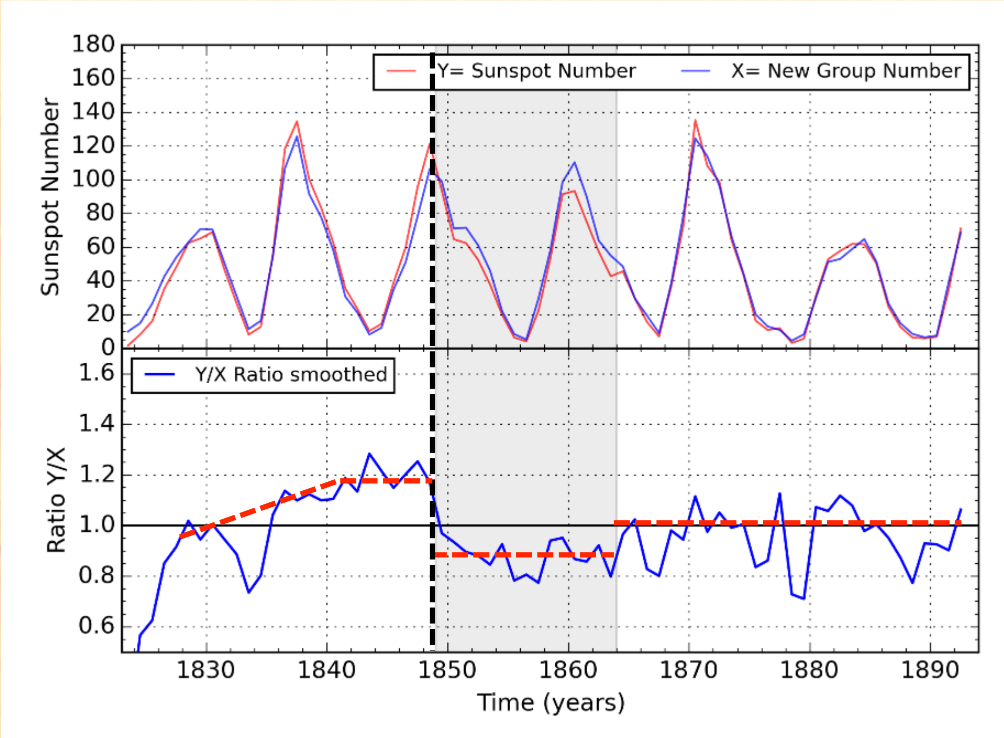
Sunspot Number corrections: overview



The Schwabe-Wolf transition (1849-1864)

- **1849: 20% downward jump** in the SN relative to the original Schwabe numbers *(Leussu et al. 2013)*

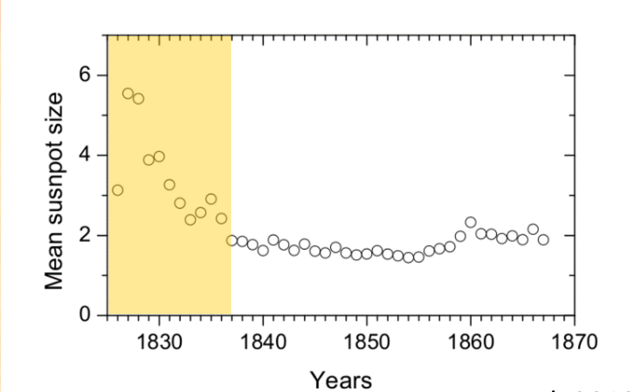
- Comparison with the Group Number over a wider time interval *(Backbone GN, Svalgaard & Schatten 2016)*



  – Schwabe upward trend 1826-1840

  ⇨ **14% upward jump in 1864**

  ⇨ Equal scale before 1830 (cycle 7) and after 1864 (cycle 11)



Leussu et al. 2013

The Schwabe-Wolf transition (1849-1864)

- Using th
  Number
  - **14% up**
  - Schwab
    1849
  - Early va
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Sonnenfleckenbeobachtungen im Jahr 1864.

Wolf, Mittheilungen über die Sonnenflecken.

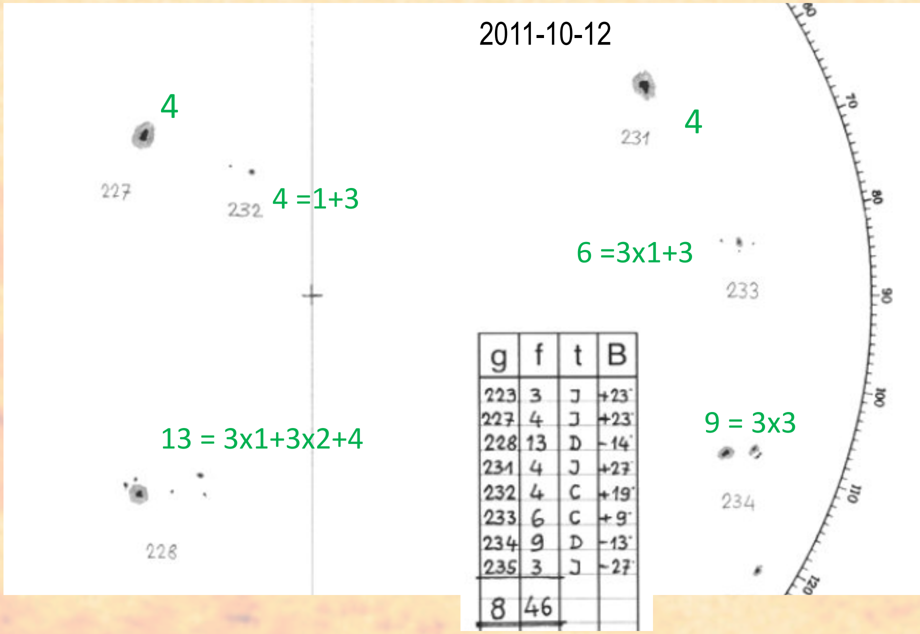
194

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
1	1. 1†	3.15*	5.13*	3. 4*	1. 5*	3. 9*	1. 2*	3.17	3.15	3. 4	5.32	5.17†
2	2. 5w	3.10*	6.13*	1. 1*	1. 3*	5.85w	4.16	2. 7†	3.12	2. 5	4.22†	—
3	2. 3†	3.11*	7.14†	2. 4*	3. 4†	4.17*	4.15	3.13	3.11	2. 3	5.30†	—
4	1. 3*	2.14†	5. 9*	—	3. 7†	5.21*	3. 5*	3.18	4.17	4.16	4.31 w	2. 5*
5	1. 1†	2.20†	5.21w	2. 3*	3. 4*	6.23*	4.21	4.17	2. 8	2.11	4.28 w	2. 2†
6	2. 8†	1. 7†	4.— w	3. 9*	3. 4*	6.21*	4.22	5.13	2. 8	2. 9	3.23	1. 2
7	3.11†	2.16*	3. 5*	3. 9*	2. 4*	7.26*	3. 6*	7.29	2. 5	2. 3	3.12†	1. 1*
8	3. 6†	2.59•	3. 4*	3. 6*	2. 3*	4.18*	3. 8*	6.53	2. 6	3.10	3.25	1. 1
9	3. 4†	2.10*	5. 8†	3. 6*	2. 3*	7.32†	4.47	6.77	2.14	3.16	3.26	1. 2
10	2. 4*	2.11*	4. 5*	2. 4*	2. 2*	5.16†	4.47	5.28*	2.26	2. 5	4.20†	1. 1
11	2. 3†	3.11†	4. 9*	2. 4*	1. 1*	3. 6†	4.19*	4.27*	2.16	3. 7	4.19†	1. 8†
12	3. 4†	1. 1*	4.27*	2. 5*	3. 5†	2. 5*	4.87	5.93	2. 8†	1. 2	4.27 w	1. 4*
13	3. 7†	2.10†	3. 7*	2. 4*	2. 9†	3. 8*	4.21*	6.84	2.18	1. 8	4.15	1. 2 w
14	4.21•	1. 3*	3. 7*	2. 3*	1. 4*	3. 22	3.41	4.75	2. 9	1.28	1. 1*	—
15	3. 5*	1. 3*	3. 7*	2. 3*	2. 7*	3.11†	4.75	4.24*	1. 1	1.25	2. 17	1.20
16	4. 9*	2. 4*	3. 7*	1. 1*	2. 7*	3. 8*	3.15*	3.41	2.10	1.11	2.—†	1.29 w
17	5.13†	3. 7*	4. 7*	5. 6†	2.10*	2. 7*	3.47	2. 5*	2.10	1. 5	3.21	1.14†
18	5.61 w	5.20†	5. 8*	1. 1*	2.10*	5.19	3.10*	3. 8	2. 8†	1. 2	3.15 w	1. 9†
19	4.16†	3. 4*	3. 5*	1. 1*	2.10*	1. 4*	2. 5*	1.13	1. 2*	1. 8	3.13	1.17
20	5.21*	5.19w	3. 5*	1. 1*	3.12*	2.14	3.10	1.13	2. 7	1. 7	3.13	—
21	6.19*	3. 4*	3. 5*	1. 1*	4. 9*	2. 9	4.20	1. 9	2. 5	2. 6*	—	1.13 w
22	5.19*	2. 3*	4. 5*	1. 1*	4. 9*	1.22	2. 4*	1. 3	1. 1	2. 3	2. 7*	0. 0
23	5.18*	2. 4*	4.10†	1. 1*	3. 5*	1.16	3.10†	1. 2	0. 0	4.34	4.21	1. 7†
24	5.16†	2. 3*	4. 6*	1. 1*	2. 3*	1.13	1. 1*	1. 1†	2. 5	4.19†	5.28	—
25	5.18*	2. 2*	4. 7*	2. 4†	1. 4*	2.15	2. 9	0. 0	4. 6	3.24	—	—
26	5.14*	3. 4*	4. 7*	1. 1†	1. 4*	1. 4*	1. 1*	0. 0	3. 5	3.17	3.—†	2. 3†
27	3.13*	3. 5*	4. 7*	1. 1†	2. 9	2. 4†	2.17	1. 5	3. 8	3.36	2.33	2. 9
28	2.13*	4. 8*	5.10†	0. 0†	3. 5*	1. 1*	2. 5*	2. 7	2. 6	2.12	3.49	—
29	2.10†	6.45*	4. 7*	0. 0†	2. 4*	1. 7	2. 3*	2.15	2. 5	2.31 w	3.69 w	2.12†
30	2.11*		3.15†	2. 6†	3. 4*	1. 2*	3.12	3.30	2. 3	3.26 w	4.52	1. 2
31	2.13*		3. 5*		3. 7*		4.11	3.23		3.15†		1. 2
Mittel	57,5	47,2	67,3	30,0	40,9	58,3	57,2	57,9	30,5	35,5	59,1	24,1

- Combina
  - Initia
    - D
  - July 1864: transition between Wolf (small portable refractor) and a new assistant using the standard 80mm Zürich refractor *(Wolf 1865)*

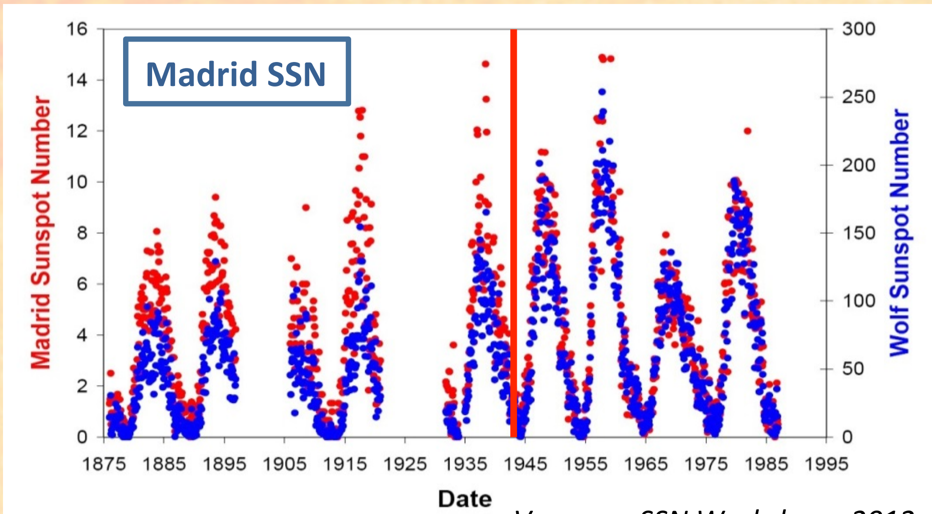
The 1947 Waldmeier jump

- **Sunspot weighting**:
  - Large spots are counted >1 (up to 5)
  - Progressive introduction over 1932 – 1940
  - Waldmeier (Director 1945) applies it systematically



- Appears in all cross-comparisons:
  - long-duration stations (e.g. Madrid) *(Vaquero 2012)*
  - Sunspot area (RGO) *(Svalgaard 2012)*

- Amplitude: ~ 20%



Vaquero, SSN Workshop, 2012

A lower value ? *(Lockwood et al. 2014)*

Original series SN and GN:

– **Fc= 1.116**

Uncorrected biases:

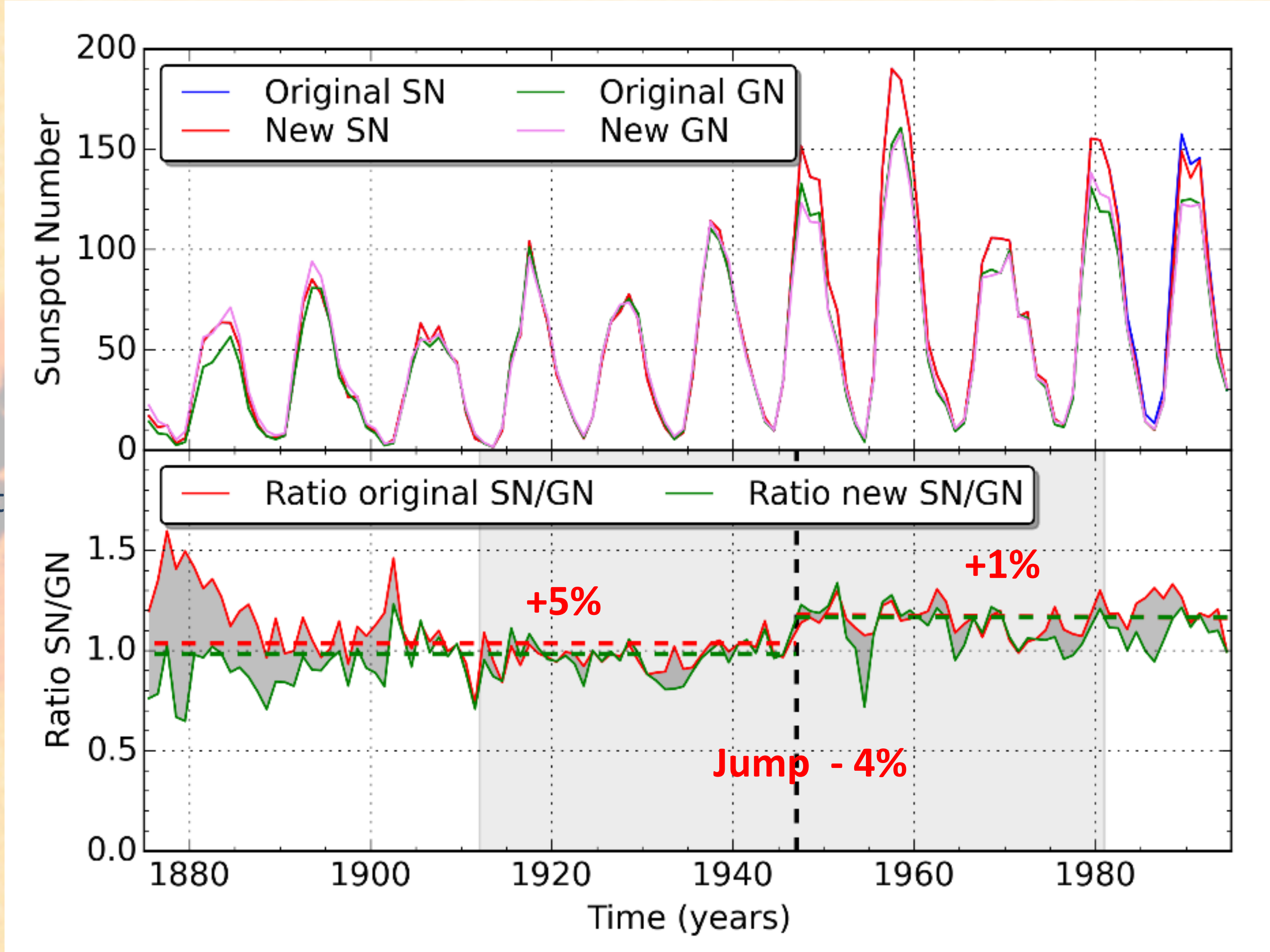
– GN: RGO inhomogeneity (1884-1915)

– SN: Locarno drift (1981-2010)

With homogeneous data sets:

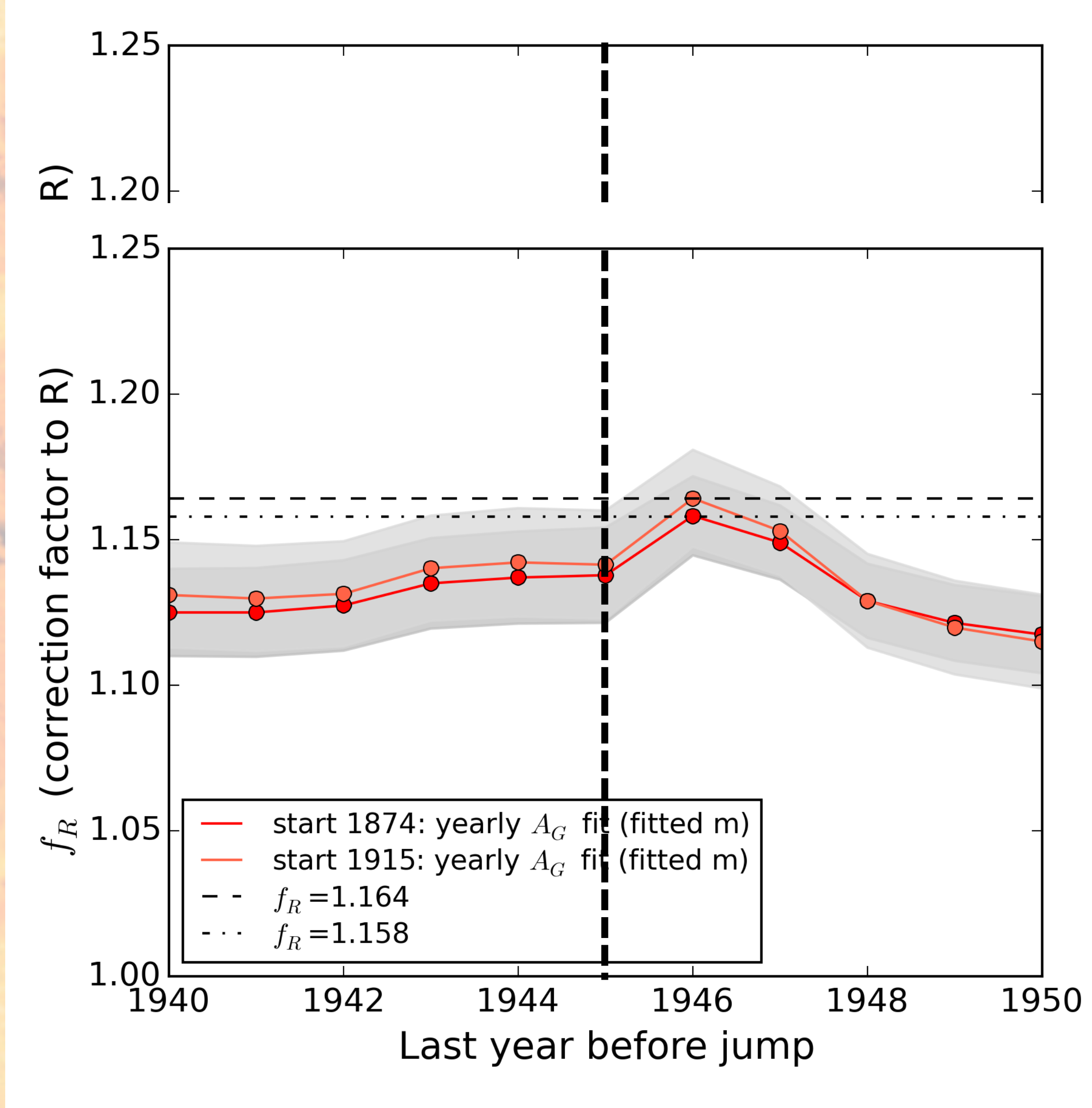
x 1.04

Fc=1.171



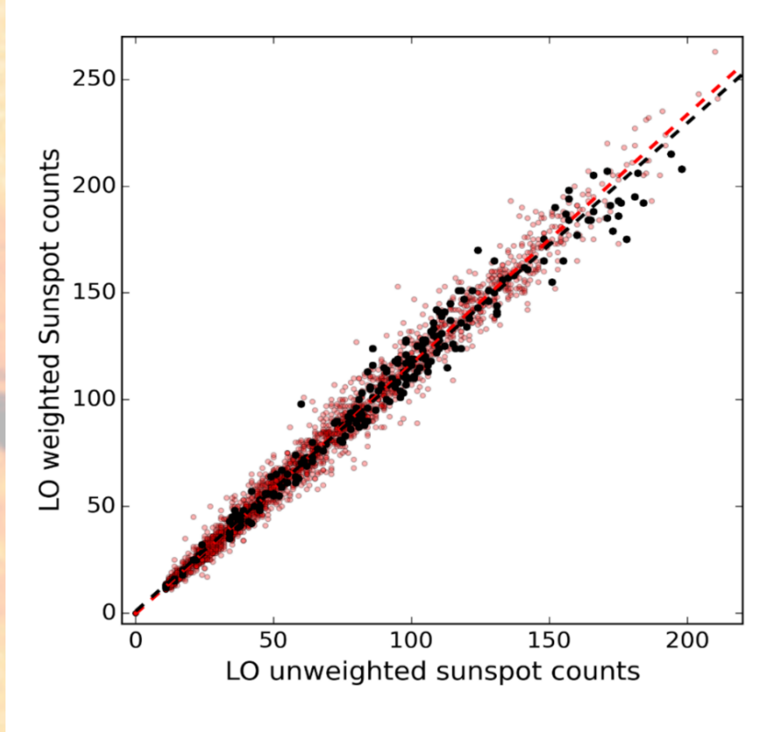
A lower value ? *(Lockwood et al. 2014)*

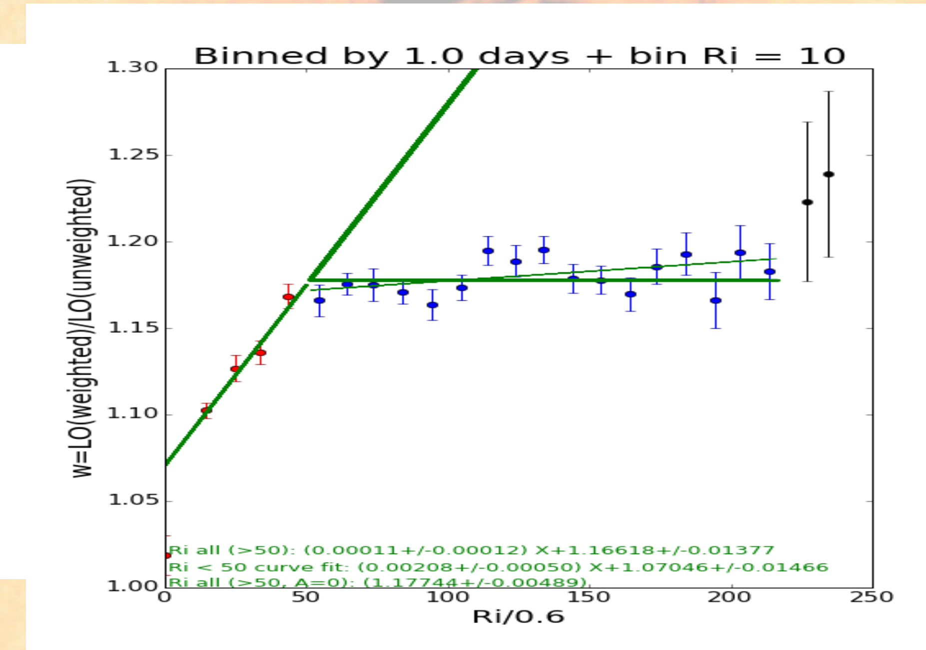
- Strong dependency on the time boundaries:
  - Begin – end:
    - inclusion of other defects (G_N)
  - Position of the separating date: 1946-1947
    - Main factor for the comparisons with sunspot group areas (A_G)
- Use of past external indices has:
  - Limited reliability
  - Limited accuracy



Weighting factor: direct determination

- Locarno station trained to the method (since 1955): **still in use !**
- Simultaneous weighted/unweighted counts (Specola station, Locarno):
  - 215 direct double counts (M. Cagnotti, Locarno, 2014-2015)
  - 3661 Locarno drawings recounted (1997-2014, L. Svalgaard)





- **Mean ratio**

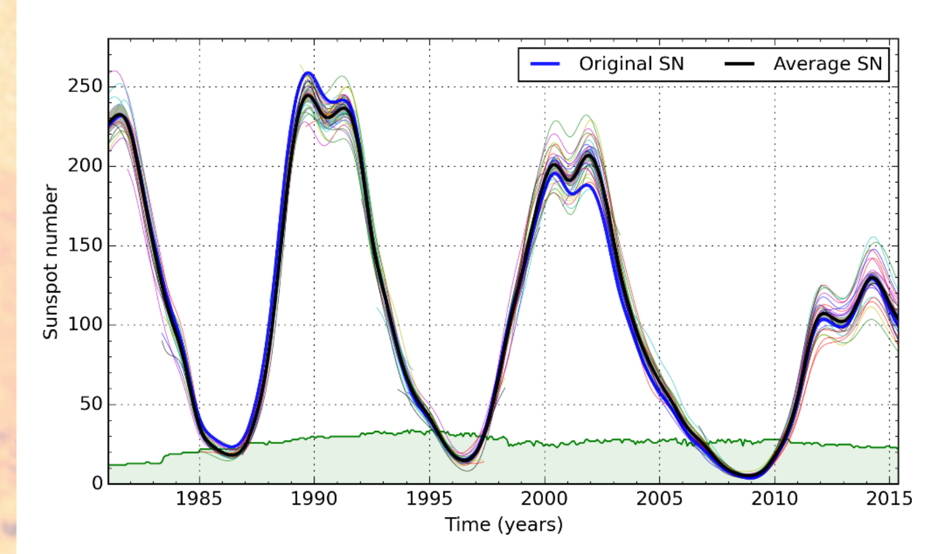
  ~ 1.16 +/- 0.035
- Dependence on solar activity for SN < 50

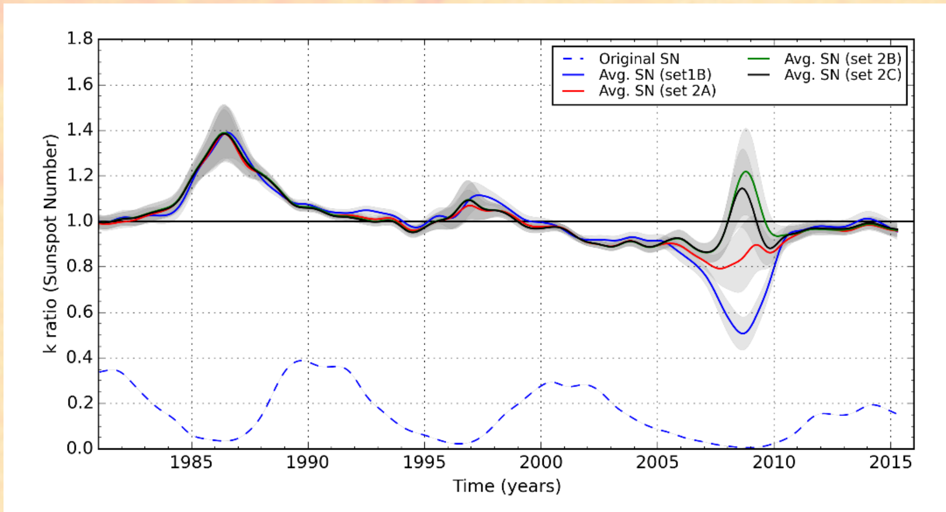
⇨ Maximum asymptotic mean factor:

1.177 +/- 0.005

Specola's variable drift (1981-2015)

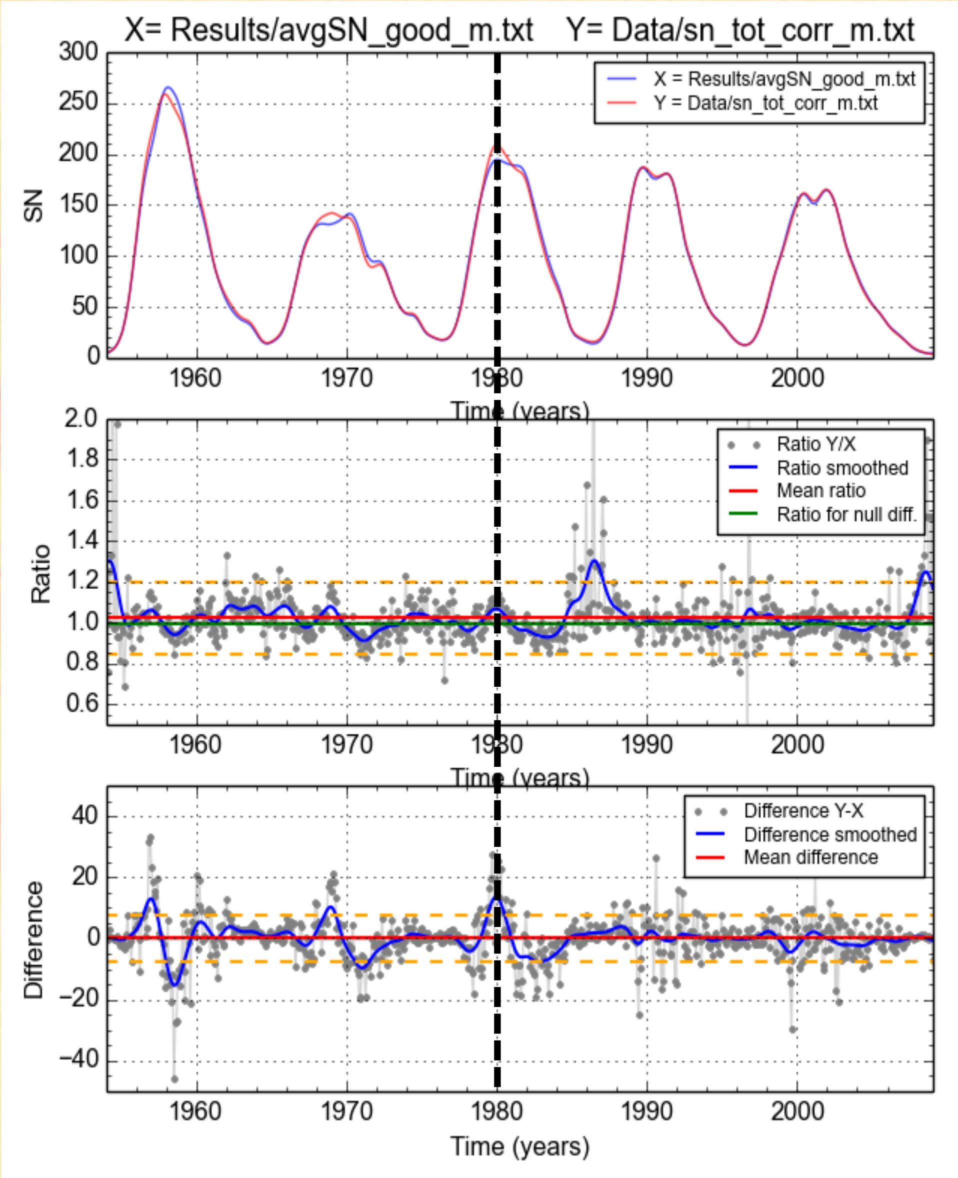
- **Direct reconstruction of the SN from a subset of 42 long-duration** and stable **stations** in the WDC – SILSO database *(Clette et al. 2014, Clette & Lefèvre 2016)*:
  - Consistent results with different sets of stations
  - Variable trend: recent years close to the initial 1981 scale
  - Correction factor: monthly mean k ratio with the original SN series





The 1981 Zurich-Locarno transition

- Extended analysis 1955-2015
- 1981-2015 correction applied after 1981:
  - Constant ratio
  - Average ratio before and after 1981: **1.01 +/- 0.012**
- Constant scale over 1947 - 2015

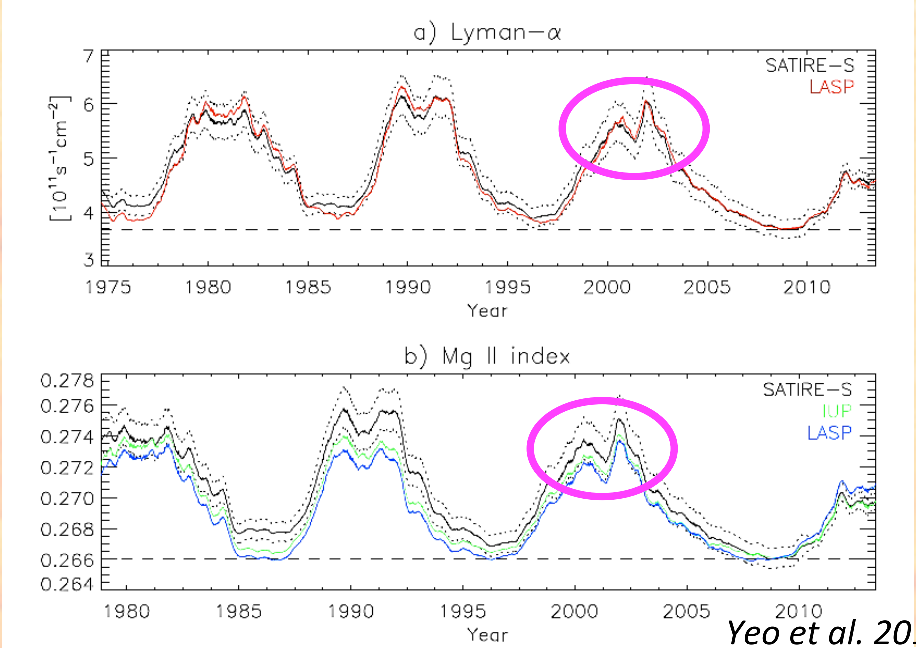


Better agreement with modern solar indices

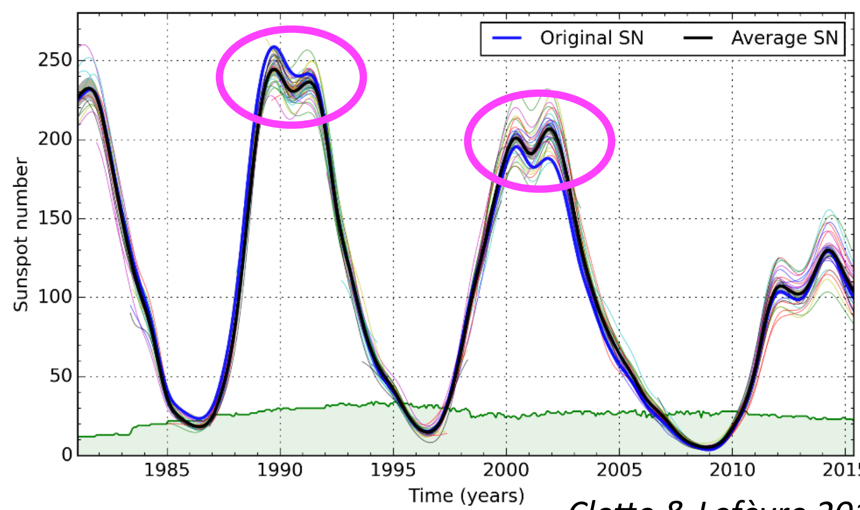
- Amplitude and shape of recent solar cycle maxima:
  - Mismatch between original SN and solar irradiances (TSI, MgII, Lyα, total sunspot magnetic flux)

- Second peak in cycle 23 (November 2001) now higher than first peak (July 2000)

➡ **Main unexplained discrepancies are eliminated.**



Yeo et al. 2014

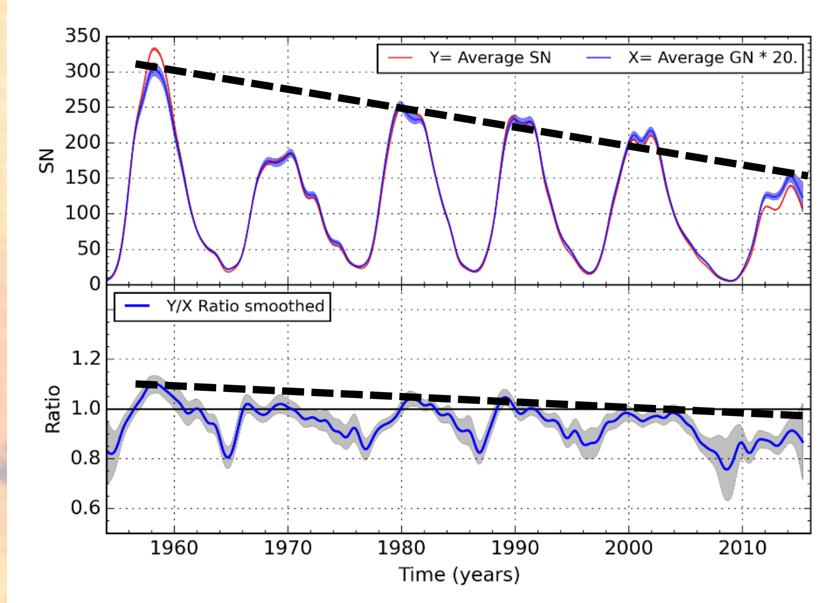


Clette & Lefèvre 2015

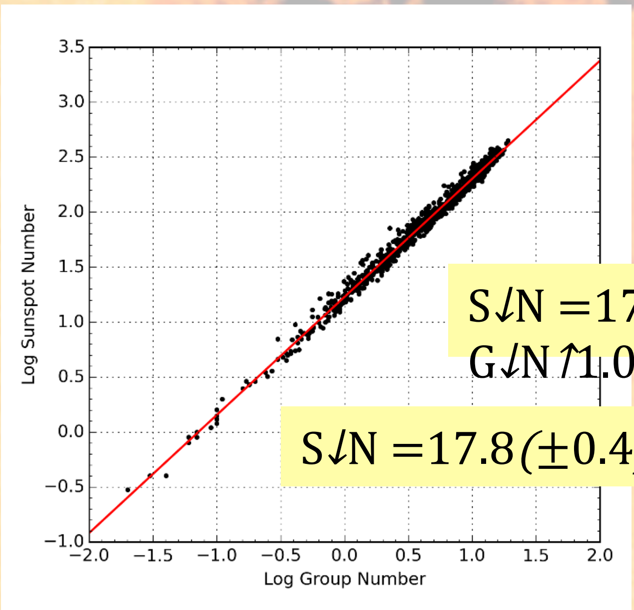
A non-linear SN-GN relation

A sunspot deficit in recent solar cycles?

- **Reconstruction of SN and GN from the same base set of stations** over 1945-2045 *(Clette & Lefèvre 2016)*:
  - Cycle modulation in the ratio
  - Trend in the ratio follows the maxima of successive cycles *(cf. Tlatov 2012, Clette, Lefèvre 2012, Svalgaard 2013, Clette et al. 2014)*

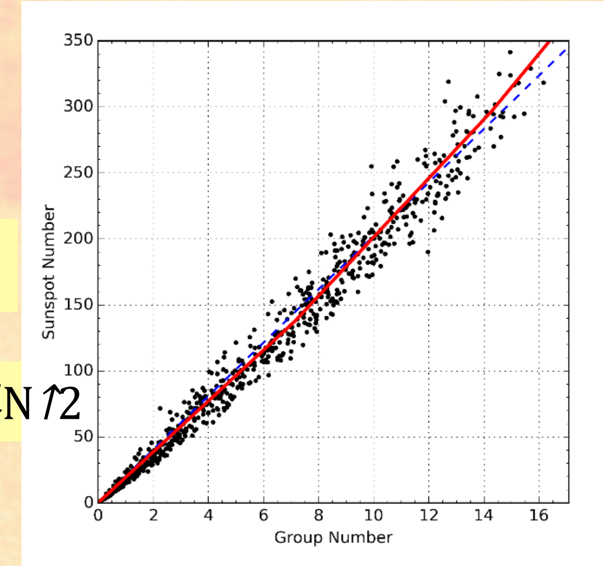


⇨ **Constant non-linear relation:**

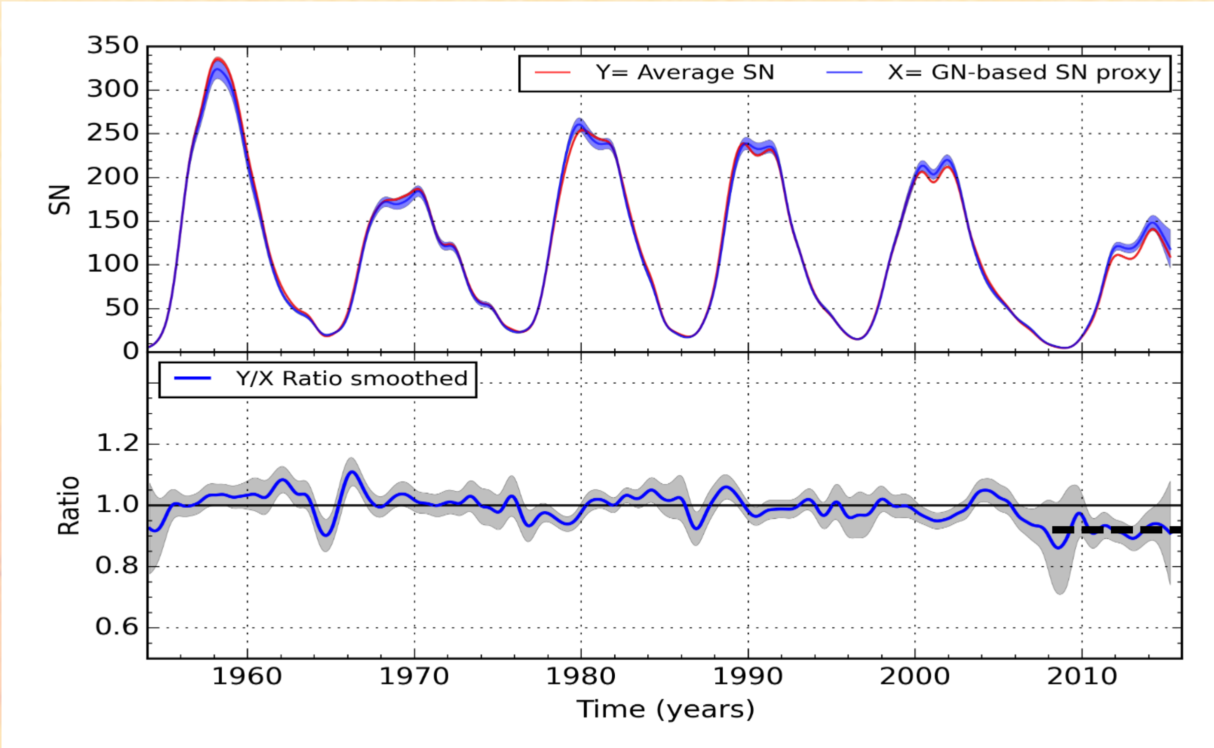


$$S_N = 17.11(\pm 0.13)\, G_N^{1.07(\pm 0.010)}$$

$$S_N = 17.8(\pm 0.4)\, G_N + 0{,}21\ (\pm 0.03)\, G_N^{2}$$



A sunspot deficit in recent solar cycles?



- GN-based proxy of the SN :
  - No more cycle modulation: constant ratio over 1945 - 2008

⇨ The average number of spots per group obeys a constant relation
  - The recent spot deficit is a natural consequence of the activity decline

⇨ 10% deficit only starts in cycle 24 *(deficit of large groups? Kilcik et al. 2015)*

SN/GN residuals

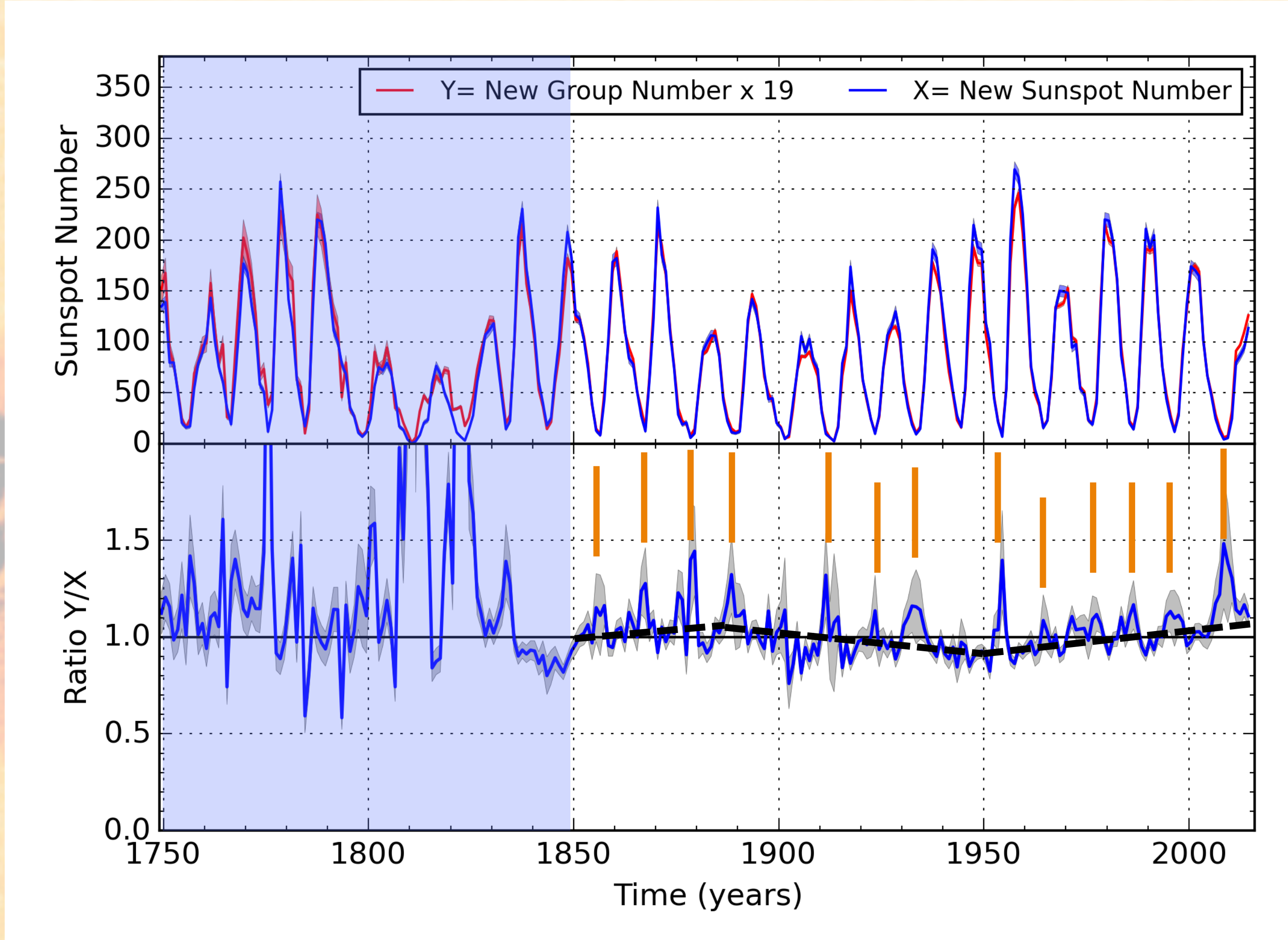
New SN compared to the backbone GN *(Svalgaard & Schatten 2015)*

Non-random residuals:

- solar cycle modulation
- cycle trend

Detailed solar relation between SN and GN emerge after corrections

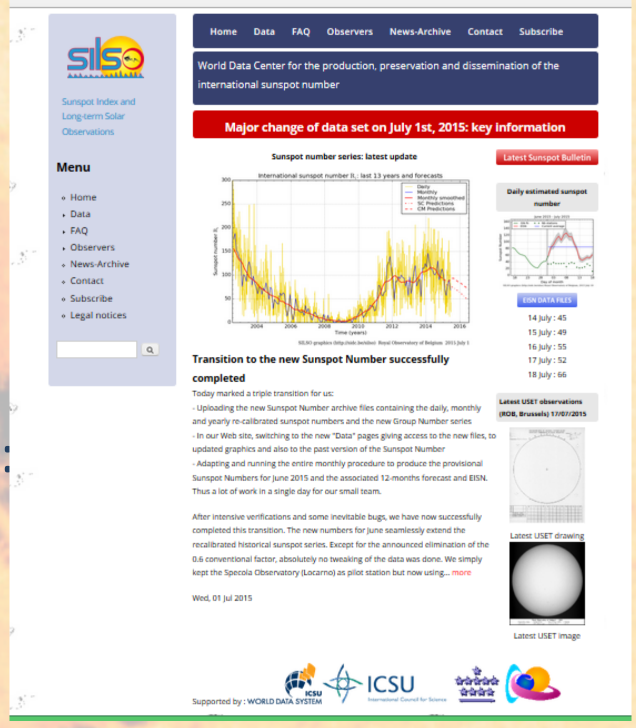
SN-GN comparisons must take into account this non-linear relation



Official release and next steps

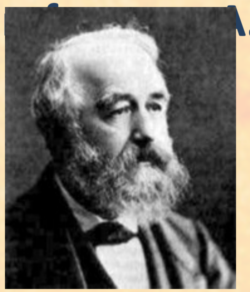
New series and conventions (Version 2.0)

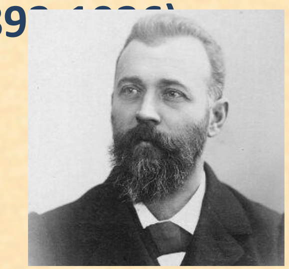
- **Operational transition to the new SN:**
  July 1st, 2015
  - **New SILSO Web site** (since early 2014)
  - Adaptation of entire software for all SILSO products: hemispheric numbers, daily estimated SN (EISN), 12-month predictions

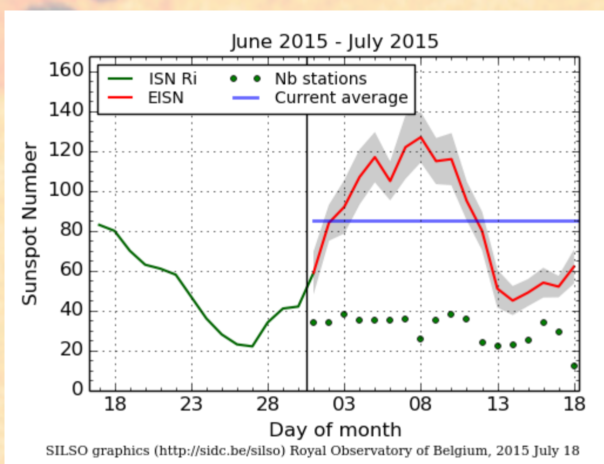


- **Unchanged base method for the total SN** but:
  - Pilot station: **Specola-Locarno un-weighted counts** (original Wolf formula)
  - **Agreement within 4% (monthly means)**
- **New symbol: S_N**
- **Determination of uncertainties**
- **New scale convention: Zürich factor 0.6 set to 1.0**
  - **New** … **A. Wolfer (189**

POSTER LON 6
Lefèvre et al.







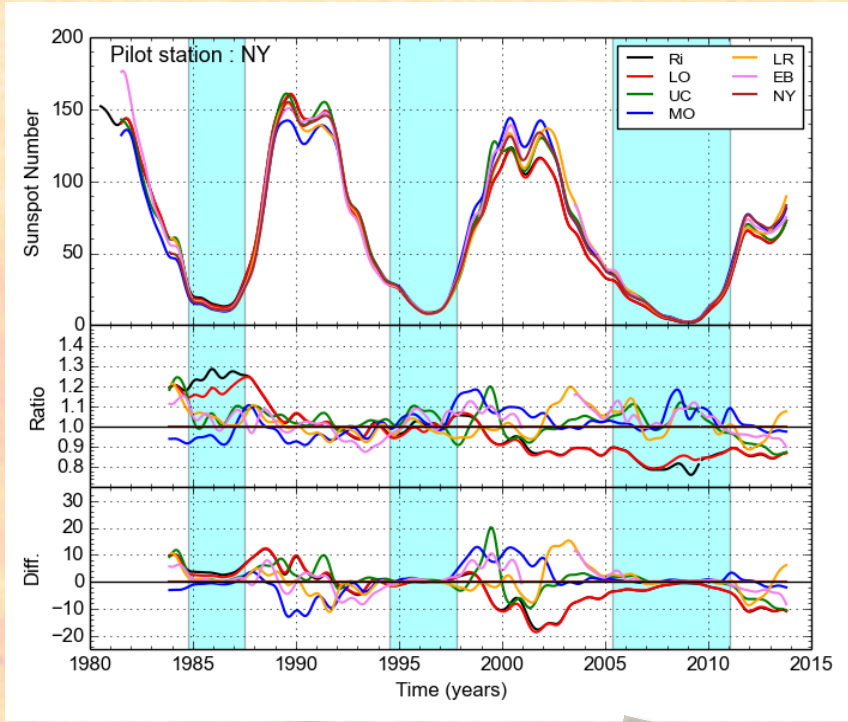
Next goals for sunspot number V3.0

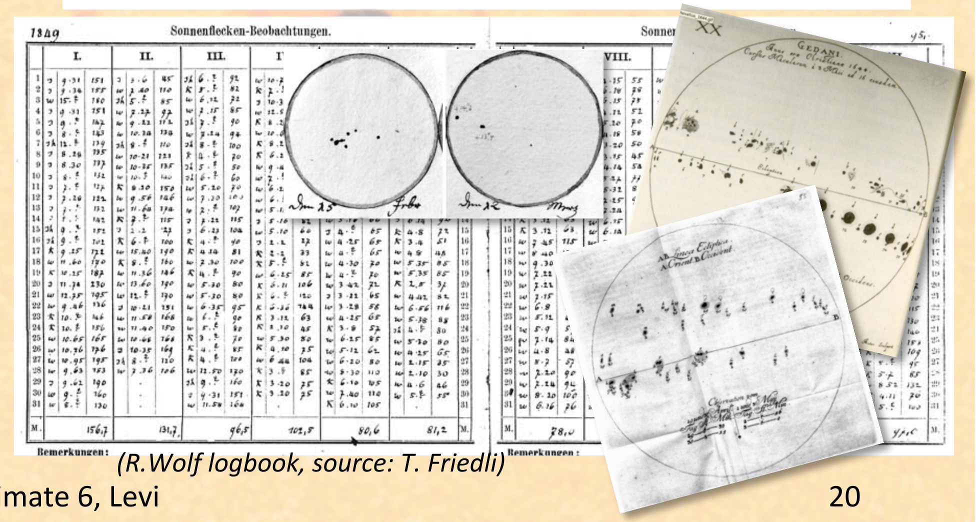
- **New method** for the operational SN production:
  - **Multi-station reference** (instead of single pilot station)
  - **Advanced statistical methods** (Bayesian & non-linear regressions, multiscale decomposition, PCA)

⇨ Full re-calculation of the SN since 1981

- **Archive of original observations**:
  - Zürich original logbooks
  - All auxiliary stations and observers used by Zürich
  - Additional observers

⇨ Full reconstruction from raw data with modern tools and knowledge (1700 – 1980)





(R.Wolf logbook, source: T. Friedli)

A vigorous immediate response

A recent wave of new results: SN

Reference	Topic	Pros	Cons
Leussu et al. 2013	1849 Schwabe Wolf transition	• Use of original Schwabe documents • True 20% jump in 1849	• Conclusions extrapolated outside the limited 1826-1868 data interval • Early Schwabe drift not taken into account
Lockwood et al. 2014	1947 Waldemeier jump	• Unbiased statistical estimator for jump factor • Use of multiple indices (RGO GN, spot area)	• Use of uncorrected original SN and GN • Influence of time windows ignored • Inclusion of the Leussu et al. 2013 20% correction
Lockwood et al. 2016	1947 Waldmeier jump	• Use of an external comparison (FoF2 ionospheric index)	• Only 15 years before 1947 transition • Homogeneity of early data is uncertain
Friedli 2016	Reconstruction of the Zurich SN series (1849-1981)	• Direct exploitation of original documents (Wolf)	• Only single standard Zurich observer • Assumed stability not verified

- Interesting ideas but new mistakes
- 2 new SN series proposed

A recent wave of new results: GN

Reference	Topic	Pros	Cons
Svalgaard & Schatten 2015	GN 1610 - 2015	• Daisy-chaining replaced by 5 primary "backbone" observers • Different group-splitting practices taken into account	• K factors by simple linear regressions • Yearly means • Staudacher k factor applied to 1610-1749 • 7% Zurich classification effect not proven
Lockwood et al. 2016	Biases in the determination of k factors	• Effects of non-proportionality and non-linearity on linear regression	• Simulation based on photographic data (RGO) • Only considers the acuity to detect small groups
Usoskin et al. 2016	GN 1749 - 1899 New active-days method	• Innovative approach • No need for k coefficients • Can bridge data gaps	• Calibration on simulated data (RGO catalogue) • Only considers the acuity to detect small groups • Wolf-Wolfer comparison: unexplained non-linearity
Cliver & Ling 2016	GN 1830 - 1995	• Reconstruction of original Hoyt & Schatten method • Diagnostic of 1884-1915 bias factor	• Same daisy-chaining as the original GN • K factors by linear regression

- 3 new GN series proposed

A recent wave of new results: Maunder Minimum

Reference	Topic	Pros	Cons
Zolotova & Ponyavin 2015	Maunder Minimum: underestimated activity	• Reference to historical documents • Hypothesis: selective record of planetary transits	• Over-generalisation from limited evidence • Only considers sunspot records • Maximum daily number leads to overestimate
Usoskin et al. 2015	Maunder Minimum	• Multiple solar activity records • Use of revised GN database *(Vaquero et al. 2015)*	• Limited accuracy of indirect proxies

- Interesting ideas but new mistakes

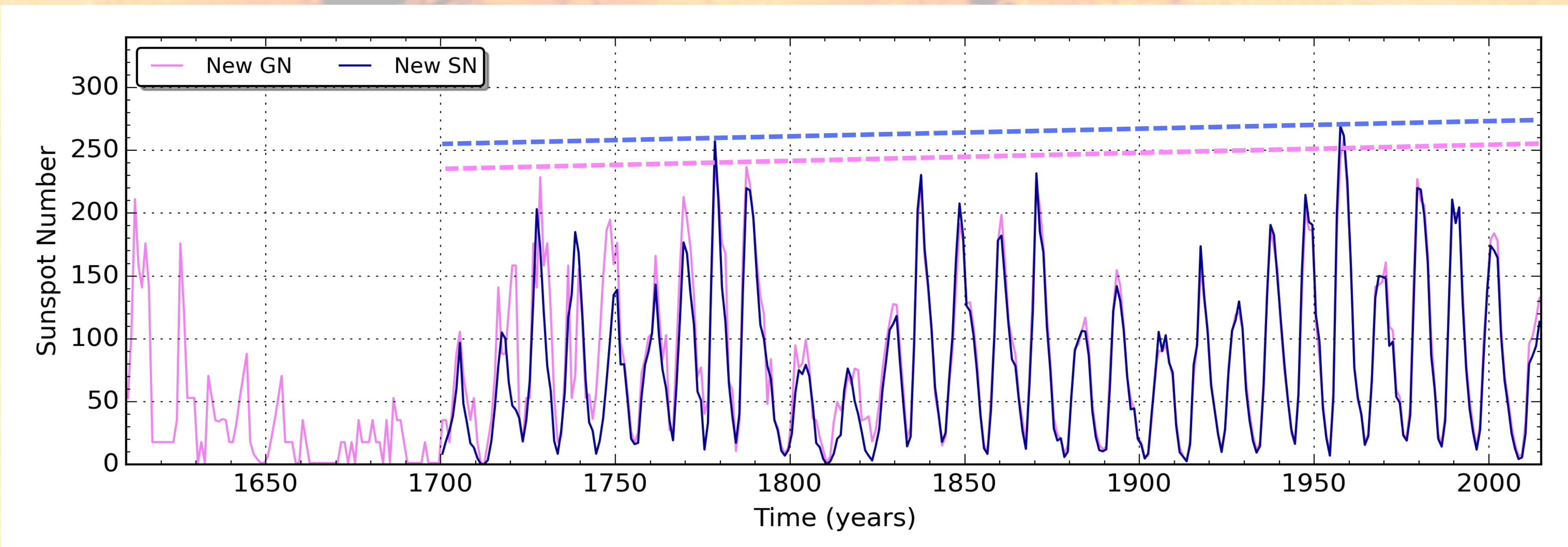
- Interesting approaches: inspiration for the SN
  - K coefficients: total regression, Bayesian estimators
  - No time averaging (individual observations)
  - Active-days method
- GN results not directly applicable to Wolf numbers:
  - different statistics for group and spot contributions
- **GN database: extended and critically revised** *(Vaquero et al. 2015, 2016)*

⇨ **An important foundation for all reconstructions**

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**



Lessons learned (1)

- **Hasty production of new end-to-end series**:
  - – Precipitation prevents proper deep verification:
    - Papers criticized before their actual publication (ArXiv citations)
  - – Methods not mature (full validation takes time!)
  - – Valid hypotheses unduly generalized outside the tested domain
  - – Advances from other teams are ignored   > errors are repeated

  ⇨ **Publish new useful tools rather than questionable alternate series**

⇨ **Slows down progress:** Echternach procession!

- **Proliferation of new « tentative » series**:

  ⇨ **Spreads confusion among users !**

Lessons learned (2)

- **New series immediately attacked as a risky manipulation** due to:
  - Use of k coefficients
  - Use of temporal means
  - Daisy-chaining of observers
  - Lack of verification
  - Insufficient documentation
  - Opaque production

  - **Least square regression**
  - **In some studies**
  - **Alternate approaches**
  - **Multiple cross-comparisons**
  - **Papers, SILSO Web site**
  - **Since 2012, 9 papers (3P, 1RV, 5P in press) Sol. Phys. Topical Issue (32 papers)**

- **Original series defended as more trustworthy,** in spite of:
  - Use of k coefficients
  - Use of temporal means
  - Daisy-chaining of observers
  - Lack of verification
  - Insufficient documentation
  - Opaque production

  - **Crude ratio of temporal means**
  - **Systematic (yearly)**
  - **Full daisy-chaining**
  - **Faulty RGO data, SN never revised**
  - **Methods largely undocumented**
  - **Internal production of the WDC**

To live in peace, live hidden

Steering a transition

A profound transition

Fixed unquestioned relic → **Modern evolving data set**

Formerly (Zurich, SIDC)

Repository + mechanical extension of the heritage series (frozen method)

Now (WDC –SILSO)

Clearinghouse for all new published results (whole series)

- Evaluation of methods, data validation, implementation
- Upgrade of the production method to follow progresses

Version tracking

- Since July 2015, implementation of a **versioning scheme Va.b**:
  - Main number **a**: major modification, large section of the series
  - Sub-version **b**: punctual corrections, secondary changes (e.g. error estimates, file format)
  - Included in all filenames
- **Full incremental documentation**:
  - File description, metadata
  - References and links to publications
- **Archive of past versions**:
  - Marked as deprecated
  - For reference, to compare with past publications

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Sunspot Index and Long-term Solar Observations

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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://ssnworkshop.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 [1/1749 - 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 [1/1992 - 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

Scientific supervision

- **Advisory committee for the World Data Center SILSO**:

More collaboration !

- Share the new idea before promoting a new series
- Accept to be only **partly** right !
- Be open to good points made by others

Internal strife undermines the credibility of all results

Our needs:

- **Clear priorities on which to focus future work**
- **Viable scheme for validating and merging results**

Stay tuned ….

World Data Center – SILSO

Sunspot Index and Long-term Solar Observations

http://sidc.be/silso