Assembling all corrections preview and specification

Frédéric Clette

SILSO: World Data Center – Sunspot Index

Royal Observatory of Belgium

Objectives of the discussion

- **Preview the combined effect of corrections**: simulation !
  - Original SN and GN series multiplied by correction factors
  - Schematic corrections: start/end dates, ratio (constant or linear ramp)
- Period : 1800 – present
  - Last 200 years = essential part, as calibration is propagated backward in time
  - Most mature: *18th century « backbone » still in progress*

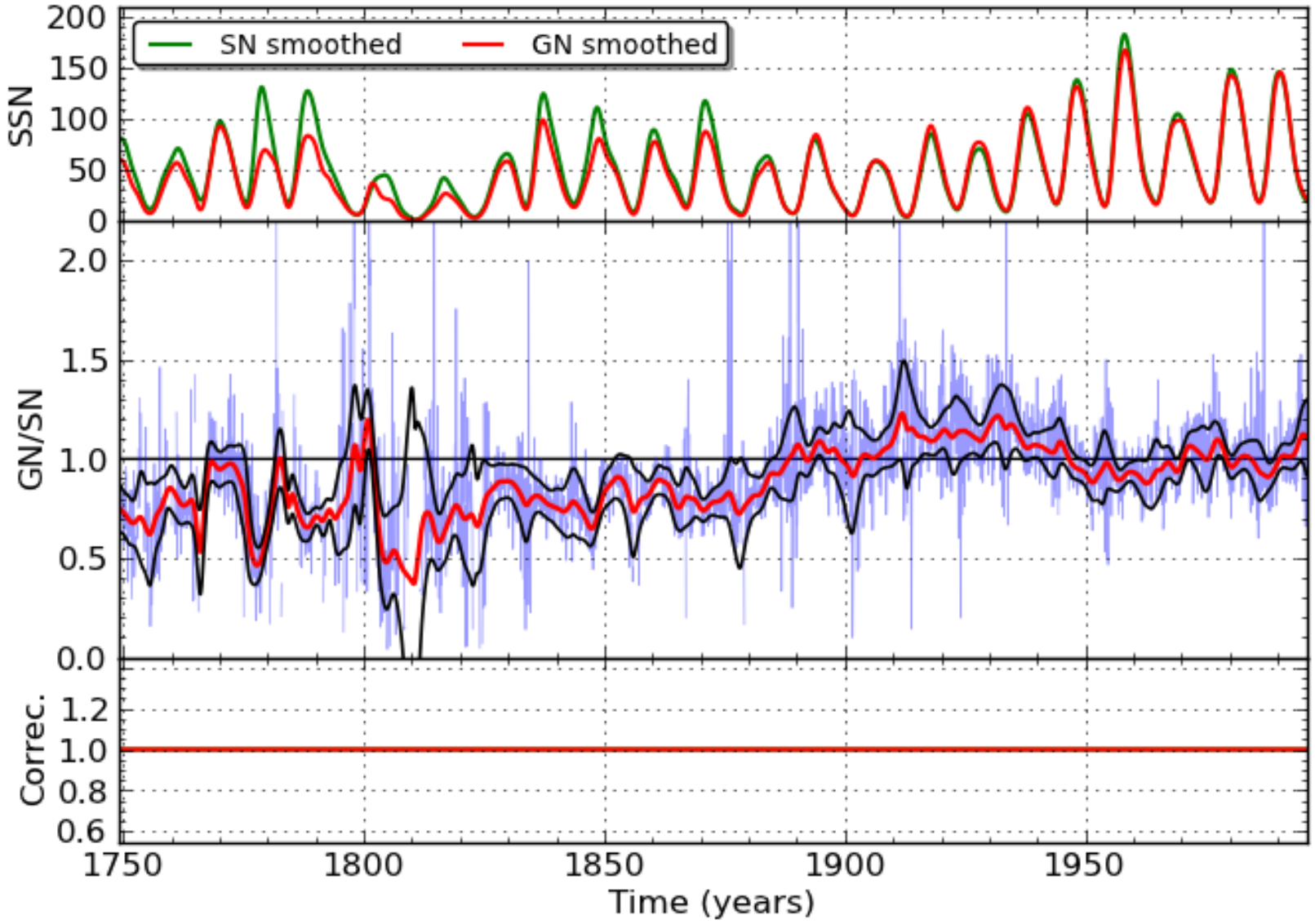
- Current status:
  - Multiple corrections established separately
  - Estimates of a correction value and rough time intervals (« about »)

- What we need for publishing a revised SN series:
  - Final value of each correction, with a confidence interval (error bars)
  - Precise transitions
  - Combining corrections
  - Verifying the compatibility between corrections

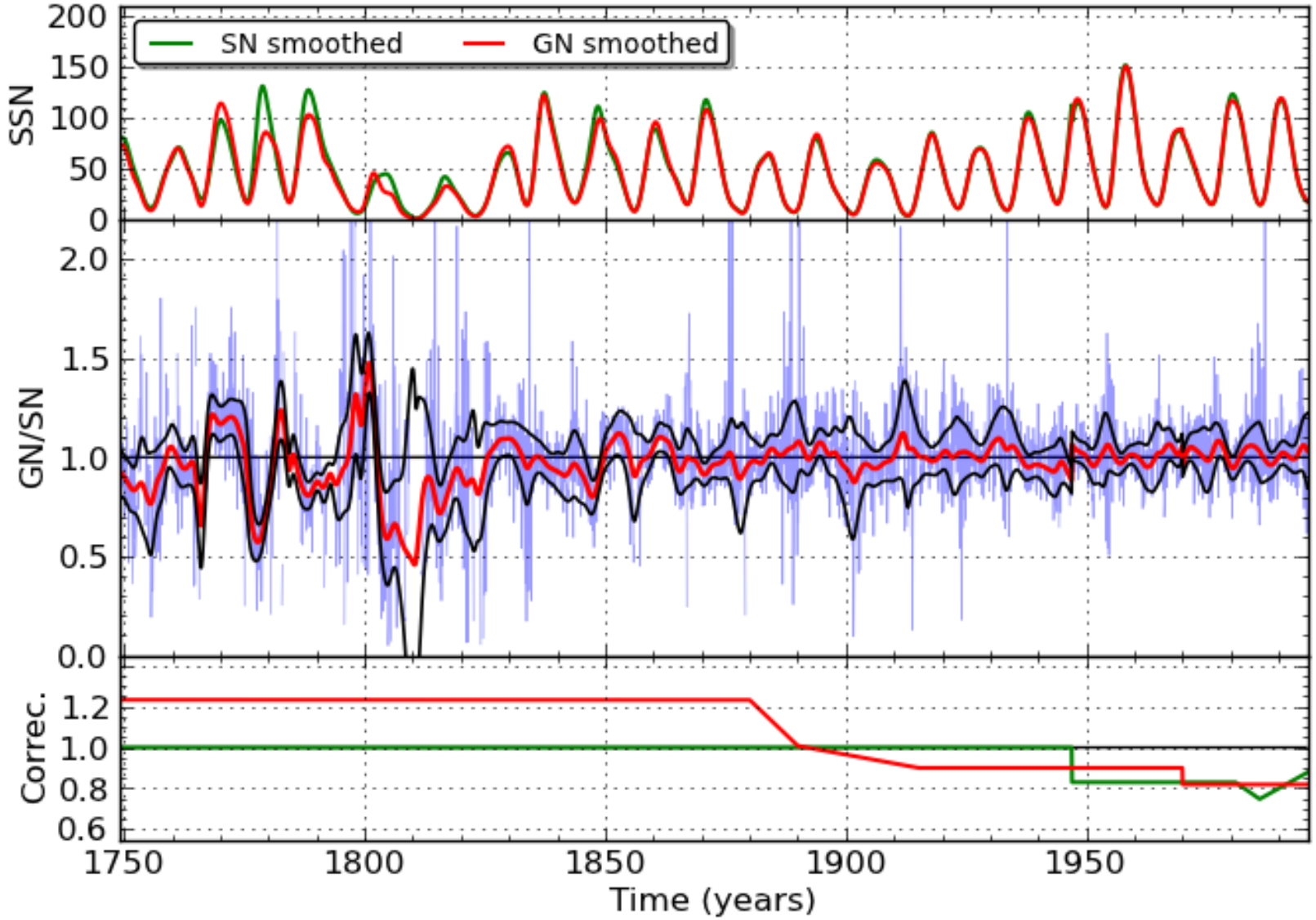
Questions to be answered

- *Which corrections must be and not be included?*
- *Refining the time of corrections*
  - Exact start & end times
  - Step transition or progressive ramp ? Profile of the ramp? (linear, …)
- *Refining the amplitude of corrections:*
  - *What is the precision? +/- standard error*
  - *What is the accuracy? Acceptable range? Criterions for the upper/lower limits?*
- *Time resolution of correction: daily, monthly, yearly?*
- *Are corrections mutually compatible or contradictory?*
- *Remaining drifts and biases? Missing corrections?*

Starting point: the original SN & GN series

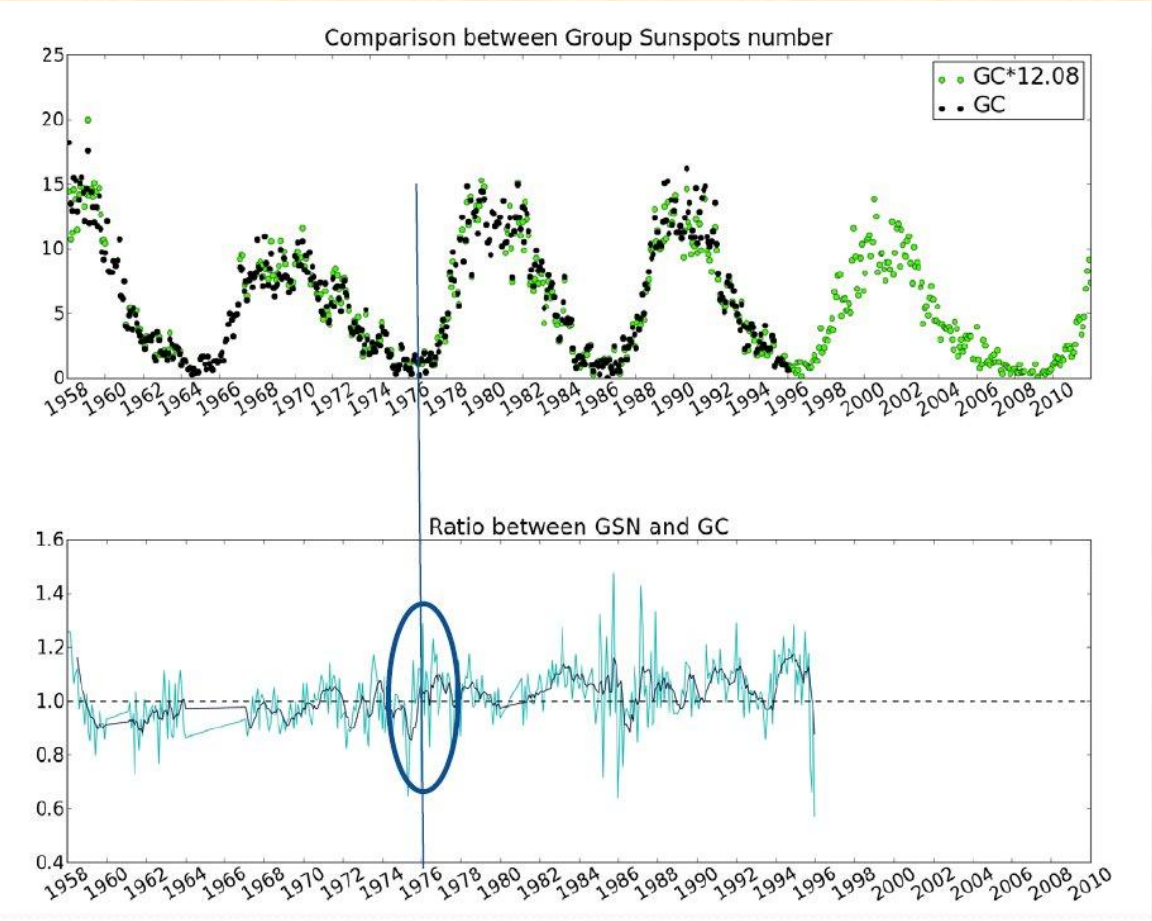


All corrections



Reconstructed Group Number: 1975 jump

- Reconstruction and extension of the Group Number R_G up to 2012 (WDC – SILSO database):
  - Good overall match with original R_G
  - New R_G calculated from the same data set as R_i
- Comparison with original H&S R_G:
  - Ratio near 1.0
  - Jump around 1975 (transition from RGO to SOON data)
- **R_G scale increased by ~10% after 1975**

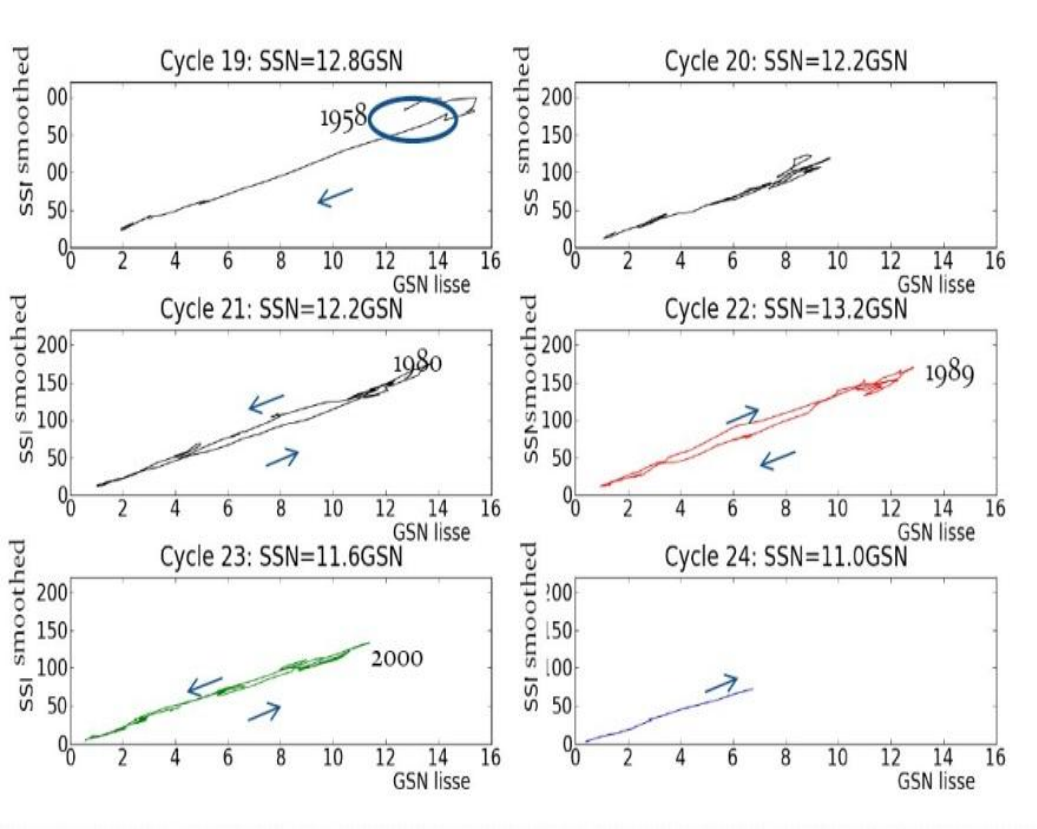


Wauters & Clette, SSN Workshop 2013

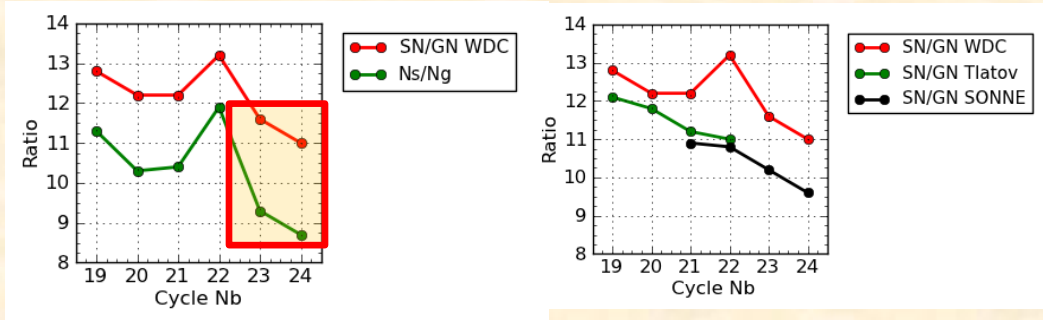
Cycle 23 anomalies: impact on the R_i / R_g ratio

- Changing R_i/R_G ratio:
  - Stable over cycles 19 to 22
  - Decline in cycle 23 and early part of cycle 24

⇨ Decrease of the average number of spots per group by ~30%



Cycle	Ns/Ng	North	South	R_i/R_G	North	South
19	11.3			12.8		
20	10.3			12.2		
21	10.4			12.2		
22	11.9	12.5	10.7	13.2	13.5	12.5
23	*9.3*	*9.5*	*8.7*	*11.6*	*11.5*	*11.9*
24	*8.5*	*8.7*	*6.4*	*11.0*	*11.2*	*10.3*



About error bars and uncertainties

An important distinction:

- **Precision** (standard deviation, standard error):
  - Random dispersion of observations (noise)
  - Established statistically
  - **Requires multiple simultaneous observations**
    (« modern » part of the SN)

- **Accuracy**: (systematic errors, confidence interval)
  - Absolute scale of the measured quantity.
  - Based only on the knowledge of intrinsic factors of the measuring process
  - « Model » of the instrument and measuring process:
    - Combination of the influence of each instrumental factor established separately (physical model, laboratory tests, **statistical regression study**, etc.)

About error bars and uncertainties

- Which factors ?:
  - Human factors: vision *(aging)*, subjective choices (small spots, *group splitting*)
  - Observing conditions: ***telescope (aperture, magnification)***, seeing effects, projection (drawing) versus eyepiece image
  - Processing method and rules: **umbral splitting**, **sunspot weighting**, **k personal coefficients**

- The main accuracy factors are associated with the processing method (applied systematically to all observations)
- Most other factors lead to random noise (precision) as observations are done by independant uncorrelated observers, except for:
  - Smaller cruder telescopes (aperture <50-70mm), mainly before the 19th century
  - Change in group splitting practices (evolution of scientific knowledge)
  - Personal aging and telescope change *when a single observer defines the global scale of the SN* (mainly before the 19th century).

The 1880 RGO transition (GN)

- Size of correction:
- Transition:
  - Progressive ramp
  - Start time:
  - End time:
  - Correction profile vs time

- Correction function?
- Replacement by the backbone reconstruction?
  - Only yearly values?
  - Monthly values or interpolation?
  - Daily values
- Contribution of: L.Svalgaard, D.Hathaway + J.Vaquero ?

The Waldmeier 1947 transition (SN)

- Size of correction: function of SN , 1.1 to 1.3, avg. 1.2
- Transition:
  - Progressive ramp or sharp jump ? Sharp jump !
  - Start time: (near time of cycle 17-18 minimum): 1947, Jan. 1st
  - Correction profile vs time (function of SN): no, constant correction

- Correction factor?
  - Decreasing all values after the transition
  - Monthly values or interpolation?
  - Daily values
- Contribution of: L. Svalgaard, D.Hathaway

The RGO-SOON 1976 transition (GN)

- Size of correction: ~9%
- Transition:
  - Sharp jump
  - Time: Dec 31, 1976 ? (cf. Hoyt & Schatten)

- To do: calculation of a GN from SILSO data
  - Determination of scale factor over 1976-1998
  - Replacement of H&S values by new GN values after 1976
  - Daily, monthly, yearly values
- Contribution of: F. Clette

The Specola drifts 1980-2014 (SN)

- Size of correction: multi-station average k over 1980-2014
- Transition:
  - Continuous variation (average k)
  - Start time: 1981
- Full recalculation of SN number with a new/corrected reference
  - Daily, monthly, yearly values
- Contribution of: F. Clette

The Specola drifts 1980-2014 (SN)

- Open questions:
  - Single station (Locarno, other) or multi-station reference ?
  - What is the optimal number of stations?
    - Many: more difficult to keep track of events at each stations
    - Few: limited statistical validation
  - How to combine stations?
    - Average of raw numbers without k scaling (implies stations with very similar k)
    - Maintenance of a restricted k coefficient system within the core group
  - Only professional observatories or also dedicated amateurs?
  - Should we avoid stations contributing also to the AAVSO network ?

More corrections

- Cycle 10 correction (GN and SN)
  - Valid correction (no full agreement with diurnal geomag. index)
  - Size of the correction: 1.25
  - Time interval Min to min
  - GN replaced by reconstructed GN?
  - Daily & monthly values? SN correction?
  - Contribution from: L.Svalgaard, R. Arlt

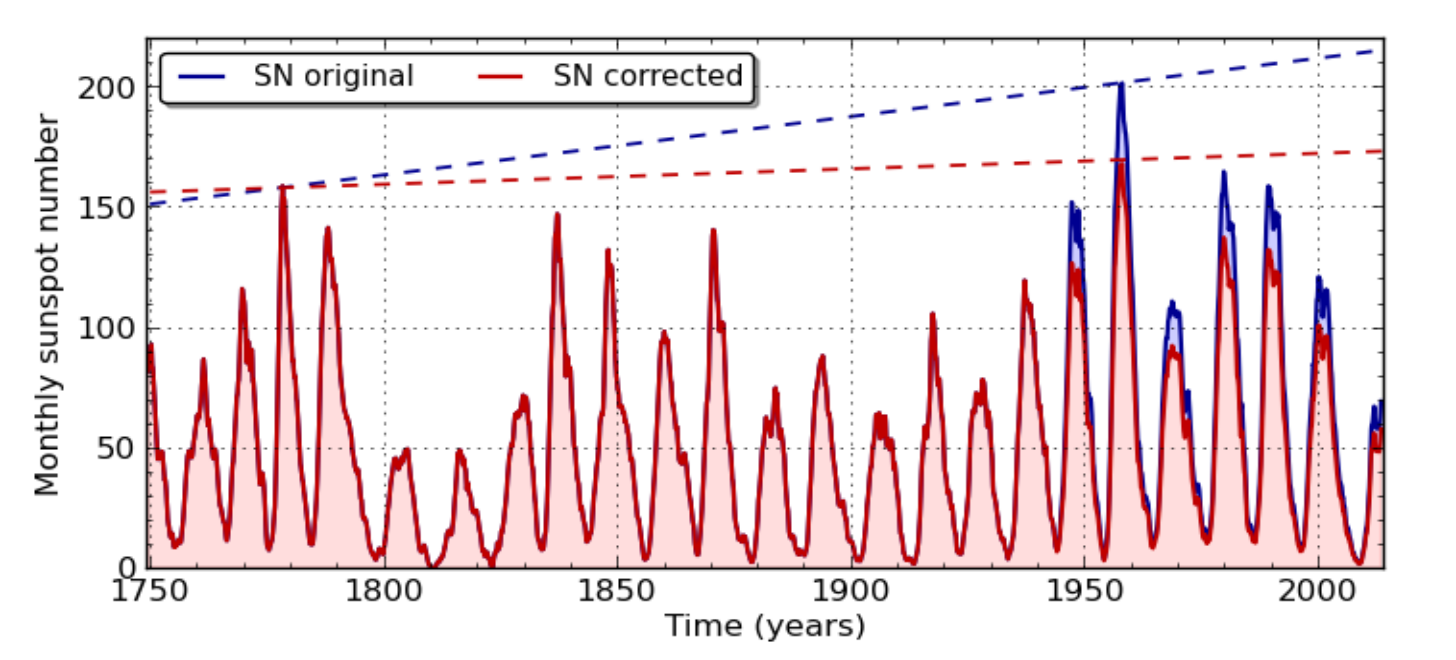
- Schwabe-Wolf transition (20%, SN)
  - No correction needed: due to misinterpretation of early Schwabe data.
  - Contribution from, L.Svalgaard, R. Arlt

- Cycle 5 correction (GN) ?
  - Better agreement between reconstructed GN and original SN
  - Correction by Wolfer needs to be verified
  - Large uncertainties: no correction of the SN is considered at this stage
  - Contribution from: L.Svalgaard (+ J.Vaquero, E.Cliver, R.Arlt)

Effect on long-term trends: SN series

- Most fundamental consequence:

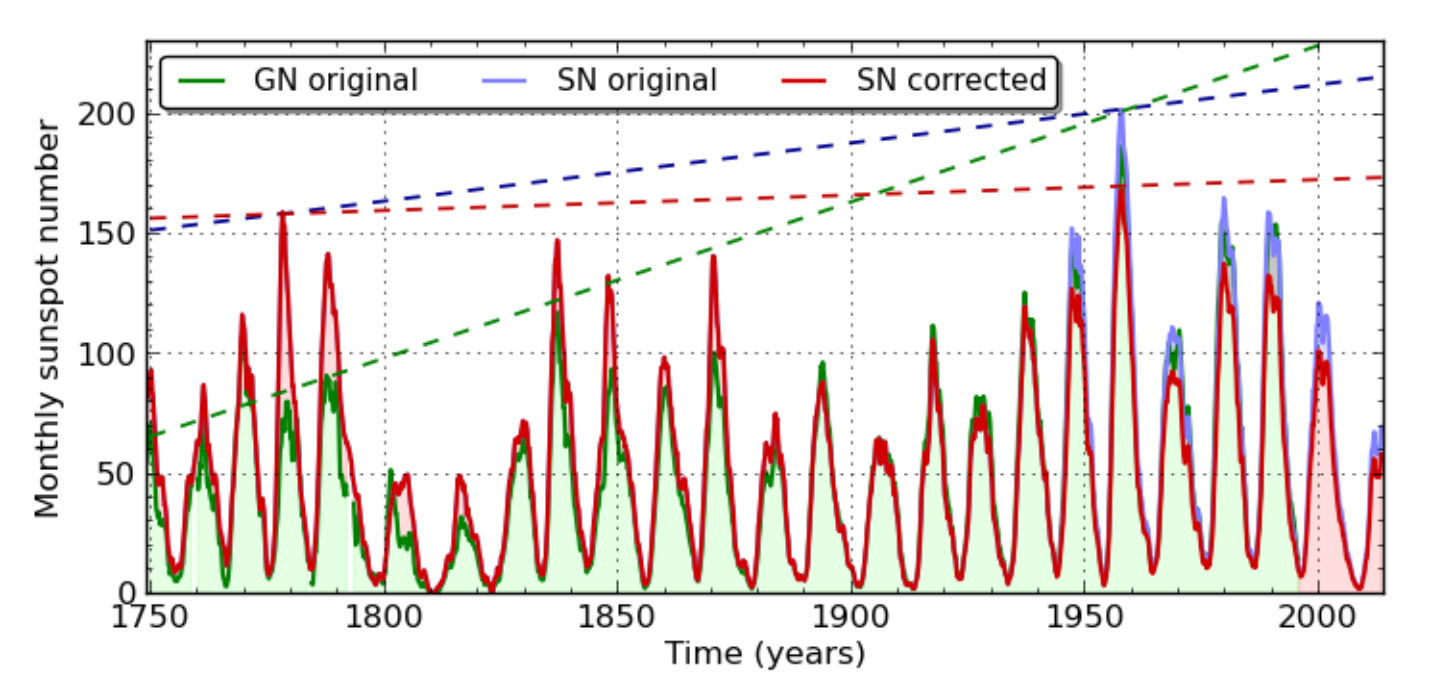
  The rising trend in solar cycle maxima since the Maunder minimum almost vanishes.



- SN: Waldmeier weighting correction

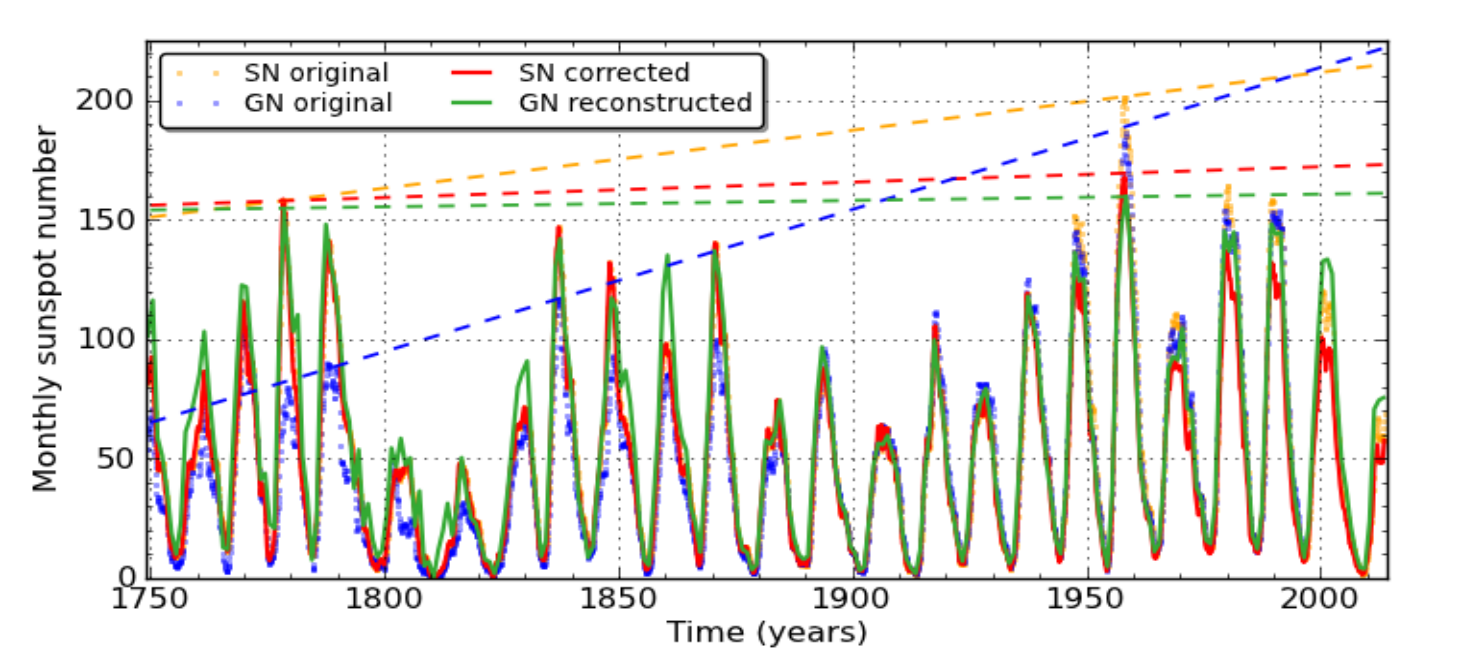
Effect on long-term trends: SN & GN series

- Group Number: large trend



Effect on long-term trends: reconstructed GN series

- Group Number : backbone reconstruction
  - Upward trend almost vanishes

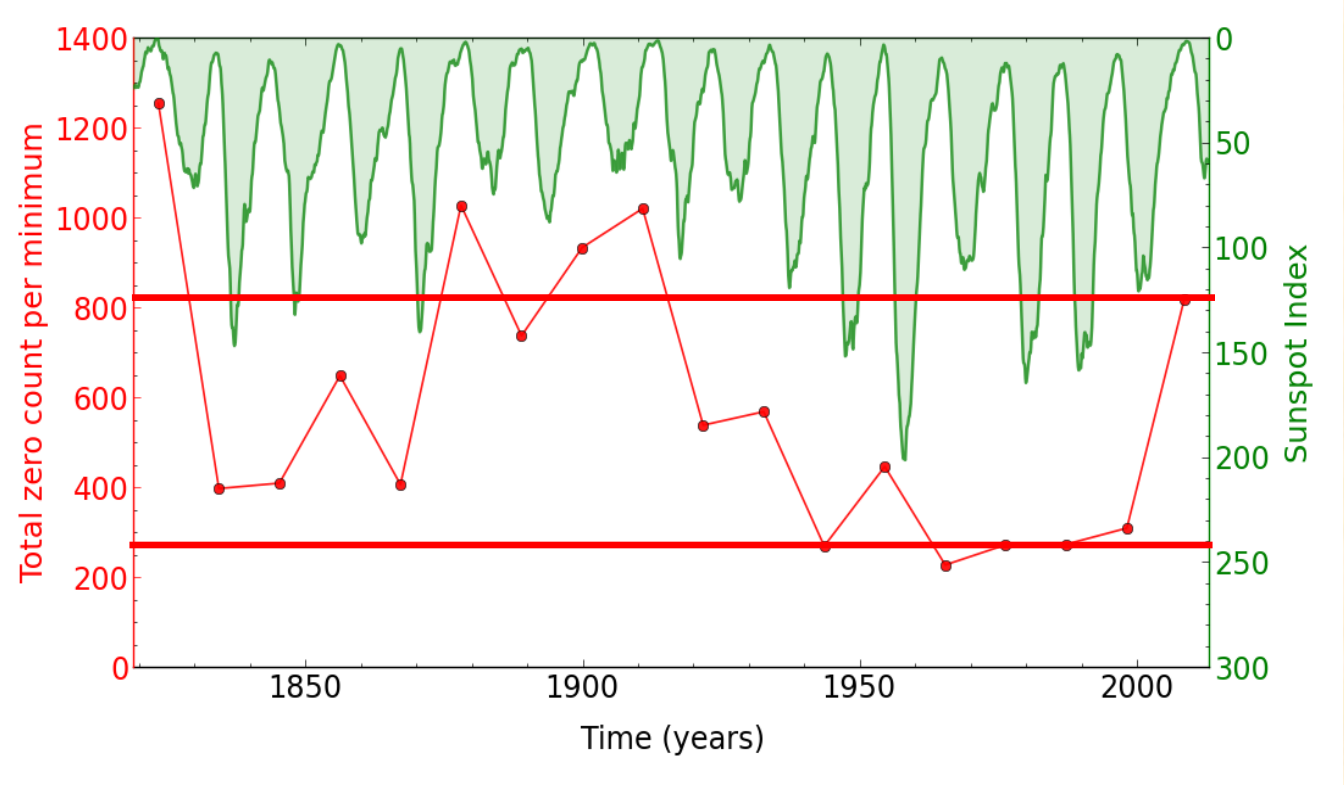


- Implies a fast recovery after the Maunder Minimum

But late 20th century may still be a peculiar episode

An alternate indicator: number of spotless days

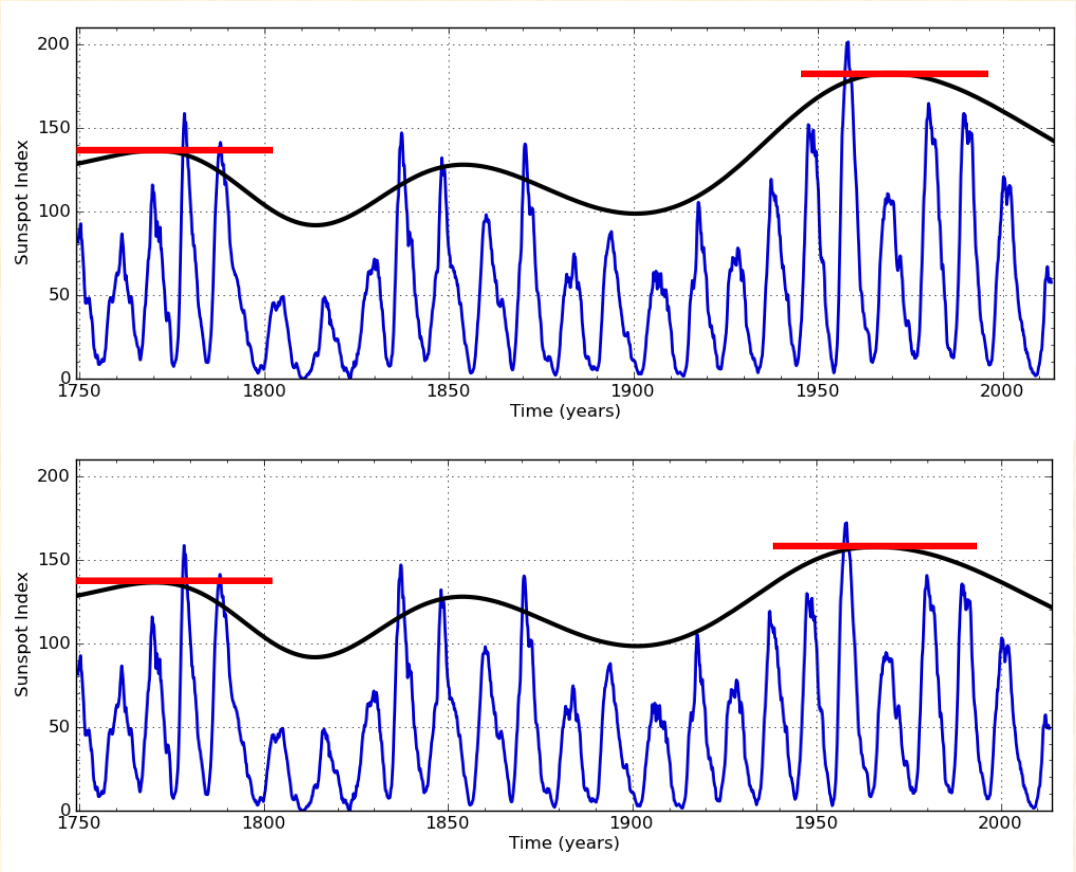
- Strong anti-correlation with the cycle amplitude
- Cycle 23-24 minimum (~800 days): Similar to cycles 12 to 15



- Dalton minimum (1798- 1822) :Spotless days count > 1200
- Last six minima: lowest spotless day counts ! (~250 days)

Long-term integration: a moderate Modern Maximum

- Time-integrated responses to the solar input:
  - Cosmogenic isotopes: deposition processes (ice, sediments)
  - Earth climate: thermal inertia of oceans
- Gaussian Running mean over 22 years (2 solar cycles):



Original series

Ratio Max cycles 3-19 = 1.27

Ratio 22-yr envelope = 1.30

Corrected series

Ratio Max cycles 3-19 = 1.08

Ratio 22-yr envelope = 1.17

→ The clustering of high solar cycles reduces the time-integrated effects of the corrections by 50%