



Sunspot number, group number and F_{10.7} : new insights

Frédéric Clette, Laure Lefèvre, Shreya Bhattacharya

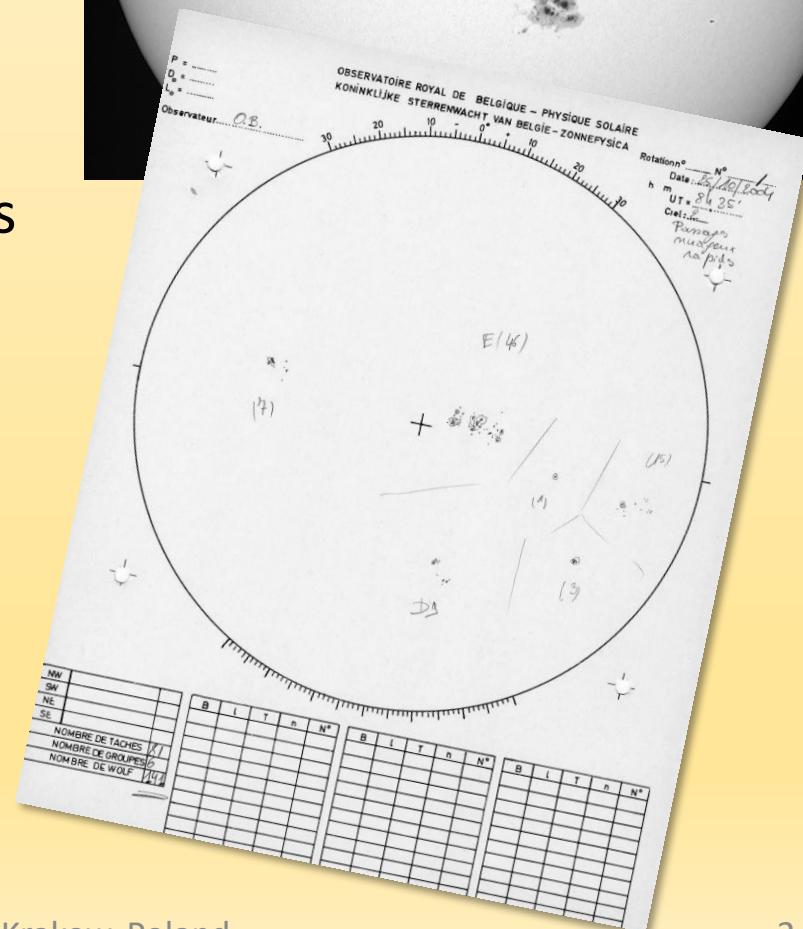
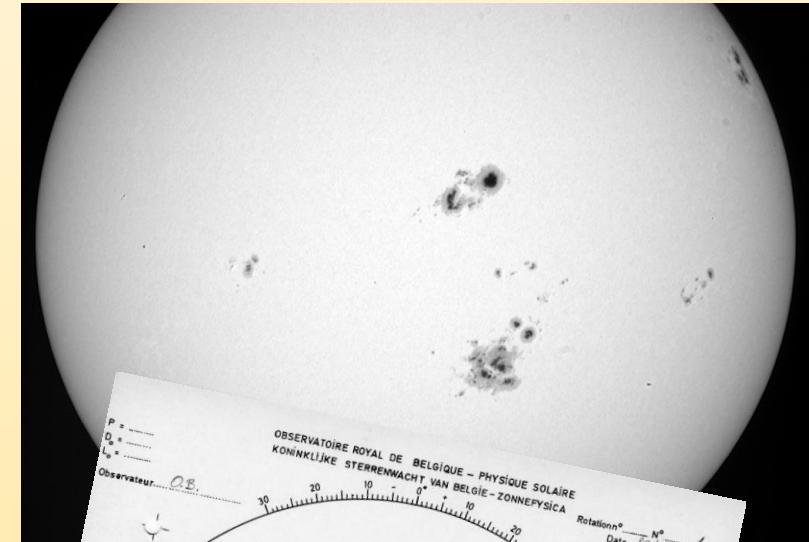
World Data Center SILSO

Royal Observatory of Belgium, Brussels



Outline

- Sunspot and Group number:
the differences
 - Sunspot number recalibration
 - Group number reconstructions
 - Benchmarks and proxies
 - A byproduct:
revisiting the $F_{10.7}$ index
 - Conclusions



Introduction: two sunspot number time series

Sunspot Number

$$S_N = 10 \text{ Ng} + \text{Ns}$$

- Origin: R. Wolf (1849)
- Start: 1700 (end of Maunder minimum)
- Continuous production to present



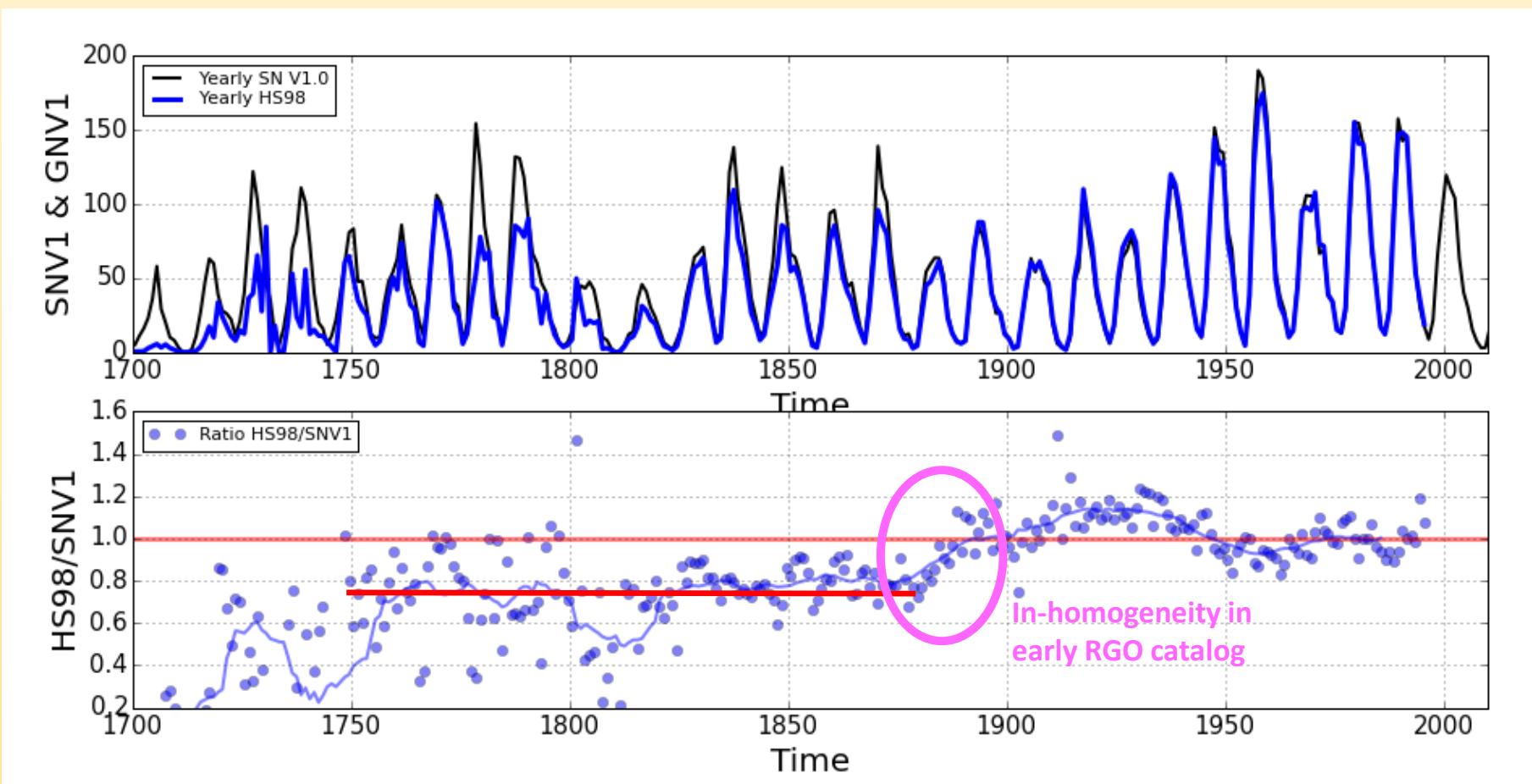
- Production in 3 parts:
 - **1700-1849**: reconstruction from historical documents
 - **1849-1980**: Zurich Observatory
 - **1981-now**: World Data Center SILSO, Brussels
- Calibration:
 - **Pilot station: Zurich Observatory**
 - Successive primary observers
 - Specola Observatory Locarno (since 1981)
 - Standard telescope, trained observers

Sunspot group number

$$G_N = 20.13 \text{ Ng}$$

- Origin: Hoyt and Schatten (1998)
- Start: 1610 (telescope)
- End: 1995 (paper publication)
- Production:
 - Single recent reconstruction
 - Based on an **extended set of raw historical data**
- Calibration:
 - “Daisy-chaining” of observers backwards in time
 - Starting reference: **Royal Greenwich Observatory photographic catalog (1875-1975)**

SN introduction: a primordial disagreement



- Very good match after 1900
- Large disagreement before the 20th century: G_N lower than S_N by up to 40%

Recalibration effort

- Community effort started in Sept. 2011
- **4 Sunspot Number Workshops**
 - Renewed interest for the S_N
 - Several new reconstructions

Synthesis in:

- **Solar Physics:** Topical Issue « Recalibration of the Sunspot Number», **Volume 291 9-10, 2016**, Eds. Clette, Cliver, Lefèvre, Vaquero, Svalgaard, **35 articles**

• ISSI Team 2018-2022:

(www.issibern.ch/teams/sunspotnoser/)

- Work on new SN version (V3)
- Steps to a continuous “update – QC – vetting” process (IAU framework)
- **Focused topical collaborations**

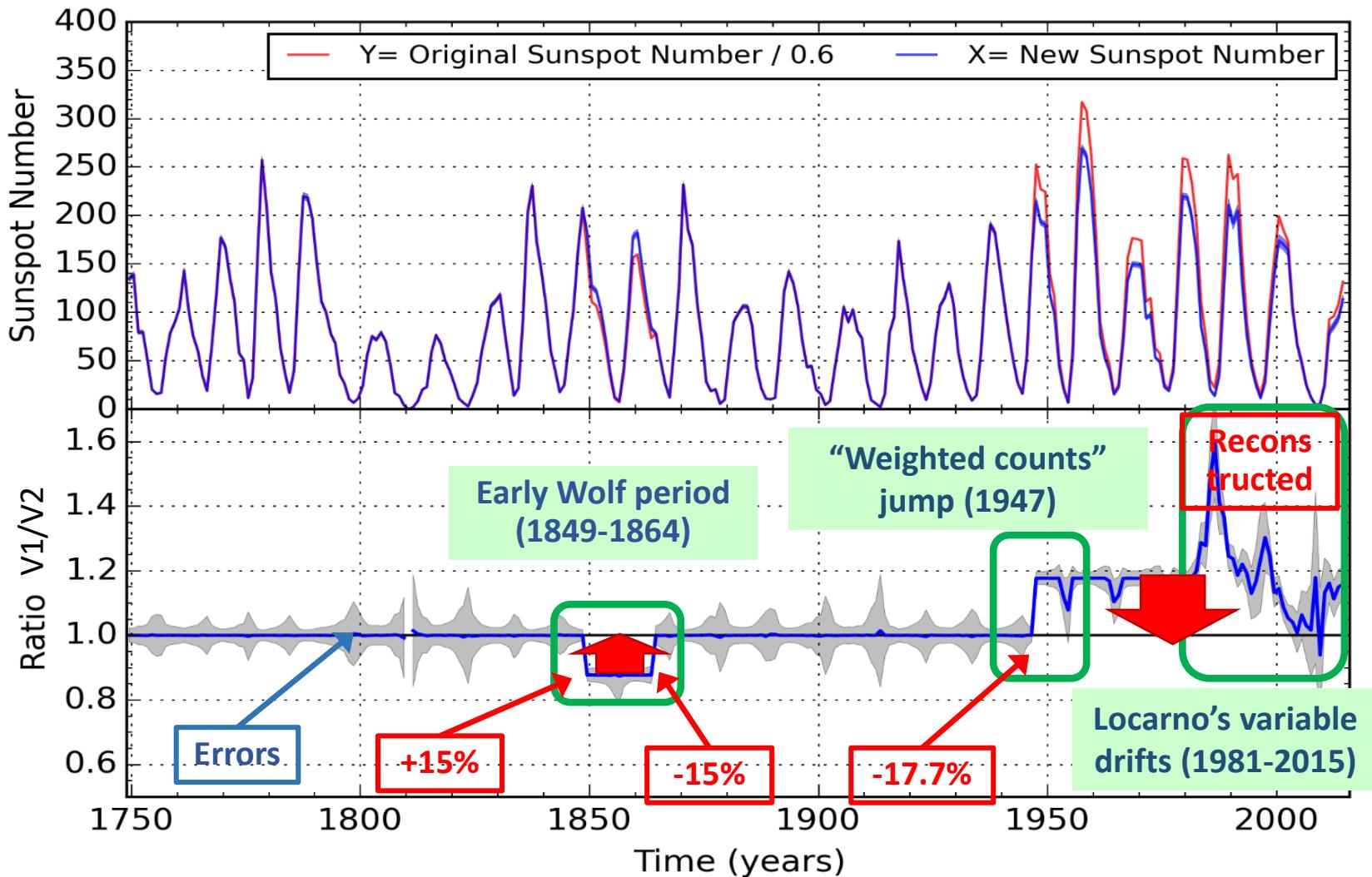


NSO, Sac Peak,
USA, Sept. 2011



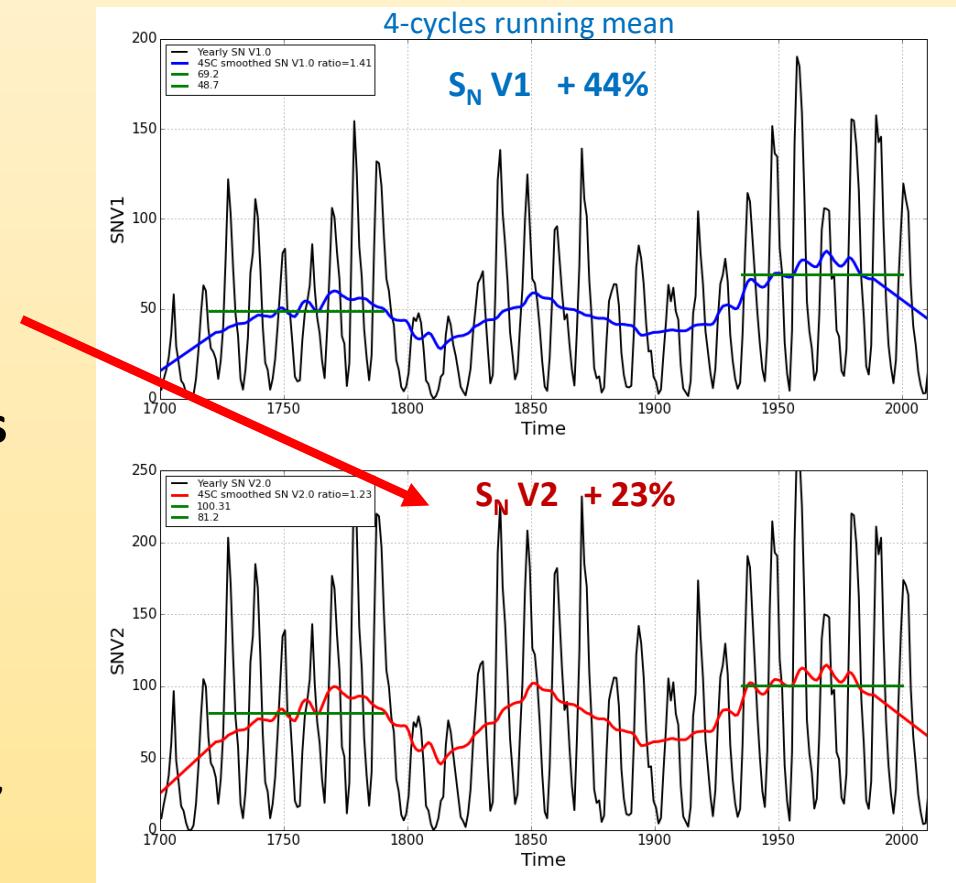
ISSI Bern, Switzerland
Jan. 2018

S_N revision: version 2.0 (release: July 2015)



Why does it matter? Diverse impacts

- Past solar forcing on climate:
 - Nature of grand minima: onset and exit?
 - Nature of grand maxima: no higher amplitude, but longer duration of high sequence
- Constraints on dynamo models
- Mid and long-term forecasts
- S_N - G_N proxies put recent solar measurements in a long-term context:
 - Reconstitution of past irradiance, solar wind, etc. (e.g. SATIRE)
- Calibration reference for solar, geomagnetic and ionospheric proxies



S_N database: Zurich data recovery

625) Alfred Wolfer, Beobachtungen der Sonnenflecken auf der Sternwarte in Zürich im Jahre 1890. (Fortsetzung zu 604.)

1890		1890		1890		1890		1890	
I	1 1.1	II	14 1.1	III	17 0.0	IV	15 1.2	V	19 1.11
-	2 1.1	-	16 0.0*	-	18 0.0	-	16 1.3	-	11 2.11
-	4 1.1	-	20 0.0	-	19 0.0	-	17 0.0	-	12 2.13
-	5 1.1	-	21 0.0	-	21 0.0	-	18 0.0	-	14 0.0
-	6 2.5	-	22 0.0	-	-	-	-	-	-
-	18 0.0	-	25 0.0	-	-	-	-	-	-
-	19 1.3*	-	26 0.0	-	-	-	-	-	-
-	20 1.3*	-	27 0.0	-	-	-	-	-	-
-	24 0.0	-	28 1.1	-	-	-	-	-	-
-	25 0.0	-	-	-	-	-	-	-	-
-	26 0.0	-	-	-	-	-	-	-	-
-	27 0.0	-	-	-	-	-	-	-	-
-	28 0.0	-	-	-	-	-	-	-	-
-	29 0.0	-	-	-	-	-	-	-	-
-	30 1.2	-	-	-	-	-	-	-	-
-	31 1.6	-	-	-	-	-	-	-	-
II	1 1.5	-	-	-	-	-	-	-	-
-	1 1.5	-	-	-	-	-	-	-	-
-	2 0.0	-	-	-	-	-	-	-	-
-	3 0.0	-	-	-	-	-	-	-	-
-	4 0.0	-	-	-	-	-	-	-	-
-	5 0.0	-	-	-	-	-	-	-	-
-	6 0.0	-	-	-	-	-	-	-	-
-	7 0.0	-	-	-	-	-	-	-	-
-	8 0.0	-	-	-	-	-	-	-	-
-	9 0.0	-	-	-	-	-	-	-	-
-	10 0.0	-	-	-	-	-	-	-	-
-	11 0.0	-	-	-	-	-	-	-	-
-	12 0.0	-	-	-	-	-	-	-	-

NB.
kleinern F.
April 1945

Mitthei

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	g, f, k	g, f, k	g, f, k	g, f, k	g, f, k	g, f, k	g, f, k	g, f, k	g, f, k	g, f, k	g, f, k	g, f, k
1	5.102 0.62		8.88 0.59	15.124 0.54	2.17 0.54	17.70 0.53		9.126 0.53	9.51 0.65		10.40 0.65	
2	5.121 0.60	6.99 0.59	9.88 0.57	12.114 0.64	2.25 0.67	17.73 0.56	10.132 0.55	11.02 0.62	9.60 0.58			
3	6.13 0.64	6.119 0.58	9.95 0.53	12.146 0.52	2.32 0.60	7.03 0.53	11.110 0.58	7.43 0.65	9.51 0.60			
4	3.9 0.62	4.102 0.77	9.93 0.57	11.510 0.54	2.24 0.57	7.104 0.60	9.78 0.58	8.58 0.58	5.49 0.60	11.66 0.59		
5	2.11 0.60		6.116 0.56	10.162 0.53	2.22 0.60	8.109 0.63	6.48 0.58	5.22 0.60	8.67 0.60			
6		6.97 0.55	10.32 0.56	8.119 0.58	2.30 0.65	8.109 0.63	6.44 0.58	5.22 0.60	8.67 0.60			
7			8.44 0.57	5.33 0.65			6.44 0.58	6.47 0.62		11.64 0.64		
8	2.4 0.63	7.115 0.79	9.96 0.59	6.58 0.70	8.60 0.54	4.45 0.57	6.47 0.60					
9	2.114 0.50		8.80 0.55	6.50 0.62	5.77 0.55	5.77 0.62	3.38 0.59	6.38 0.58				
10				6.46 0.59	6.38 0.62	5.98 0.61	5.36 0.57	(9.87) 0.73				
11	4.20 0.56	10.117 0.53	6.61 0.55	6.89 0.65	5.39 0.59	7.55 0.61	5.35 0.57	5.36 0.58	13.118 0.53	10.99 0.63		
12	2.11		8.68 0.48	7.94 0.65	3.88 0.60	6.30 0.65	6.44 0.65	7.05 0.59	13.145 0.62			
13			11.50 0.60	6.36 0.59	5.38 0.72	3.31 0.60	7.93 0.58	8.38 0.62	10.136 0.56			
14	3.70 0.64	8.55 0.57	5.51 0.61	8.44 0.61	8.44 0.62	6.94 0.58	6.94 0.58	6.94 0.58	10.78 0.60			
15	7.80 0.64	7.90 0.53	5.35 0.61	4.60 0.65	10.32 0.53	6.24 0.58	6.92 0.62	12.40 0.62	(11.132) 0.60			
16	6.42 0.59	5.38 0.60	5.33 0.59	4.37 0.65	4.26 0.55	2.77 0.53	5.10 0.58	11.23 0.65				
17	6.83 0.58		6.60 0.54	4.42 0.62	7.39 0.60	5.74 0.54	6.70 0.62	7.21 0.62				
18	5.56 0.55	5.51 0.54	8.31 0.54	6.47 0.60	11.50 0.57	9.49 0.50	8.77 0.60	11.16 0.58	10.58 0.60			
19	5.49 0.57		9.94 0.57				6.68 0.60	13.110 0.49				
20	5.37 0.59						8.68 0.60	13.110 0.49				
21							6.70 0.67	13.110 0.49				
22	5.24 0.59						7.101 0.62	7.91 0.58	14.103 0.58			
23	6.39 0.57						6.49 0.62	7.118 0.59	13.121 0.56			
24	4.39 0.75						7.111 0.57	9.33 0.58	11.107 0.63	9.120 0.57		
25							9.43 0.57	12.112 0.57	10.149 0.61			
26	10.42 0.63	4.44 0.61	6.59 0.56	7.80 0.64	6.62 0.65	1.219 0.58	12.117 0.58		8.107 0.61			
27	9.72 0.53	4.45 0.61	7.66 0.57	7.80 0.64	6.71 0.65	6.66 0.58	11.144 0.58	10.149 0.61				
28	9.52 0.61	5.40 0.61	10.43 0.56	6.40 0.76	8.85 0.56	7.81 0.55	11.112 0.58	(9.82) 0.61				
29			5.63 0.52	13.81 0.56	7.64 0.65	7.64 0.55	6.36 0.60	7.02 0.57	10.08 0.65	(9.46) 0.72		
30			10.62 0.57	12.78 0.54	4.13 0.70	8.117 0.58	10.09 0.58	10.01 0.64	8.34 0.60			
31	6.24 0.60		9.61 0.62				8.118 0.60	13.07 0.60				
Σ	10.83	8.28	11.09	13.86	13.98	12.10	13.16	7.00	10.51	14.60	8.78	243
N	19	18	14	19	19	23	24	23	21	21	22	12
M	0.60	0.59	0.58	0.60	0.60	0.58	0.60	0.58	0.61	0.59	0.61	0.59

Long-lost Waldmeier's source tables (1945-1980): found in 2018

298 Wolf, astronomische Mittheilungen.

1890	1890	1890	1890	1890
VI	6 1.10	VII	11 2.18	VIII
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-	8 1.8	-	14 2.3	15 1.2
-	10 2.3	-	15 0.0	16 0.0
-	12 0.0	-	16 0.0	18 0.0
-	13 0.0	-	17 0.0	19 0.0*

1890	1890	1890	1890	1890
VI	6 1.10	VII	11 2.18	VIII
-	7 1.11	-	13 2.5	14 0.0
-	8 1.8	-	14 2.3	15 1.2
-	10 2.3	-	15 0.0	16 0.0
-	12 0.0	-	16 0.0	18 0.0
-	13 0.0	-	17 0.0	19 0.0*

Sonnenflecken-Beobachtungen
Sonnenflecken-Beobachtungen

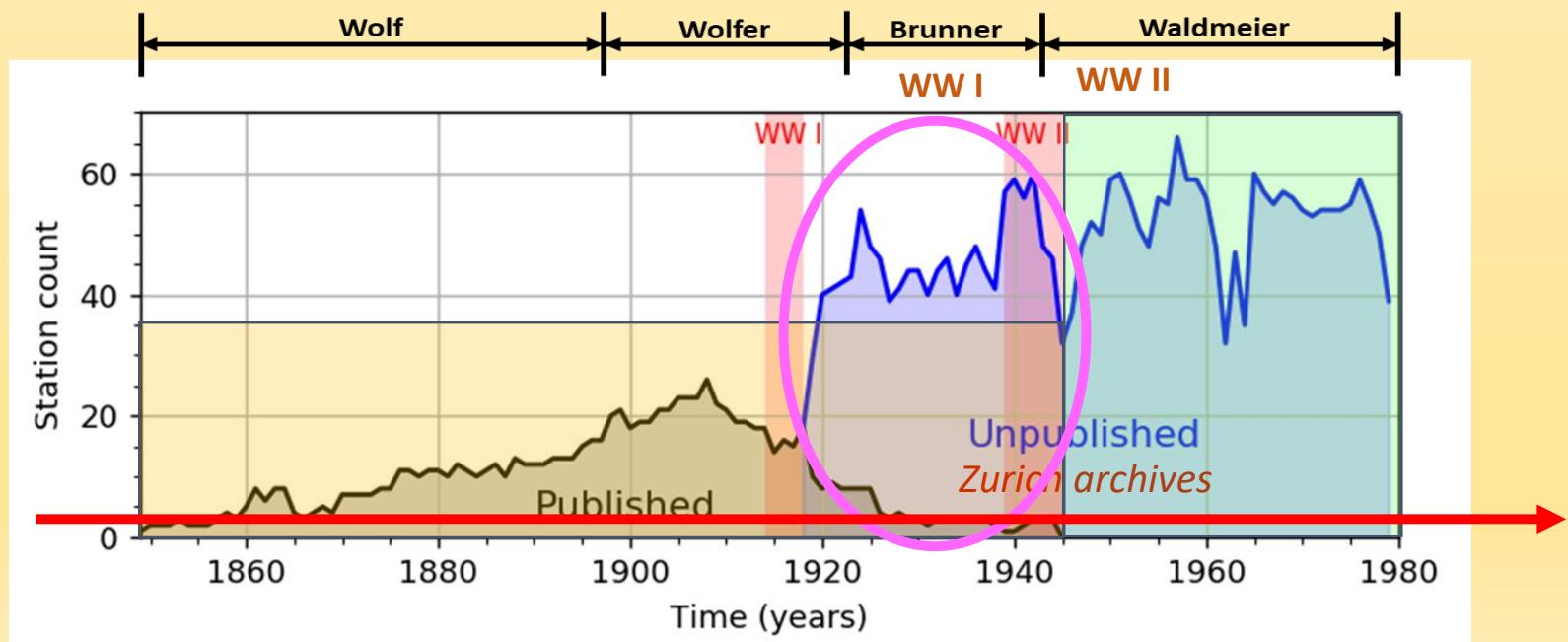
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Beobachter: B. Beck, Amstelk., Eijzen, Sternwarte, Zürich
Methode: R-Kreisdiagramm (Objektivöffnung: 8 cm)
Vergr.: 64 X

Bemerkungen:
Sonnenfleckenbeobachtungen

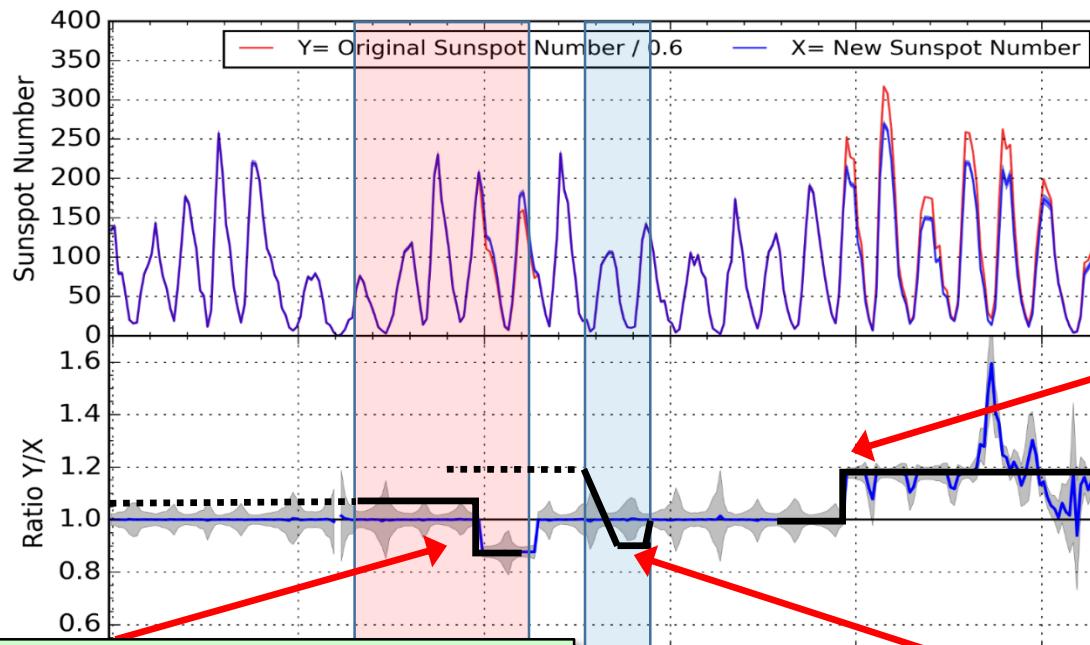
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S_N database: major advances (Clette et al. 2020)

- All published input data from Zurich (*Astronomische Mittheilungen der Sternwarte Zurich*):
 - Fully digitized up to 1944 (internal and auxiliary observers)
 - Unpublished data (archives) 1919- 1980:
 - Original sourcebooks recovered: all source data between 1945 and 1970
 - Scanned by the Library & Archives of ETH Zurich (2019-2021)
 - Extraction of all values (~300.000) in preparation (FARSUN brain.be project, 2023)
- Full continuity up to 1980 (transition to SILSO, Brussels)
- Still partly missing: auxiliary data 1919-1944



S_N ongoing corrections



1947 jump +17.7 %

Clette et al. 2021

- Global agreement on jump amplitude
- Variable inflation factor 1-1.2
- Timing of jump explained: sharp break in Zurich team and network

Schwabe - Wolf -20%

Bhattacharya et al. 2022

- Past hints: Leussu et al.(2013), Senthamizh et al. (2015)
- Data: Interval 1811-1868

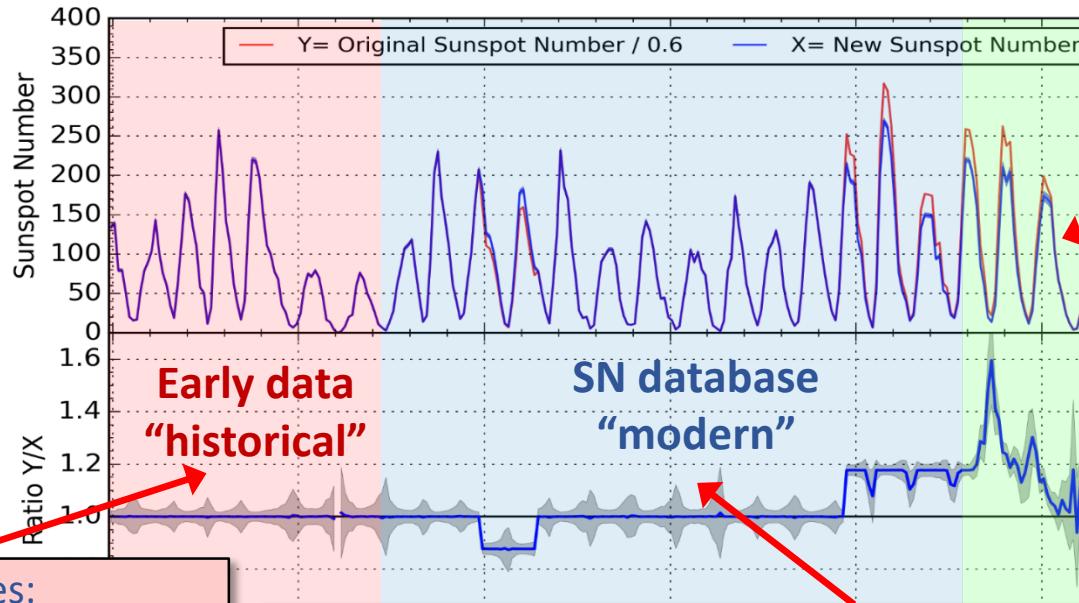
Wolf - Wolfer -20% ?

Friedli 2020

- Work by E.Frenkel (1913) revisited

- All recent papers: productive COVID period !
- Most corrections = abrupt transitions
 - Are corrections applicable to all earlier data?
 - No slow drifts between jump? (stability of primary reference observers)

S_N : towards a full end-to-end S_N reconstruction

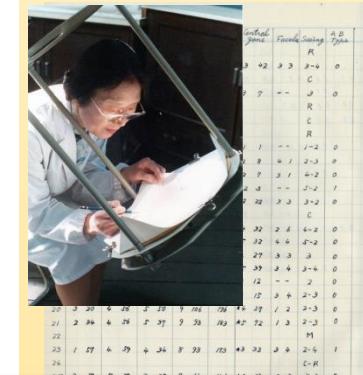


- Challenging issues:
 - Sparse data
 - No clear distinction between spots and groups
- Role of sunspot drawings!
 - Allows recounting
 - Statistics of individual
- S_N Database (all Zurich records):
 - Waldmeier archives (FARSUN project, SILSO, late 2023)
 - Adding new and revised data sets:
 - Carrington 1853-1861 (Bhattasharya, Teague, 2022)
 - Madrid 1935-1986 (Aparicio et al. 2018, 2022)
 - I. Koyama 1945-1986 (Hayakawa et al. 2020)
 - + recovery of still-missing Zurich archives 1919-1944?
 - Inclusion of uncertainty data mining techniques

Time consuming part: data encoding (> 300 000 values)

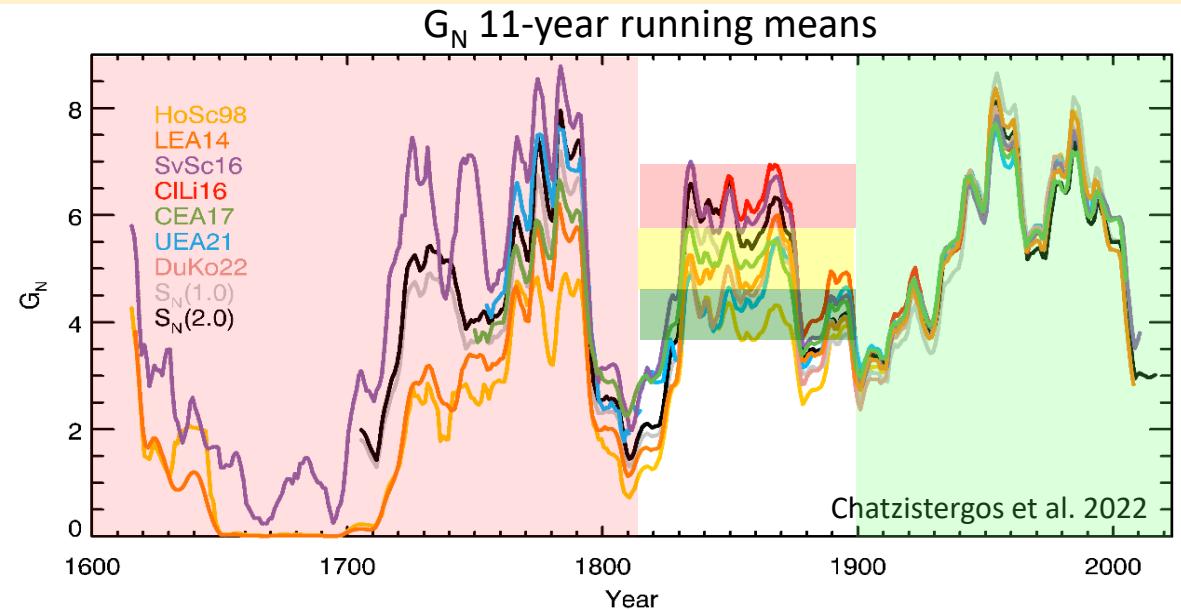
V2.1/2.2 (Schwabe-Wolf-Wolfer corrections) > 2023 (Bhattasharya PhD)

V3.0 (full reconstruction back to 1818) > 2024- 2025 (FARSUN)



G_N revision: multiple series

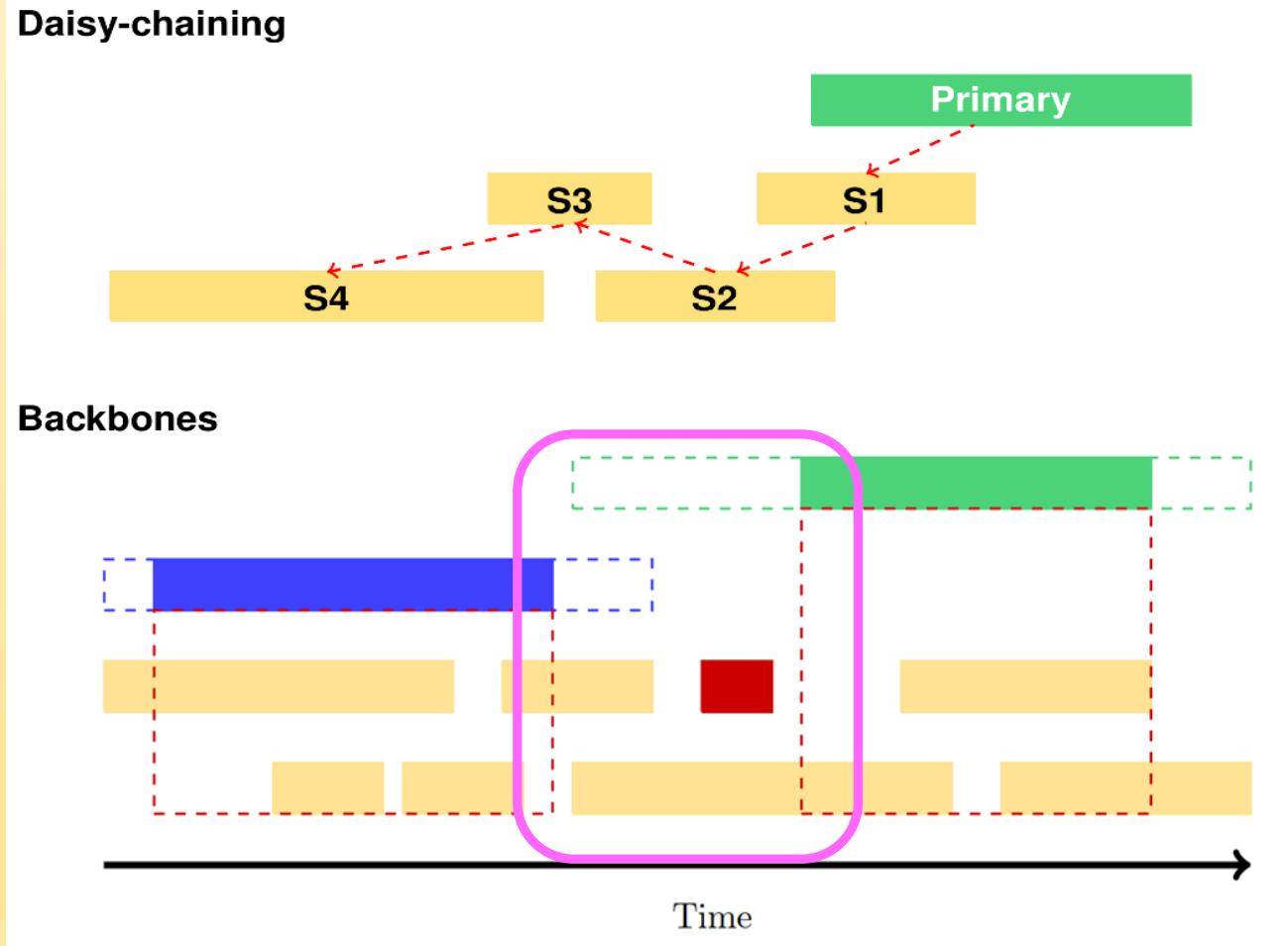
- 10-year smoothed series (*Chatzistergos*)
- 7 G_N series:
 - Range (19th century): 40%
 - 3 rough classes: **high**, **medium**, **low**
- Before the 19th century:
 - Large uncertainties
 - Simple propagation of 19th century scaling



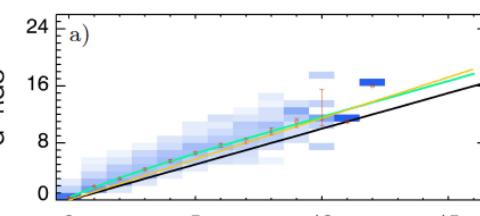
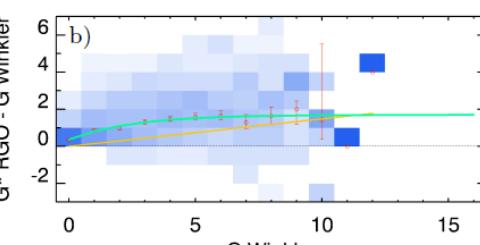
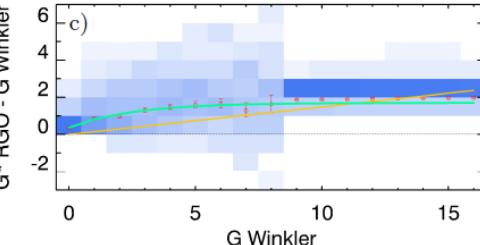
ID	Publication	Method	Scale
<i>SN(1.0)</i>	Zurich (<i>original</i>)	<i>SN, pilot station</i>	<i>High</i>
HoSc98	Hoyt & Schatten 1998	GN orig., daisy-chain	Low
LEA14	Lockwood et al. 2014	H&S GN-based SN correction	Med-Low
<i>SN(2.0)</i>	Clette et al. 2016	<i>SN(1.0) corrected, pilot station</i>	<i>High</i>
SvSc16	Svalgaard & Schatten 2016	Backbone 1	High
CILi16	Cliver & Ling 2016	HoSc98 correction, daisy-chain	High
CEA17	Chatzistergos et al. 2017	Backbone 2	Med-High
UEA21	Usoskin et al. 2016, 2021	Active-day fraction	Med-Low
DoKo22	Dudok de Wit 2022	Tied ranking	Med-Low

Space Climate 8, Krakow, Poland

G_N methods: daisy-chaining versus backbones



G_N methods: Observer-pair comparison

	Cliver & Ling 2016	Svalgaard & Schatten 2016	Chatzistergos et al. 2017
Method	• Daisy-chaining	• Backbone	• Advanced backbone
Innovations	• Crit of H 1995		<p>primary s) only</p> <ul style="list-style-type: none"> More primary observers No temporal averaging (daily values) Corrections through cross-probability distributions (non-parametric CPD)
Assets	<ul style="list-style-type: none"> Dia Mis from tele Dri bef 		<p>bias</p> <p>few</p> <ul style="list-style-type: none"> Direct overlap between primary observers Allows non-linear relations between observer pairs Error estimate
Issues	<ul style="list-style-type: none"> Bac acc Not rec 184 		<p>secondary</p> <p>averaging</p> <p>sample</p> <ul style="list-style-type: none"> Lack of data at high G_N values (Monte-Carlo simulation) Observers assumed to be most mature (global CPD)
Result	• High	• Highest	• Intermediate

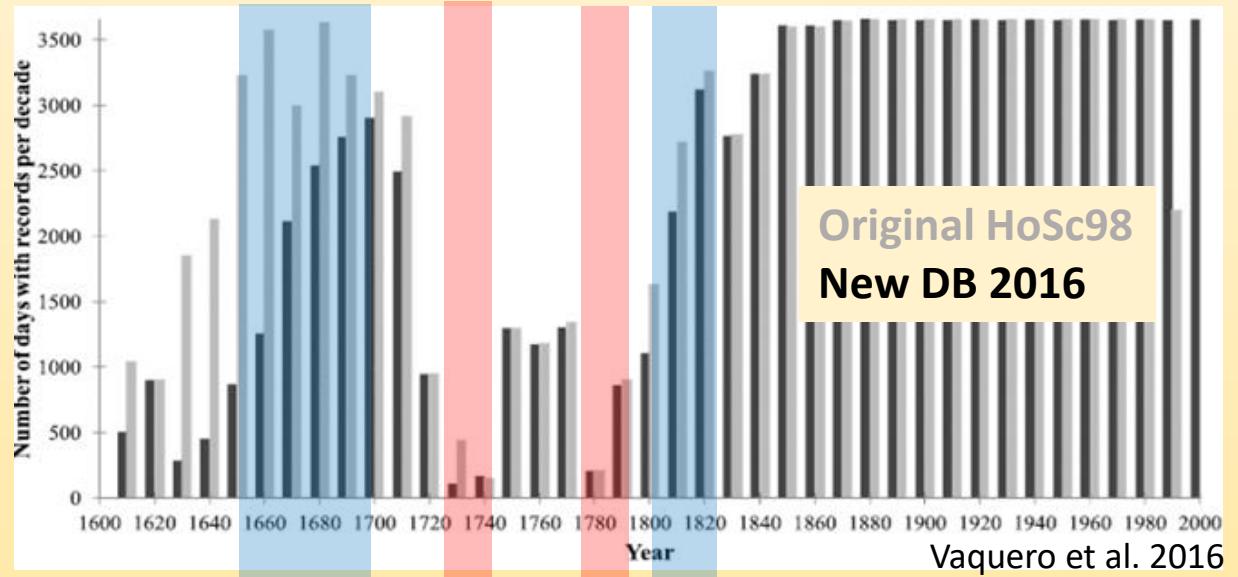
G_N methods: Observer-pair comparison

	Usoskin et al. 2016, 2021 Willamo et al. 2017, 2018	Muñoz-Jaramillo (preliminary)	Dudok de Wit & Kopp (2022, in preparation)
Method	<ul style="list-style-type: none"> Active-day fraction (ADF) 	<ul style="list-style-type: none"> Segmented ADF 	<ul style="list-style-type: none"> Tied ranking
Innovations	<ul style="list-style-type: none"> Statistics of days with $G_N=0$ and $G_N > 0$ Single “perfect” observer (RGO 1900-1976) Degraded data: S_S minimum area threshold (acuity) 	<ul style="list-style-type: none"> Objective selection of suitable reference activity areas 	<ul style="list-style-type: none"> Ranking of G_N values
Assets	<ul style="list-style-type: none"> No observer-pair comparisons Non-parametric correction (RGO-based) via cross-probability distribution (CPD) Error estimate 	<ul style="list-style-type: none"> Better activity ranking 	<p>CDF of ADF</p> <p>ADF for observer winkler</p>
Issues	<ul style="list-style-type: none"> Bias when different activity levels between RGO and observer (Willamo et al. 2018) Unreported spotless days Effect of group splitting (beyond acuity factor) Works only when $ADF < 0.8$ 	<ul style="list-style-type: none"> In values next to pure ADF 	<p>gaps</p> <ul style="list-style-type: none"> No understanding (yet) of the mutual influence of gap-filling and ranking steps.
Result	<ul style="list-style-type: none"> Medium-low 	<ul style="list-style-type: none"> No series yet 	<ul style="list-style-type: none"> Medium-low

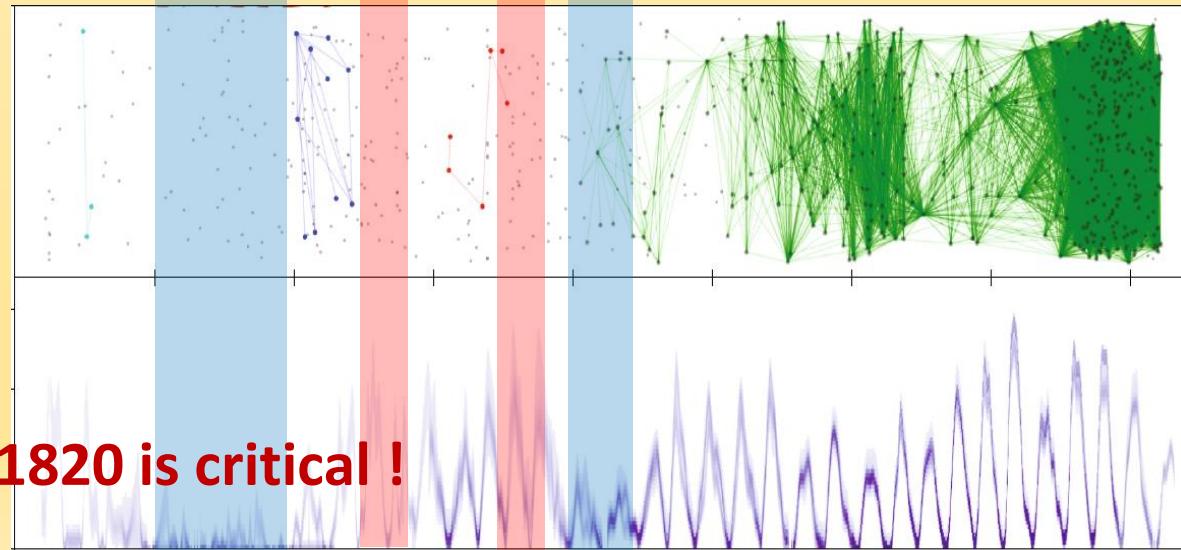
Not yet fully validated!

G_N reconstruction: archive of source data

- Updated G_N database (*Vaquero et al. 2016*):
 - Additions
 - Corrections
 - Eliminations
- Main gaps in 18th century:
 - 1740-1750
 - 1780 – 1800



- Major spotless periods:
 - 1650 – 1715 (Maunder)
 - 1800-1820 (Dalton)



➡ Adding data before 1820 is critical !

GN-SN data: intensive recoveries !

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<https://doi.org/10.3847/1538-4357/abdd34>

Thaddäus Derfflinger's Sunspot Observations during 1802–1824: A P

Hisatomi	1610 -1699		1700-1799		1800-1899		1900 - 1999	
¹ G. Hisatomi ² UK Solar System Observatory ³ THE ASTROPHYSICAL JOURNAL © 2021. The American Astronomical Society	T. Harriot	1610-1613	Plantade	1705-1726	T. Derfflinger	1802-1824	Madrid	1876-1986
Sunspot Observations	C. Scheiner	1611-1631	P. Becker	1708-1710	Prantner	1804-1844	Stonyhurst Coll.	1886-1940
Hisashi Ueda ¹ Institute of Space and Earth Environmental Research ³ UK Solar System Observatory	J. Tardé	1615-1617	J-H. Müller	1709	F. Hallaschka	1814-1816	Laboratory,	1914-1920
Reconstruction and Analysis (1610-1800)	C. Malapert	1618-1626	J-C Müller	1719-1720	H. Schwabe	1825-1867	M. Aguilar	1929-1941
V.M.S.	C. Scheiner	~1620	J.F. Weidler	1728-1729	A. Colla	1830-1843	Coimbra Obs	1931-1933
	Derham	~1620	P. Wargentin	1747	Kunitomo	1835-1836	R. Carrasco	1945-1996
	J. Smogulecki	1621-1625	J.C. Staudacher	1749-1796	W.C. Bond	1847-1849	E. Strach	1969-2008
	D. Mögling	1626-1629	C. Horrebow	1761-1776	R. Carrington	1853-1861		
	P. Gassendi	~1630	Japan	1749-1750	G. Spoerer	1861-1894		
	G. Marcgraf	1636-1642	B. Oriani	1778-1779	A. Secchi	1871-1875		
	Rheita	1642	Toaldo	1779				
	Hevelius	1642-1645	Comparetti	1779				
	M. Fogelius	1650-1700	I. Zenbei	1793				
	H. Siverus	1650-1700	Armagh Obs.	1795-1797				
	Cassini	1671						
	J-C. Gallet	1677						
	G. Kirch	1680-1709						
	Eimmart Obs.	1681-1718						
	J. Flamsteed	1672-1703						
	H. Hayakawa	1703-1704						

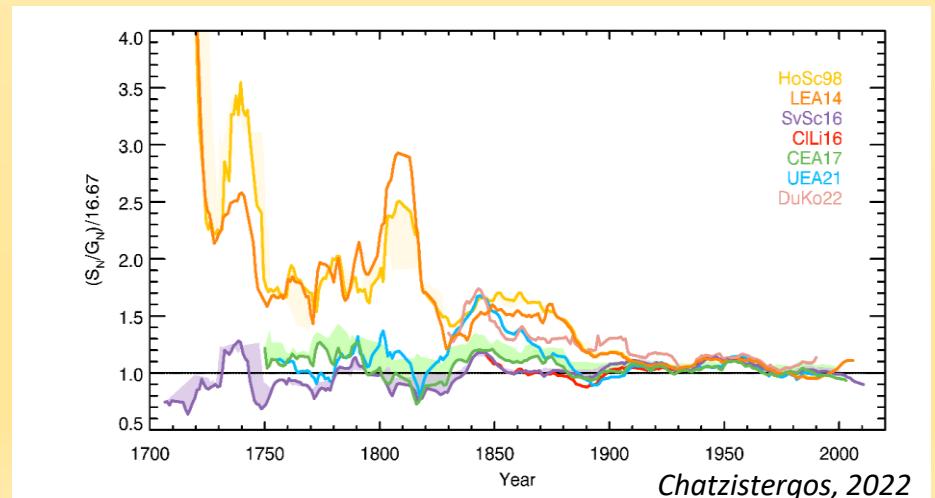
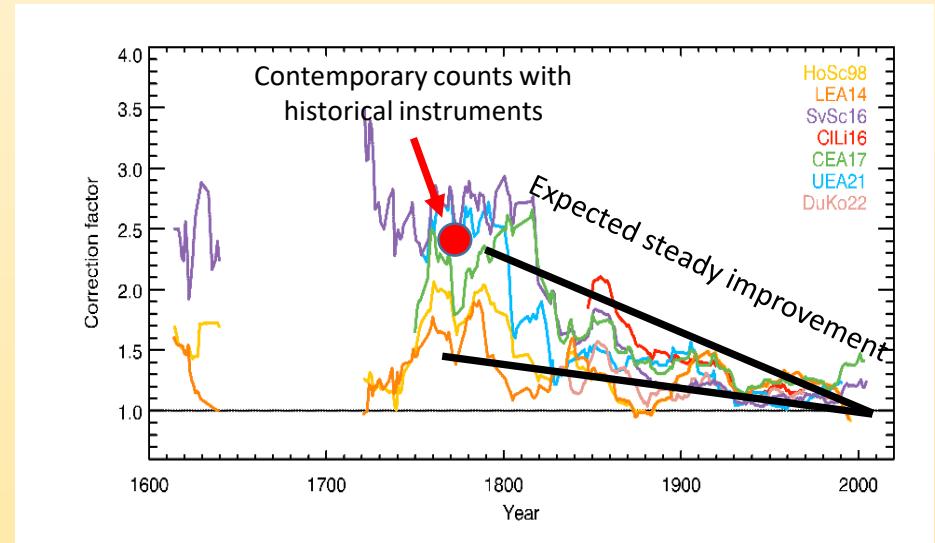
M.S. Carrasco⁷ · Bruno P. Besser^{8,9} · Shoma Uneme² · Shinsuke Imada²

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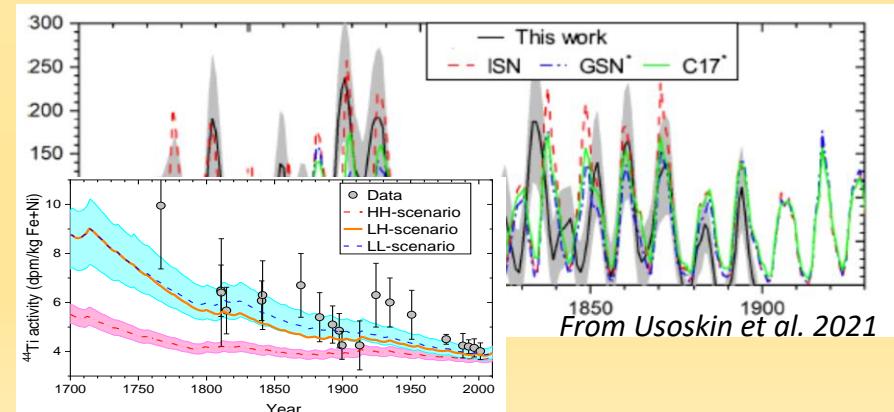
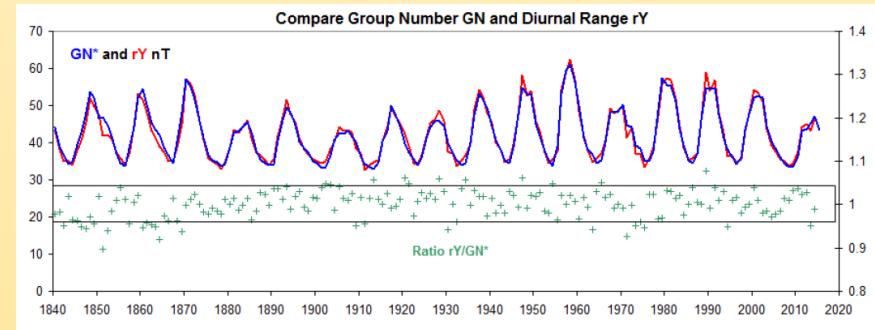
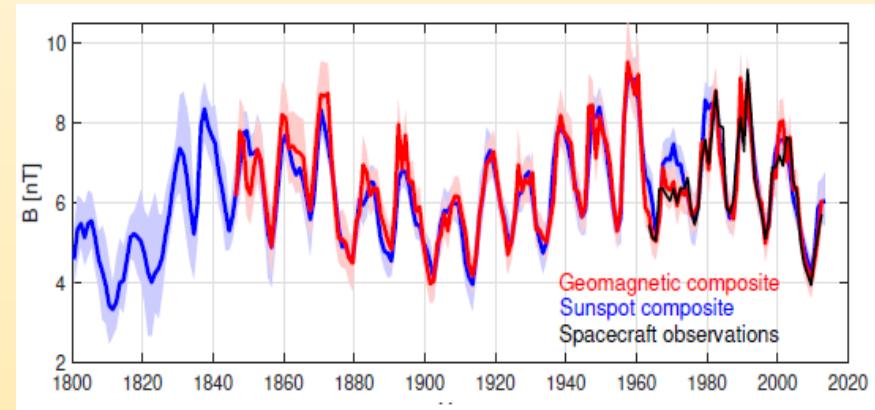
Benchmarks

- Progress in telescope optics:
 - Ratios between reconstructed and raw uncorrected series
 - Historical optics (*Svalgaard*)
 - Mathematically degraded images (*Karachik, Pevtsov, Nagovitsyn, 2019*)
- Equivalence $G_N \leftrightarrow S_N$:
 - Same underlying process (magnetic flux emergence)
 - S_N construction is completely independent (pilot station back to 1849)



Solar activity proxies

- **Geomagnetic indices:**
 - Open magnetic flux in solar wind
 - Recent re-calibration (ISSI team)
(Owens *et al.* 2016)
- **Diurnal modulation of the geomagnetic East component rY :**
 - Proxy of solar UV irradiance
 - Yearly means 1840-present
(Svalgaard, 2015)
- **Cosmogenic isotopes (^{10}Be , ^{14}C , ^{44}Ti):**
 - Proxy of solar wind (modulation potential)
 - ^{14}C from trees (Usoskin *et al.* 2021)
 - ^{44}Ti from meteorites (Asvestari *et al.* 2017)



GN benchmark & proxies: overview

	Recons. G_N	Optical progress	S_N V2.0	Geomag. Open B	Diurnal rY	Isotopes ^{14}C , ^{44}Ti
HIGH	SvSc2016 CILI16 SN V1/2	BEST	BEST	BEST	BEST	NO
MEDIUM	CEA17 DuKo22 UEA21	FAIR LOW	FAIR LOW	FAIR LOW	FAIR LOW	FAIR HIGH
LOW	HoSc88 LEA14	NO	NO	NO	NO	BEST

- Low reconstructions are excluded by most benchmarks & proxies
- Intermediate reconstructions are mostly compatible but never optimal
- Still contradictory diagnostics: subject to revision !

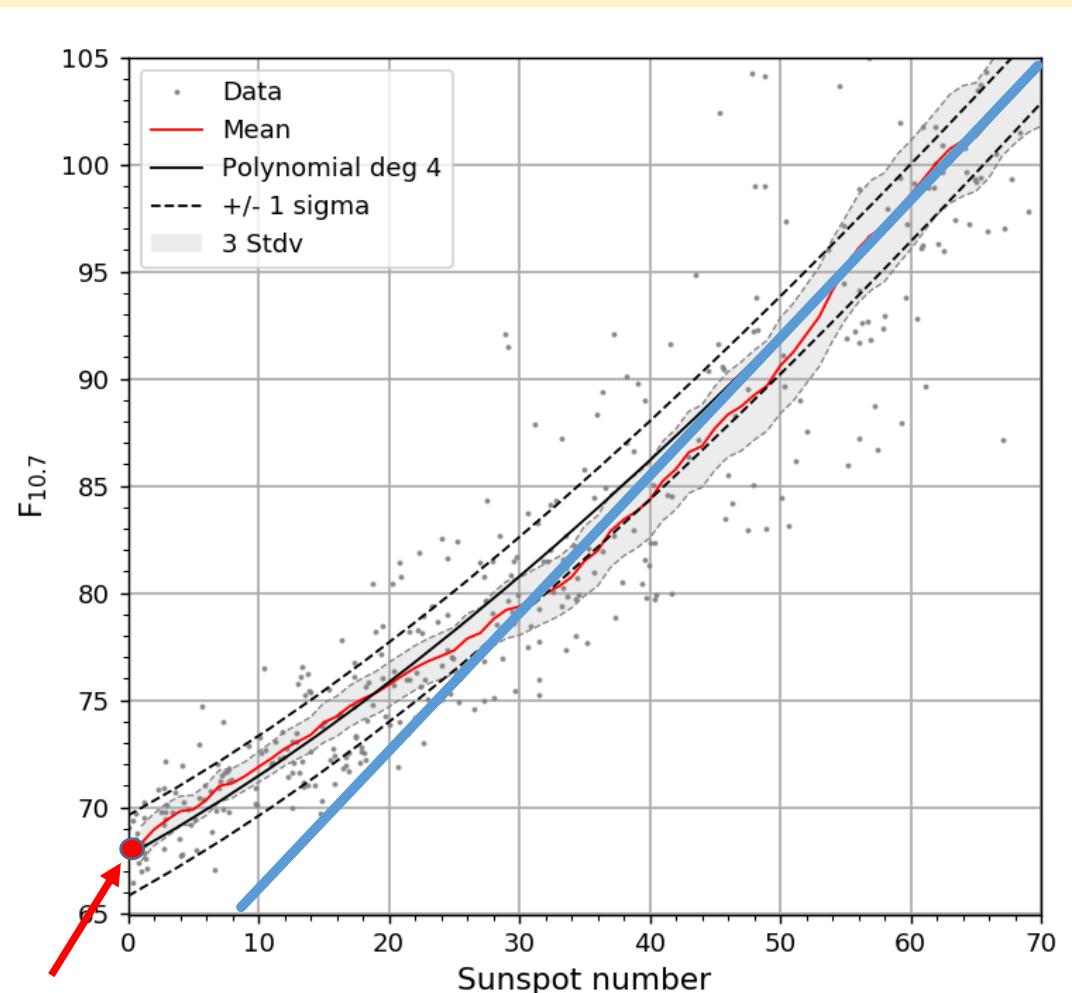
G_N reconstruction: prospects

- Further development of the advanced backbone
 - Single common data set for testing/benchmarking all methods
 - Benchmarks: tracking the progresses in solar activity proxies
 - e.g. single solar cycles resolved in ^{14}C isotope records (Usoskin et al. 2021, A&A)
 - When everything breaks down! All methods are inapplicable during grand minima and when data are too sparse
 - Sunspot drawings= ground truth: e.g. statistics of group types
 - Local use of proxies (geomagnetism) to bridge gaps < 10-20 years
 - Remaining problems common to all methods:
 1. Hypothesis of scale uniformity of individual observers
 2. Effect of random temporal distribution of sparse data
(cf. Usoskin, Mursula & Kovaltsov 2003, ESAsp)
 - Addressed by S_N uncertainty quantification (Mathieu et al. 2019)
- ➡ Next step: mutual adaptation of methods for $S_N \leftrightarrow G_N$

$F_{10.7}$ background radio flux: relation with S_N

- Past results:
 - Many disagreeing S_N - $F_{10.7}$ relations
 - No error range
- 4th degree polynomial:
 - Needed for good fit in the low range
 - Polyn. values + errors
- Linear for $S_N > 35$

$$\begin{aligned}\hat{F}_{10.7} \\ = 67.73 (\pm 1.13) \\ + 0.337(0.056) S_N \\ + 3.69 (\pm 0.77) \cdot 10^{-3} S_N^2 \\ - 1.52(\pm 0.38) \cdot 10^{-5} S_N^3 \\ + 1.33(\pm 0.62) \cdot 10^{-8} S_N^4\end{aligned}$$



Mean “all-quiet” $F_{10.7}(0) = 67$ sfu

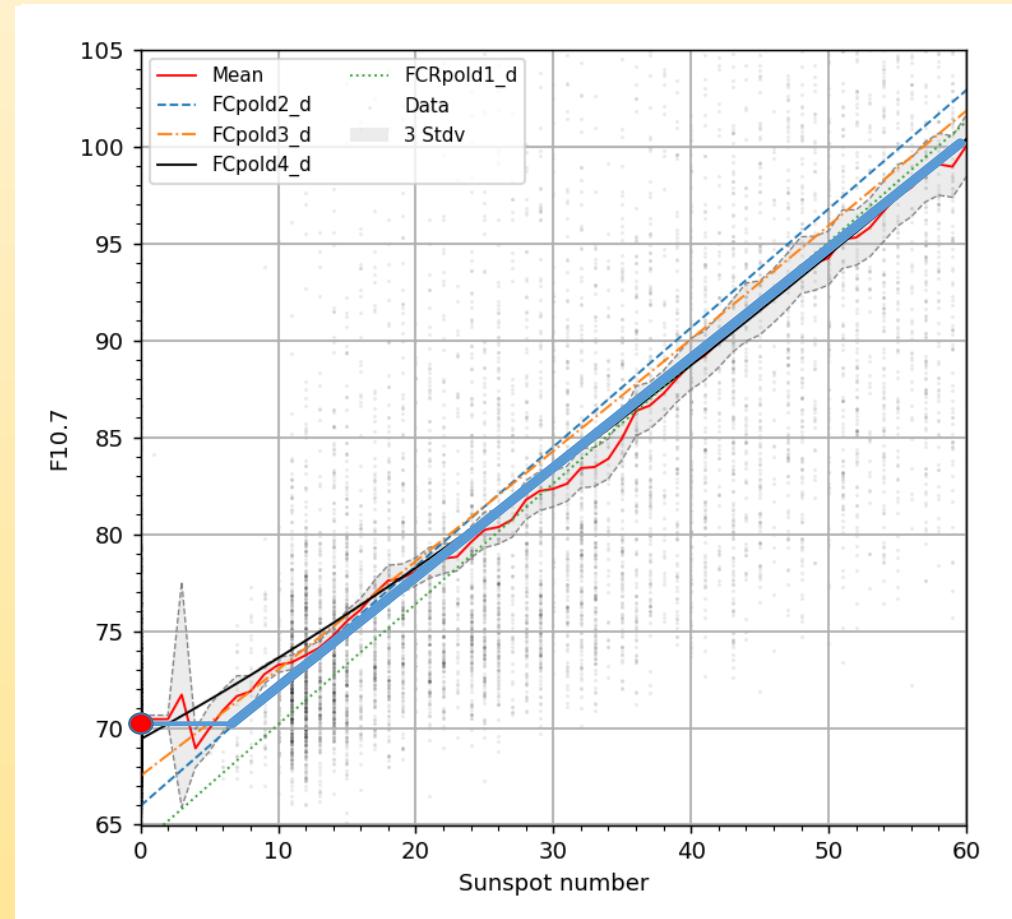
Function of the duration of spotless interval: lowest for ~30 day averages

Model: pure temporal averaging effect

- Raw daily data:
 - Fully linear down to first spot
 - $S_N=0$ is offset (0-11 jump)

$$S_N = 10 N_G + N_S$$

- Synthetic $F_{10.7}$ series:
 - Linear conversion of actual daily S_N series to $F_{10.7}$
 - Monthly averaging



- Matches the observed low-range non-linearity (also for yearly means)
- Non-linearity due to the $S_N=0$ offset point temporally convolved with the frequency of spotless days.

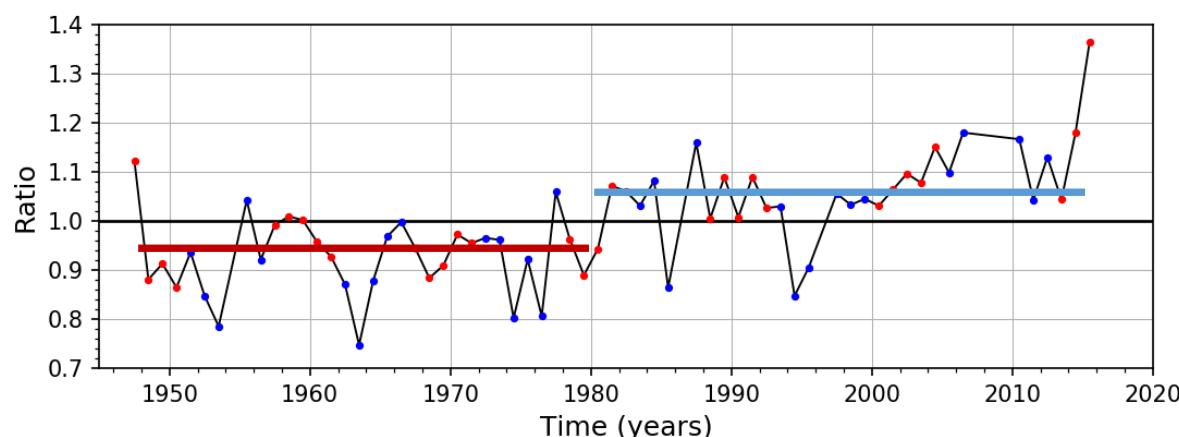
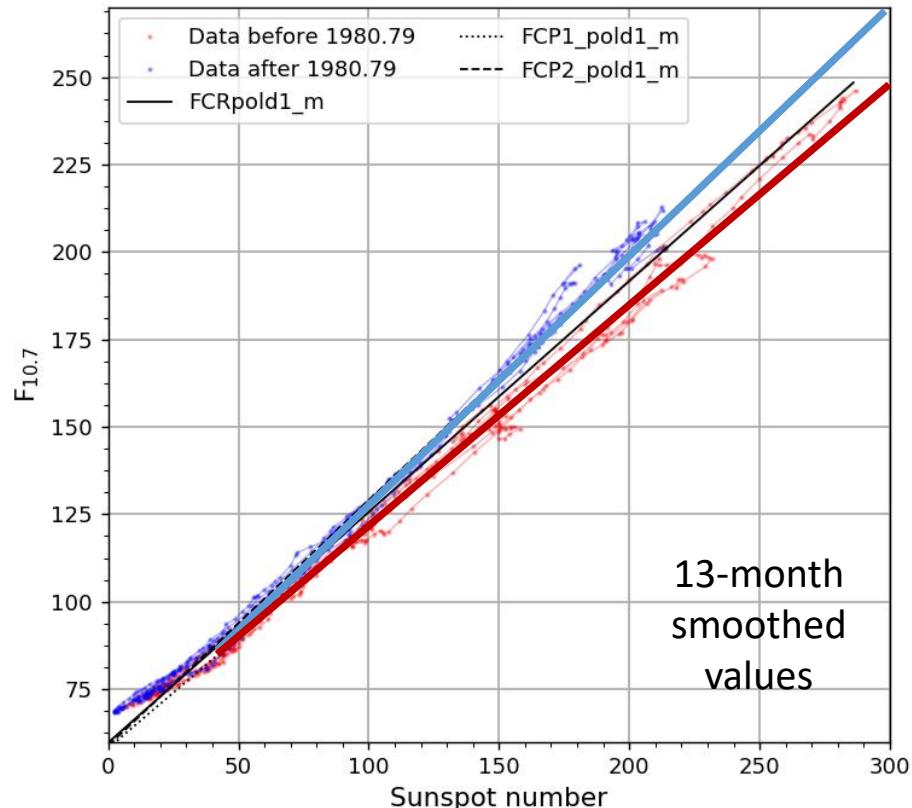
A sharp jump in 1980

- Abrupt upward jump in 1980:
 - Before 1980: $S = 0.6345 (\pm 0.0066)$
 - After 1980: $S = 0.7020 (\pm 0.0089)$
 - Ratio: $1.106 \pm 0.017 (10.6 \%)$
 - Time: Dec. 1980 – Jan 1981

Good global homogeneity of both series before and after the jump

- Very high linear correlation (V2 better than V1)

Validation of both series



Separate proxies needed for each half-series !

1947-1980

$$\begin{aligned}\hat{F}_{10.7} \\ = 66.64 (\pm 1.48) \\ + 0.366(0.067) S_N \\ + 2.59 (\pm 0.86) \cdot 10^{-3} S_N^2 \\ - 0.99 (\pm 0.40) \cdot 10^{-5} S_N^3 \\ + 1.33 (\pm 0.62) \cdot 10^{-8} S_N^4\end{aligned}$$

1981-present

$$\begin{aligned}\hat{F}_{10.7} \\ = 67.84 (\pm 1.06) \\ + 0.386(0.044) S_N \\ + 2.86 (\pm 0.45) \cdot 10^{-3} S_N^2 \\ - 0.73 (\pm 0.13) \cdot 10^{-5} S_N^3\end{aligned}$$

Whole series

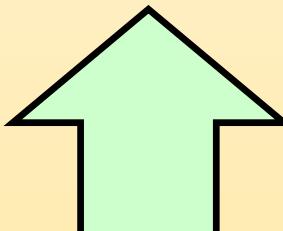
$$\begin{aligned}\hat{F}_{10.7} \\ = 67.73 (\pm 1.13) \\ + 0.337(0.056) S_N \\ + 3.69 (\pm 0.77) \cdot 10^{-3} S_N^2 \\ - 1.52 (\pm 0.38) \cdot 10^{-5} S_N^3 \\ + 1.97 (\pm 0.60) \cdot 10^{-8} S_N^4\end{aligned}$$

1980 jump: retracing the historical cause

- Two main $F_{10.7}$ construction eras (*non-overlapping*):

Covington (1947-1979)

- Manual measuring from paper recorder rolls



Tapping (1982-now)

- Computer processing of digital measurements

Transition team (1979-1981)

- Development of computerized processing
- No clear stable method

- **Processing issue:** unique change of people and method
- **No instrument calibration problem**

Clette, F. (2021), *J. Space Weather and Space Climate*, Vol. 11, id.2, 25 pp.

DOI: [10.1051/swsc/2020071](https://doi.org/10.1051/swsc/2020071)

Conclusions

- Multiple topic-focused partnerships: **welcome to join in !**
- Way forward:
 - **Combining methods, apply (only) where they work**
 - **Data uncertainties** become central
- **Next major S_N update:** release 2024
- Reconstruction of S_N & G_N series now a **continuous process**
- Steps towards a formal **version-adoption framework (IAU):**
 - Base community (ISSI Team) > In progress ...
- **A new generation of young sunspot researchers !**
 - Theo, Hisashi, Shreya, Sophie, Victor, etc.



Stay tuned



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Sunspot Index and Long-term Solar Observations

<http://sidc.be/silso>

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

