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Why the Sunspot Number Needs Re-examination & What We Have Learned So Far

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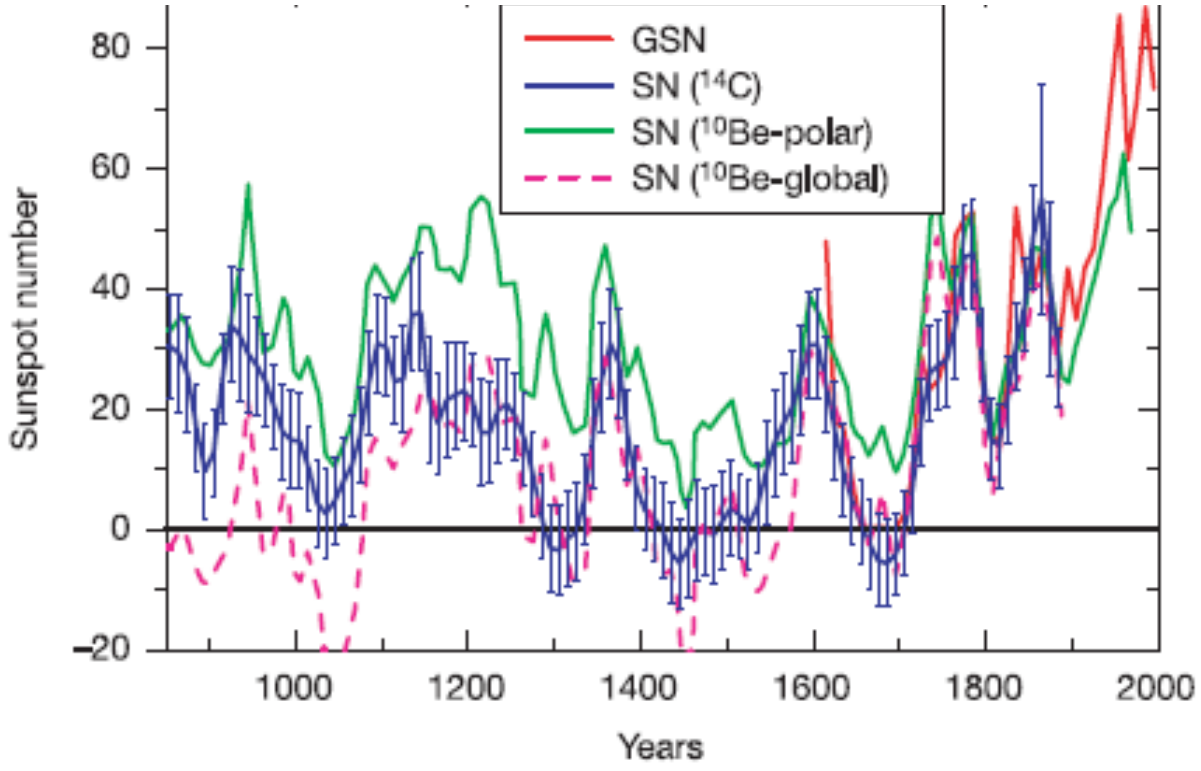
Four Reasons Why the SSN Needs Re-examination

1. It's used

Unusual activity of the Sun during recent decades compared to the previous 11,000 years

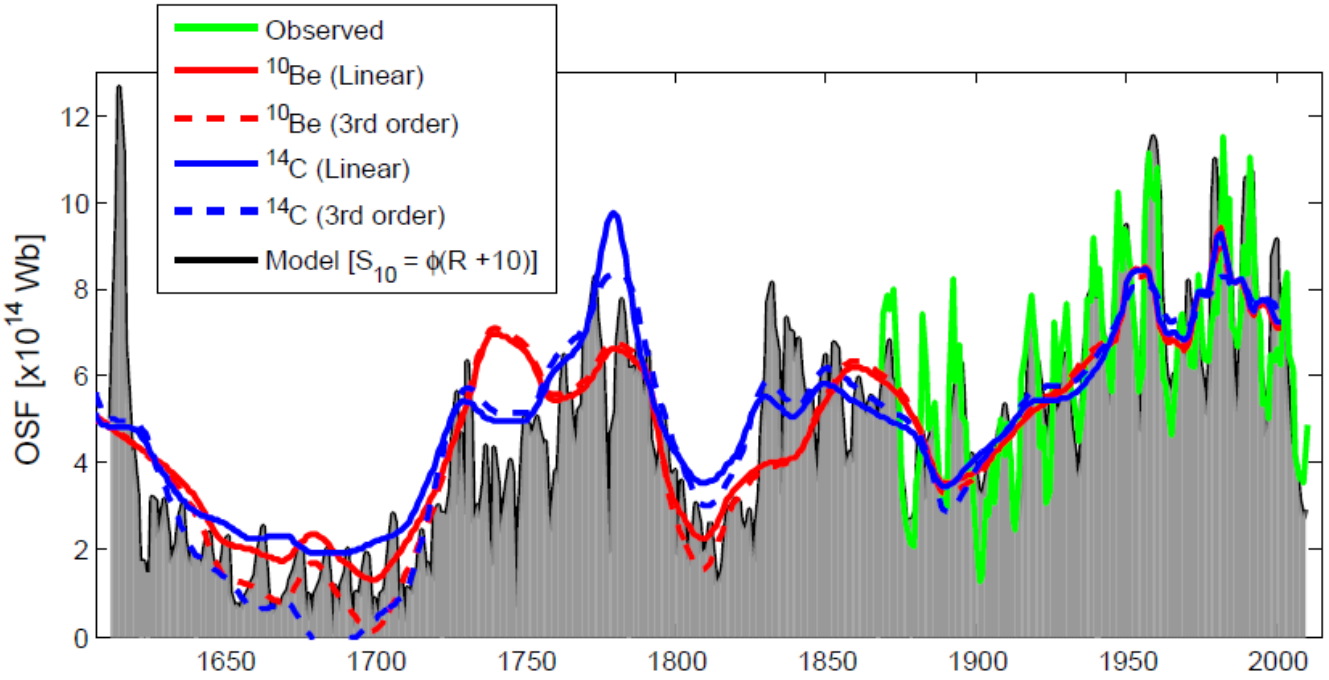
S. K. Solanki[1], I. G. Usoskin[2], B. Kromer[3], M. Schüssler[1] & J. Beer[4]

(2004)



Cyclic loss of open solar flux since 1868: The link to heliospheric current sheet tilt and implications for the Maunder minimum

M.J. Owens[1,2], M. Lockwood[1] (2012)



… we use the cyclic variation of the fractional open solar flux (OSF) loss rate with sunspot number to reconstruct OSF back to 1610.

Waldmeier relations and the solar cycle dynamics by the mean-field dynamos

V.V. Pipin[1], D.D. Sokoloff[2] and I.G. Usoskin[3]

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(2012)

Abstract. The long-term variability of the sunspot cycle, as recorded by the Wolf numbers, are imprinted in different kinds of statistical relations which relate the cycle amplitudes, duration and shapes. This subject always gets a special attention because it is important for the solar activity forecast. We discuss statistical properties of the mean-field dynamo model with the fluctuating α-effect. Also, we estimate dynamical properties of the model for the long and short time-scale and compare it with the dynamics of the sunspot numbers data sets.

EVOLUTION OF SOLAR PARAMETERS SINCE 1750 BASED ON A TRUNCATED DYNAMO MODEL

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Received 2011 April 14; accepted 2011 September 30; published 2011 December 22

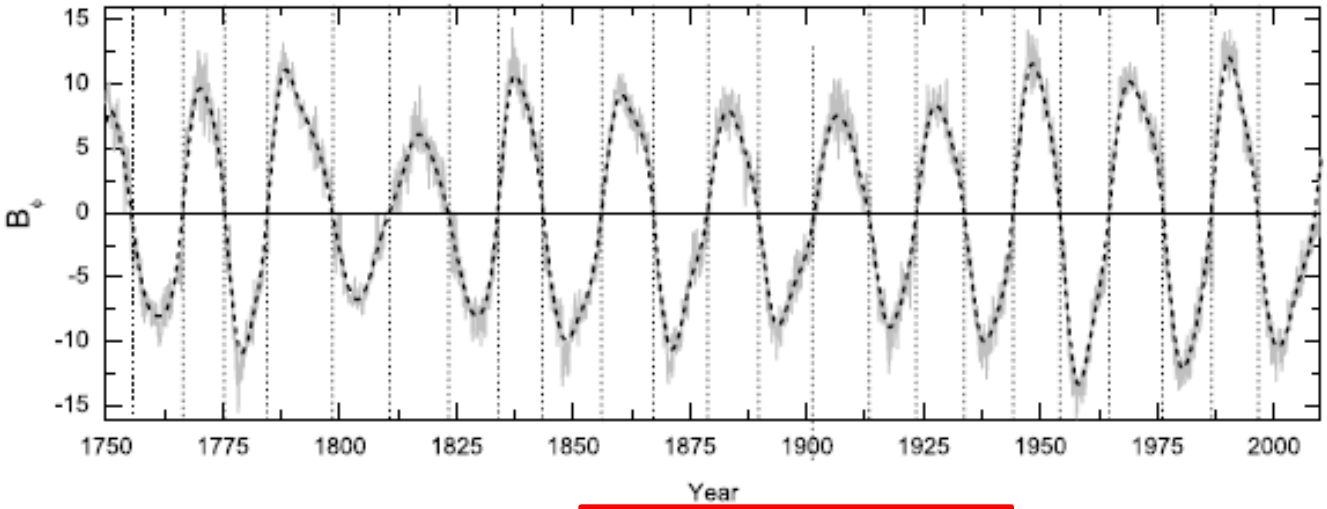

Figure 3. Black dashed line represents the built proxy for the toroidal field. B_ϕ is obtained by calculating $\sqrt{\text{SSN}}$, changing the sign of alternate cycles (represented in gray), and smoothing it down. Vertical thin dotted lines represent solar cycle minima.

THE ASTROPHYSICAL JOURNAL, 625:522–538, 2005 May 20

MODELING THE SUN'S MAGNETIC FIELD AND IRRADIANCE SINCE 1713

Y.-M. WANG, J. L. LEAN, AND N. R. SHEELEY, JR.
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Received 2004 December 10; accepted 2005 February 15

… we now take the flux emergence rate to be proportional to the observed yearly sunspot numbers

Evolution of the solar irradiance during the Holocene⋆,⋆⋆

L. E. A. Vieira[1,2], S. K. Solanki[1,3], N. A. Krivova[1], and I. Usoskin[4]

(2011)

We compute the sunspot area, i.e. the fraction of the disk covered by all sunspots on the solar disk, by making use of a linear relationship to the sunspot number (*R) (Fligge & Solanki 1997; Balmaceda et al. 2009*; *Hathaway 2010*):

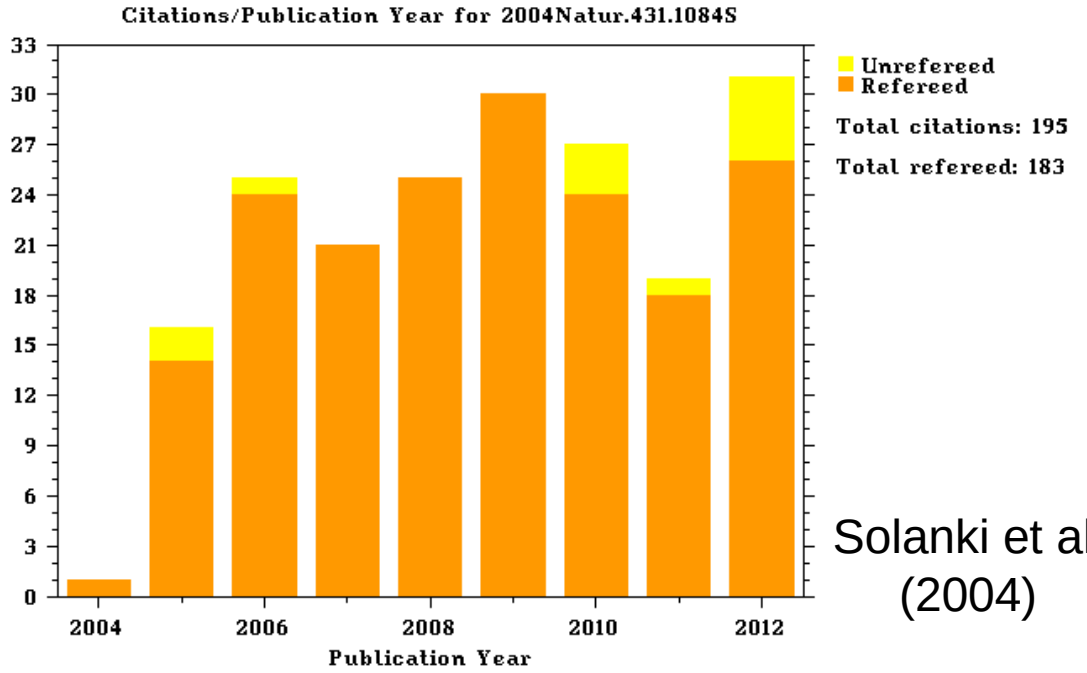
$$\alpha s = A1R + A2$$

2. It’s used for important applications

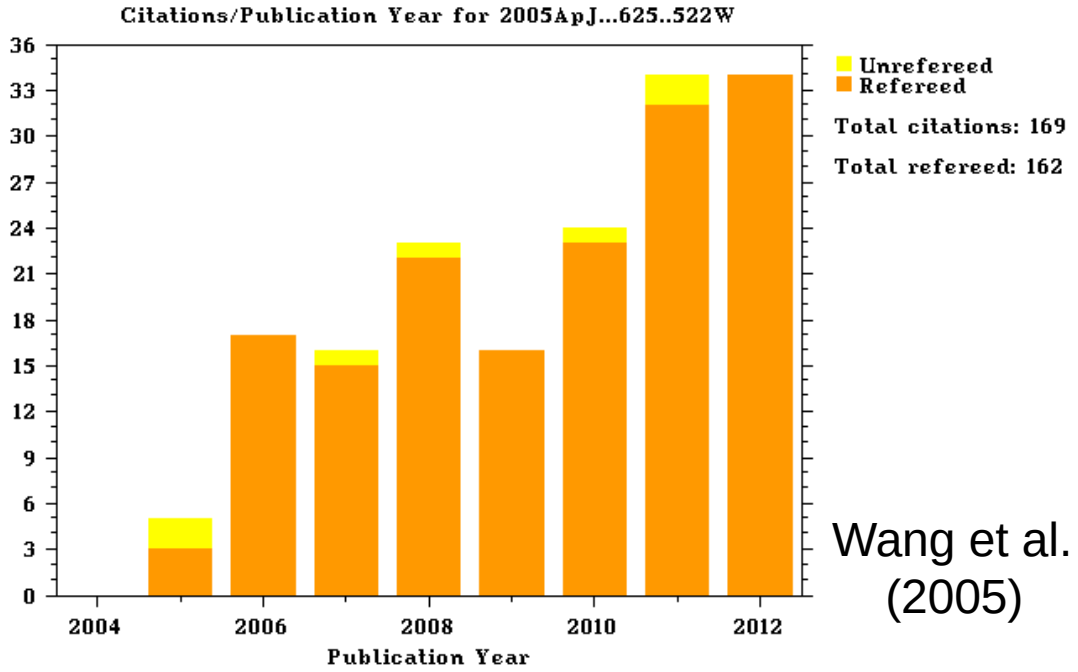
- Long-term solar variability

- Solar dynamo modeling

- Climate change

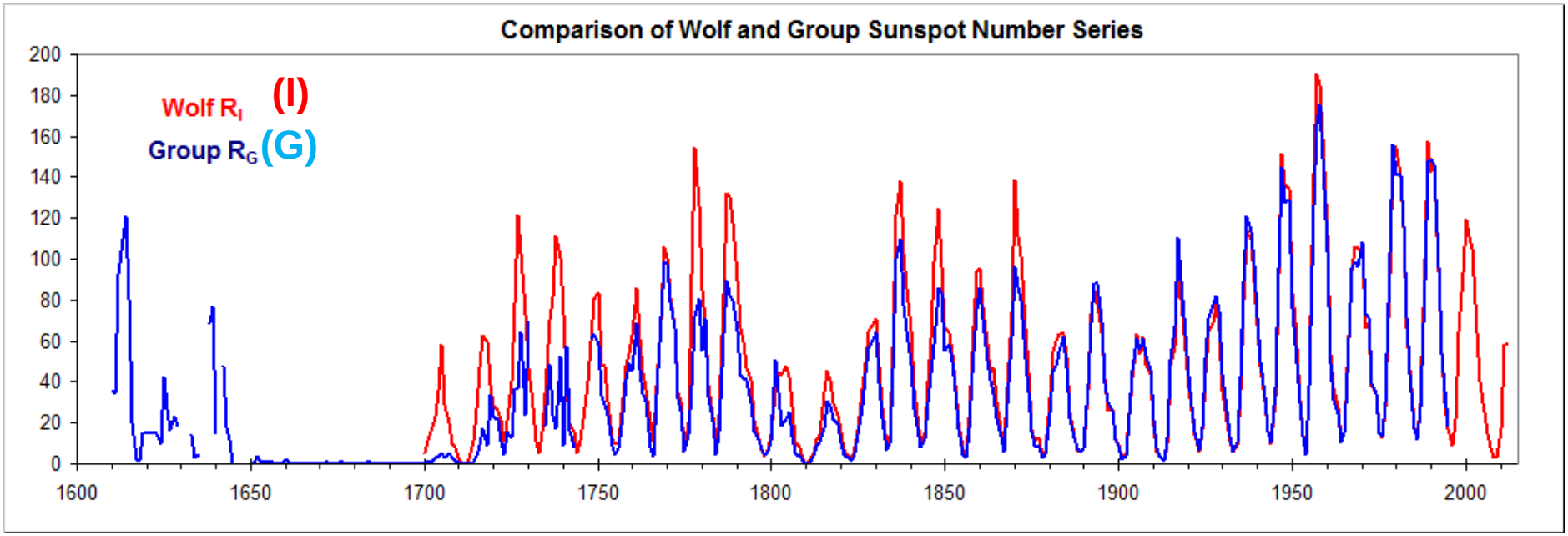


Solanki et al. (2004)



Wang et al. (2005)

3. We have two sunspot numbers
(that differ significantly before ~1885) …



(adapted from Hoyt & Schatten, 1994)

… with no consensus on which is more accurate

- Solanki et al. (2004) **G** (1610-present)
- Owens et al. (2012) **G** (1610-1995); **I** (1996-present)
- Pipin et al. (2013) **I** (1750-present)
- Passos (2012) **I** (1750-present
- Wang et al. (2005) **G** (1713-1996)
- Vieira et al. (2011) **I** (1700-present); **G** (1610-1700)

3(a). Sometimes the same authors use R_G in one paper & R_I in another

Centennial changes in the heliospheric magnetic field and open solar flux: The consensus view from geomagnetic data and cosmogenic isotopes and its implications

M. Lockwood[1,2] and M. J. Owens[1] **(2011)**

Used **G** before 1700 & **I** afterward

Cyclic loss of open solar flux since 1868: The link to heliospheric current sheet tilt and implications for the Maunder minimum

M.J. Owens[1,2], M. Lockwood[1] **(2012)**

Used **G** before 1995 & **I** afterward

"Where possible, we use group sunspot number, RG [Hoyt and Schatten, 1998], as it represents a more complete record than Zurich/International sunspot, RZ, particularly prior to 1850 [Hathaway et al., 2002]."

4. A long-term term parameter is needed to tie space-age measurements of solar & solar wind activity to > 10^4 years of cosmogenic nuclide data from tree-rings (^{14}C) and ice cores (^{10}Be)

- Sunspot number (since 1610)

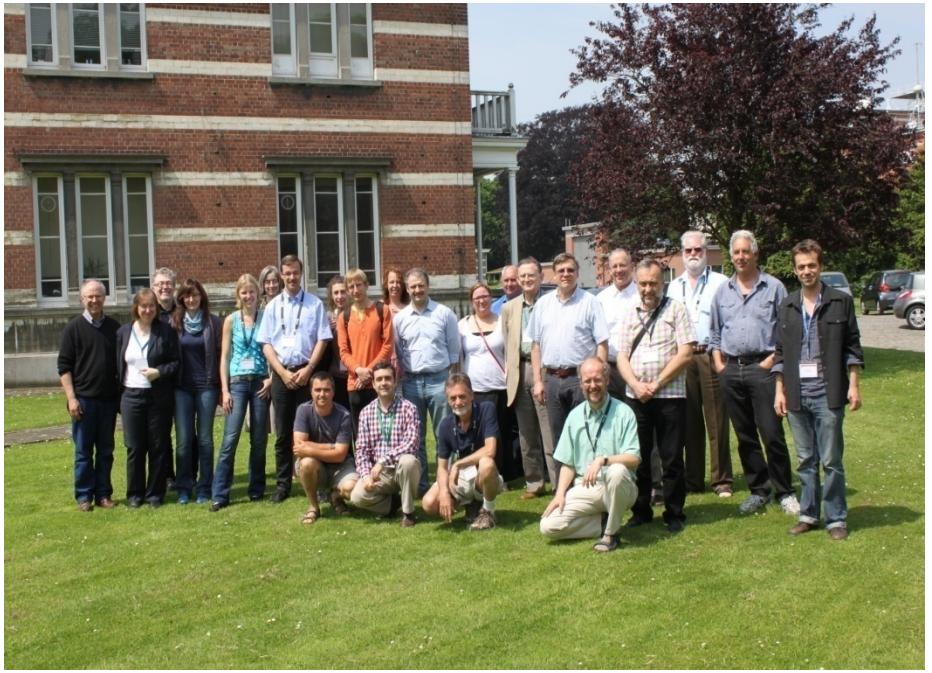
- Geomagnetic data (since ~1720)

Highlights of Workshops 1 & 2

1st SSN Workshop

NSO Sunspot, 19-22 September 2011

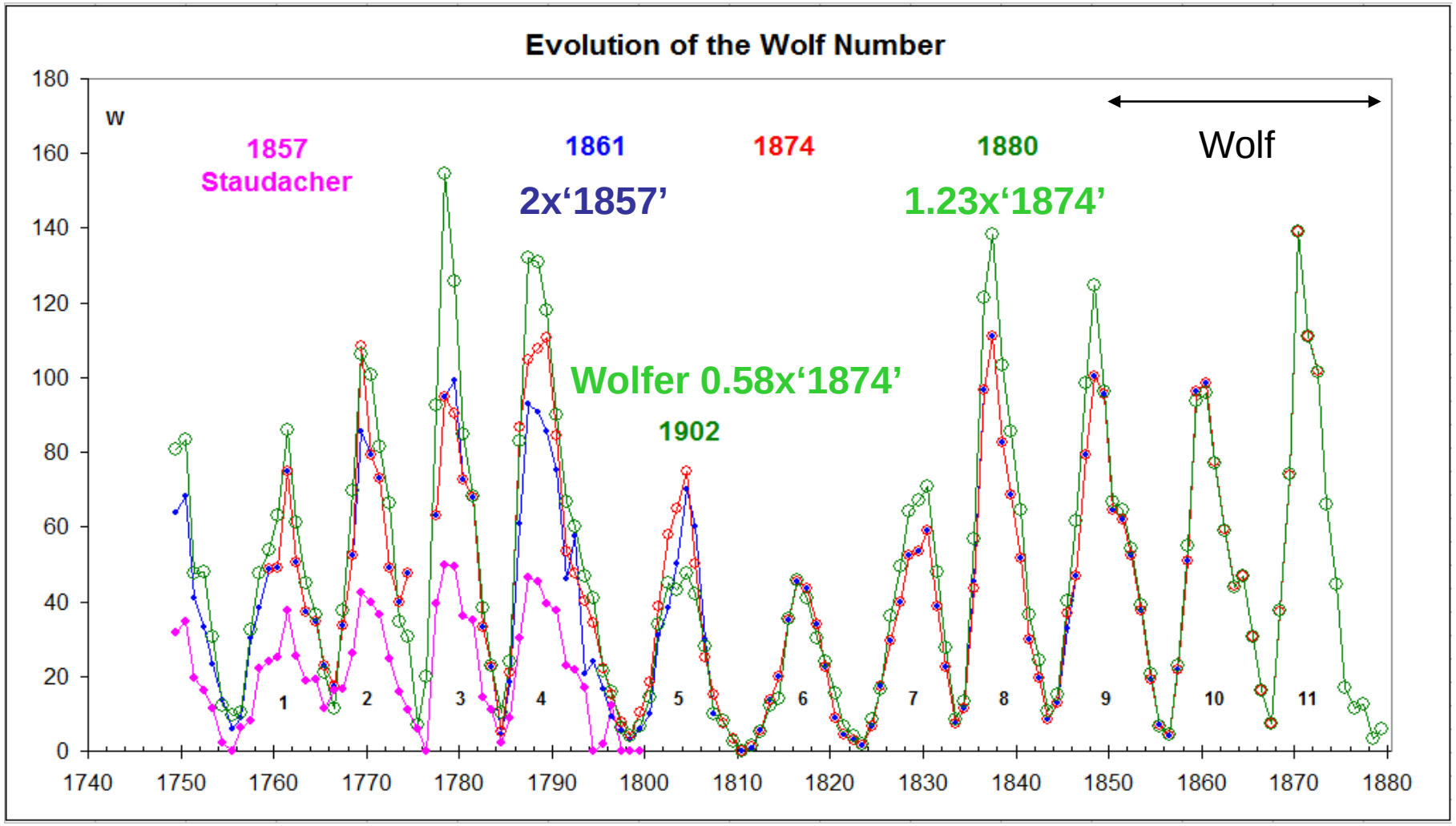
2nd SSN Workshop



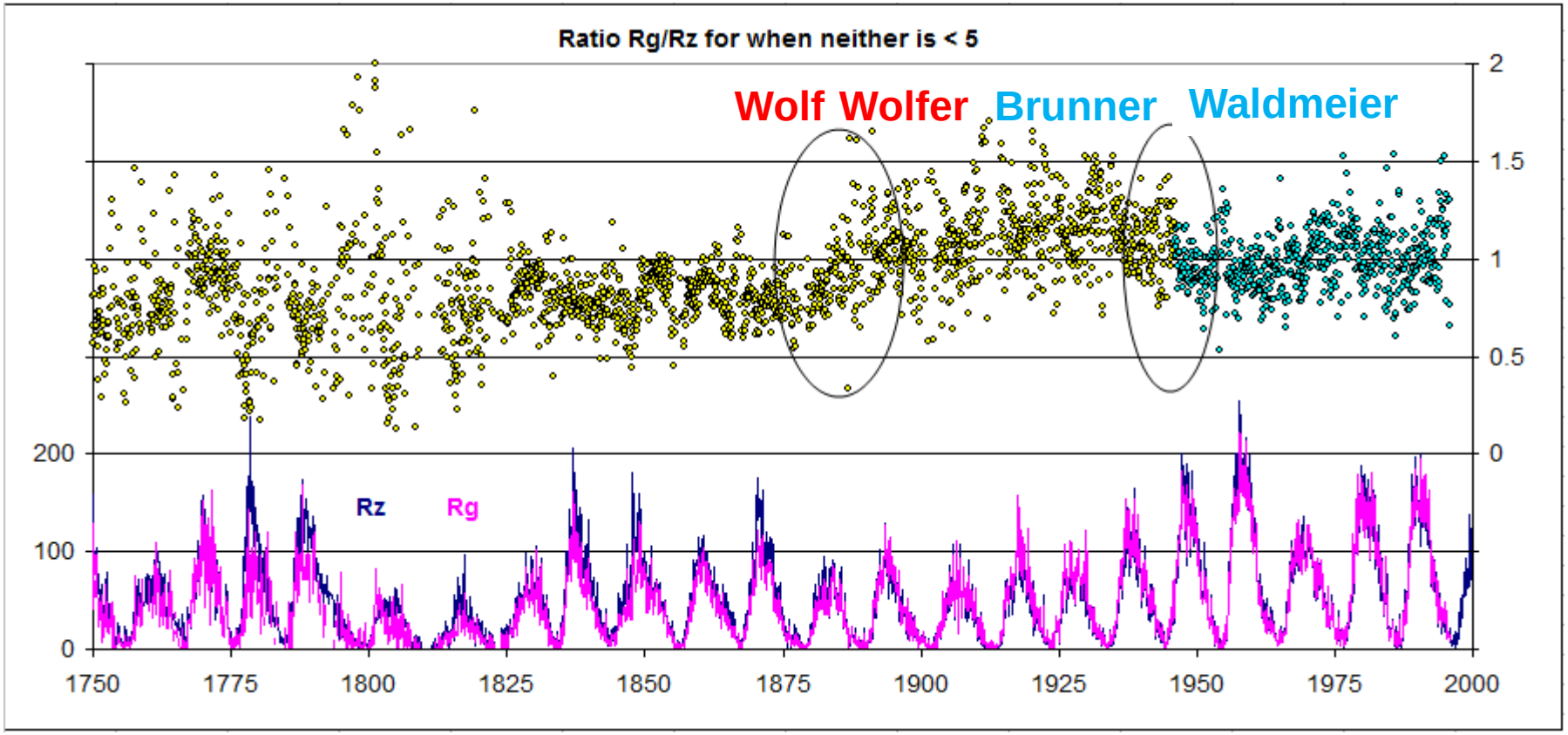
ROB Brussels, 21-25 May 2012

R_I is not a “pure” sunspot index; It is partially based on magnetic data

- During his life Wolf published several lists of his ‘Relative Sunspot Number’:
- 1857 Using Sunspot Drawings by Staudacher 1749-1799 for early SSNs
- 1861 Doubling Staudacher’s Numbers to align with the large variation of the Magnetic ‘Needle’ in the 1780s
- 1874 Adding newer data and published list
- 1880 Increasing all values before his own series [beginning 1849] by ~25% based on Milan Declination
- 1902 [Wolfer] reassessment of cycle 5 reducing it significantly, obtaining the ‘Definitive’ List in use today


Evolution of the Wolf Number
W
1857
Staudacher
1861
2x‘1857’
1874
1880
1.23x‘1874’
Wolf
Wolfer 0.58x‘1874’
1902
1
2
3
4
5
6
7
8
9
10
11
0
20
40
60
80
100
120
140
160
180
1740
1750
1760
1770
1780
1790
1800
1810
1820
1830
1840
1850
1860
1870
1880

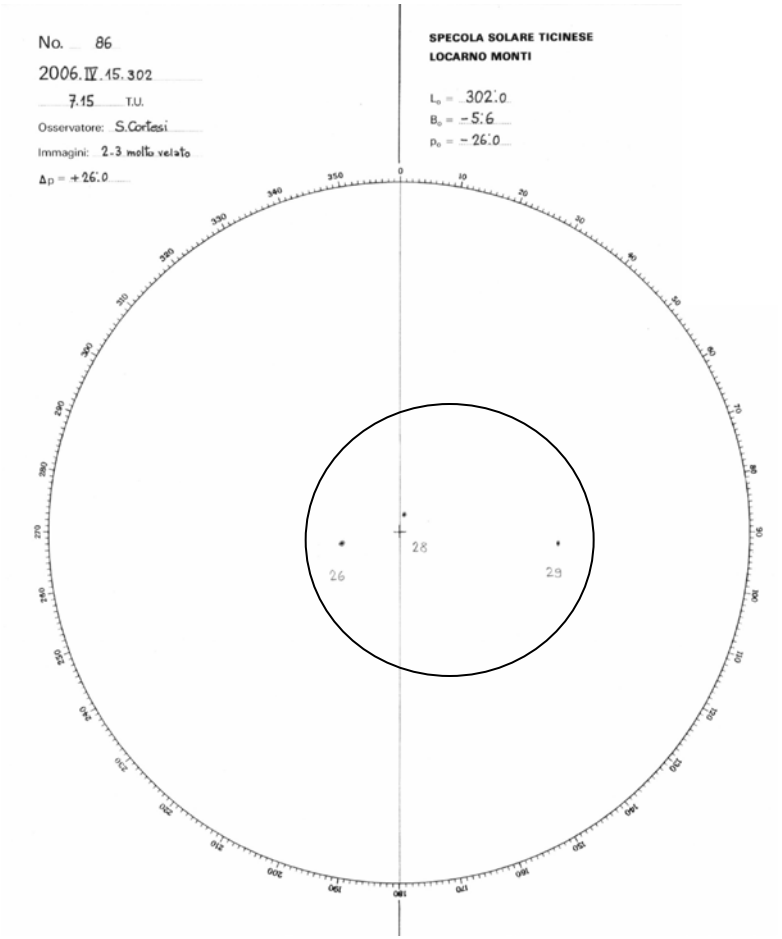
The Ratio of the Group to Zurich SSN has Two Significant Discontinuities



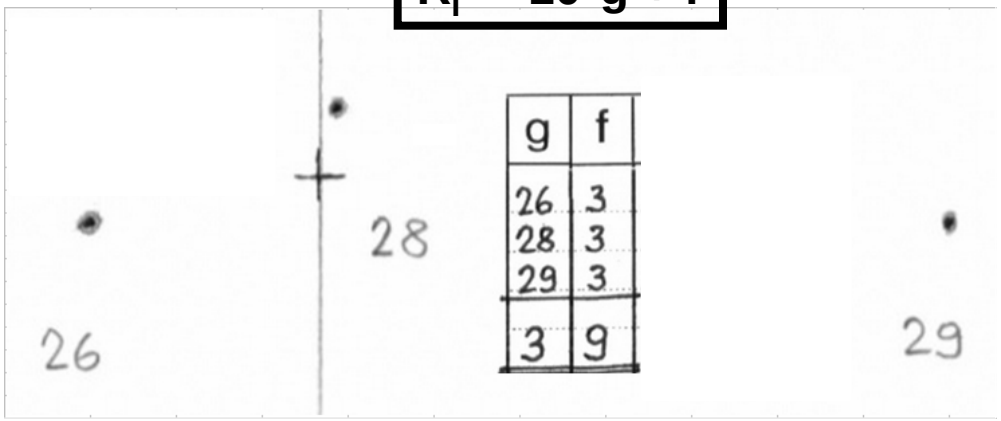
At ~1945 (after Max Waldmeier took over) and at ~1885

What caused the Waldmeier Discontinuity?

All sunspots are not equal



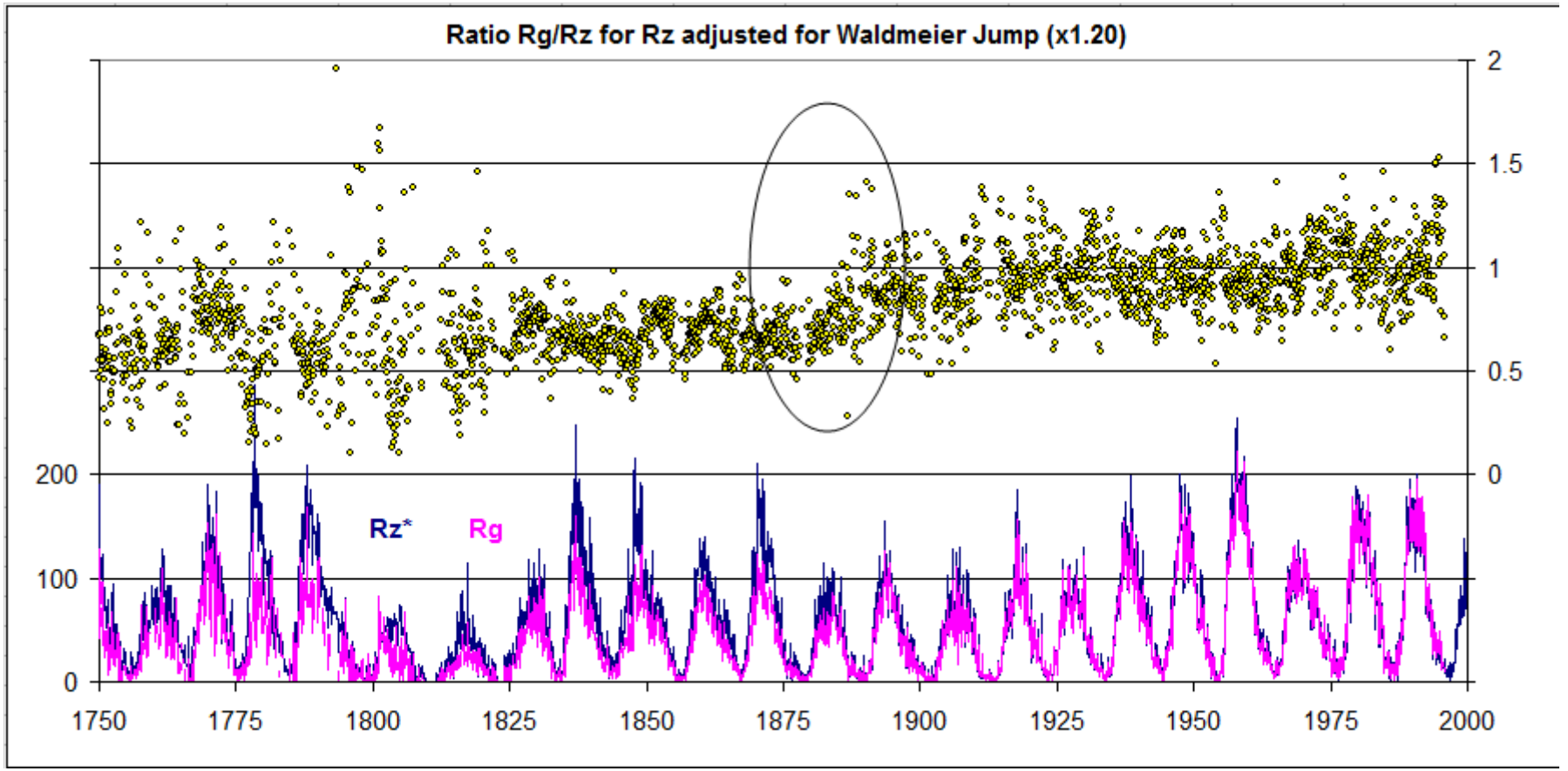
$R_I = 10*g + f$



Weights [from 1 to 5] were assigned according to the size of a spot. Here is an example where the three spots present were counted as 9, inflating the sunspot number by 18% [(3*10+9)/(3*10+3)=1.18]

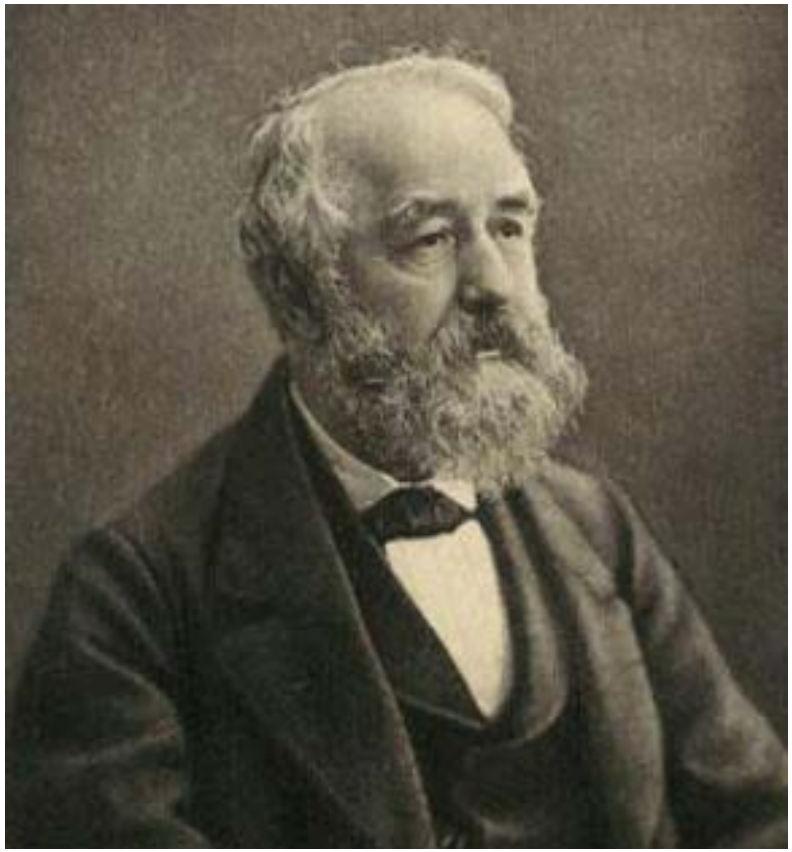
At some point during the 1940s the Zürich observers began to weight sunspots in their count

Removing the discontinuity in ~1946, by multiplying Rz before 1946 by 1.20, yields



Leaving one significant discrepancy, in ~1885

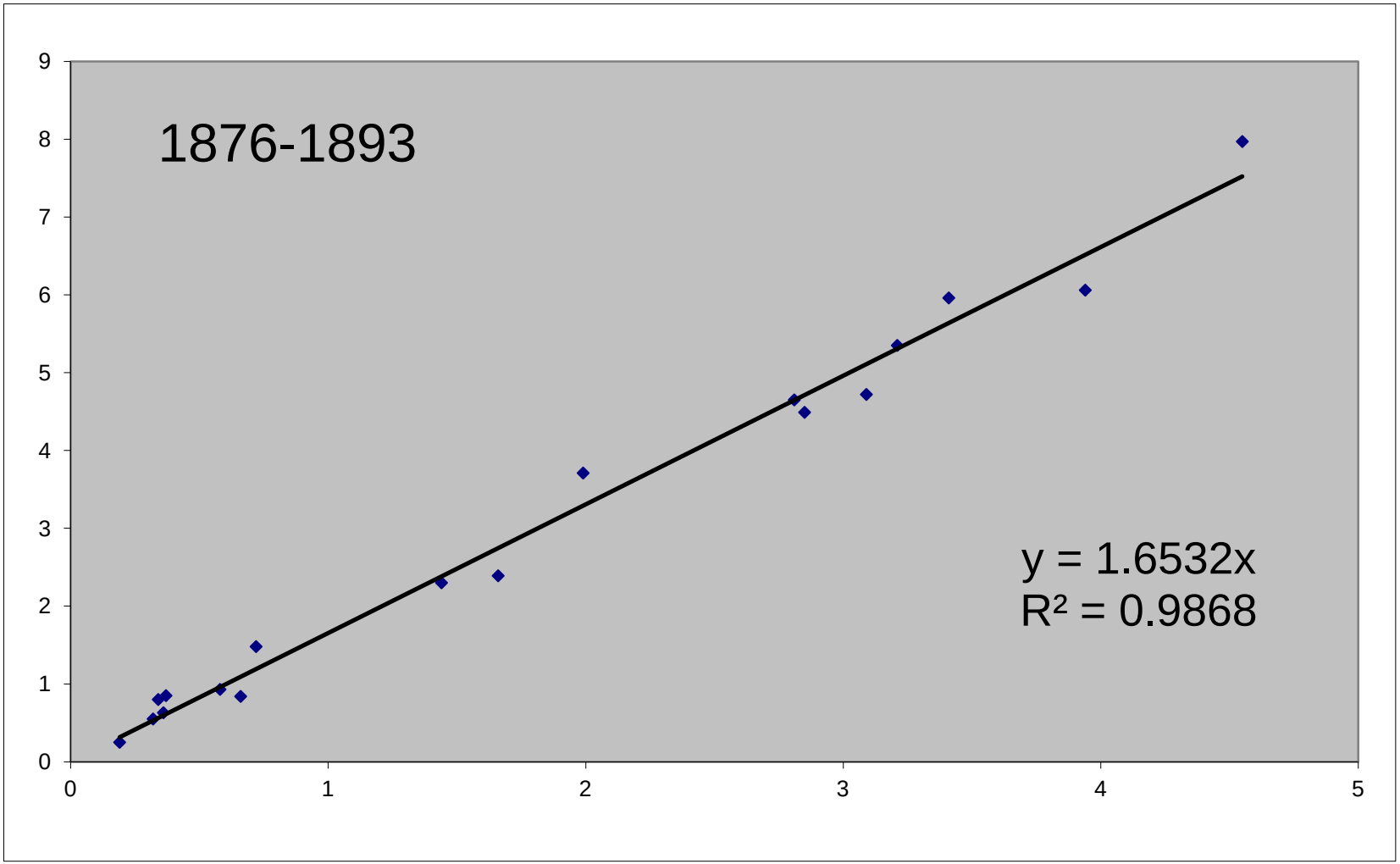
What caused the ~1885 Discontinuity?



Rudolf Wolf (1816-1893)
Observed 1849-1893

Alfred Wolfer (1854-1931)
Observed 1876-1928

- Wolf Number = k_W (10**G* + *S*)
- *G* = number of groups
- *S* = number of spots
- Group Number = 12 k_G *G*



Wolfer reported 65% more groups than Wolf

The ~1885 Discontinuity is caused by a flaw in the Hoyt & Schatten R_G

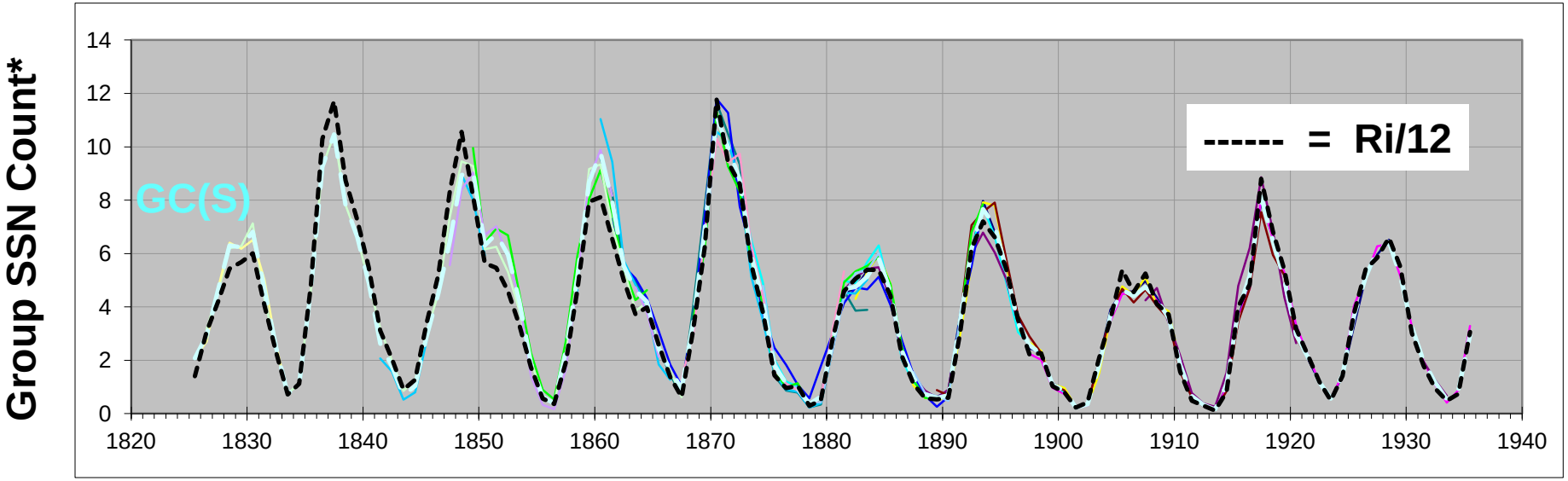
K-factor Comparison

	S (Wolfer)	H&S (RGO)
A. Wolfer	1.00	1.094
R. Wolf	1.65	1.117
K_G	1.65	1.02

Svalgaard (S) Independent Group Sunspot Number Determination

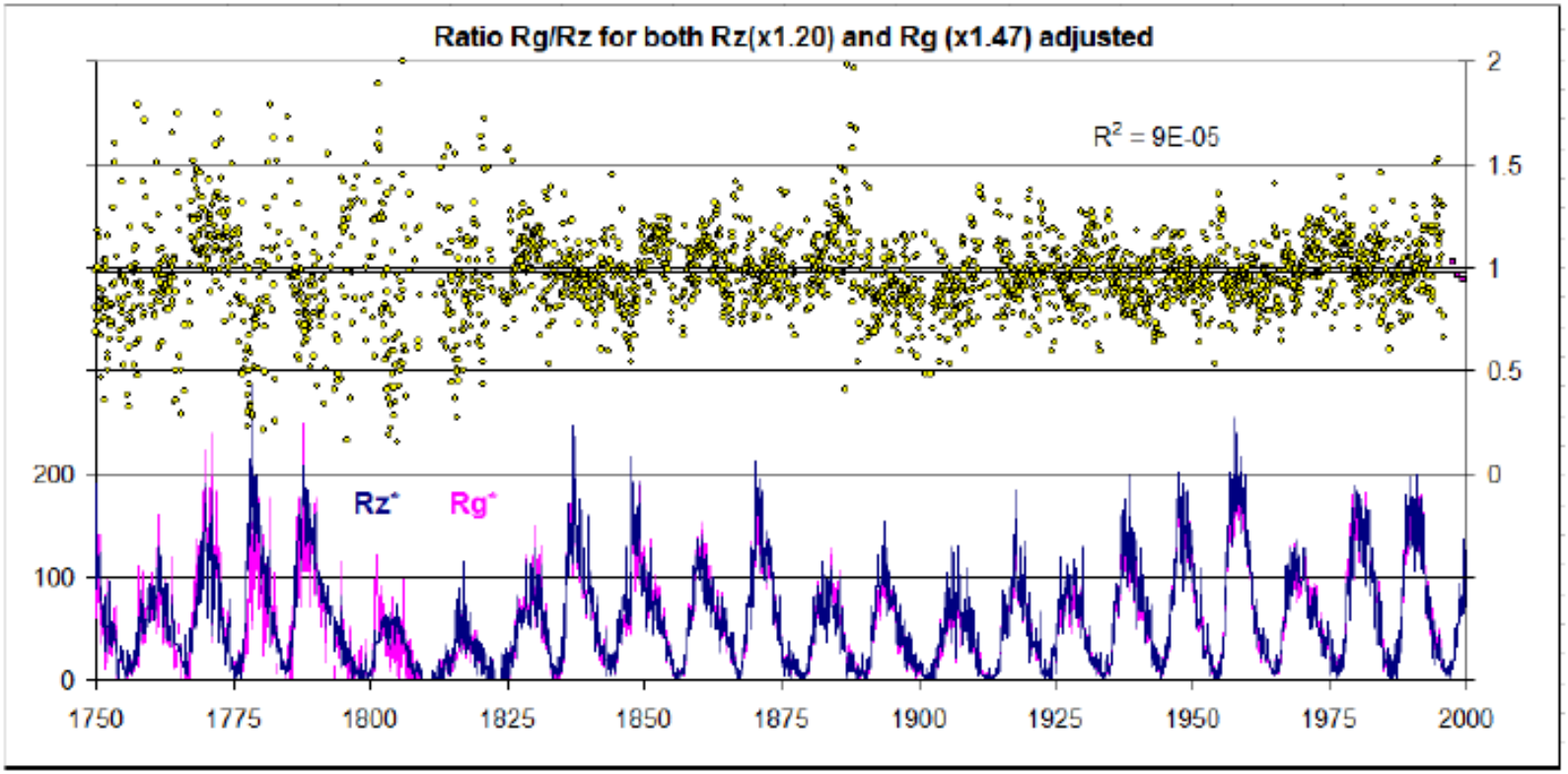
- Includes all major observers from 1825-1935
  (Wolfer, Broger, Leppig, Madrid, Moncalie, Pastorff, Quimby, Schmidt, Schwabe, Shea, Spoerer, Tacchini, Weber, Winckler, Wolf)

- Based on group counts (scaled to Wolfer)



No significant systematic difference between Ri /12 & Group Counts => R_I and R_G reconciled to 1825

Removing the discontinuity in ~1885 by multiplying Rg by 1.47, yields



Only two adjustments remove most of the disagreement after 1825

and the evidence for a recent grand maximum (1945-1995)

Goals of the SSN workshops

- Reconcile/understand the discrepancy between G & I SSN series (1610-present)

- Document tools that can be used to keep track of the SSN for the foreseeable future (regular ionospheric variation, F10, sunspot area)

- Understand what happened during the recent solar minimum (and perhaps the Maunder Minimum)

- Publish a vetted and agreed upon single SSN time series with error bars that can be used as a bridge to the millennia of proxy solar data in ice cores and tree rings

Challenges

- Locating, reducing, archiving, & intercalibrating early SSN, geomagnetic & cosmogenic nuclide data

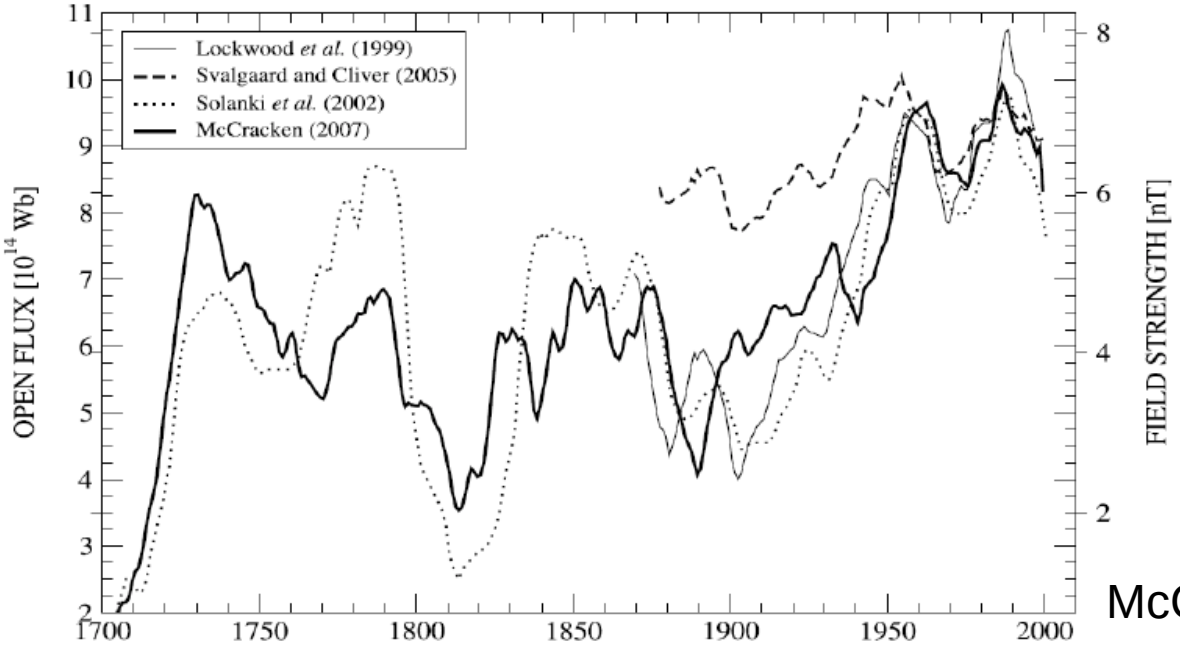
- Using these data to determine a single SSN time series

- Exploring/understanding the Livingston-Penn effect on historical sunspot data

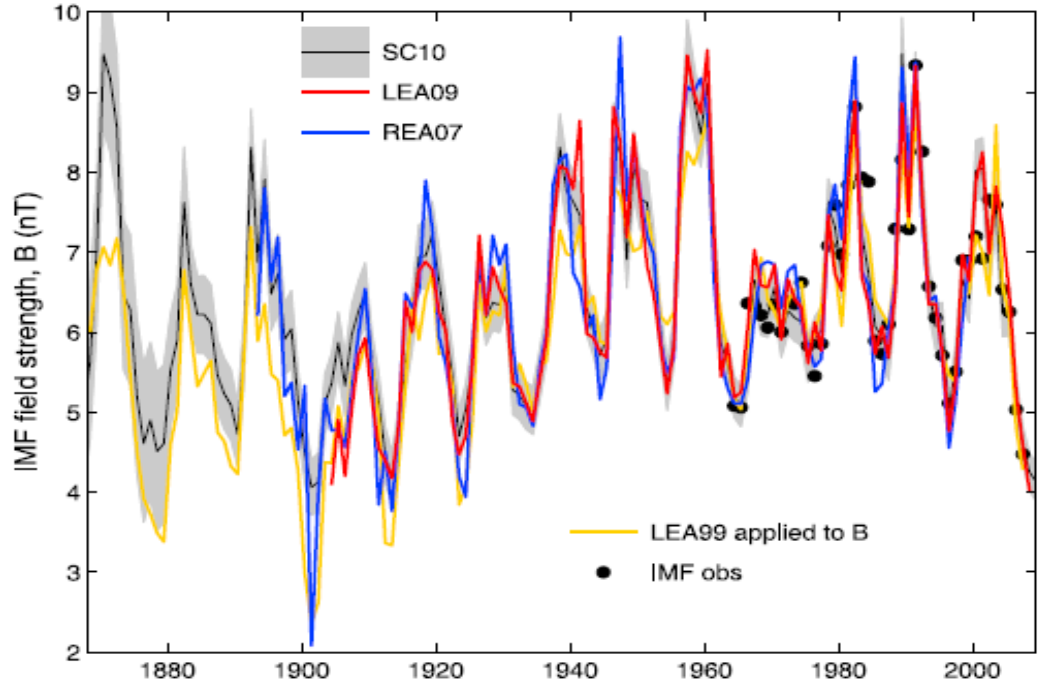
- Determining the effect of earth's decreasing dipole field strength on the regular ionospheric variation ✓

This will take time

- 1-2 more workshops over the next two 1-2 years



McCracken (2007)



Lockwood & Owens (2011)