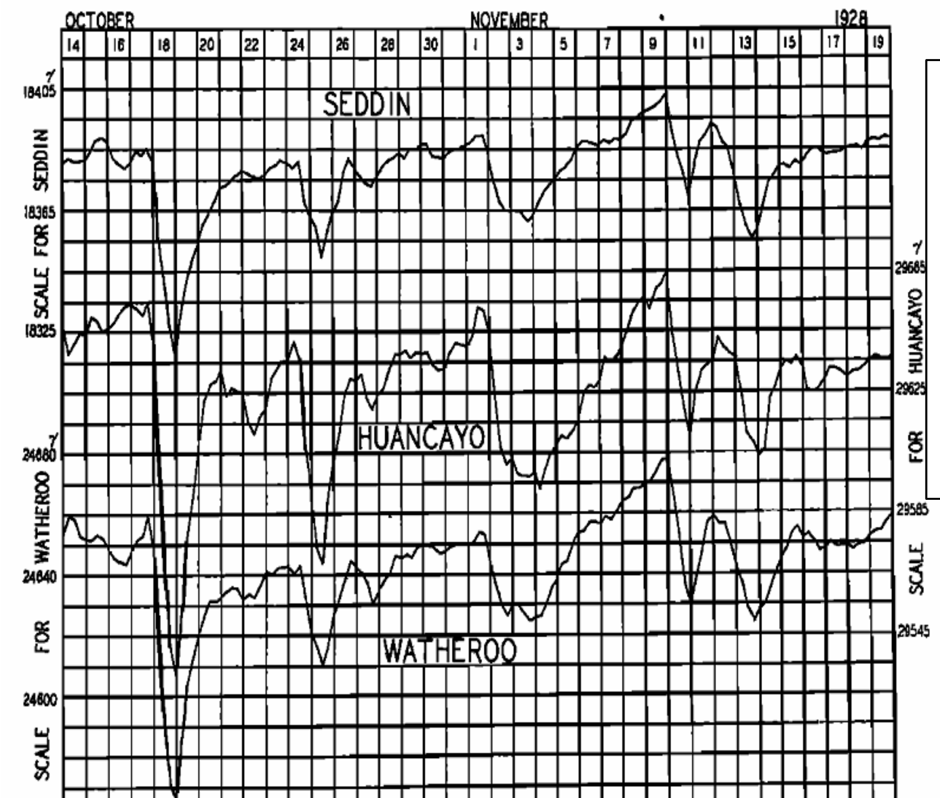
Confronting Models with Reconstructions and Data

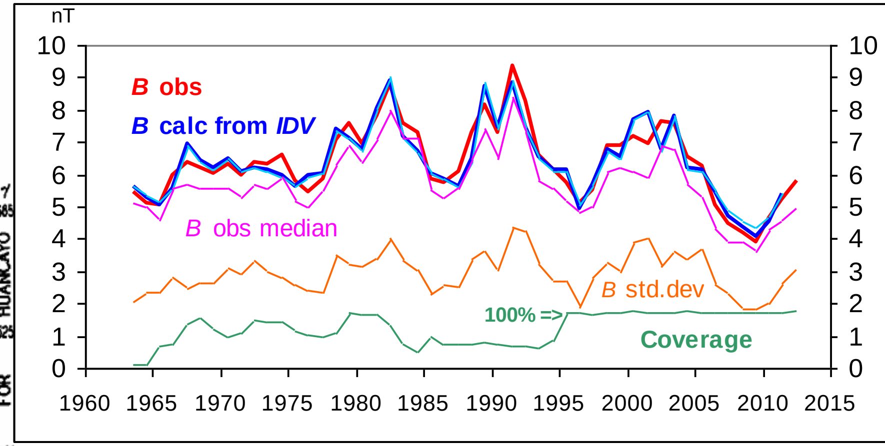
Leif Svalgaard
HEPL Stanford University
Boulder, June 2014

ESWE Workshop Presentation
Session 9: Understanding the Maunder Minimum

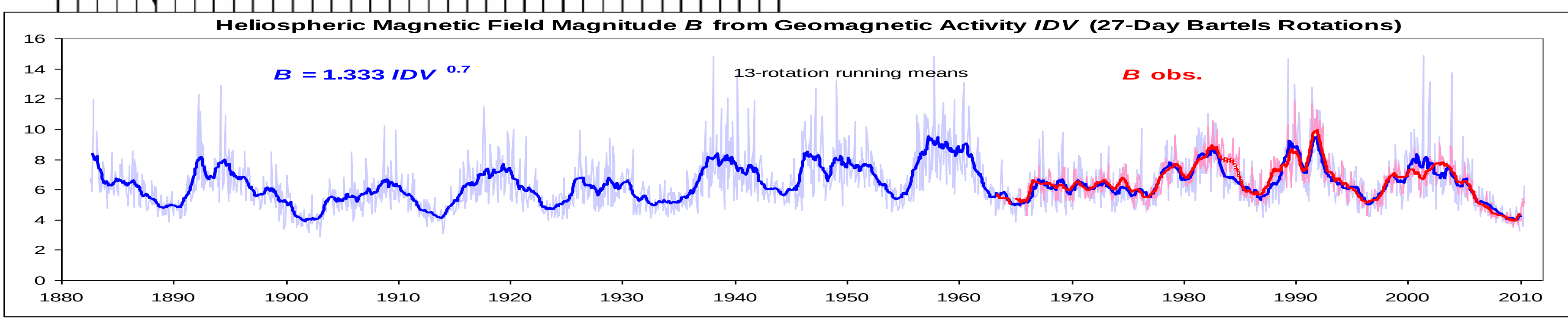
To predict Extreme Events we need to understand Ordinary Events and Ordinary ‘Background’ in the historical setting

How do we Infer HMF B?

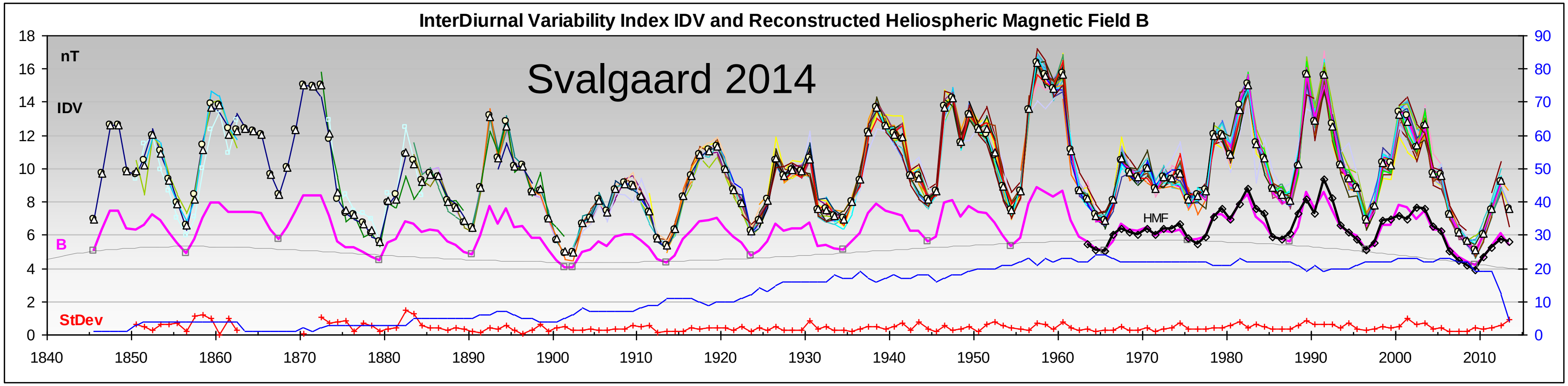


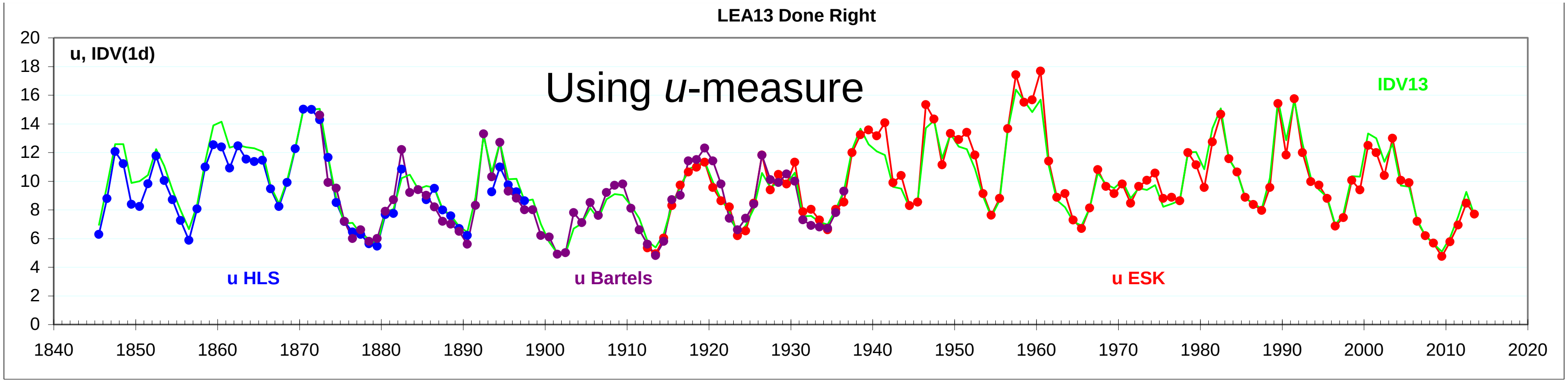


The IDV-index is the unsigned difference from one day to the next of the Horizontal Component of the geomagnetic field averaged over stations and a suitable time window. The index correlates strongly with HMF B [and not with solar wind speed]. The u-measure is like IDV using daily avg.



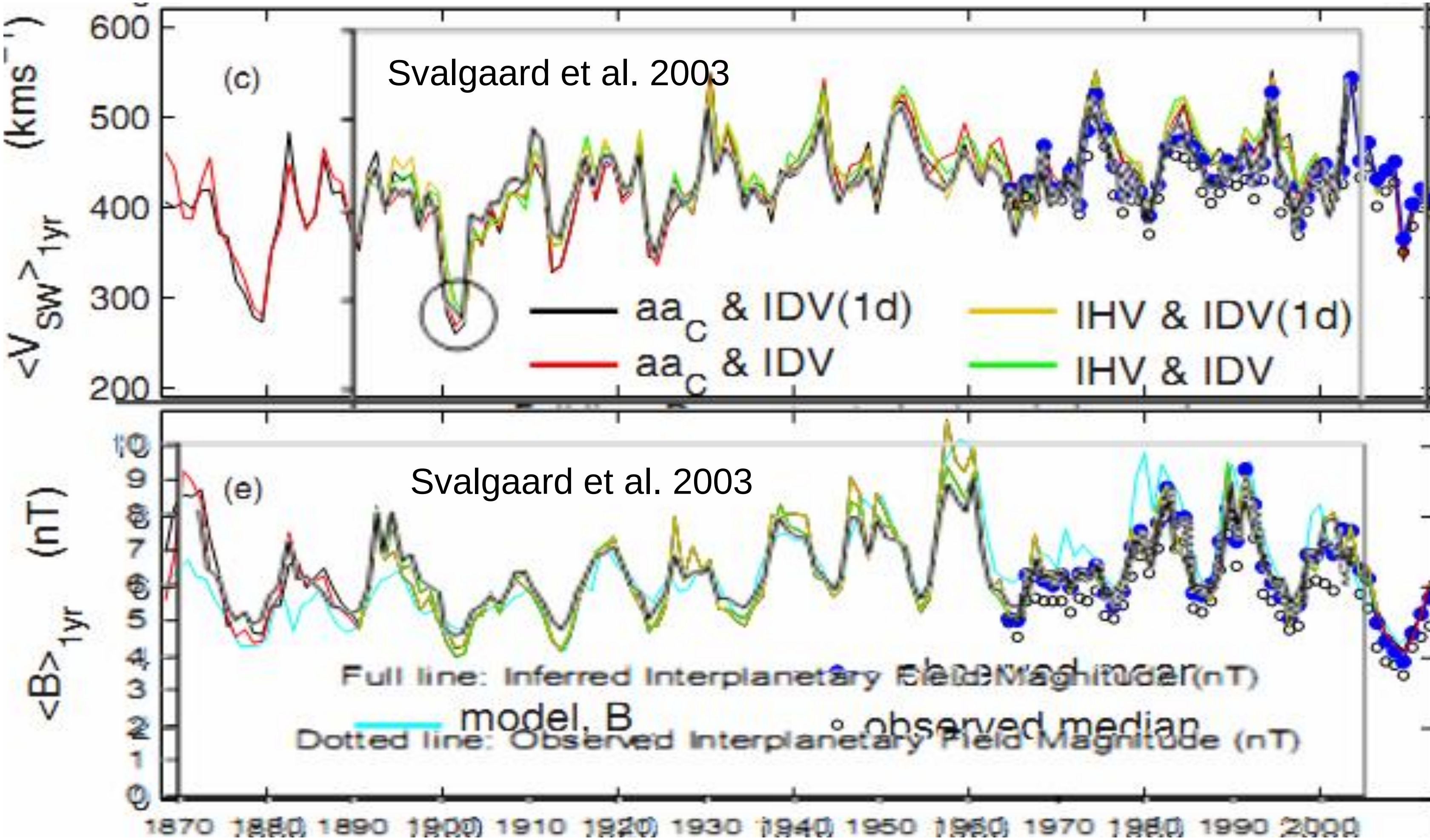
Progress in Reconstructing Solar Wind Magnetic Field back to 1840s



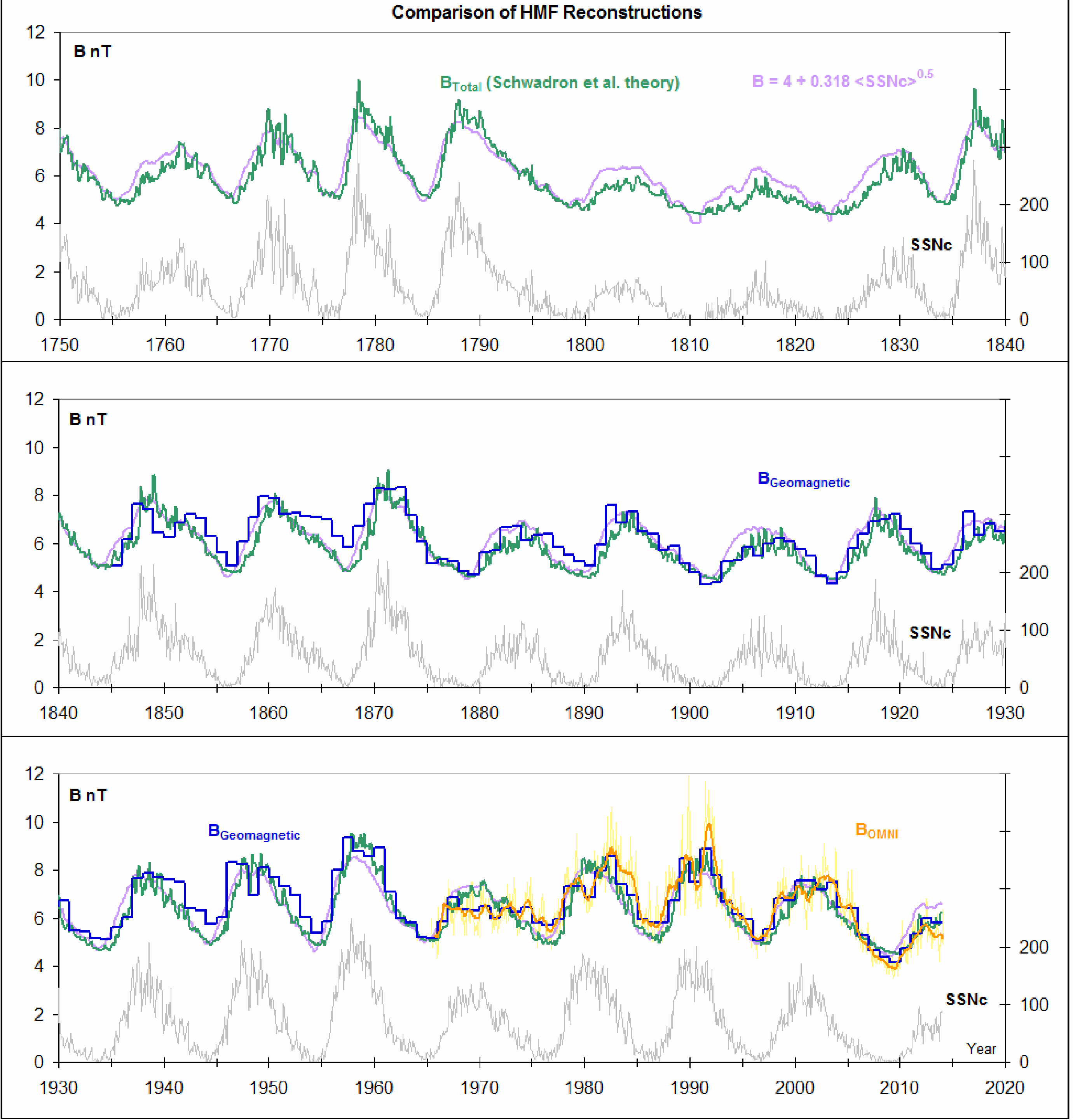


Even using only ONE station, the 'IDV' signature is strong enough to show the effect

After a Decade of Struggle, Lockwood et al. (2014) are Fast Approaching the Svalgaard et al. Reconstructions of 2003



This is a healthy development and LEA should be congratulated for their achievement, although their **model**, based on a flawed Sunspot Number series, is not doing too well



Schwadron et al. (2010) HMF B Model, with my set of parameters

von Neumann: “with four parameters I can fit an elephant, and with five I can make him wiggle his trunk”

This model has about eight parameters…

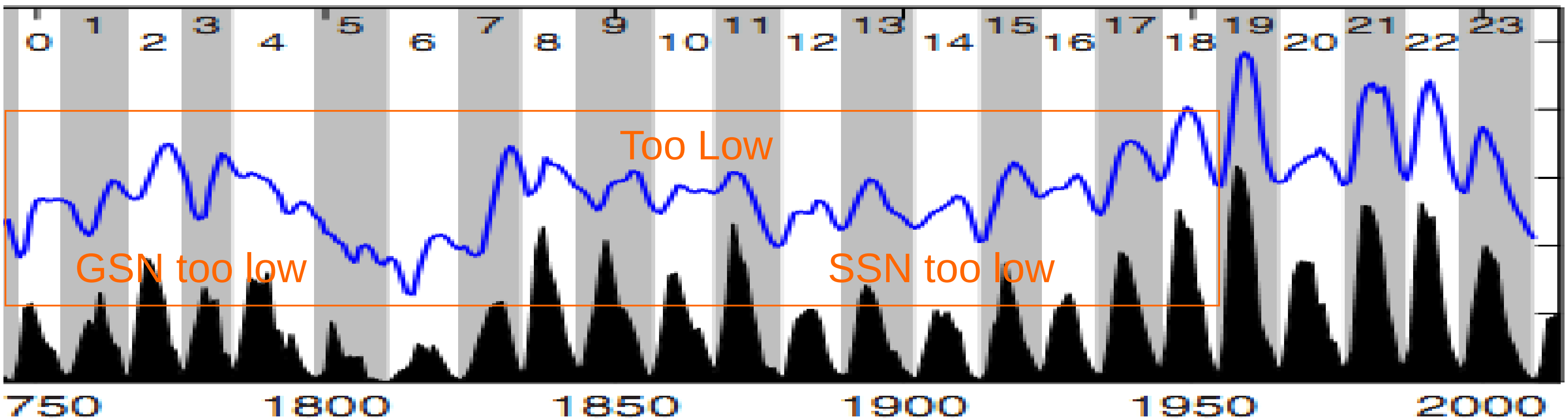
> “It is not clear if the version of the code obtained from the original authors is incomplete or in some other way inaccurate”

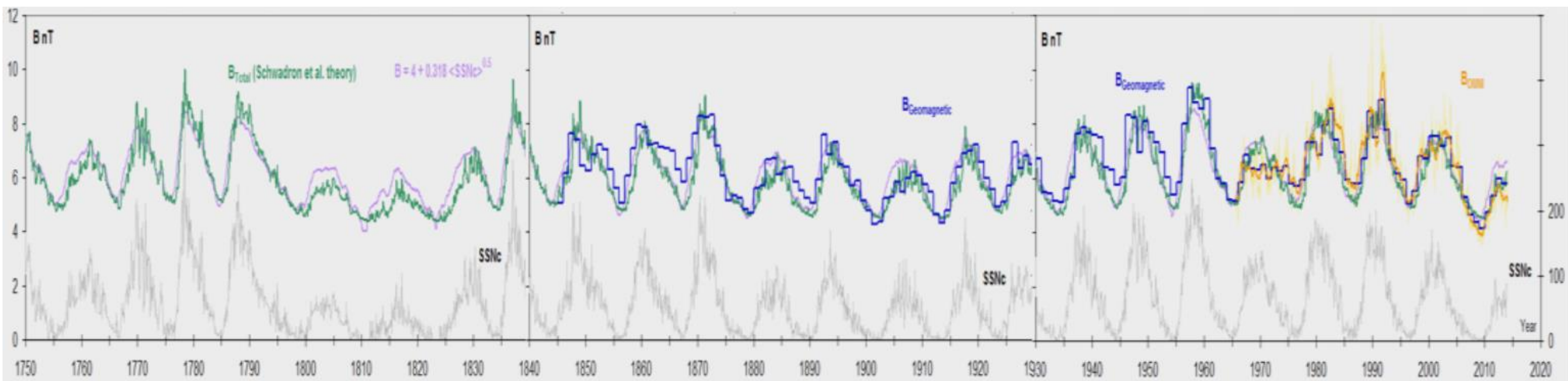
My Parameter Set

Svalgaard	Goelzer	Unit	Description
0.04	0.04	Number	Number of CMEs per day per unit sunspot number
0	0	Number	Offset in calculating ejection frequency = offset + CMEs per day * Sunspot Number
15	20	Days	Timescale for interchange reconnection
4.0	2.5	Years	Timescale for opening of closed flux
3.0	6.0	Years	Timescale for loss of flux by disconnection
1	1	10^13 Wb	Magnetic flux per CME
56	0	10^13 Wb	Magnetic flux over whole sphere for a Floor in the HMF radial B
0.6	0.5	Fraction	Fraction of flux closing on ejection
1.5	N/A	Factor	Factor to convert computed, ideal 'Parker' spiral B to messy, total B
N/A	0.5-2.4	nT	Offset to convert computed, ideal 'Parker' spiral B to messy, total B

Equally good fit with only 2½ parameters <B(year)> nT = 4 + 0.318 $SSN^{0.5}$

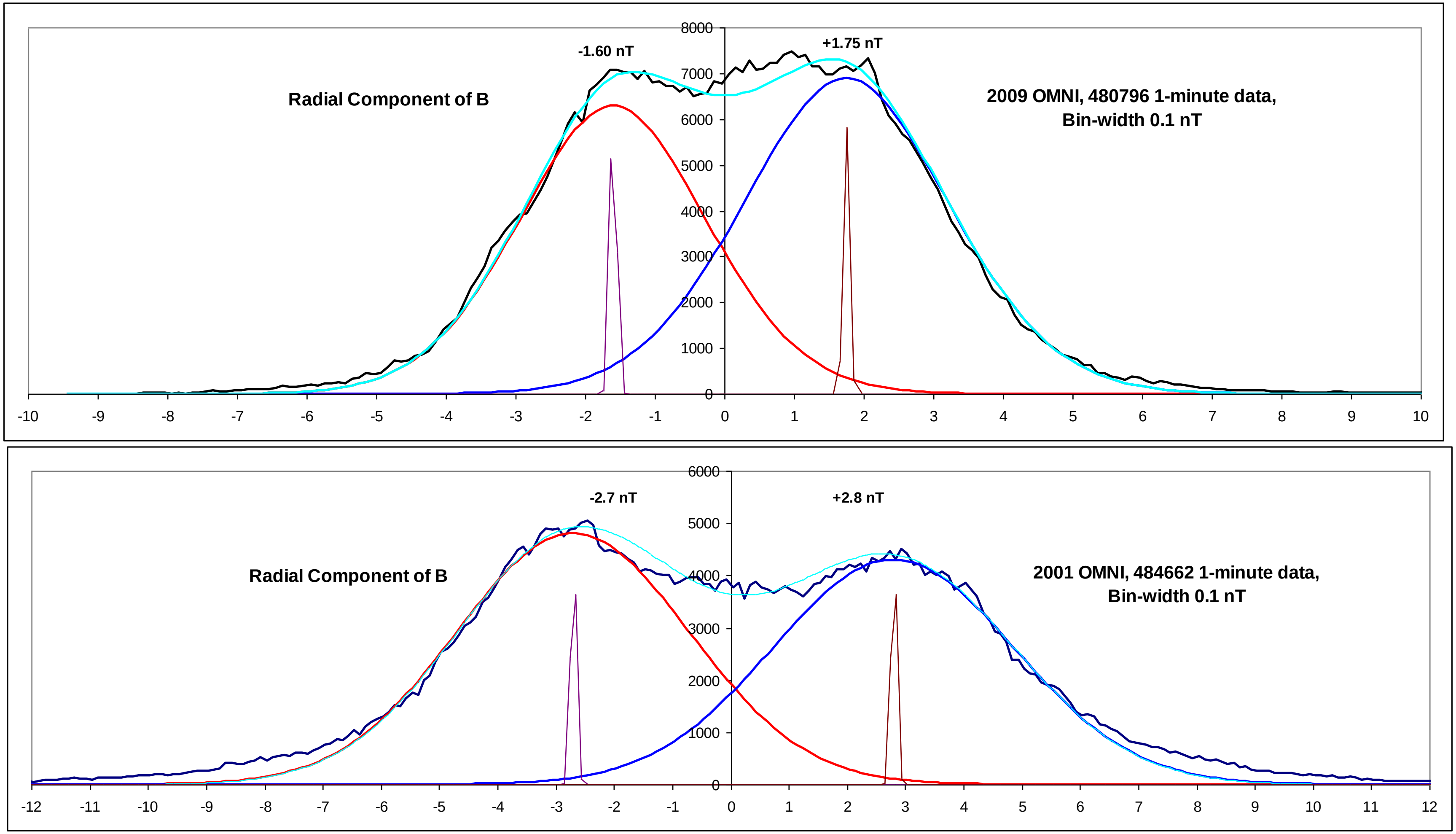
The Tale of Two Models…





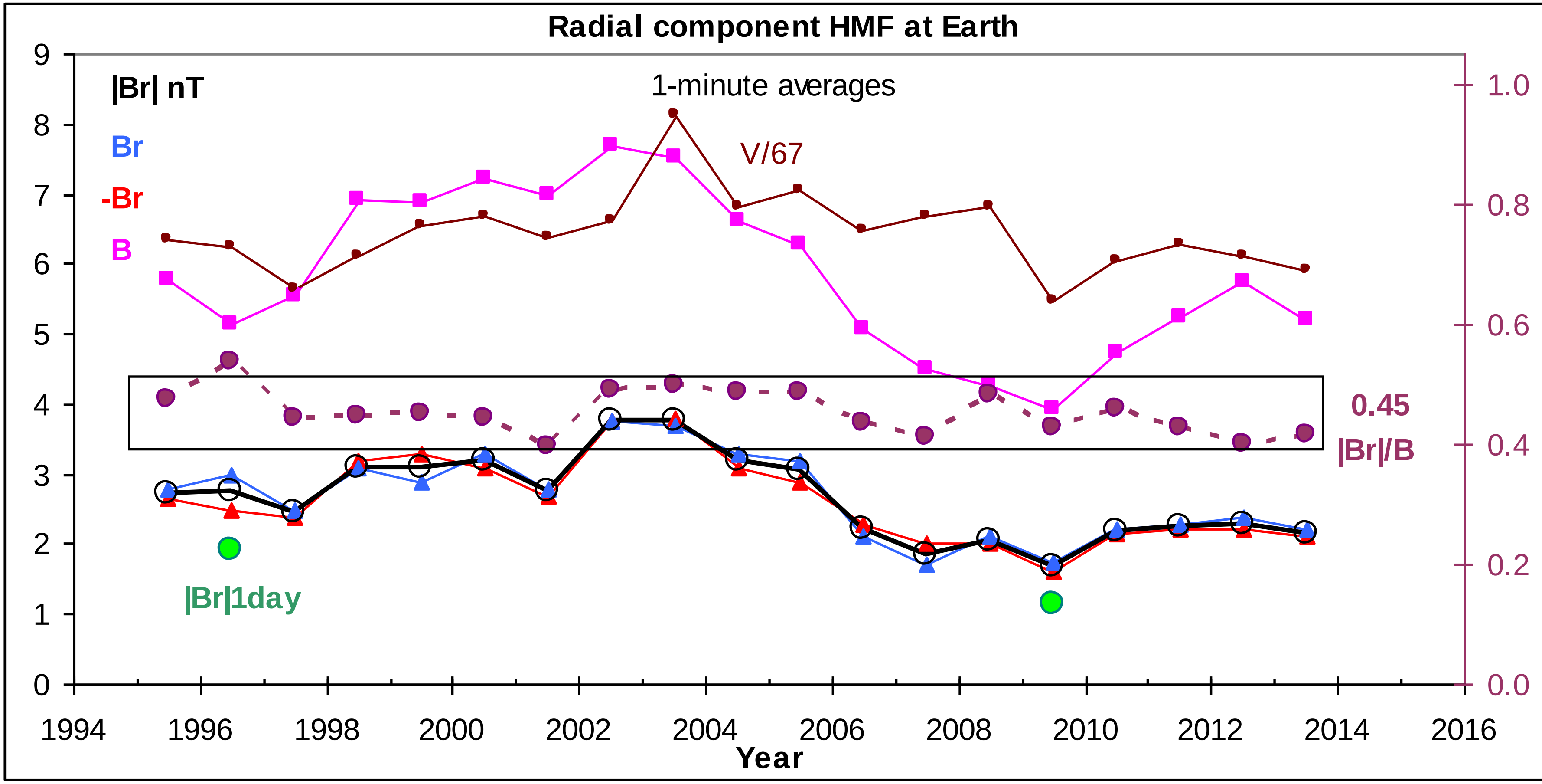
The models operate with the ‘open [radial] flux’, so it is important to get that right

Finding the Radial Component of B



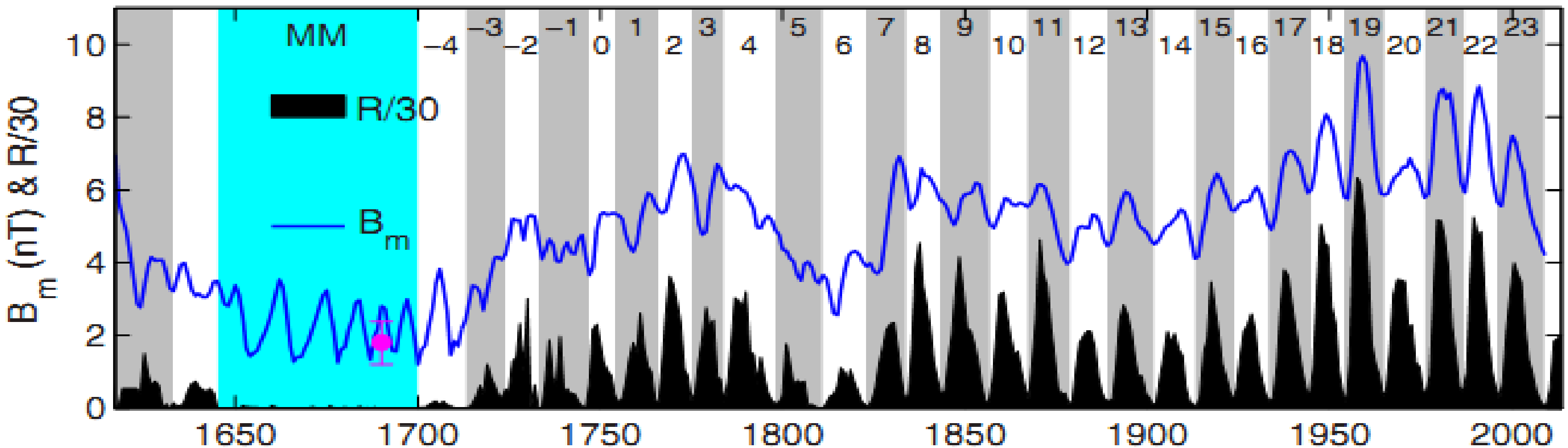
Treat the observed radial component as the sum of two Gaussians, one positive and one negative using high-resolution [1-minute] data.

Ratio |Br|/B is Nearly Constant



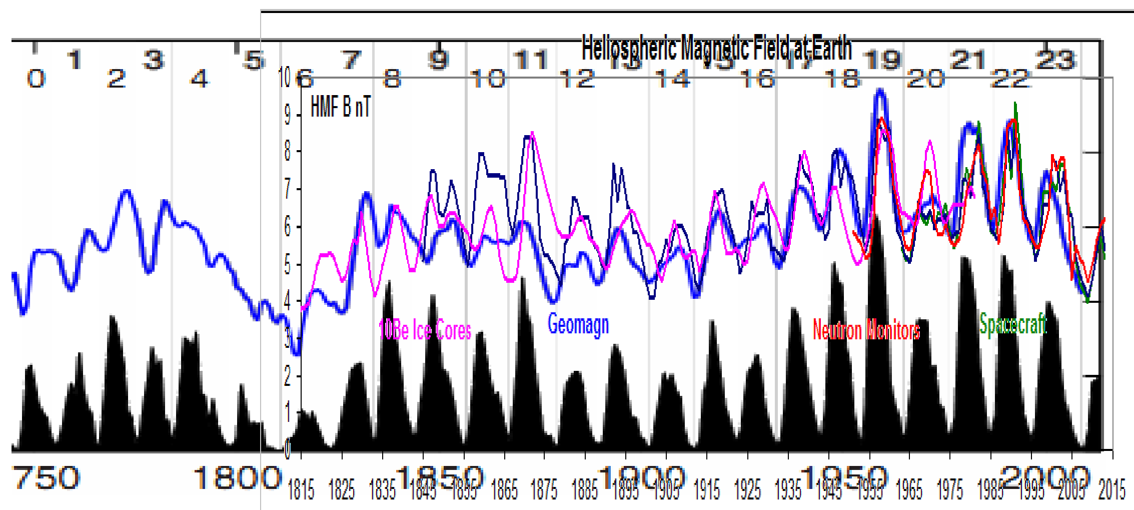
Lockwood 2014: "At the last three solar minima, the near-Earth IMF B were 5.55 nT, 5.10 nT, and 3.87 nT while |Br|**1day** were 2.28 nT (|Br|/B = 0.41), 1.91 nT (0.37), and 1.14 nT (0.29)". These are clearly seriously too low.

Comparing with 'Data'



Cosmic Ray proxies and IDV reconstructions show that the Model falls short before the 1940s.

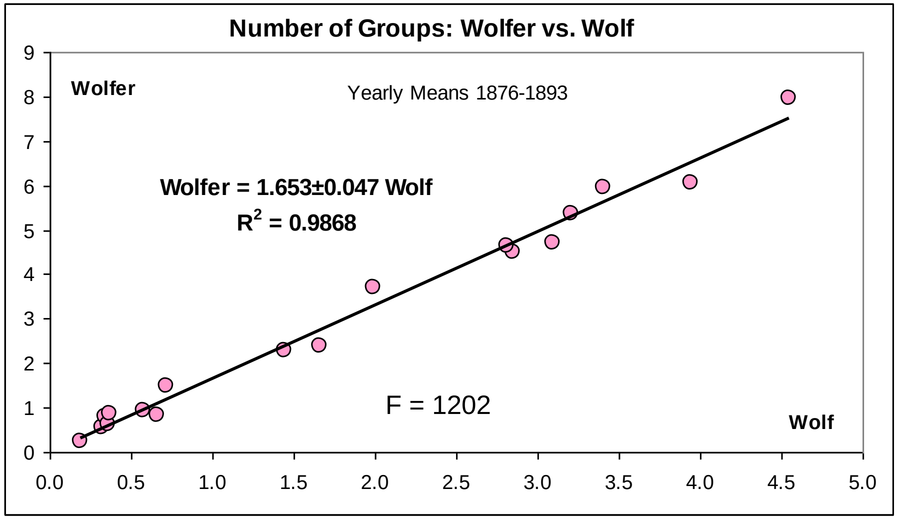
This makes it dubious that the modeled HMF B for the Maunder Minimum is quantitatively correct.

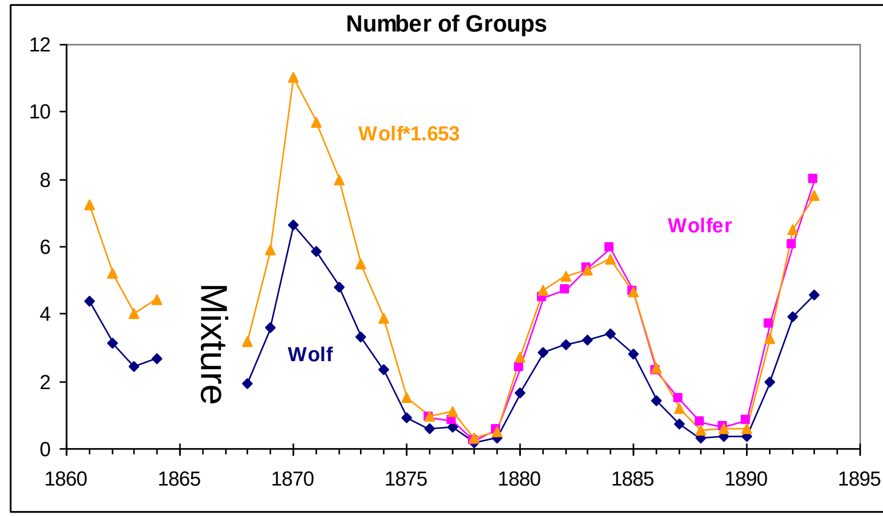


As the Sunspot Number is used as input it is important to get that right

- Four recent Sunspot Number Workshops (2011-2014) have critically examined the historical sunspot number record(s)
- There is now broad consensus among the participants that we have identified the major problems with the SSN series:
- A) Error in Wolf-Wolfer calibration for the GSN before ~1882
- B) Weighting of sunspot counts for the Int. SSN starting in 1940s
- A preliminary new series [the Wolf Number] is being constructed [ETA 2015]

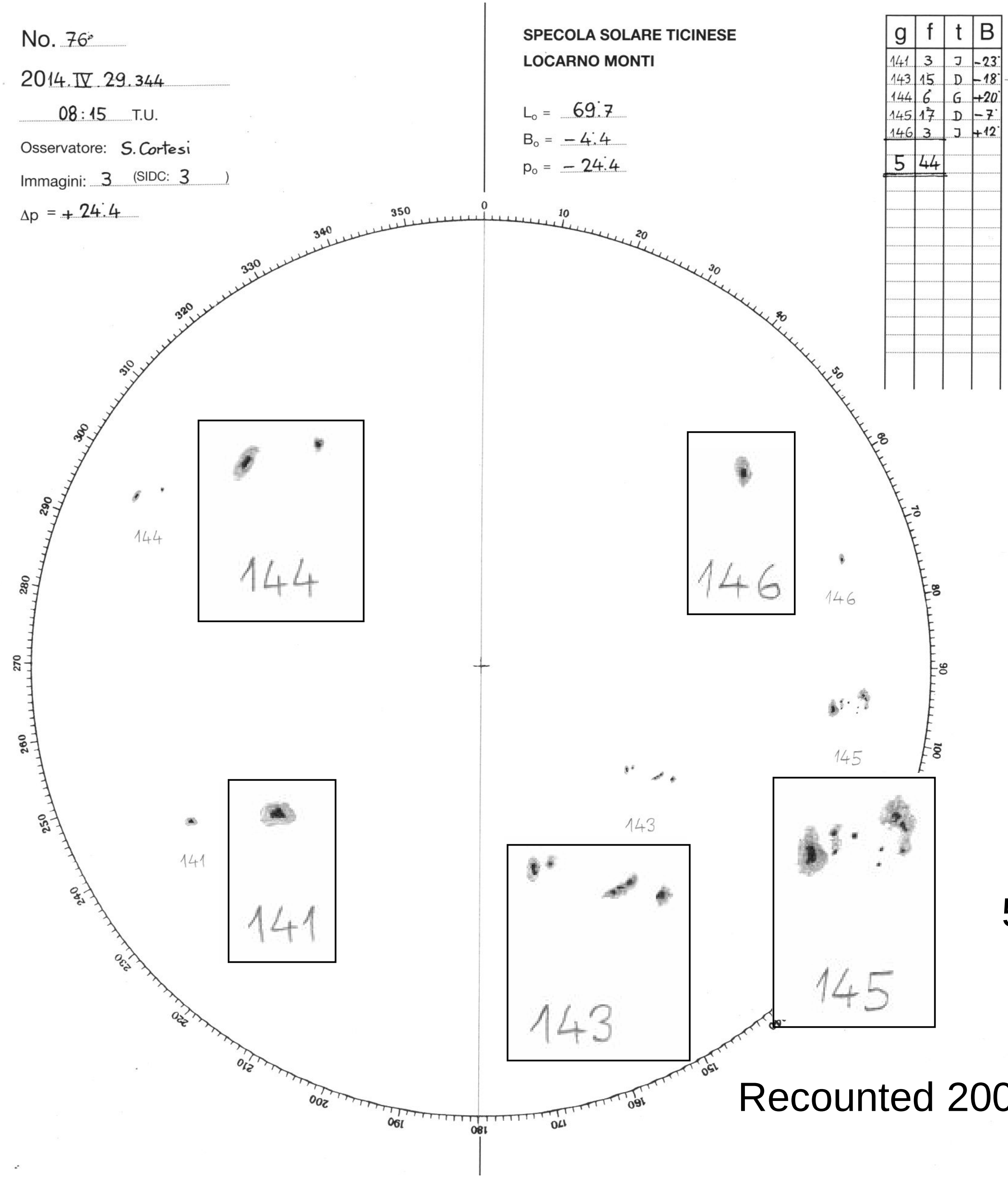
Normalization Procedure for GSN





For each Backbone we regress each observers group counts for each year against those of the primary observer, and plot the result [left panel]. Experience shows that the regression line almost always very nearly goes through the origin, so we *force* it to do that and calculate the slope and various statistics, such as 1-σ uncertainty and the *F*-value. The slope gives us what factor to multiply the observer's count by to match the primary's. The right panel shows a result for the Wolfer Backbone: blue is Wolf's count [with his small telescope], pink is Wolfer's count [with the larger telescope], and the orange curve is the blue curve multiplied by the slope. H&S have an incorrect normalization factor close to unity for Wolf-Wolfer.

Counting with no Weighting



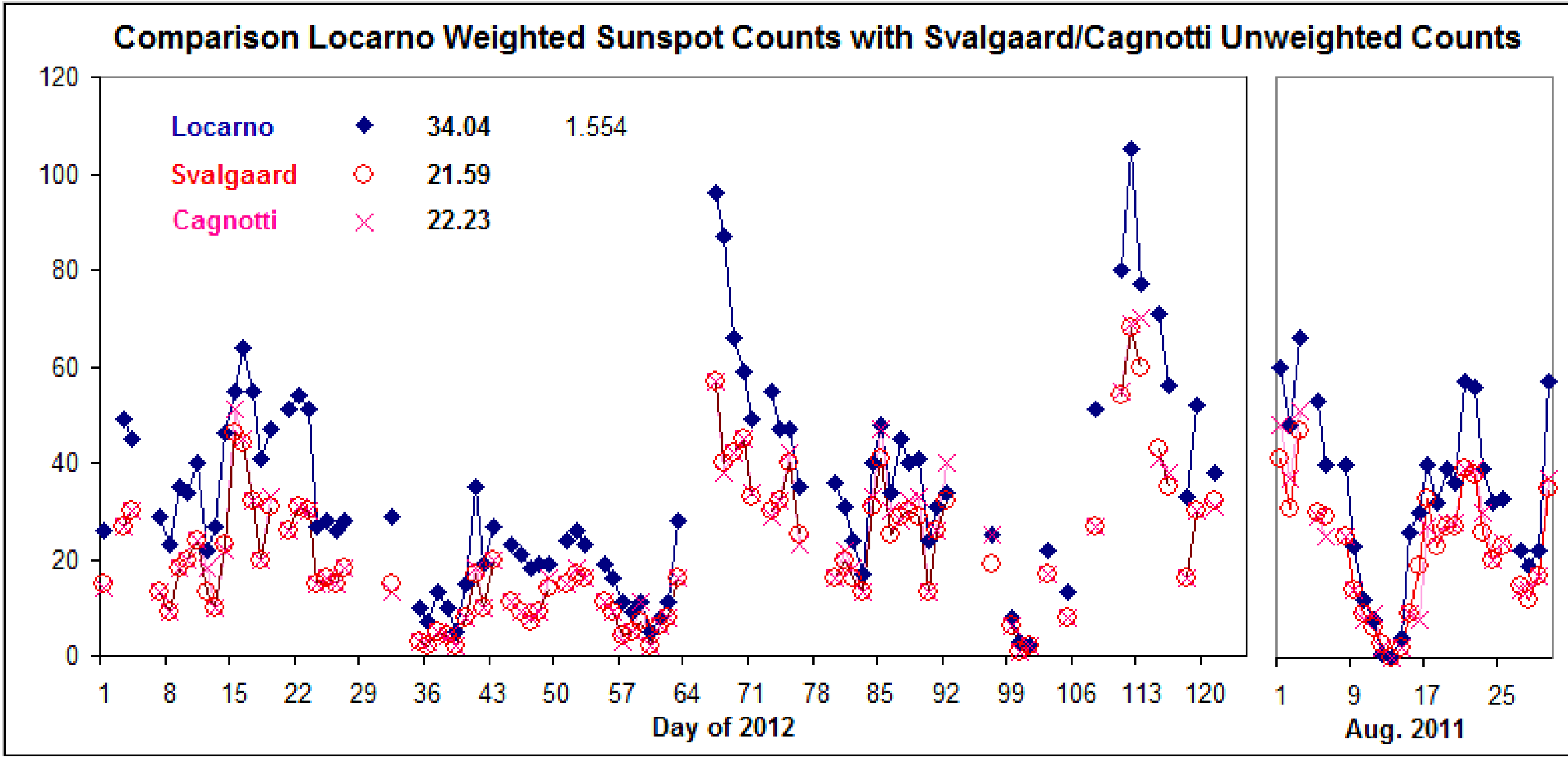
g	f	
141	3	1
143	15	6
144	6	2
145	17	9
146	3	1
5	44	19

5x10+44=94 5x10+19=69

94/69 = 1.36

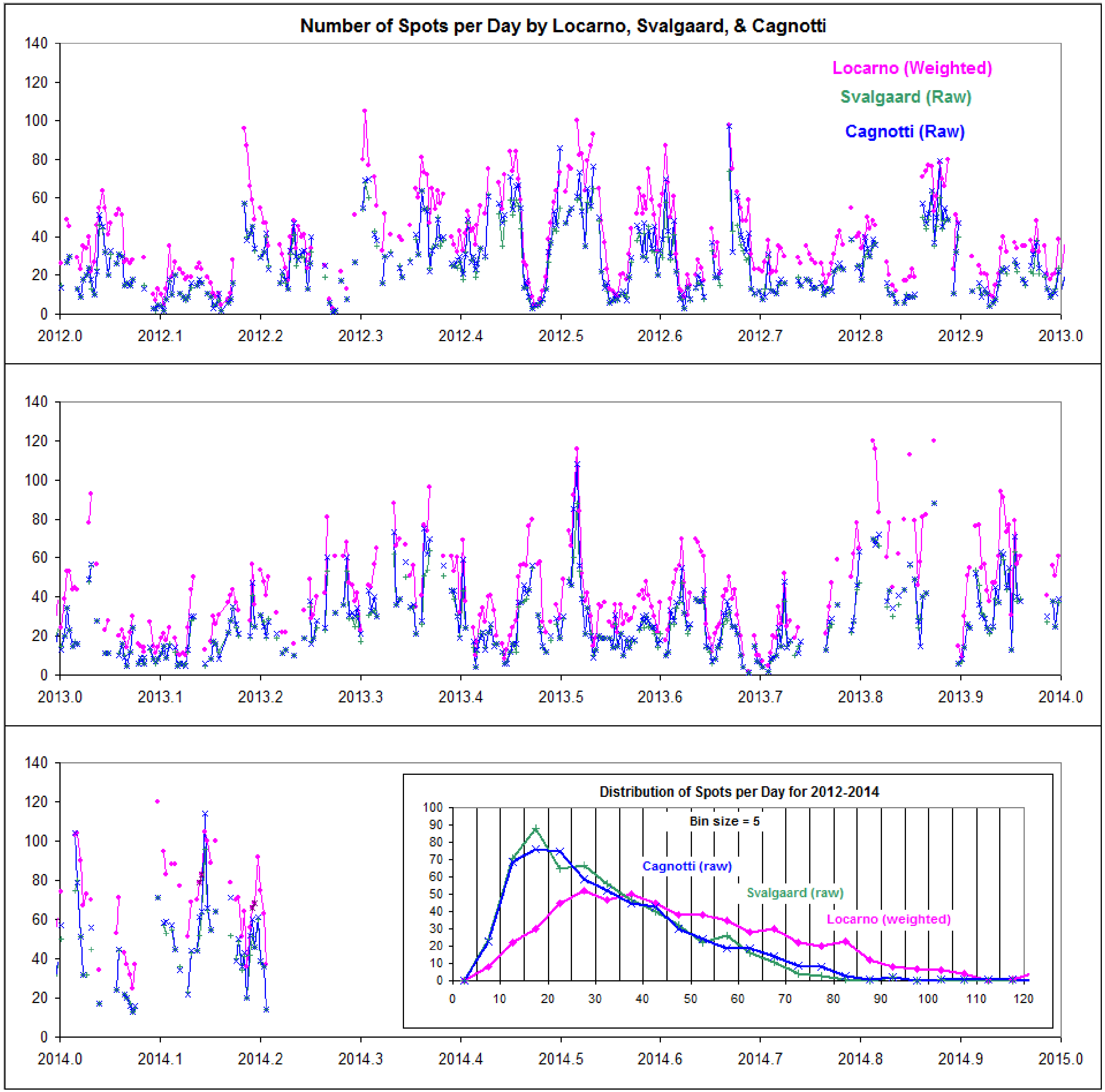
Recounted 2003-2014: ~55,000 spots

Double-Blind Test of My Re-Count



I proposed to the Locarno observers that they should also supply a raw count without weighting

For typical number of spots the weighting increases the ‘count’ of the spots by 30-60%

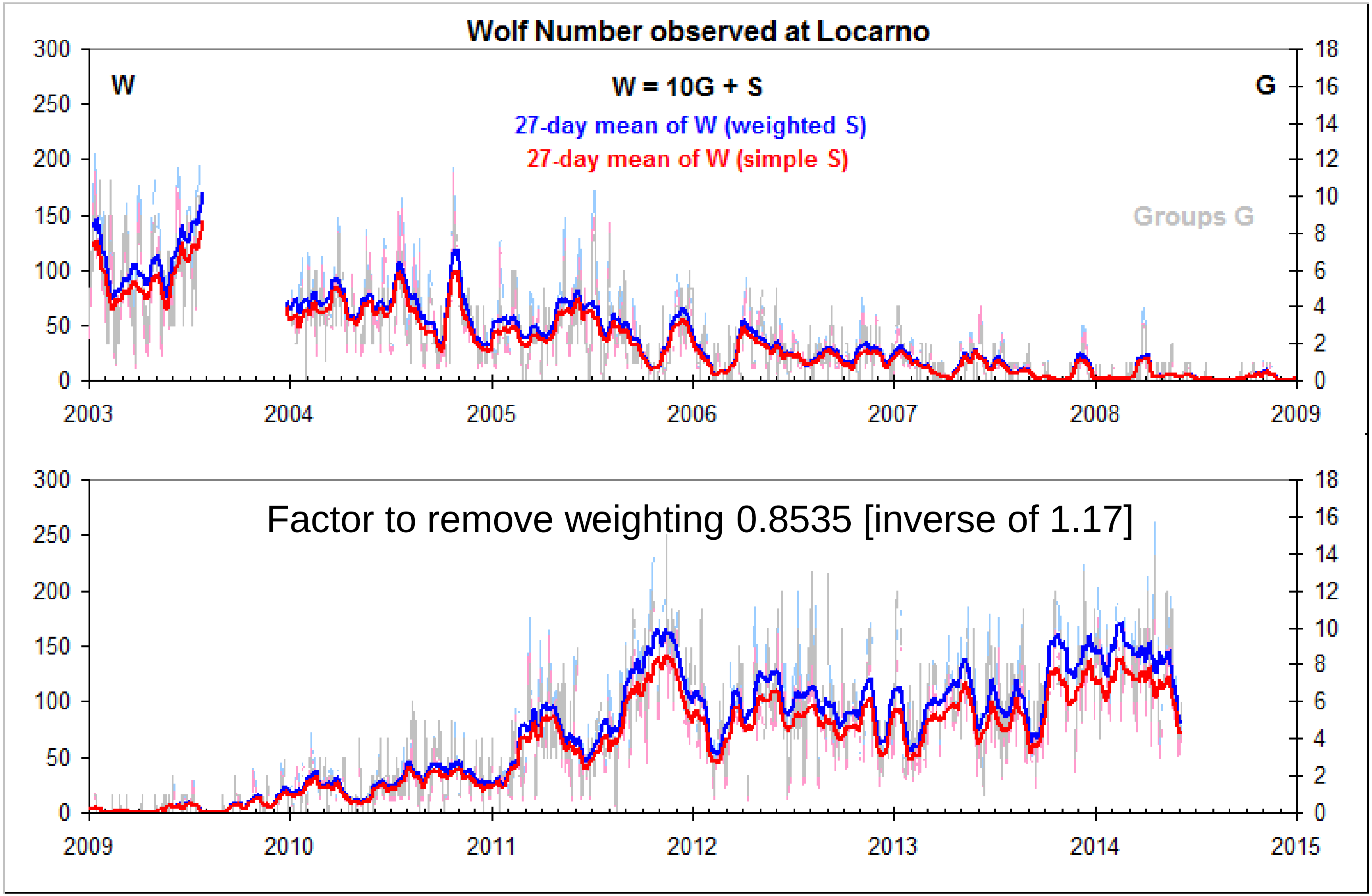


Compare Cagnotti & Svalgaard

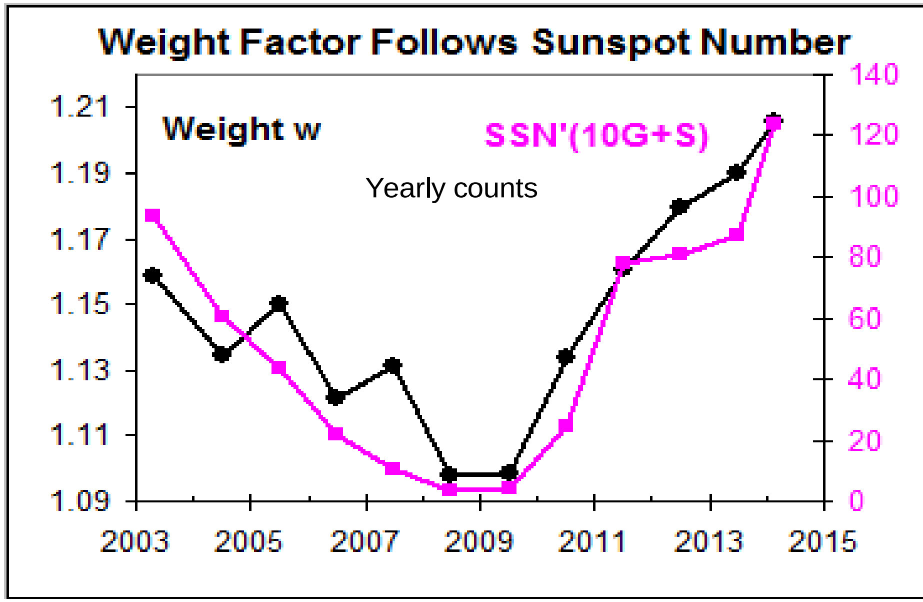
My raw counts match Marco's very well

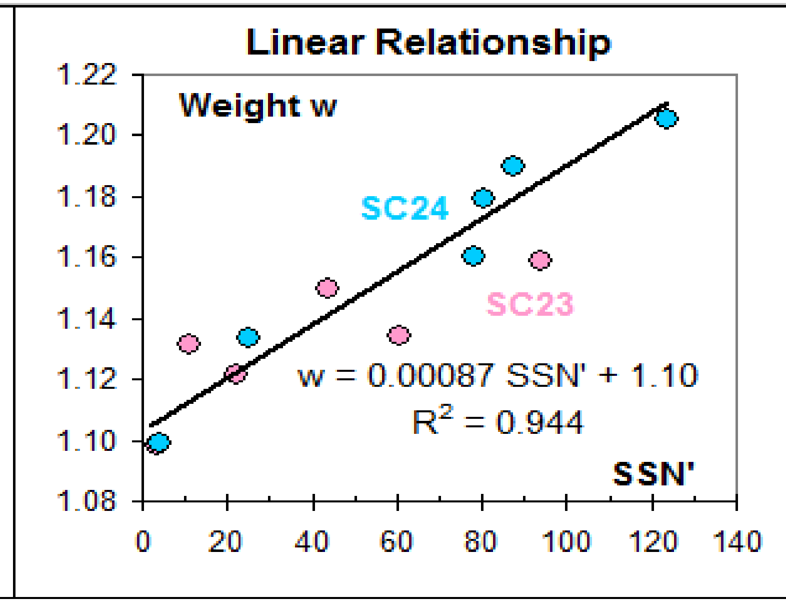
I have recounted the spots for all observations since 2003 and the Locarno observers are now taking that back to the start of their series (1957).

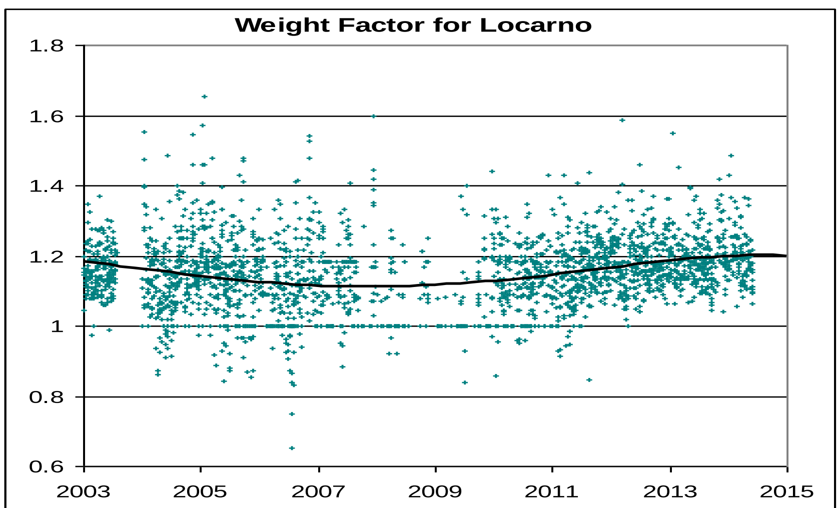
Effect on the Wolf Number



Weight Factor depends on SSN

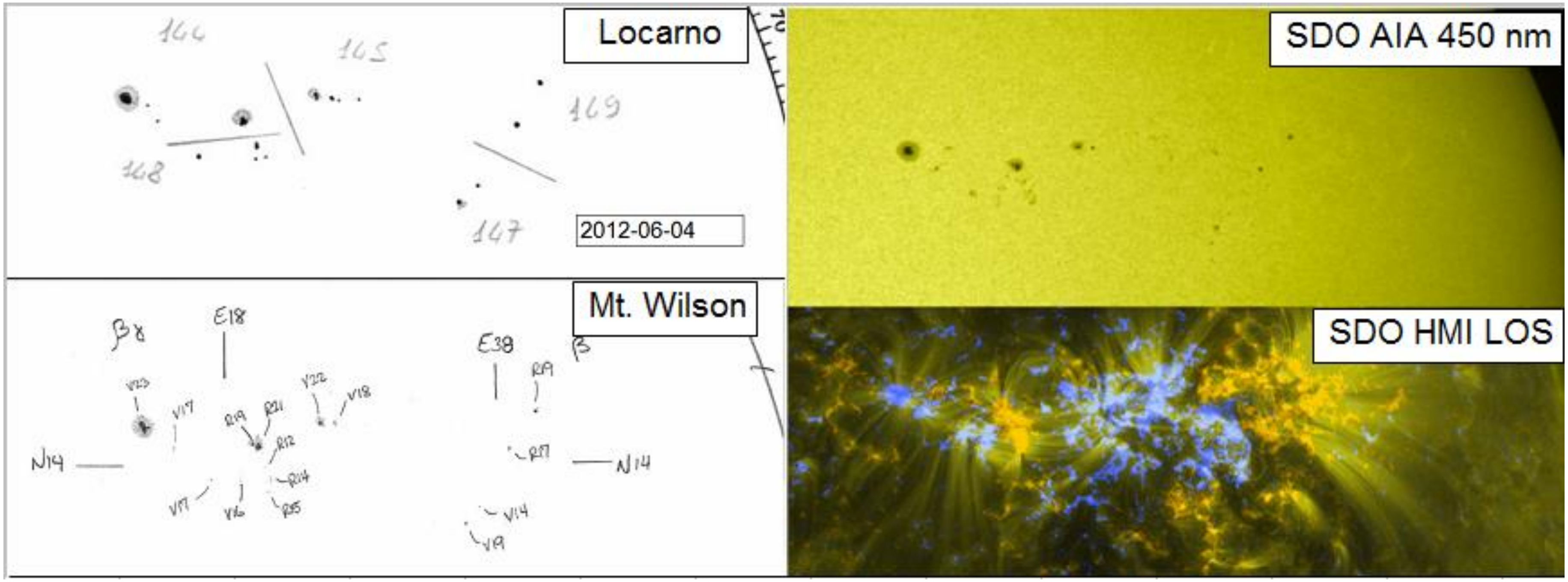


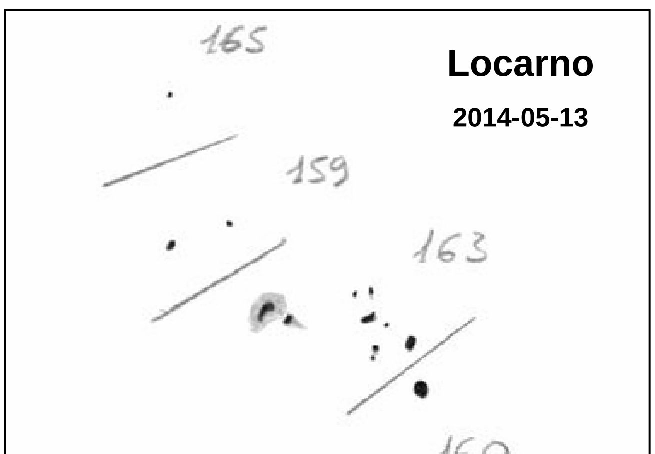


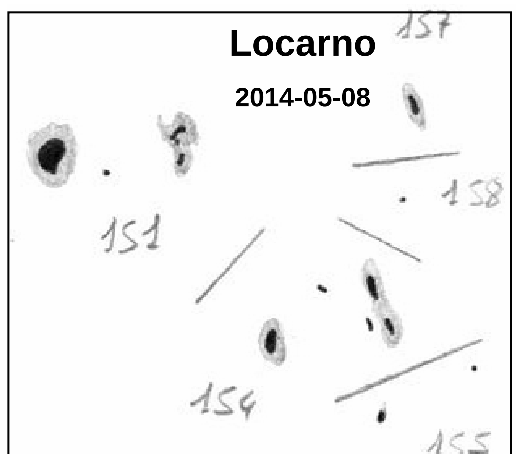


Counting 1593 [real] spots in 1981 [the first year where drawings from Locarno are readily available on the Internet at http://www.specola.ch/e/drawings.html] when the raw sunspot number was 155 yielded a weight factor of 1.25

The Difficulty in Counting Groups







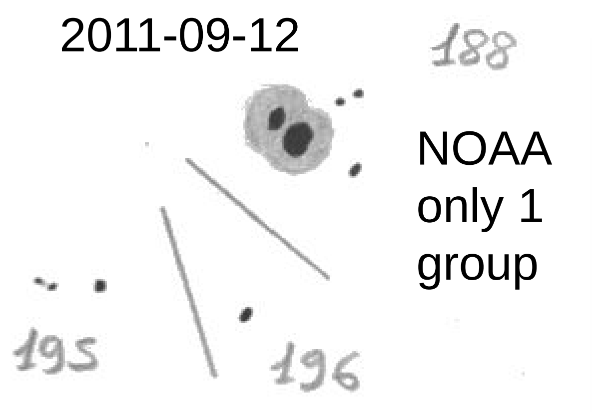
On one day out of five Locarno has at least one more group than Mt. Wilson.

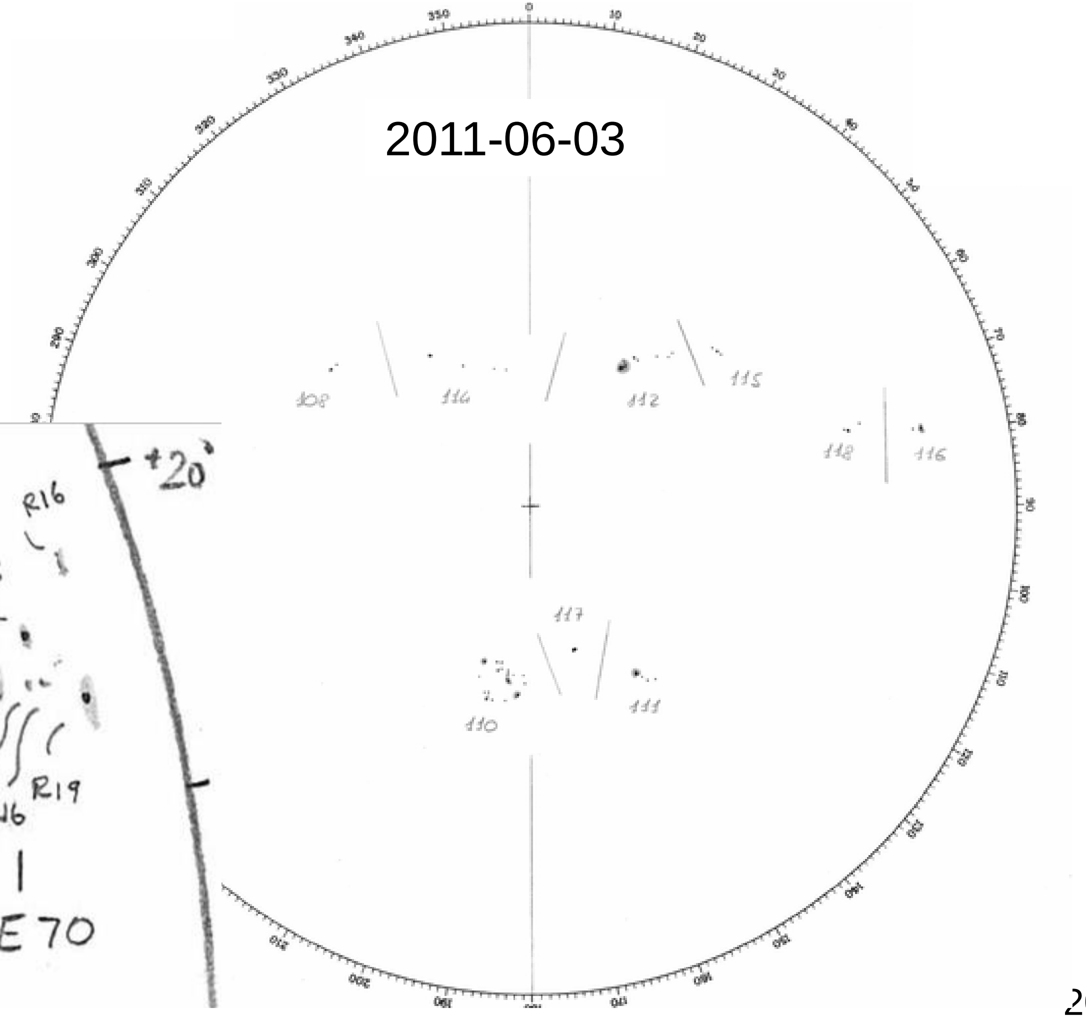
Combined Effect of Weighting and More Groups is an Inflation of the Relative Sunspot Number by 20+%

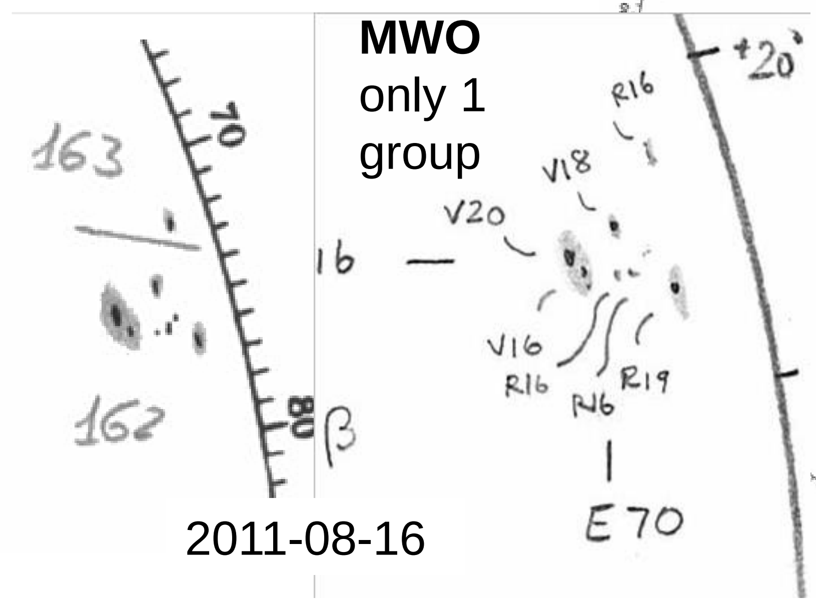
Modern Counts have too Many Groups

The Waldmeier Classification lead to Better Determination of Groups

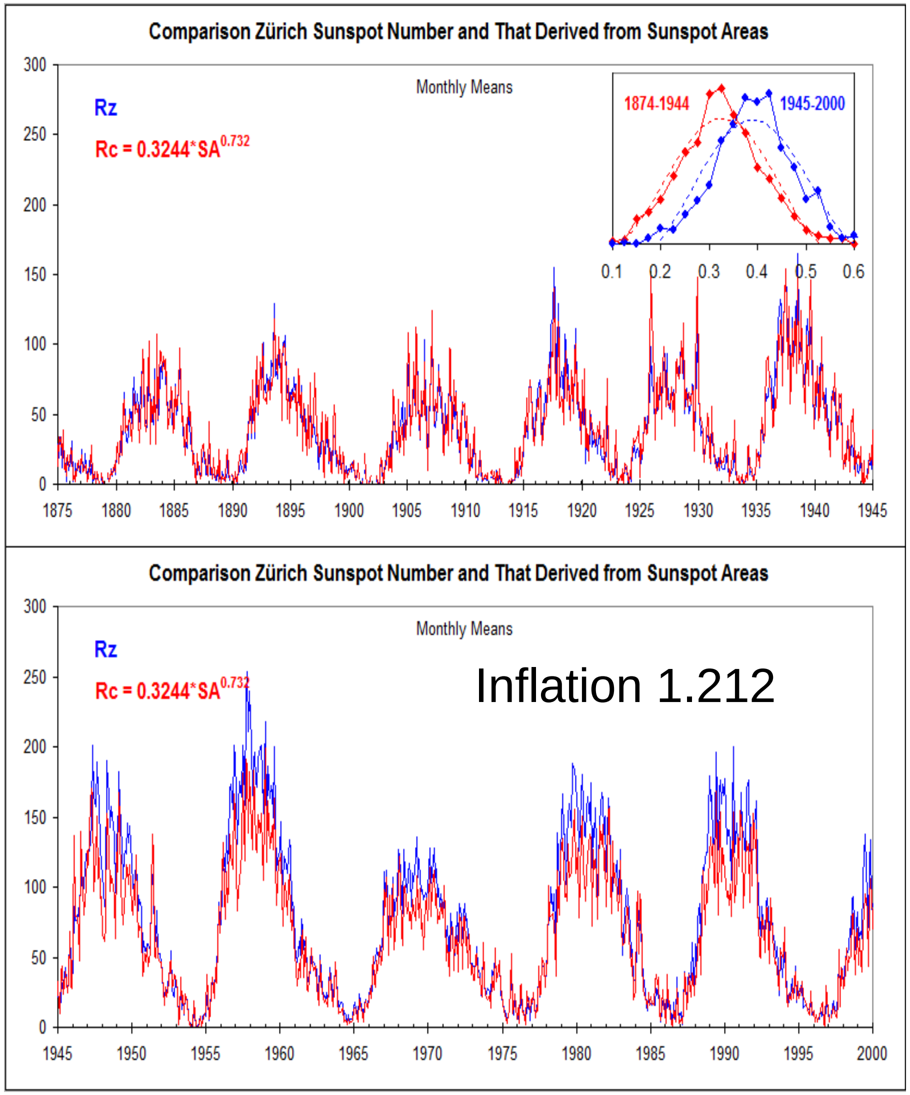
Counting spots is easy; counting groups is HARD

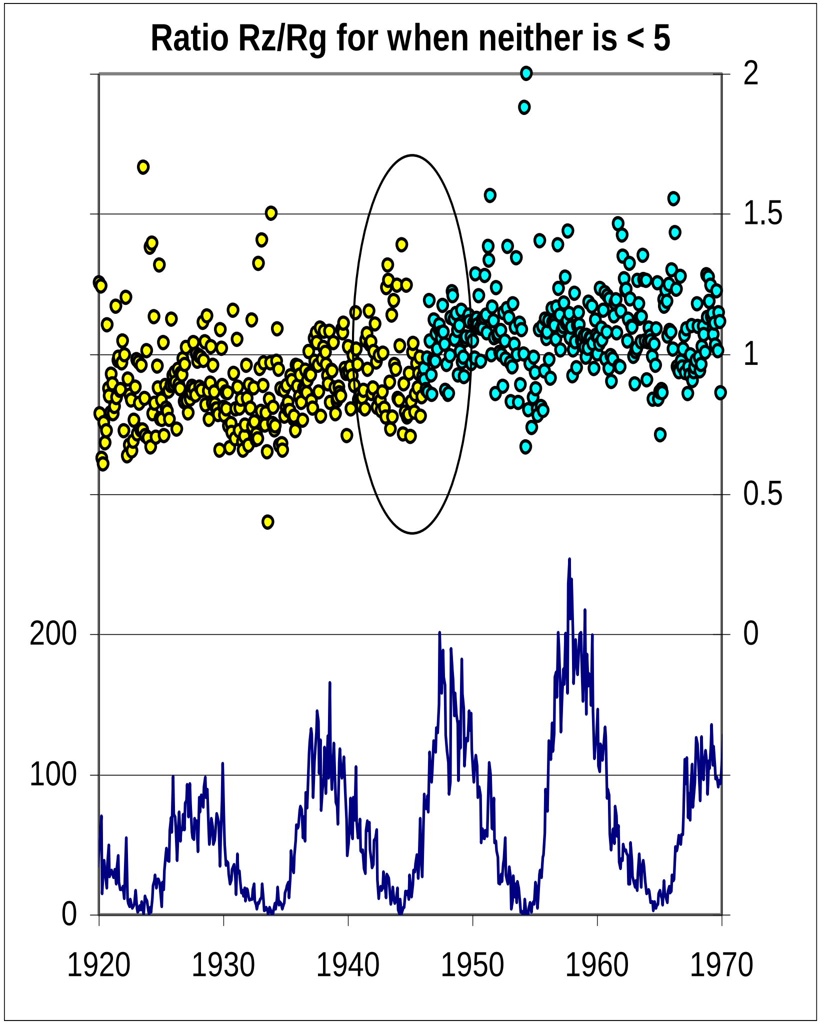




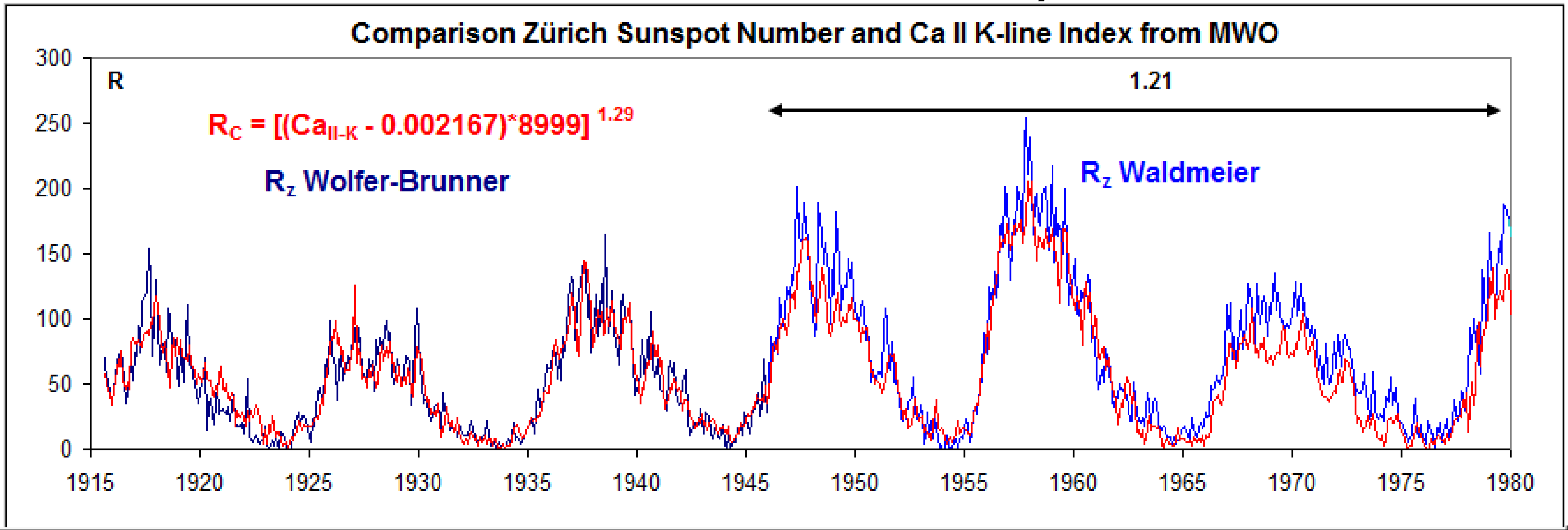


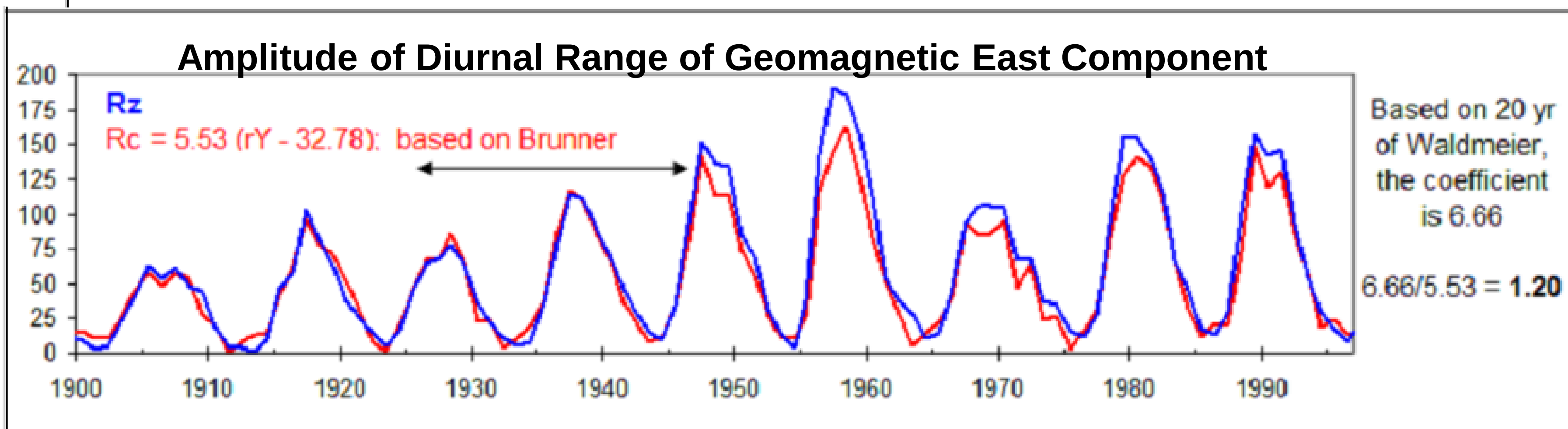
Can we see the Effect of Weighting of Spot Count in other Indices?



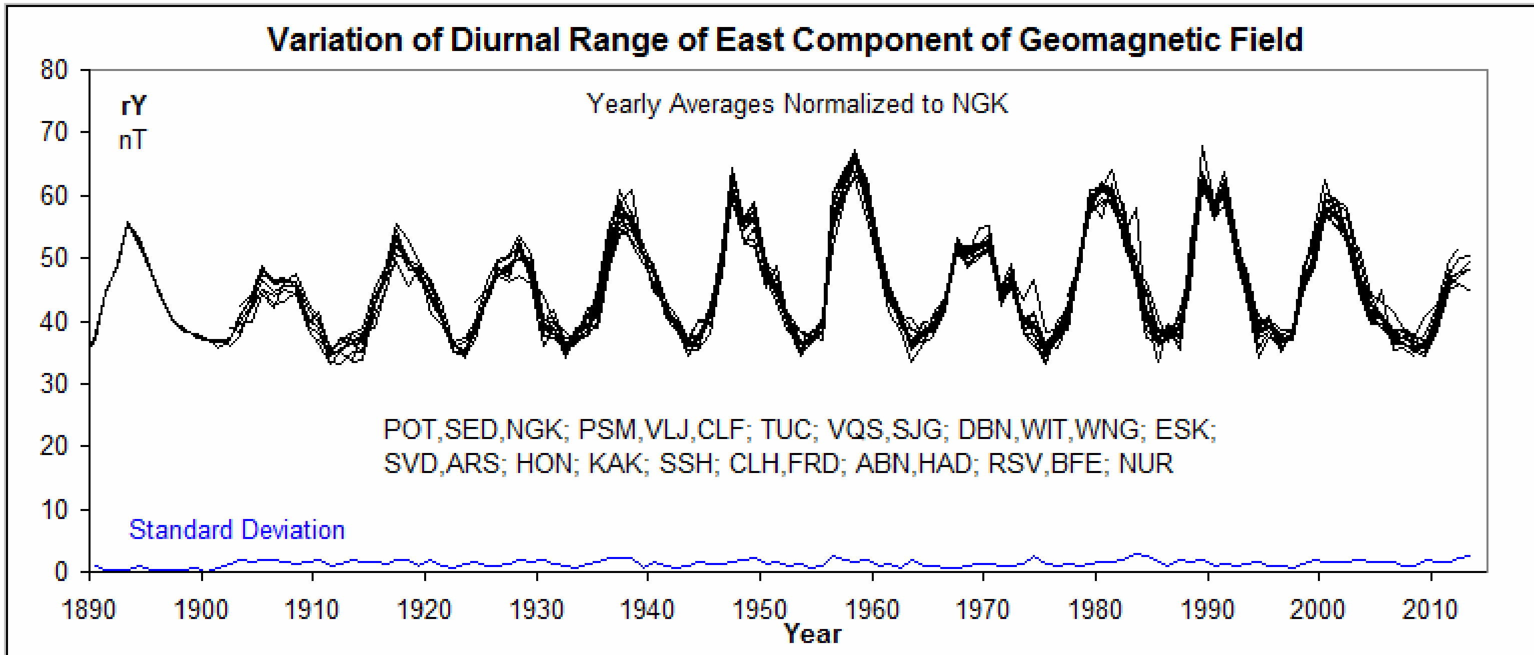


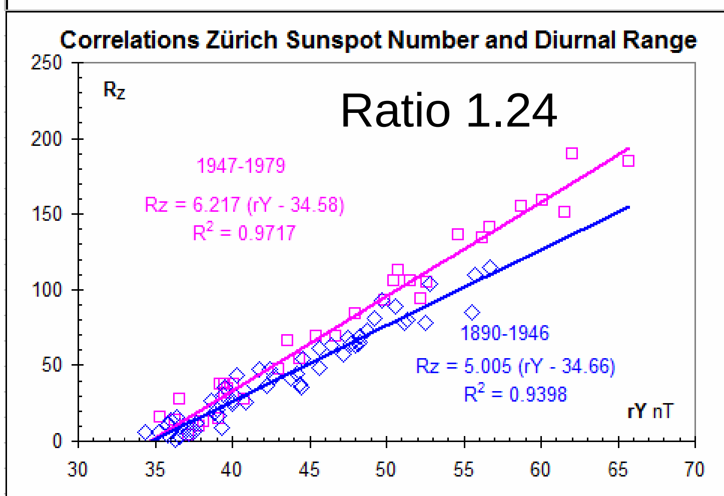
Can we see the Effect of Weighting in other Indices, II?

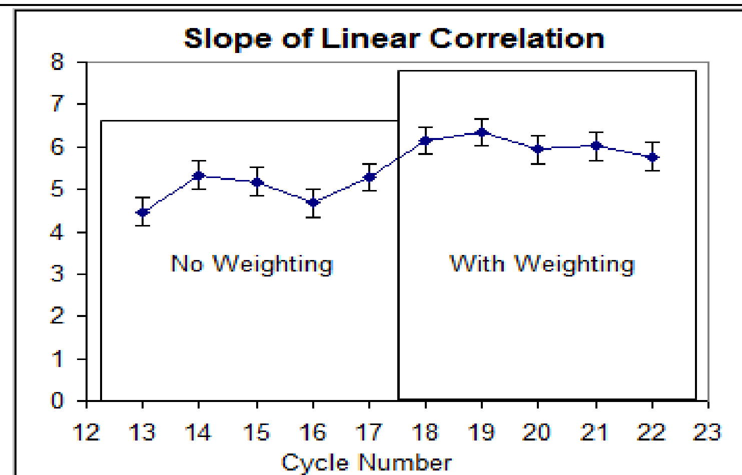




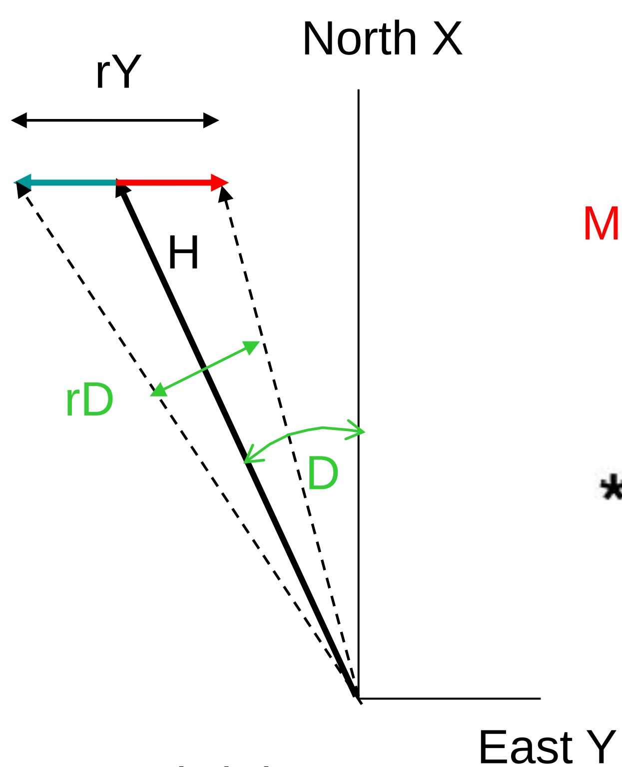
The Strong Geomagnetic Connection





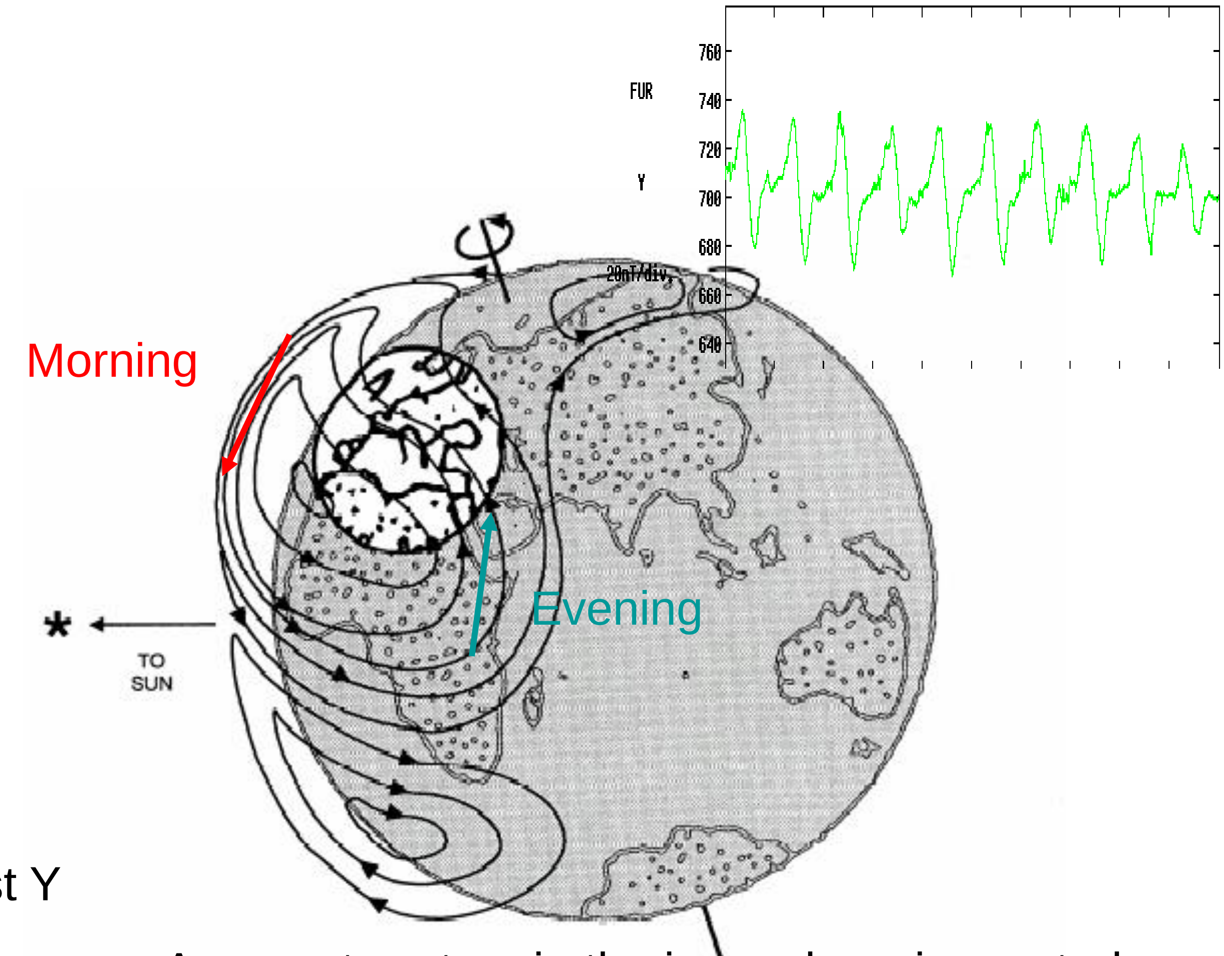


Wolf's Discovery (1852): $rD = a + b\, R_W$



$Y = H \sin(D)$

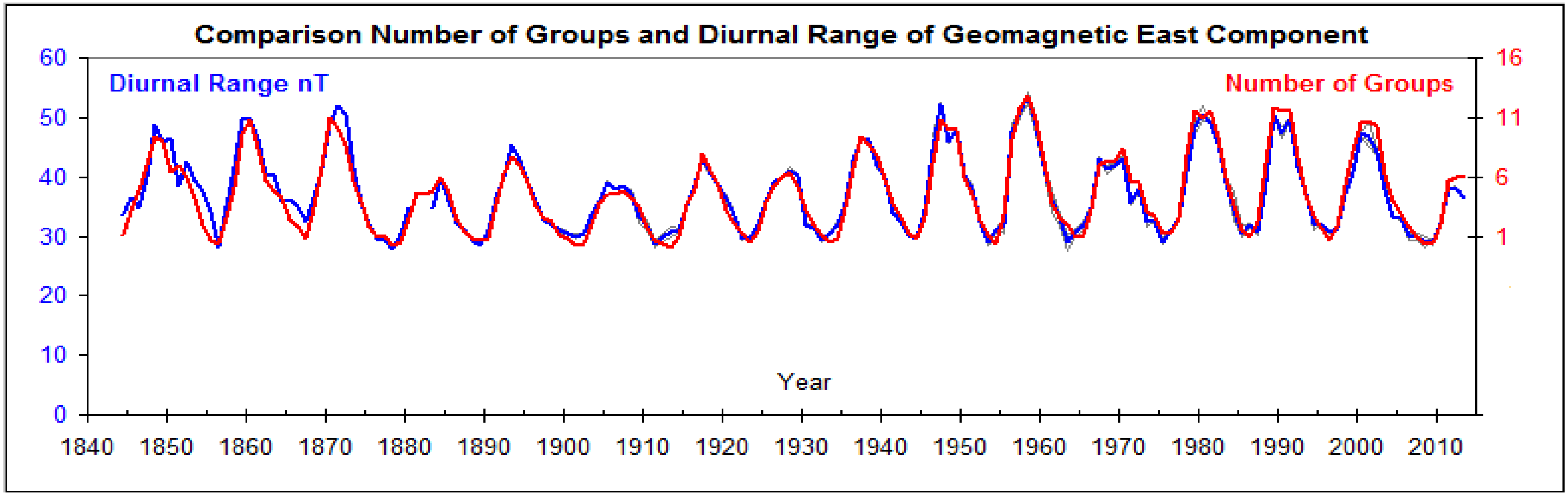
$dY = H \cos(D)\, dD$ For small dD

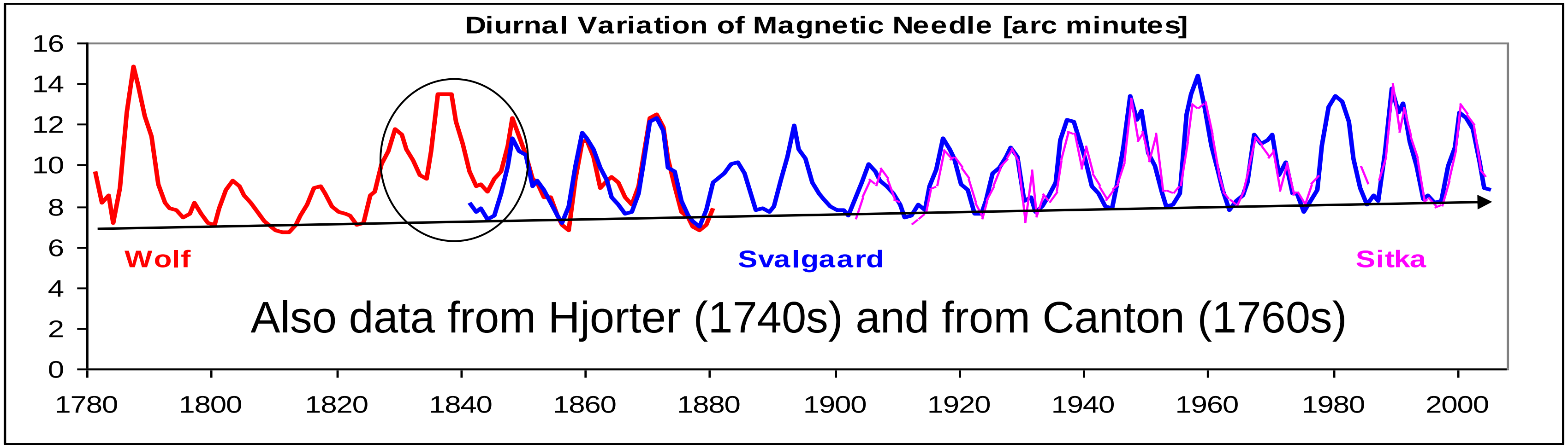


A current system in the ionosphere is created and maintained by solar FUV radiation

The magnetic effect of this system was discovered by George Graham in 1722

Effects of Solar FUV known back to the 1840s and even into the 18th century





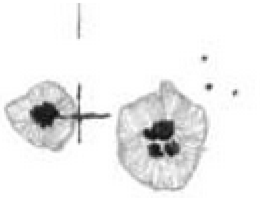
Also data from Hjorter (1740s) and from Canton (1760s)

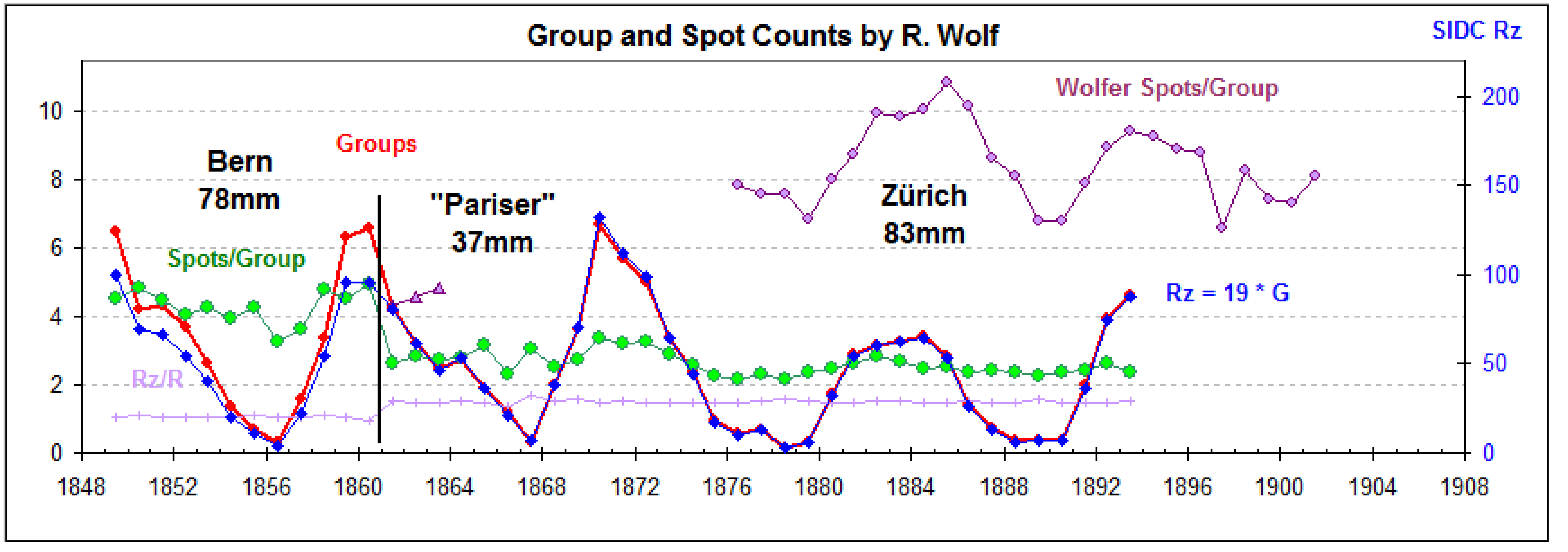
An Aside: Debunking a Myth

Original sources show that Wolf introduced the 1.25 factor with the 1860-1861 [and thereafter] tables of his relative sunspot numbers and that the factor was not determined using the ‘magnetic needle’, but by comparisons with other observers and consistent with Schwabe’s use of a weaker instrument. Now, it is true that Wolf in 1874 got the Milan data from Schiaparelli and found that they corroborated his 1.25 factor for Schwabe leading to an overdue recalculation of the entire series.

But, to reiterate: **Wolf’s adjustment was not determined by comparison in 1874 with the ‘magnetic needle’ data as assumed by Hoyt and Schatten [**In Geophysical Research Letters, Vol. 21, No. 18, Pages 2067-2070, September 1, 1994, doi/10.1029/94GL01698 Hoyt and Schatten write:
“Curiously, our Group Sunspot Numbers are similar to the Wolf Sunspot Numbers published by Wolf prior to 1868. In 1874, Wolf revised his original sunspot numbers by multiplying them by a factor of 1.25 for 1826 to 1848 and by about 1.2 to 1.5 for the earlier years. Wolf's correction was apparently determined using variations of the magnetic needle at Milan. Based upon our analysis, this correction is erroneous.”] **and others, but by comparison with Carrington and Hornstein in 1860-1861, and consistent with Schwabe’s use of a smaller telescope at lesser magnification**.

Wolf Spot to Group Ratio

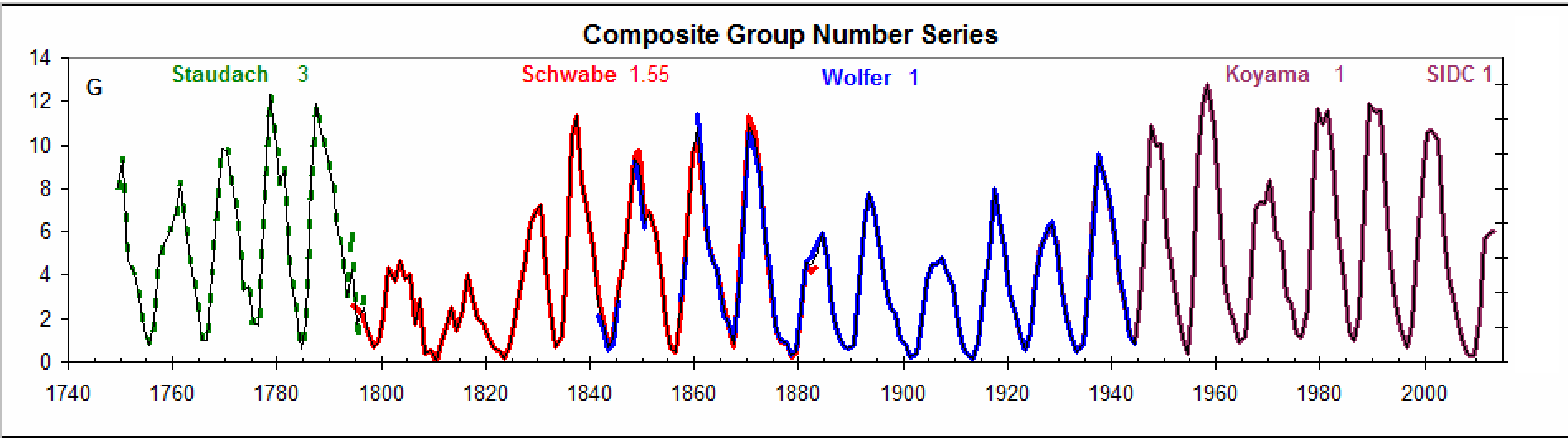




The Procession of Echternach
1L 1F 1R 1B 1F

1883 Month	Day	Wolf G	Wolf S	Wolf R	Wolfer G	Wolfer S	Wolfer R
8	16	**3**	4	34	**7**	29	99
8	17	**3**	6	36	**11**	29	139
8	18	**3**	6	36	**7**	31	101
8	19	**3**	5	35	**8**	30	110
8	20	**2**	3	23	**7**	18	88
8	21	**2**	3	23	**7**	40	110
8	22	**2**	4	24	**7**	41	111
8	23	**2**	4	24	**5**	37	87
8	24	**2**	4	24	**6**	35	95
8	25	**2**	4	24	**5**	32	82
8	26	**4**	8	48	**4**	55	95
8	27	**3**	9	39	**4**	60	100
8	28	**4**	12	52	**5**	91	141
8	29	**4**	10	50	**5**	62	112
8	30	**6**	12	72	**7**	82	152
8	31	**6**	16	76	**6**	88	148
9	1	**5**	15	65	**8**	81	161
Average		**3.29**	**7.35**	**40.29**	**6.41**	**49.47**	**113.59**
				x1.5	G Ratio	S Ratio	x0.6
To place on Wolf's scale with the 80mm				**60**	**1.95**	**6.73**	**68**

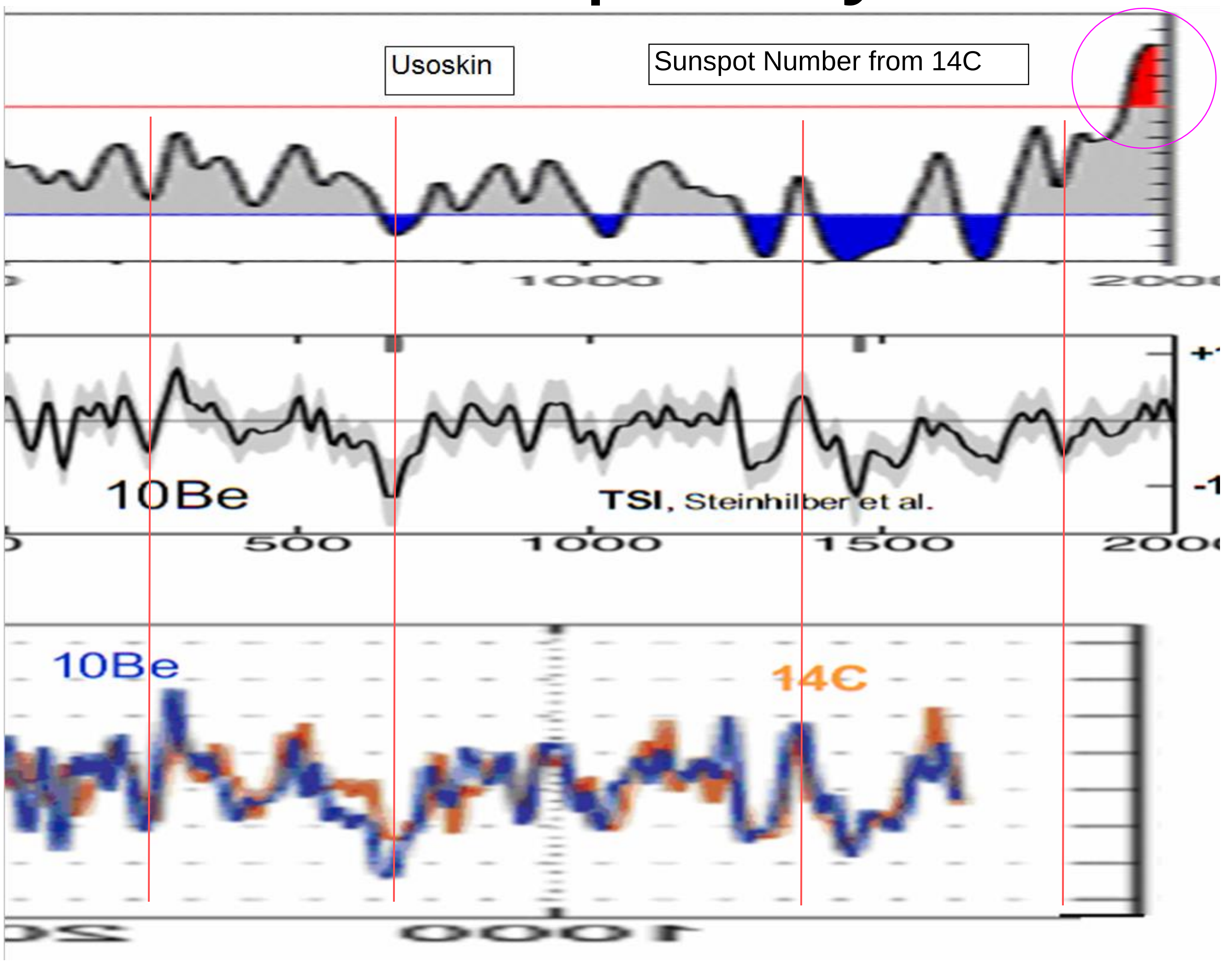
SSN4: No Modern **Grand** Maximum



The preliminary new sunspot record expressed in terms of the number of sunspot groups. The 'old' SSN record was constructed as R = 0.6 * (10g+s), where [for Wolf] 10g+s =1.5 * (10G+S). The new SSN record will be simplified to W = 10G+S with no weighting of spots S.

The new Wolf Number should be used as model input and we should understand the behavior and the fit of the model to the new perspective and to HMF B before we can extrapolate with any degree of confidence to the Maunder Minimum.

‘Modern Grand Maximum’ sometimes portrayed as Extreme

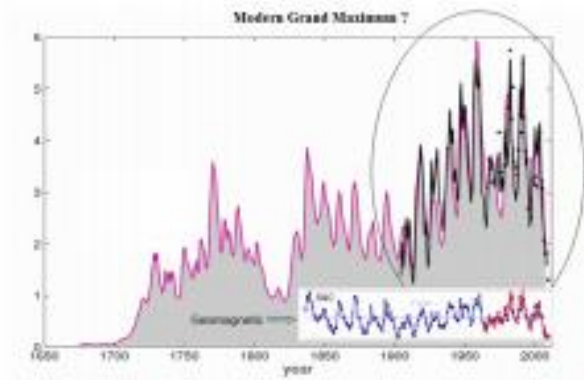


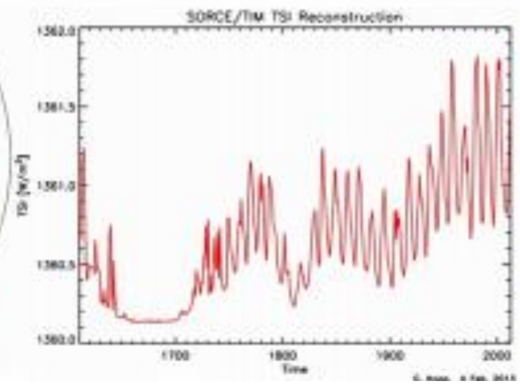
Highest in 8000, or 10,000 or 12,000 years

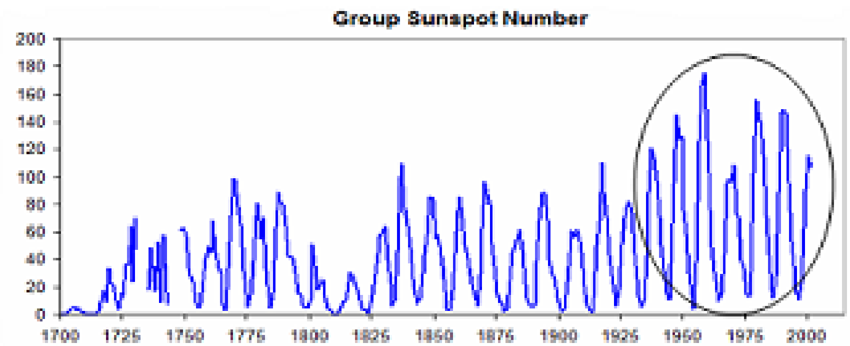
10 Be last 2000 years

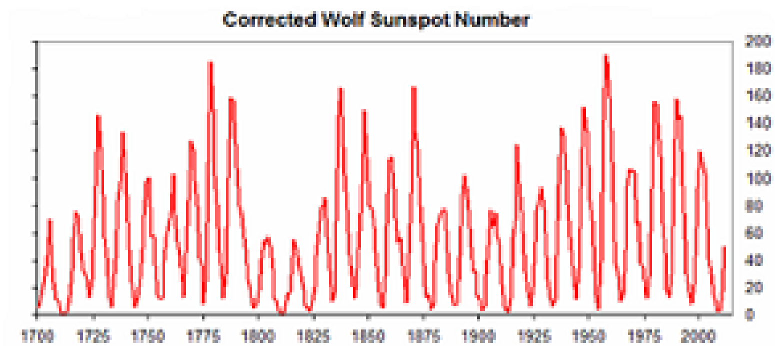
10 Be and 14 C similar last 2000 years

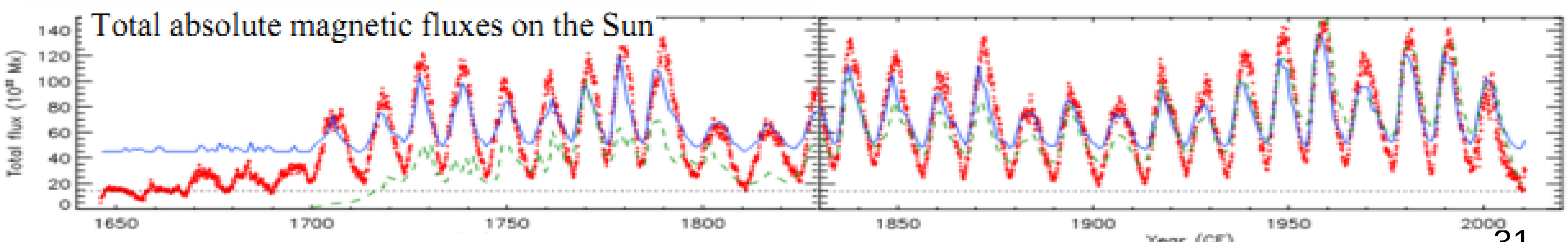
Debunking Some Myths





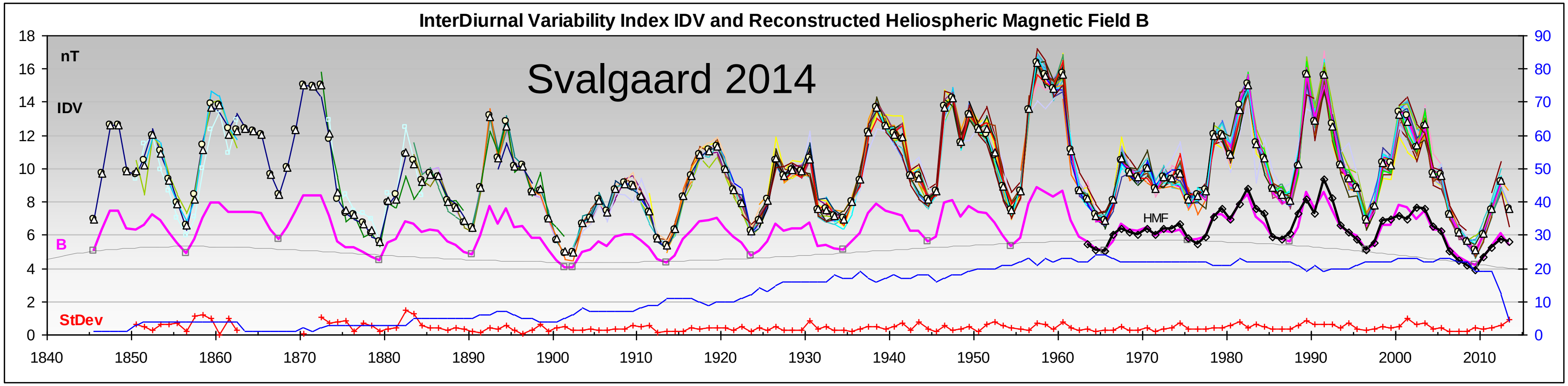


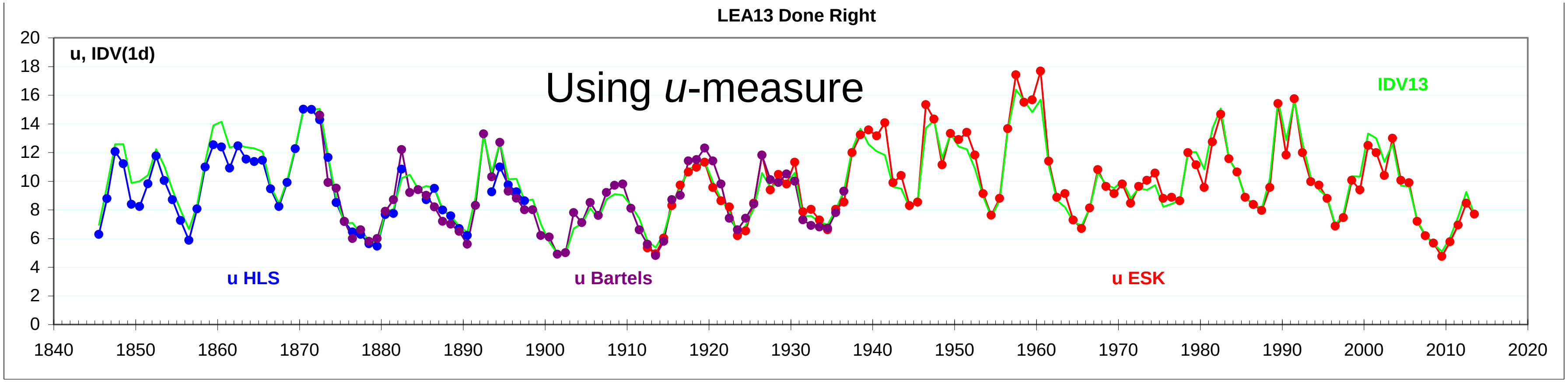




Summary of Talks and Discussions to follow

Progress in Reconstructing Solar Wind Magnetic Field back to 1840s





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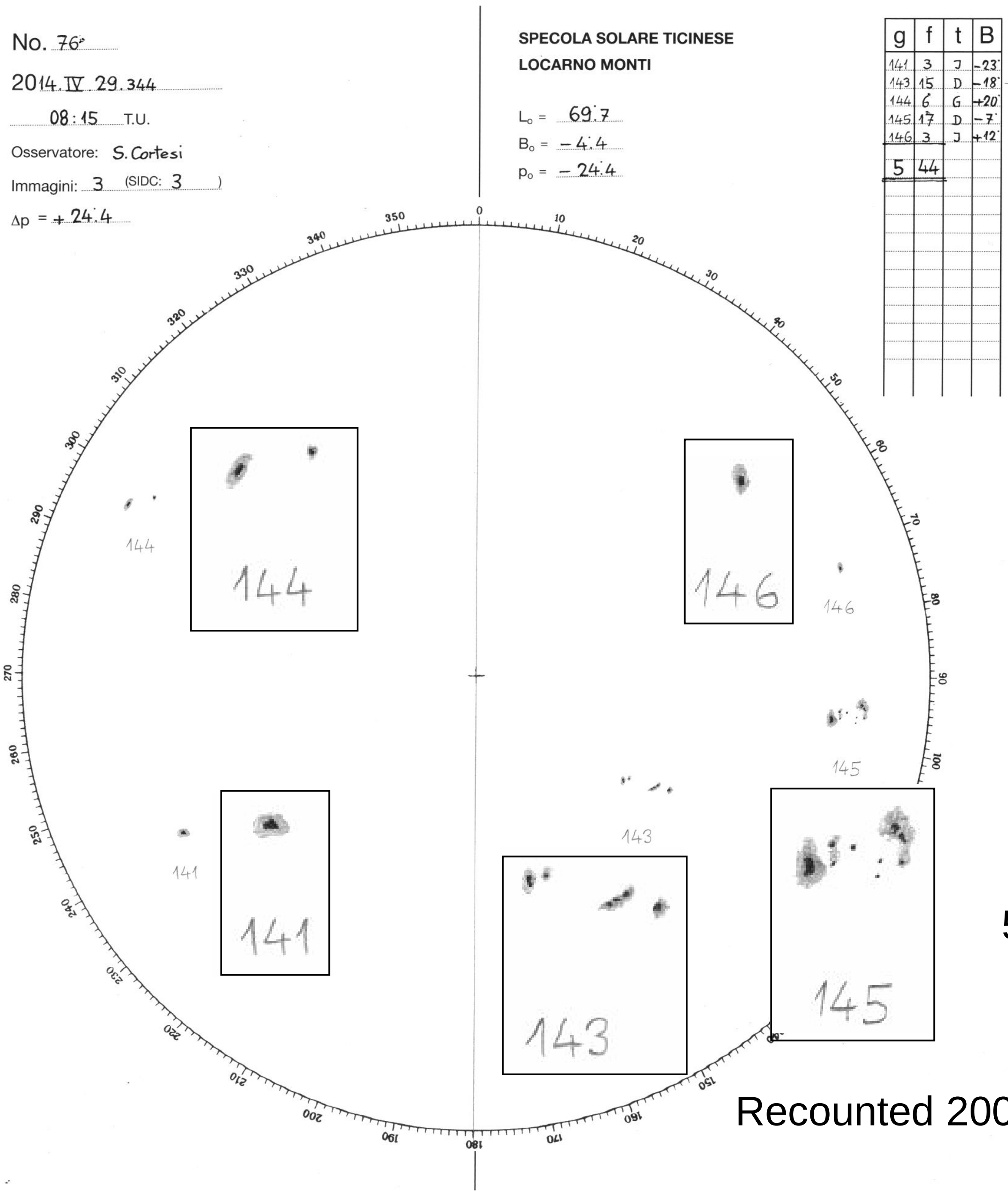
Counting with no Weighting



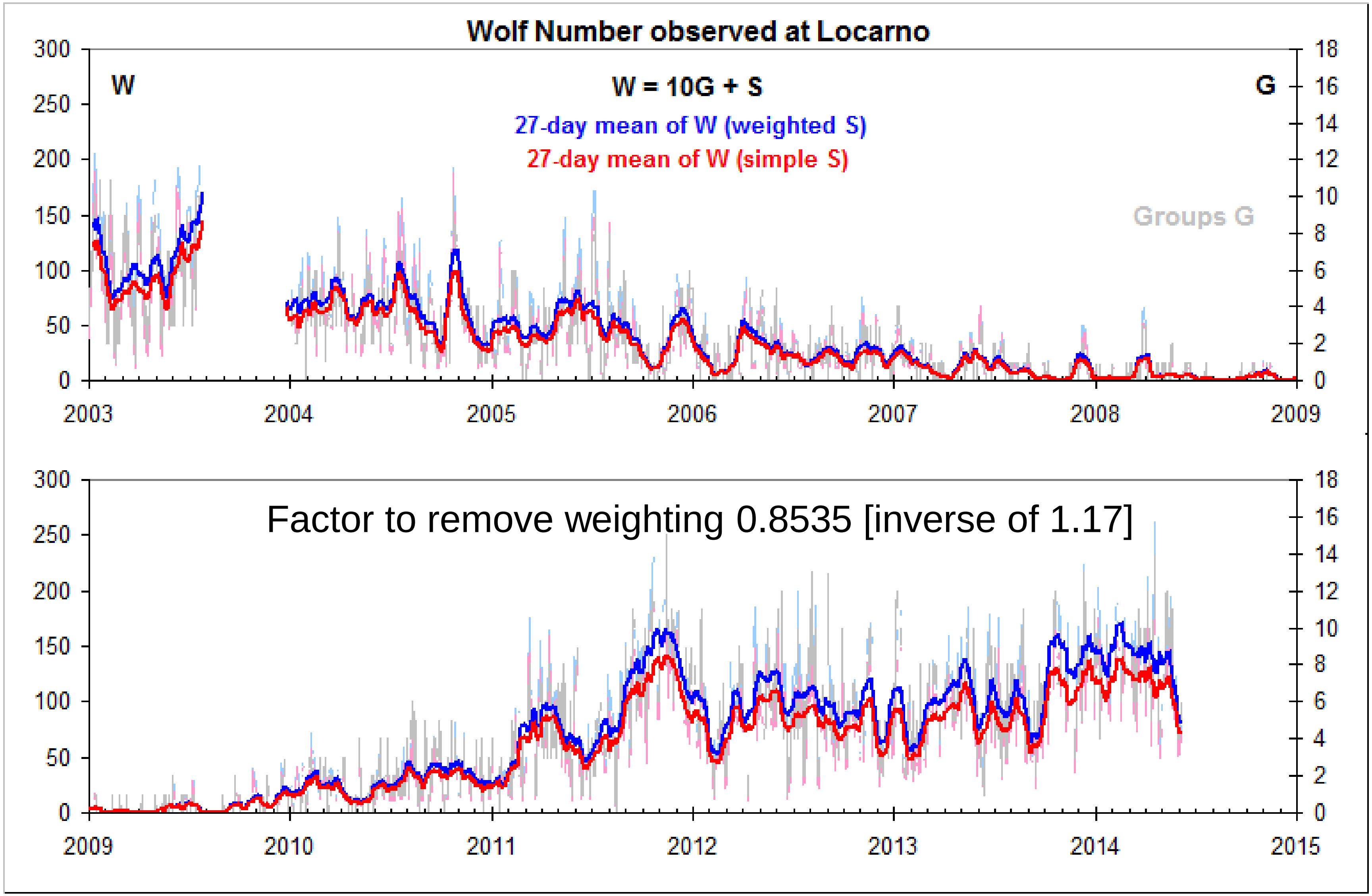
g	f	
141	3	1
143	15	6
144	6	2
145	17	9
146	3	1
5	44	19

5x10+44=94 5x10+19=69

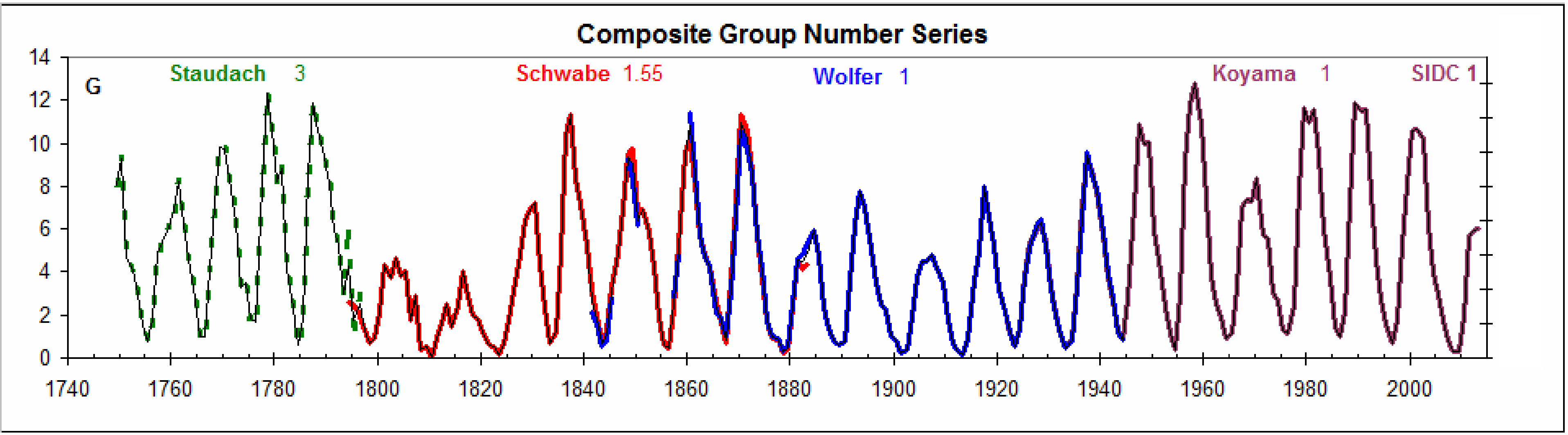
94/69 = 1.36

Recounted 2003-2014: ~55,000 spots

Effect on the Wolf Number



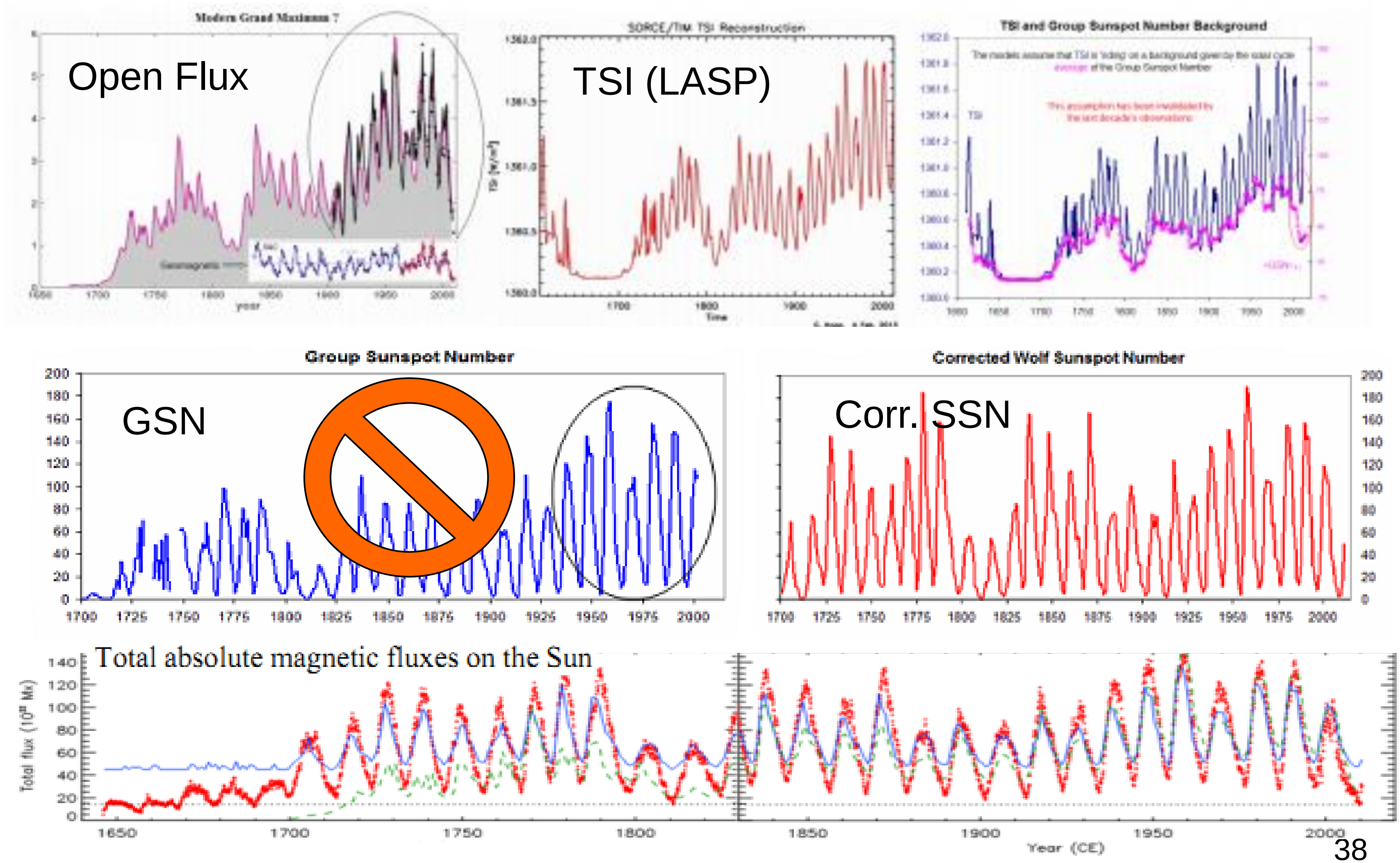
SSN4: No Modern **Grand** Maximum



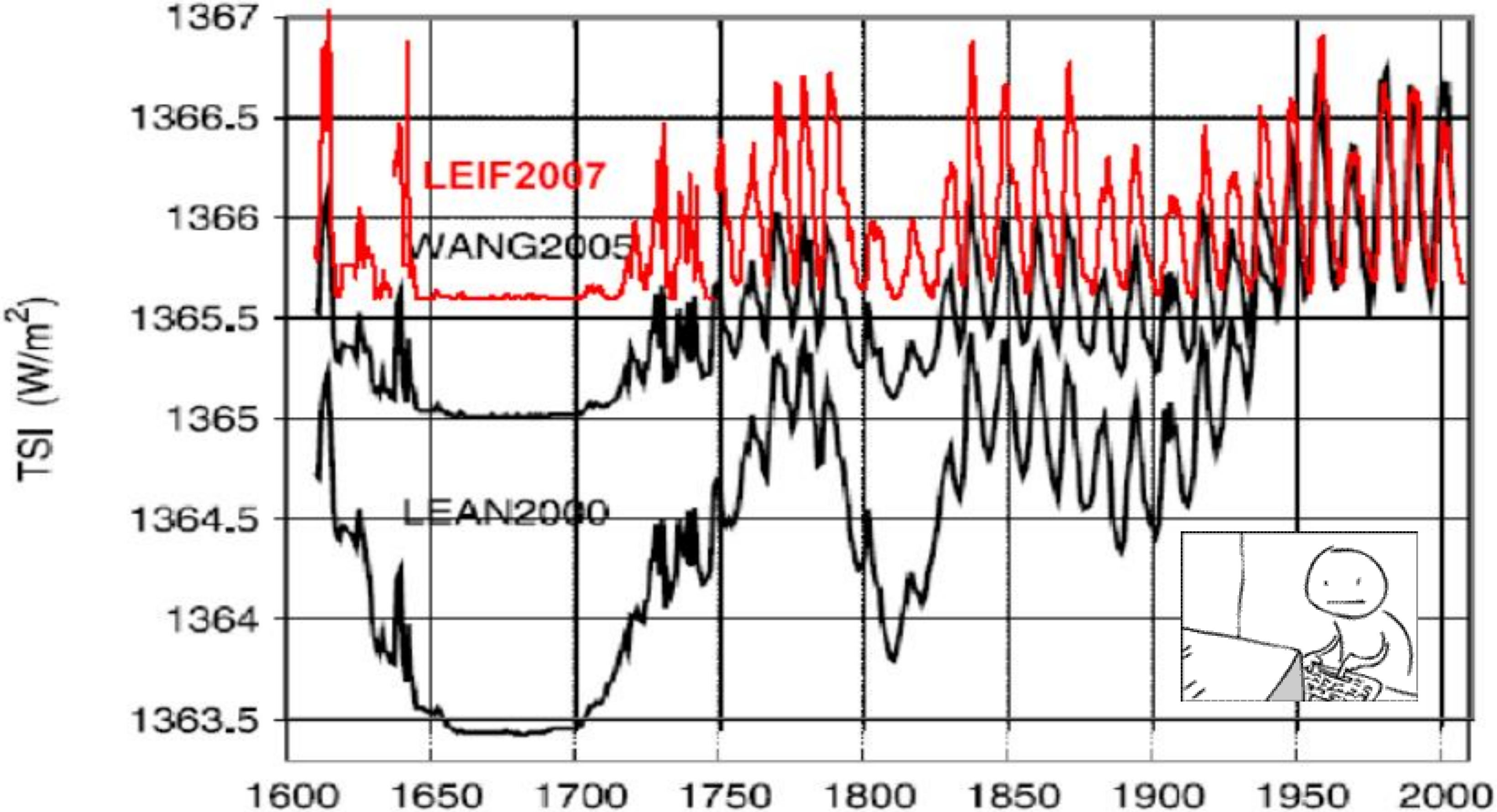
The preliminary new sunspot record expressed in terms of the number of sunspot groups. Of note is that there is a maximum in every century, none of them particularly 'Grand'.

The new Wolf Number should be used as model input and we should understand the behavior and the fit of the model to the new perspective and to HMF B before we can extrapolate with any degree of confidence to the Maunder Minimum.

No Rising Background ‘Base Level’

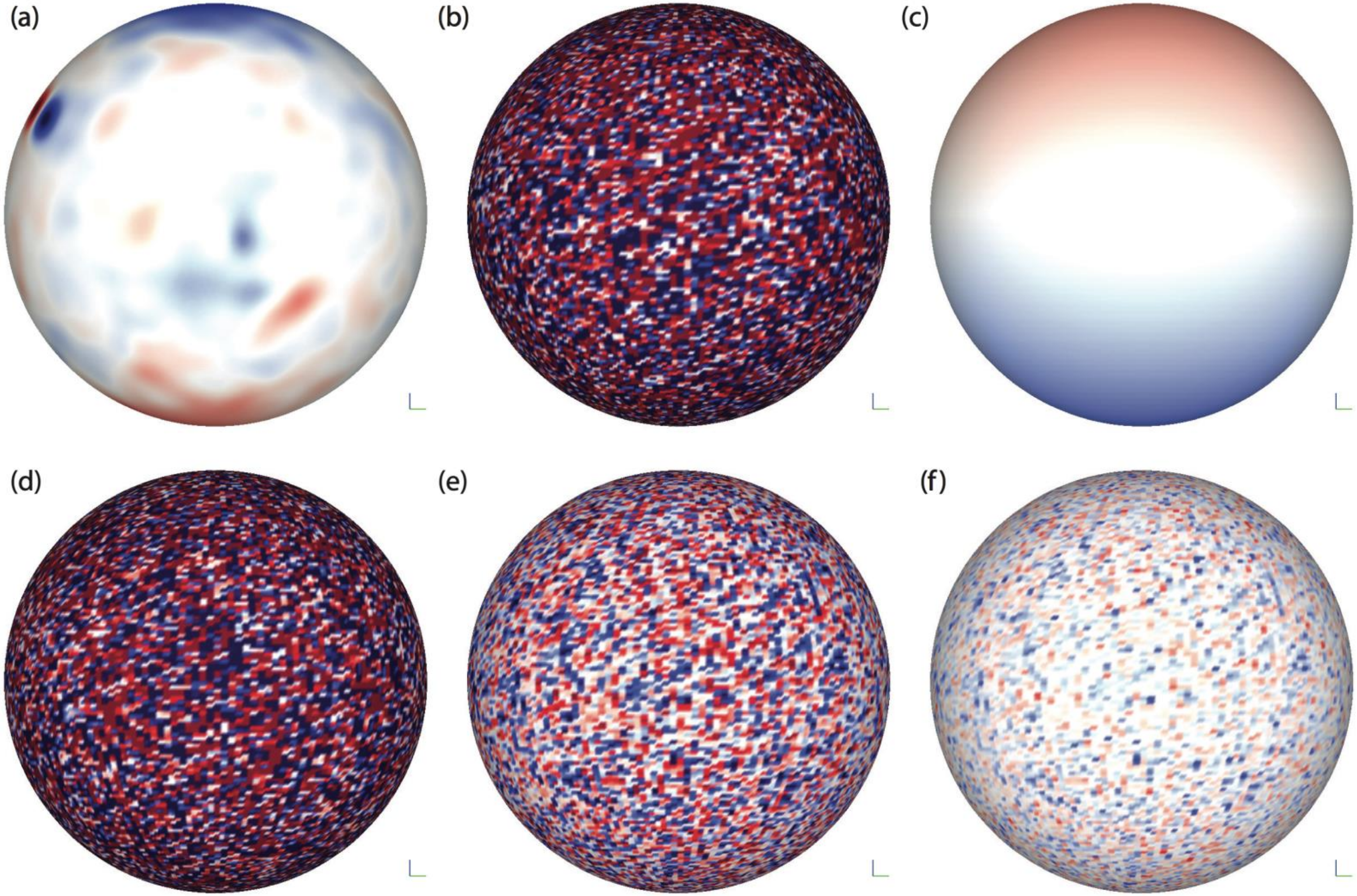


Perhaps the Maunder Minimum was Less Extreme than we Thought



The emergence of 'ephemeral regions' does not show any solar cycle dependence [e.g. Hagenaar, 2008], thus no ever-increasing background

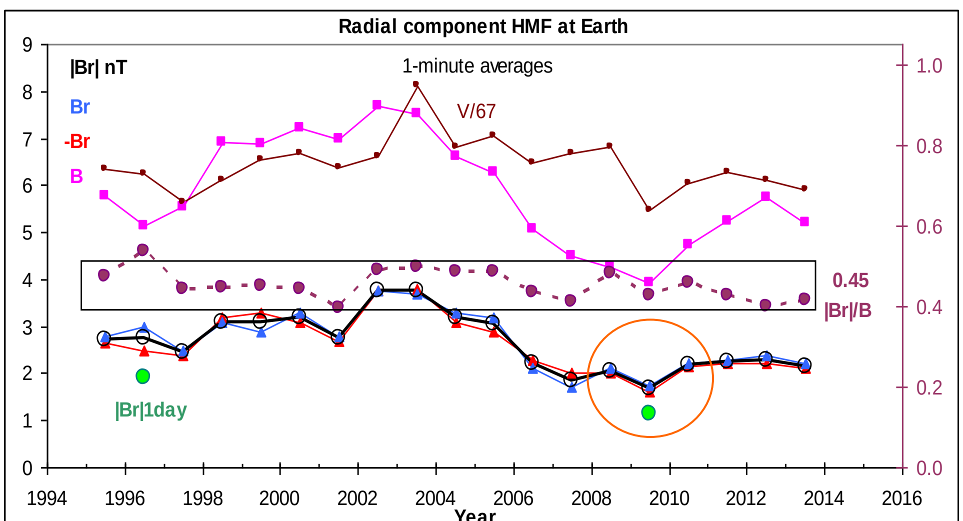
MHD Modeling [Riley et al.]

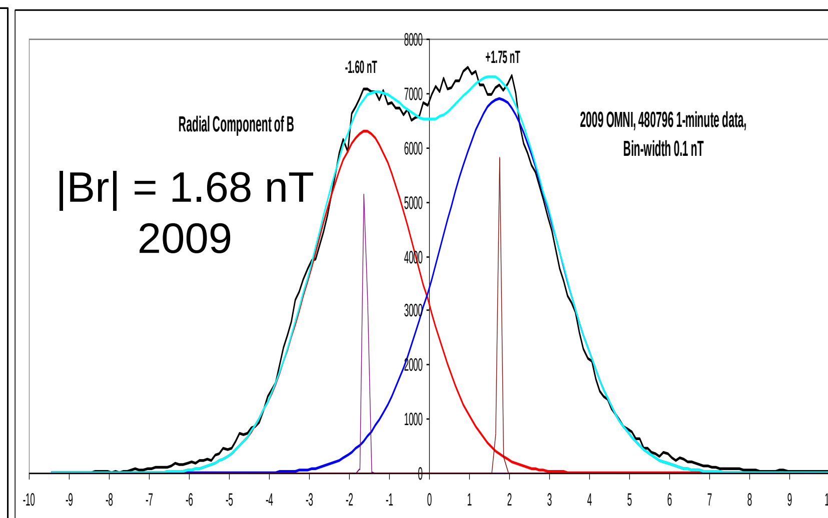


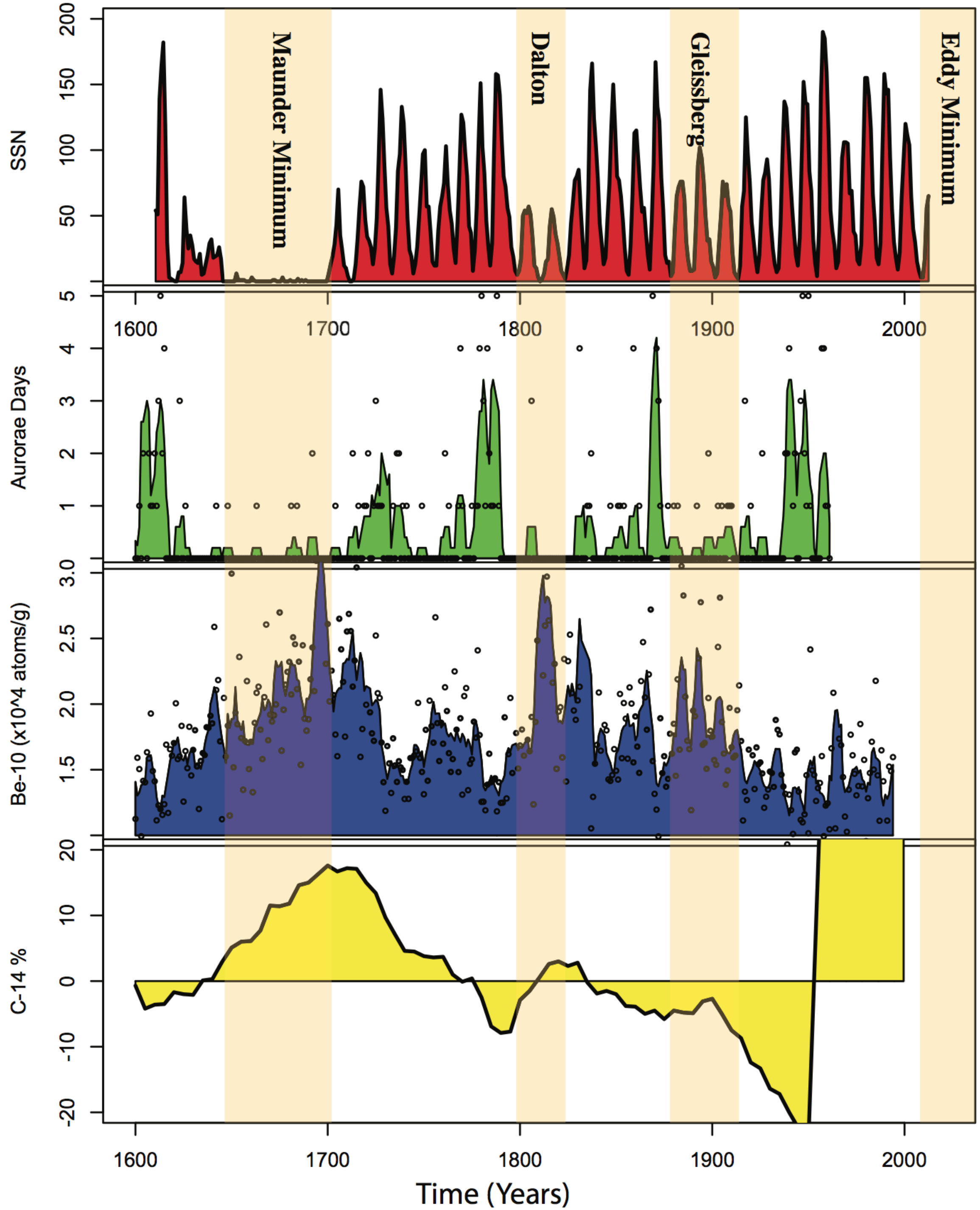
Computed Radial HMF at 1 AU

Model	Description	Open Flux
(a)	CR 2085 (06/26/09-07/23/09)	1.0 nT
(b)	Parasitic polarity (±10 G) + Large-scale dipole (3.3G)	2.4 nT
(c)	Large-scale dipole only (3.3G)	2.2 nT
(d)	Parasitic polarity (±10 G) + Large-scale dipole (1G)	1.2 nT
(e)	Parasitic polarity only (±10 G)	0.29 nT
(f)	Parasitic polarity only (±3.3 G)	0.08 nT

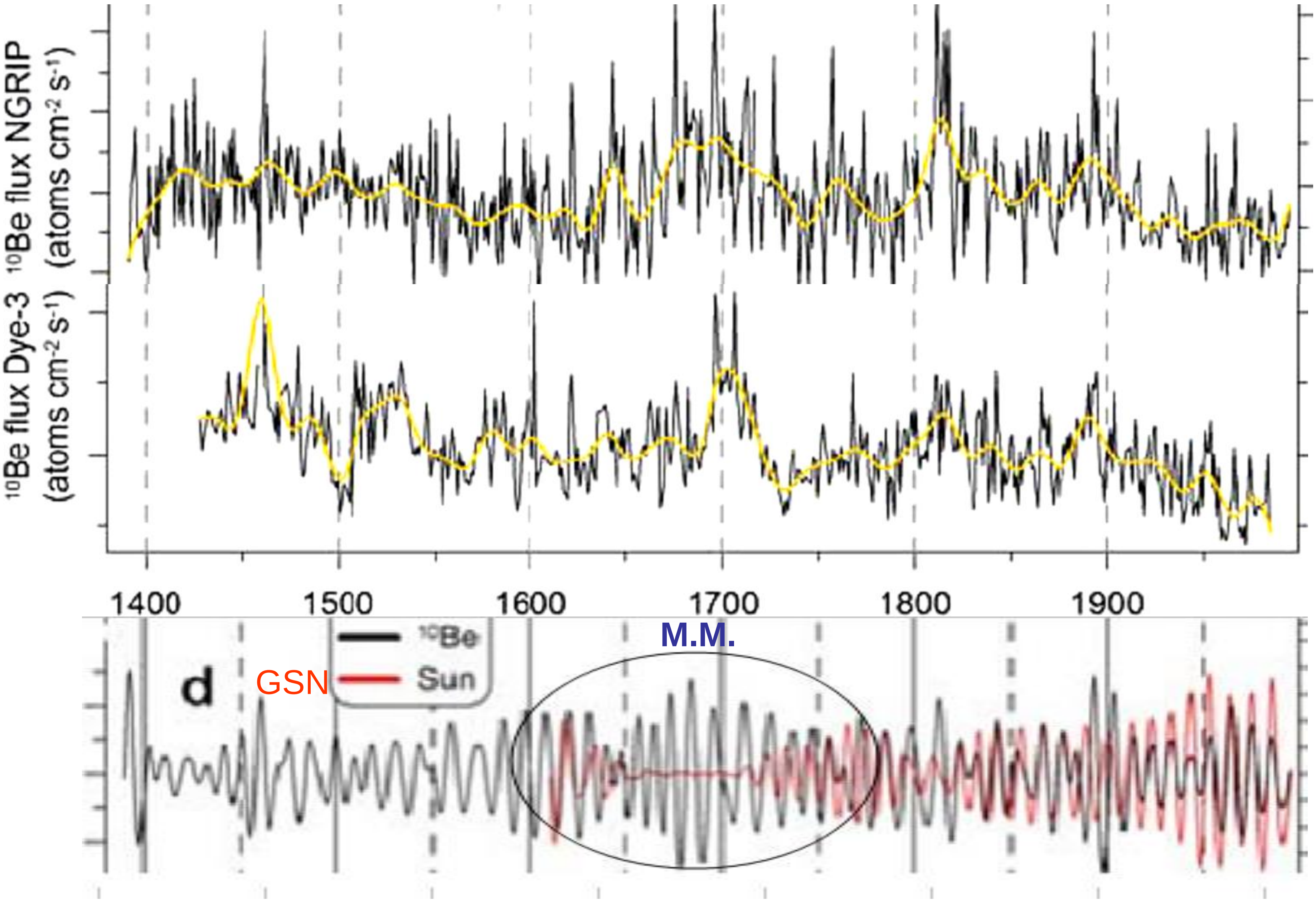
Polar Fields needed





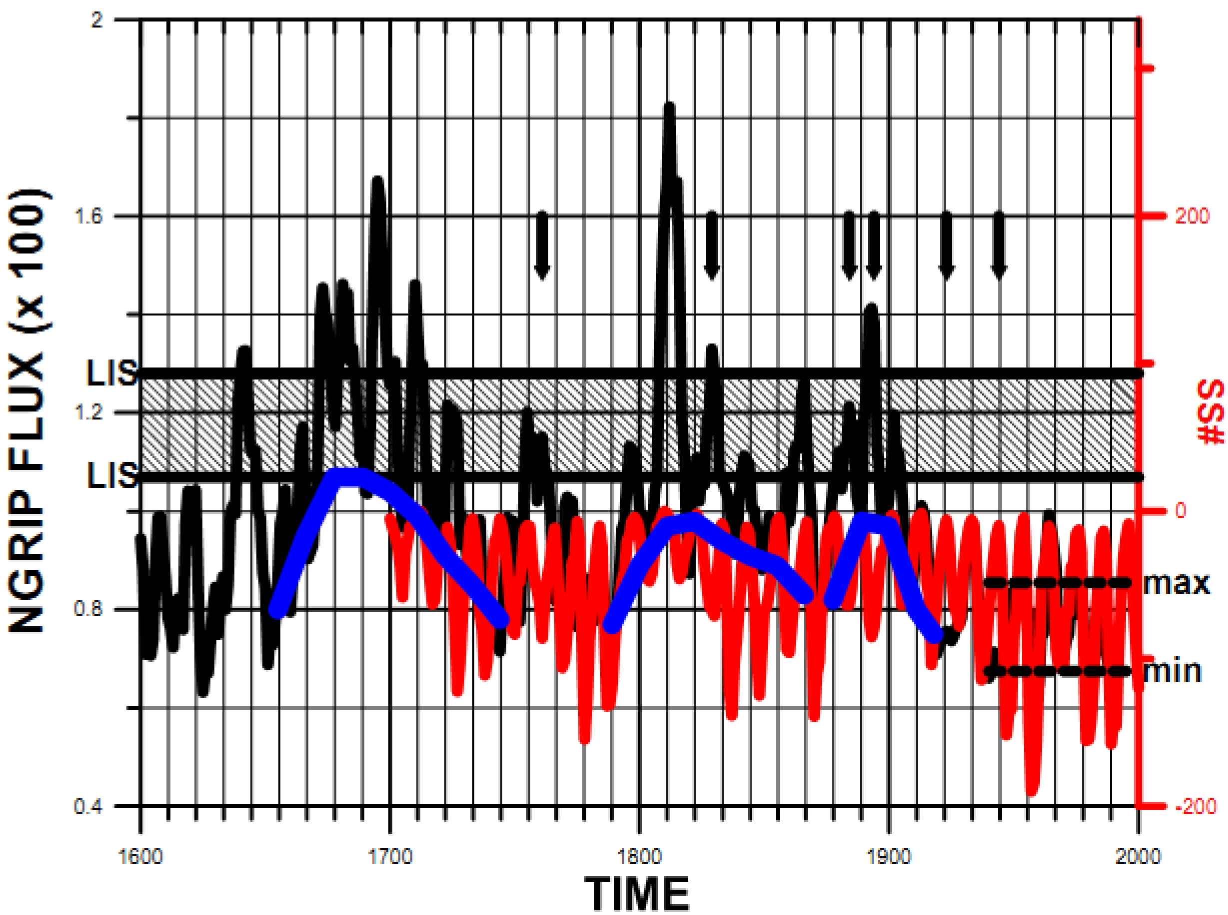


Maunder Minimum
Dalton
Gleissberg
Eddy Minimum
SSN
Aurorae Days
Be-10 (x10^4 atoms/g)
C-14 %
Time (Years)
1600
1700
1800
1900
2000



Cosmic Ray Proxy [Berggren et al., 2009]

We do not understand the 10Be modulation



"we have an upper limit to the absolute maximum 10Be flux which is only ~1.25 times the recent average maximum intensity of 10Be measured. This value corresponds to the lowest bound of the shaded region in Figure 5. This lower bound includes many other earlier time periods with 10Be flux values that exceed those possible from 10Be production alone from the full LIS spectrum. Indeed this implies that **more than 50% the 10Be flux increase around, e.g., 1700 A.D., 1810 A.D. and 1895 A.D. is due to non-production related increases!** "

"Other influences on the ice core measurements, as large as or larger than the production changes themselves, are occurring. These influences could be climatic or instrumentally based. We suggest new ice core measurements that might help in defining more clearly what these influences are and-if possible-to correct for them. " **Webber et al. arXiv:1004.2675 (2010)**

'Burning Prairie' => Magnetism

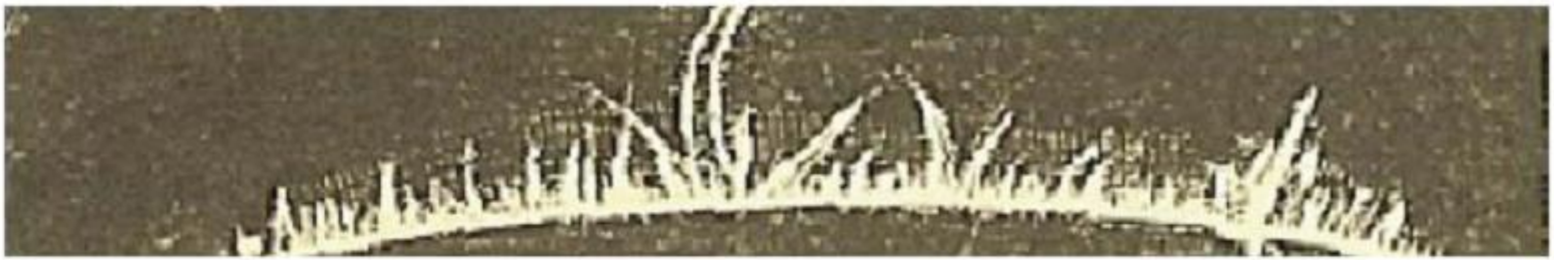


Figure 1 An early drawing of the "burning prairie" appearance of the Sun's limb made by C.A. Young, on 25 July 1872. All but the few longest individual radial structures are spicules.

It is now well known (see, *e.g.*, the overview in Foukal, 2004) that the spicule jets move upward along magnetic field lines rooted in the photosphere outside of sunspots. Thus the observation of the red flash produced by the spicules requires the presence of widespread solar magnetic fields. Historical records of solar eclipse observations provide the first known report of the red flash, observed by Stannyan at Bern, Switzerland, during the eclipse of 1706 (Young, 1883). The second observation, at the 1715 eclipse in England, was made by, among others, Edmund Halley – the Astronomer Royal. These first observations of the red flash imply that a significant level of solar magnetism must have existed even when very few spots were observed, during the latter part of the Maunder Minimum.

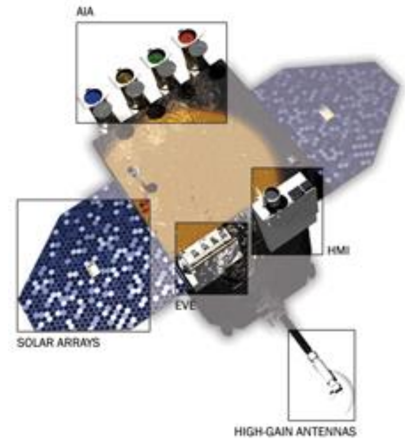
Foukal & Eddy, Solar Phys. 2007, *245*, 247-249

Birth of an Active Region

NOAA 11158, February, 2011

Solar Dynamics Observatory (SDO)

“All the Sun, All the Time”



Visible Light

Sunspots grow by the accumulation of smaller spots and pores.

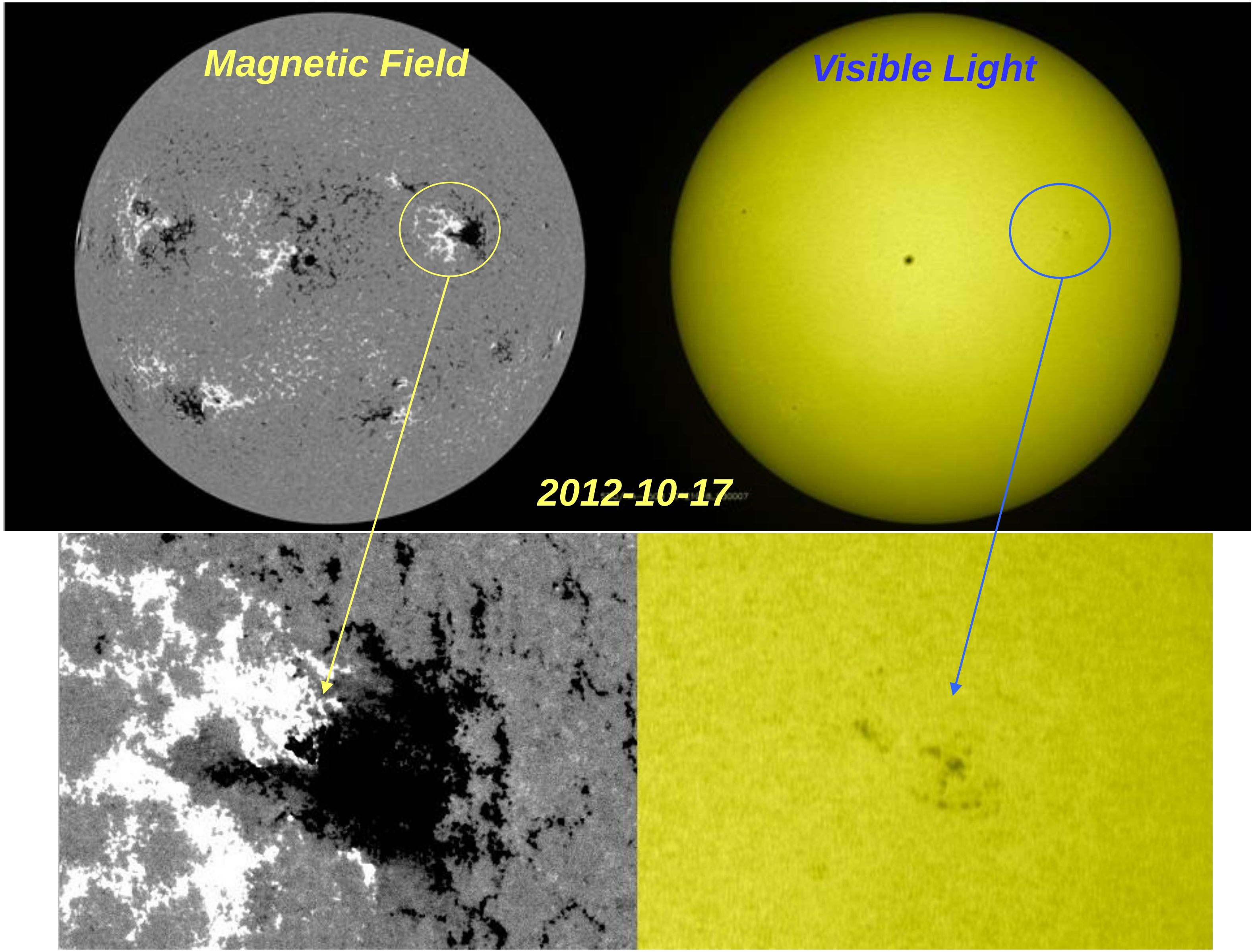
You may have to click on the area to play the movie.

It may not play on a Mac.

My Personal Working Hypothesis

- The Maunder Minimum was not a serious deficit of magnetic flux, but
- A lessening of the efficiency of the process that compacts magnetic fields into visible spots
- This may now be happening again soon
- If so, there is new solar physics to be learned

Perhaps like this:



The Maunder Minimum is as Mysterious as Ever

(but so was the notion a decade ago that we would ever successfully reconstruct the solar wind properties for the past 170 years…)