Solar Activity – Past, Present, and Future

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Slide 1

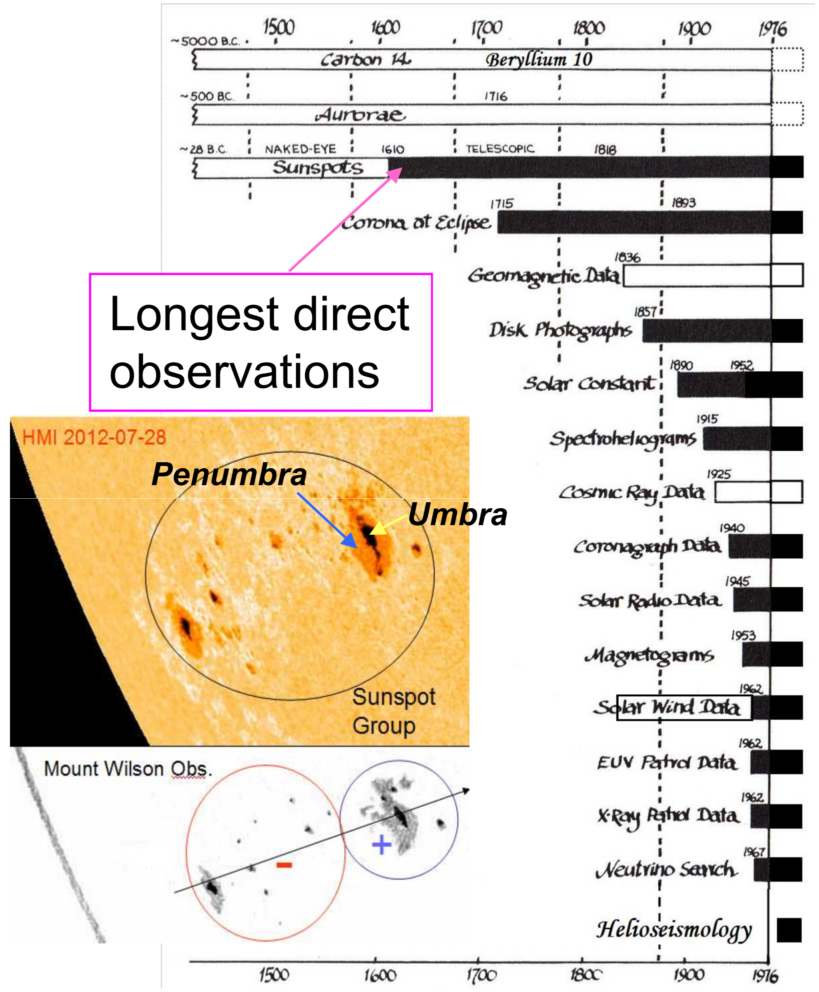
L1 The present is the key to the past and both are key to predicting the future

Leif, 10/8/2012

L2

Indicators of Solar Activity

- Sunspot Number (and Area, Magnetic Flux)
- Solar Radiation (TSI, UV, …, F10.7)
- Cosmic Ray Modulation
- Solar Wind
- Geomagnetic Variations
- Aurorae
- Ionospheric Parameters
- Oscillations
- Climate?
- More…



After Eddy, 1976

Solar Activity is Magnetic Activity

Slide 2

L2 There are many indicators of solar activity, reflecting our increasing instrumental capabilities. The longest direct observational systematic indicator is, of course, the Sunspot Number.
Sunspots occur physically connected in Groups, often with a characteristic magnetic bipolar configuration.

Auroral sightings and Cosmic Ray Proxies are important for the very long record, while disk photographs in both visible light and several spectral lines go back about a century. Our current observational capabilities make today a Golden Age for solar physics. Perhaps beyond Golden.

Leif, 10/19/2012

L3

The Sunspot Number(s)

Rudolf Wolf (1816-1893)
Observed 1849-1893

- Wolf Number = $K_W\,(10^*G + S)$
- G = number of groups
- S = number of spots

- Group Number = $12\,K_G\,G$

Ken Schatten

Douglas Hoyt and Kenneth Schatten devised the *Group Sunspot Number* using just the group count (1993).

Unfortunately a *K*-factor was also necessary here, so the result really depends on how well the *K*-factor can be determined

Slide 3

L3 Rudolf Wolf fashioned his Relative Sunspot Number as an index reflecting the importance of Groups as well as of individual spots. The K-factor compensates for differences between observers.

Ken Schatten and Douglas Hoyt devised the alternative Group Sunspot Number as simply the number of groups visible on the disk (scaled up to match the Wolf number on average - the scale factor 12). Unfortunately, a K-factor is also needed here, and its determination is the main difficulty with the Group Sunspot Number.

Leif, 10/19/2012

L4

The Wolf Number, Zürich Sunspot Number, and International Sunspot Number are all synonyms for the same data, today maintained by the Solar Influences Data Center, SIDC, in Brussels, Belgium

Problem with The ‘Wolf’ Number

The effect of Weighting the sunspot count…

Zürich Observers

Wolf	1849-1893
Wolfer	1876-1928
Brunner	1929-1944
Waldmeier	1945-1995

Slide 4

L4 We have recently noted that the Wolf Number is not as homogeneous as thought. The problem is the introduction in the 1940s of a procedure of counting spots with a weight factor according to the size and structure of the spot: large spots are counted more than once. This inflates the sunspot number.

The list of Zurich observers [directors] reminds you who the actors are in this endeavor.
Leif, 10/19/2012

L5

Waldmeier's Description of the Weighting of Sunspots that began in the 1940s

Astronomische Mitteilungen der Eidgenössischen Sternwarte Zürich
Nr. 285

1968

Die Beziehung zwischen der Sonnenflecken-relativzahl und der Gruppenzahl

Von

M. Waldmeier

Später wurden den Flecken entsprechend ihrer Größe Gewichte erteilt: Ein punktförmiger Fleck wird einfach gezählt, ein größerer, jedoch nicht mit Penumbra versehener Fleck erhält das statistische Gewicht 2, ein kleiner Hoffleck 3, ein größerer 5.

"A spot like a fine point is counted as one spot; a larger spot, but still without penumbra, gets the statistical weight 2, a smallish spot with penumbra gets 3, and a larger one gets 5." Presumably there would be spots with weight 4, too.

This very important piece of metadata was strongly downplayed and is not generally known

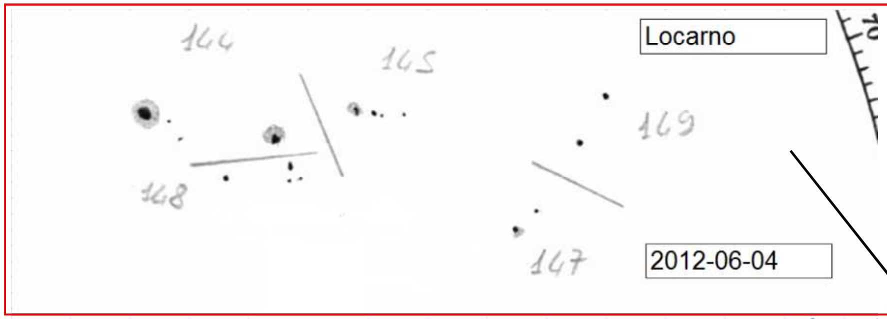
Slide 5

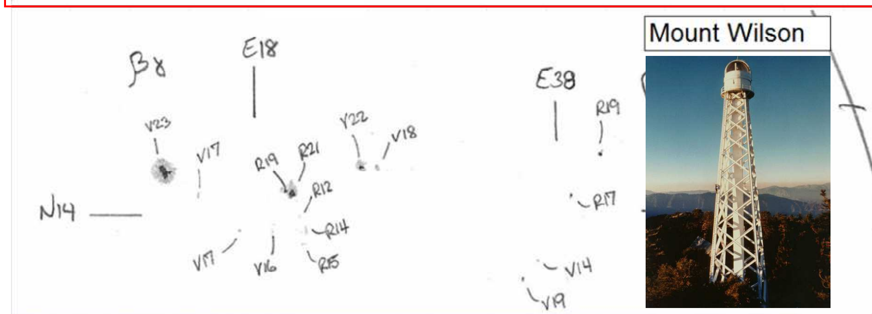
L5 Waldmeier's description [1968] of the weights assigned to spots according to their structure and size. This weighting of sunspots is not generally known.

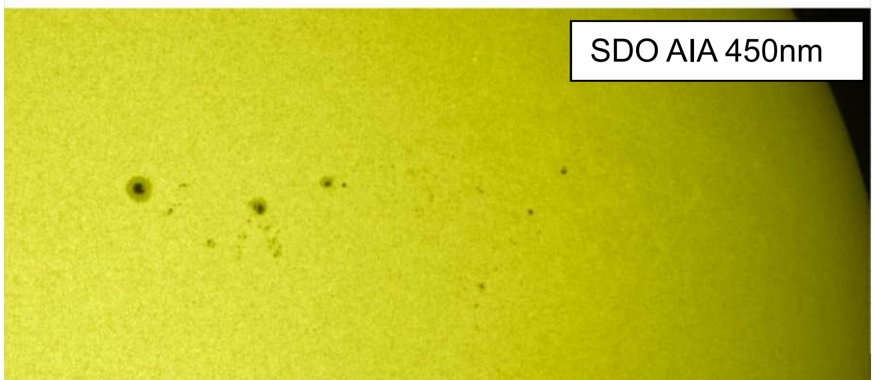
The Locarno station in southern Switzerland was operated by the Zurich observatory to provide coverage on days with poor observing conditions at Zurich.

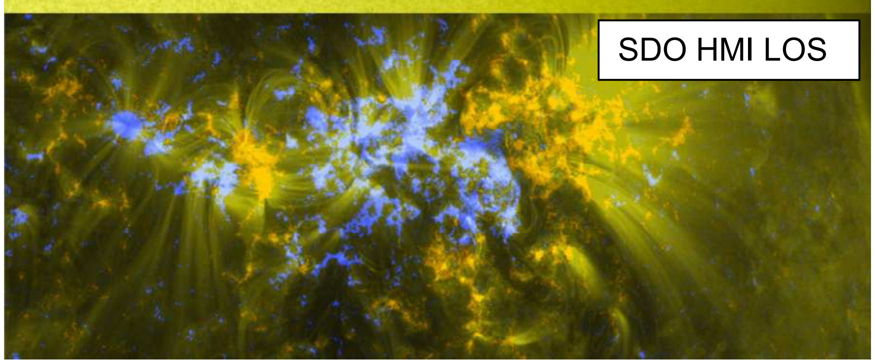
Locarno is still used as the reference station for the current provider of the sunspot number (SIDC in Brussels). And is still weighting according to Waldmeier's prescription. As far as I know, no other observers are weighting spots in their count.
Leif, 10/19/2012

L6









No Weight

g	f		B
143	4	2	-16°
144	7	4	+15°
145	5	4	+15°
146	12	6	-21°
147	4	2	+8°
148	5	4	+11°
149	4	2	+15°
150	6	2	+10°
151	1	1	+11°
152	2	2	+6°
153	2	1	-18°
11	52	30	

Groups

'Spots'

10*11+52=162; 10*11+30=140;
162/140=1.16

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

I have re-counted 43,000 spots without weighting for the last ten years of Locarno observations.

Slide 6

L6 Example of the influence of weighting: On a drawing from Locarno, the weighted count for each group is given in black, while the unweighted, raw, count of each spot within a group is given in red. The weighting increases the Relative Sunspot Number by 16%. Locarno also counts more groups than most other observers, e.g. Mount Wilson. This further inflates the SSN by about 5%.

A re-count without weighting was carried out on Locarno drawings for the last ten years.
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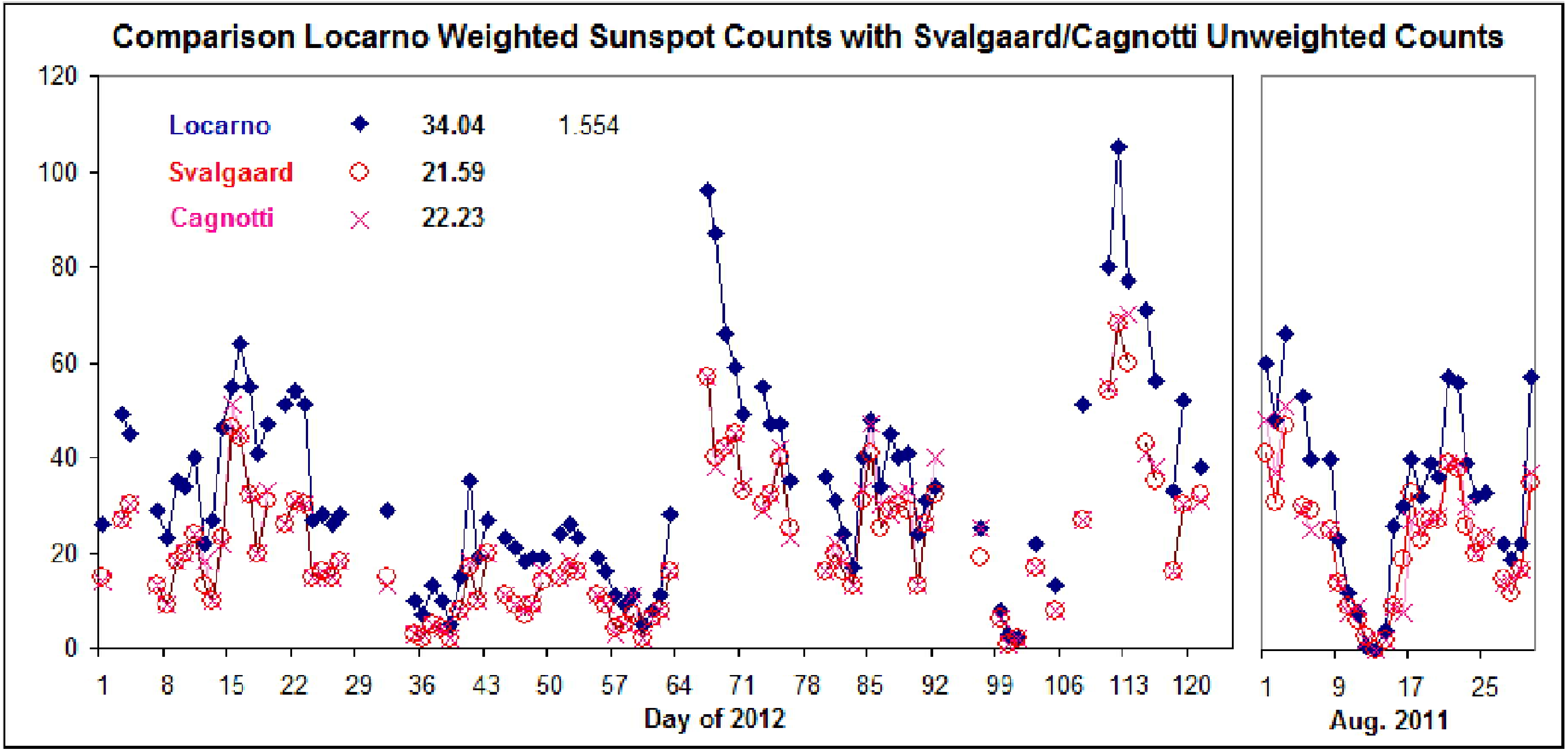
L7

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 30-50% (44% on average)

Slide 7

L7 To test if my re-count was done correctly, I asked the Locarno observers to also perform a raw count without weighting [without telling me - and I didn't tell them what my count was either]. After several months, we compared counts (exchanged via a third person) and found good agreement.

Weighting increases the count by 30-50%. For the test period by 55%, on average 44%. There is therefore no doubt about the magnitude of the effect of weighting on the official sunspot number.
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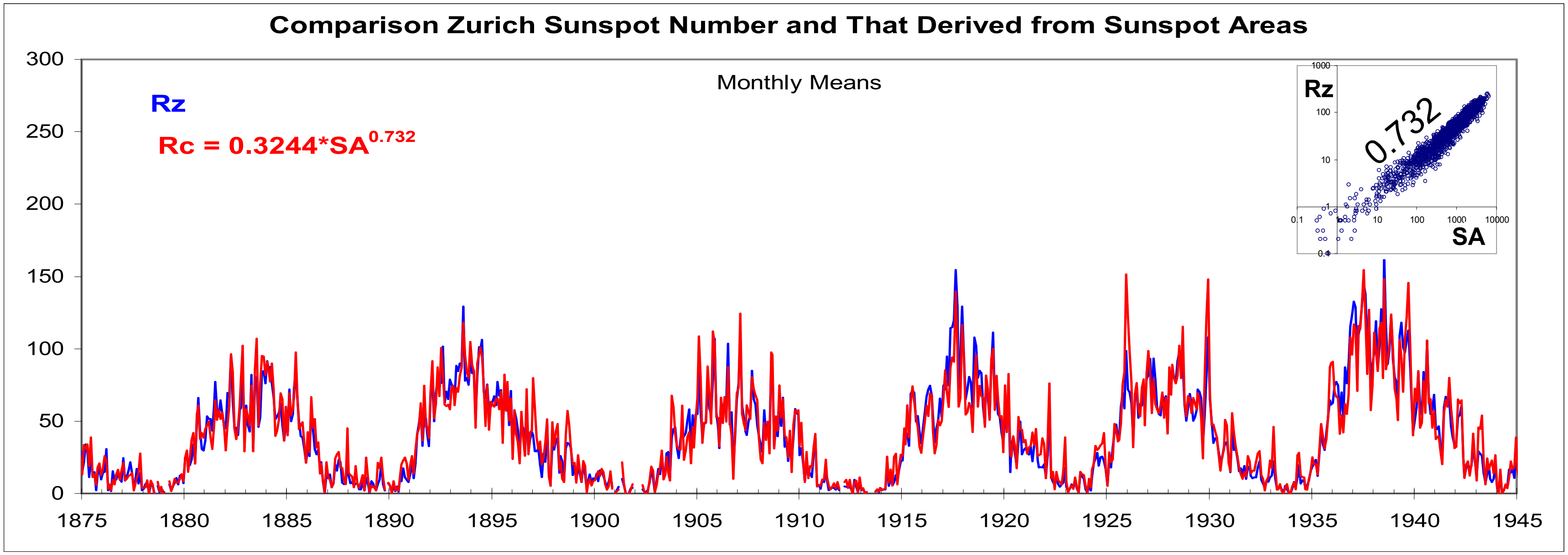
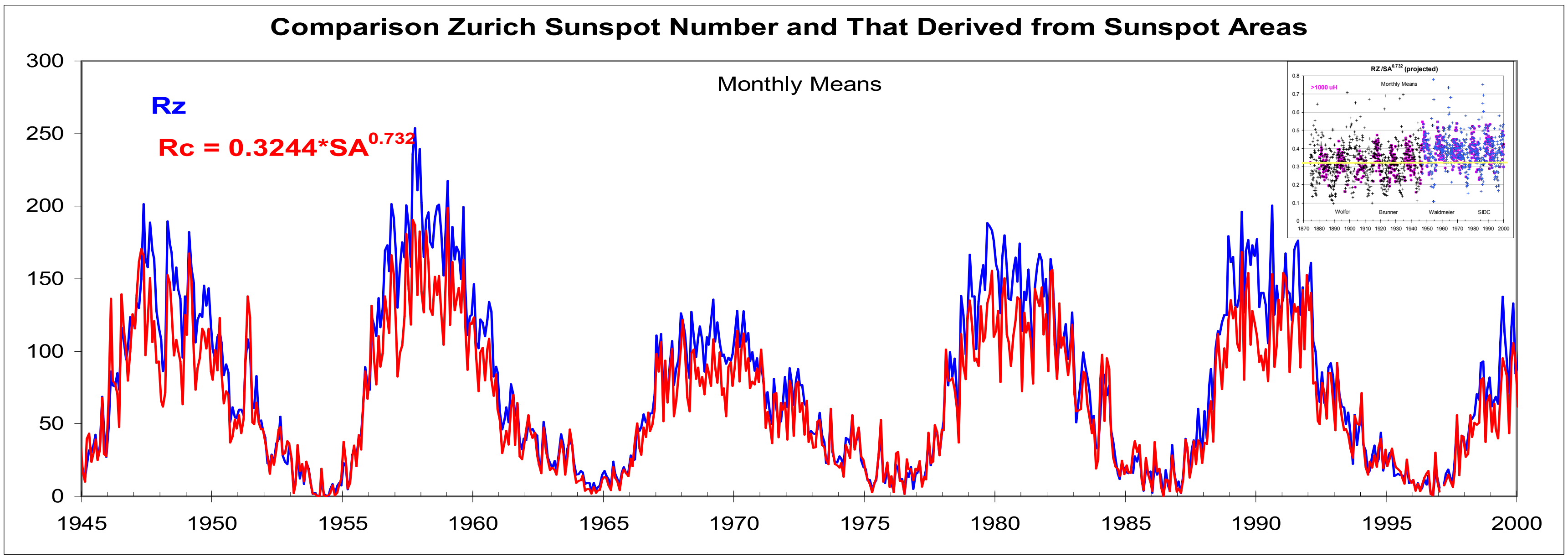
L8





The 20% Inflation Caused by Weighting Spot Counts

L8 There is a well-known relation between the Zurich sunspot number, Rz, and the area, SA, of the hemisphere covered by spots. The relation is not quite linear, but can be expressed by a power law: Rz = a SA^0.732 where the constant 'a' for the time before Waldmeier is 0.3244. The top panel shows how well the observed Rz matches the sunspot number Rc calculated using the above equation. The very good agreement is immediately evident.

On the other hand, as the lower panel shows, the observed Rz after ~1946 is clearly higher, showing the effect of weighting. The constant 'a' that would make Rc match Rz is 0.3921, or 21% higher.

The insert shows the ratio Rz/Rc, demonstrating the clear effect of sunspot weighting. This is but one example that shows the effect of weighting, there are several other indicators that show the effect as well, e.g. the Ca II index and the ionospheric F2-layer critical frequency.

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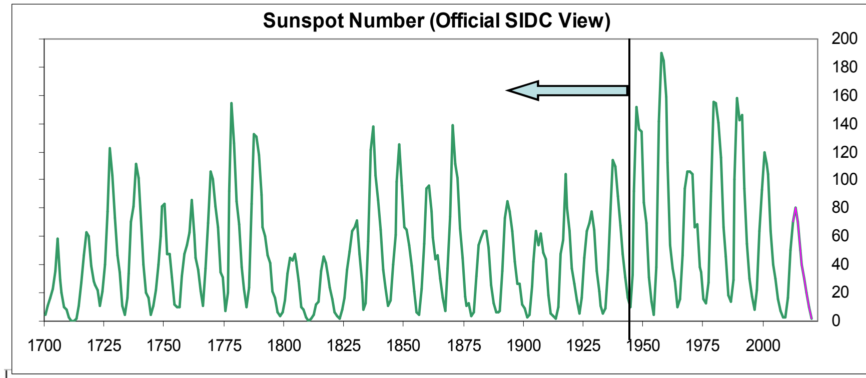
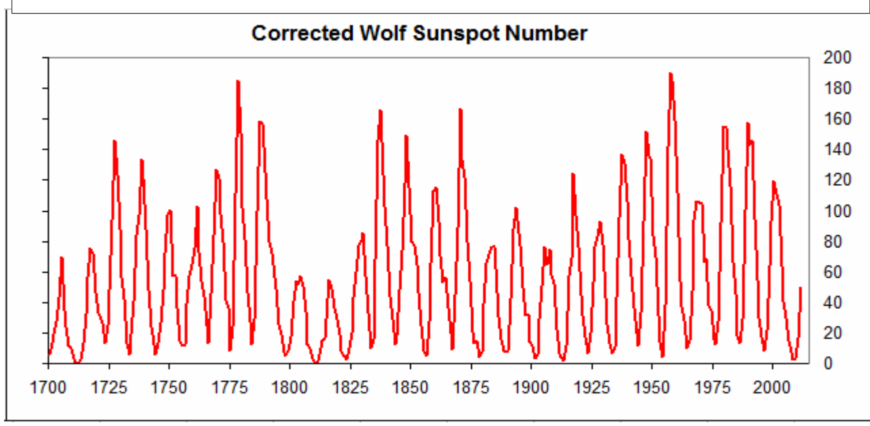
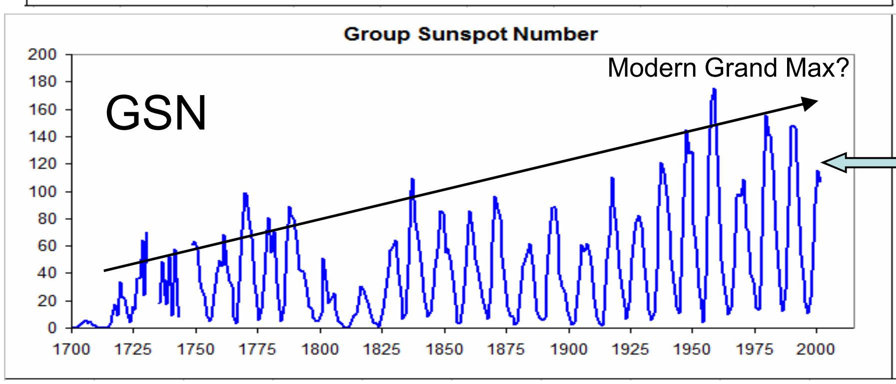
L9

Correcting for the 20% Inflation







R*corr* = R*official* * 1.2 before ~1946

This issue is so important that the official agencies responsible for producing sunspot number series have instituted a series of now ongoing Workshops to, if at all possible, converge to an agreed upon, common, corrected series:

http://ssnworkshop.wikia.com/wiki/Home

The inflation due to weighting is now an established and accepted fact

That the corrected sunspot number is so very different from the Group Sunspot Number is a problem for assessing past solar activity and for predicting future activity. This problem must be resolved.

Slide 9

L9 As the inflation turn out to be almost independent of solar activity, a possible way of correcting for it is simply to multiply all sunspot numbers before ~1946 by 1.20. Such a sweeping change is not to be done lightly, so various agencies producing sunspot numbers [SIDC Brussels; US Air Force; SWPC - NOAA; and many interested, independent solar physicists] are sponsoring and participating in a series of Workshops to provide an orderly transition backed up by the necessary documentation and practicall tools for its implementation.

One consequence of the correction is that it does not seem reasonable to talk about a Modern Grand Maximum

The inflation is no longer in doubt and must be accepted as established fact. The only question is what to do about it.

The Group Sunspot Number is already seriously lower than the Wolf number before ~1885. The correction of the Wolf number makes that discrepancy even worse. It is easy to see where people get the notion of a Modern Grand Maximum from. This will have to be resolved.

Leif, 10/19/2012

L10

Problem with the Group Sunspot Number

Determining correct K-factors…

Slide 10

L10 The solution to resolving the discrepancy between the Group and Wolf numbers [especially after correction for the inflation caused by weighting] lies in determining the correct K-factors for the many observers that contributed to the Group count.

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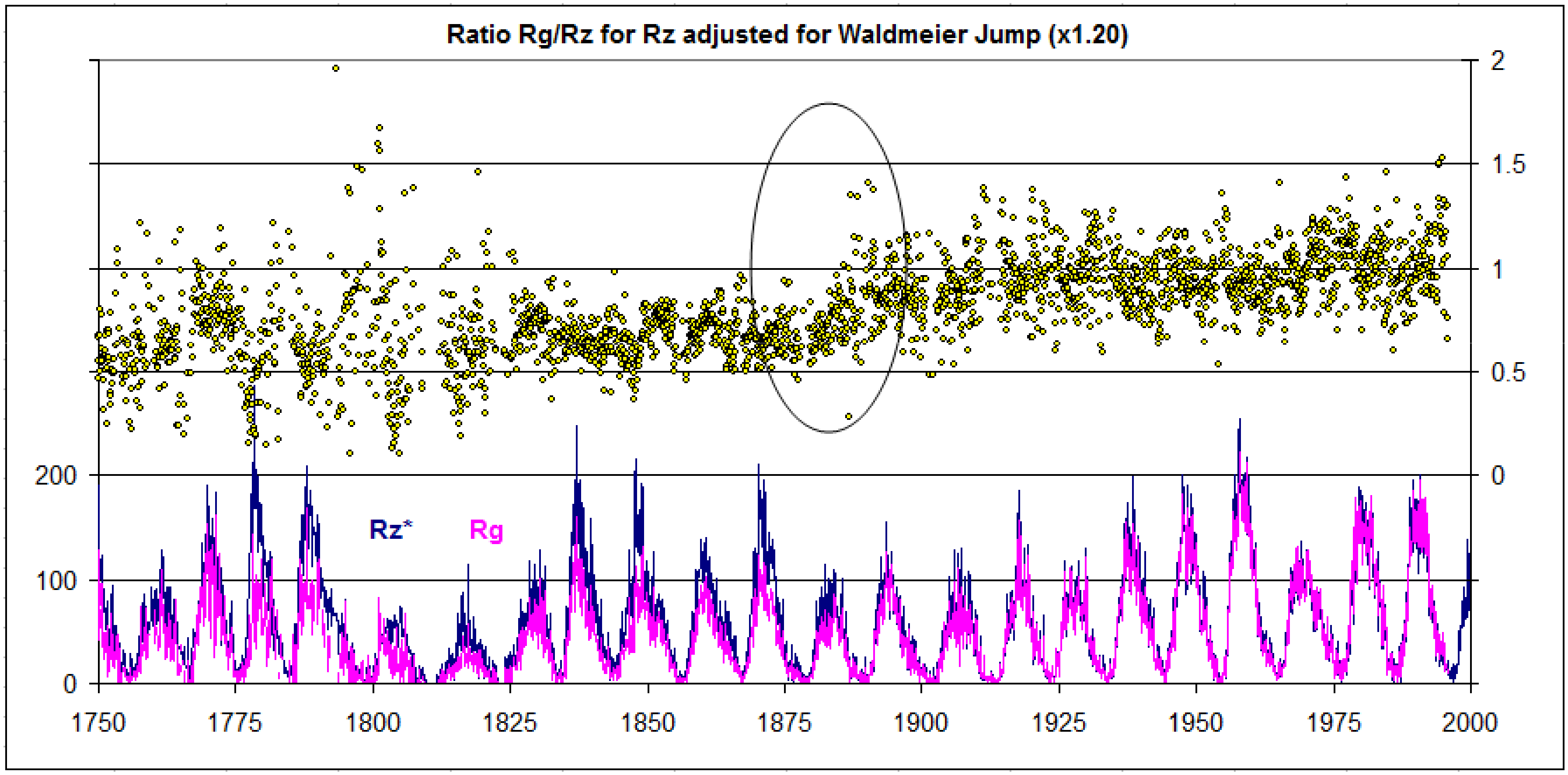
L11

The Ratio between the Group Sunspot Number and the [corrected] Sunspot number



Shows that the significant discrepancy is largely due to data from the 1880s

Slide 11

L11 The variability caused by the solar cycle makes it hard to compare the two sunspot series. Taking the ratio between the series eliminates the solar cycle and the ratio will show any sudden jumps in the difference or any trends not due to solar activity.

It is clear that the single most important inhomogeneity is a nearly discontinuous 'jump' in the mid-1880s (oval).

The lower curves show the corrected Zurich number in blue and group sunspot numbers in pink. It is clear that the blue curve reaches about the same high values in each century.

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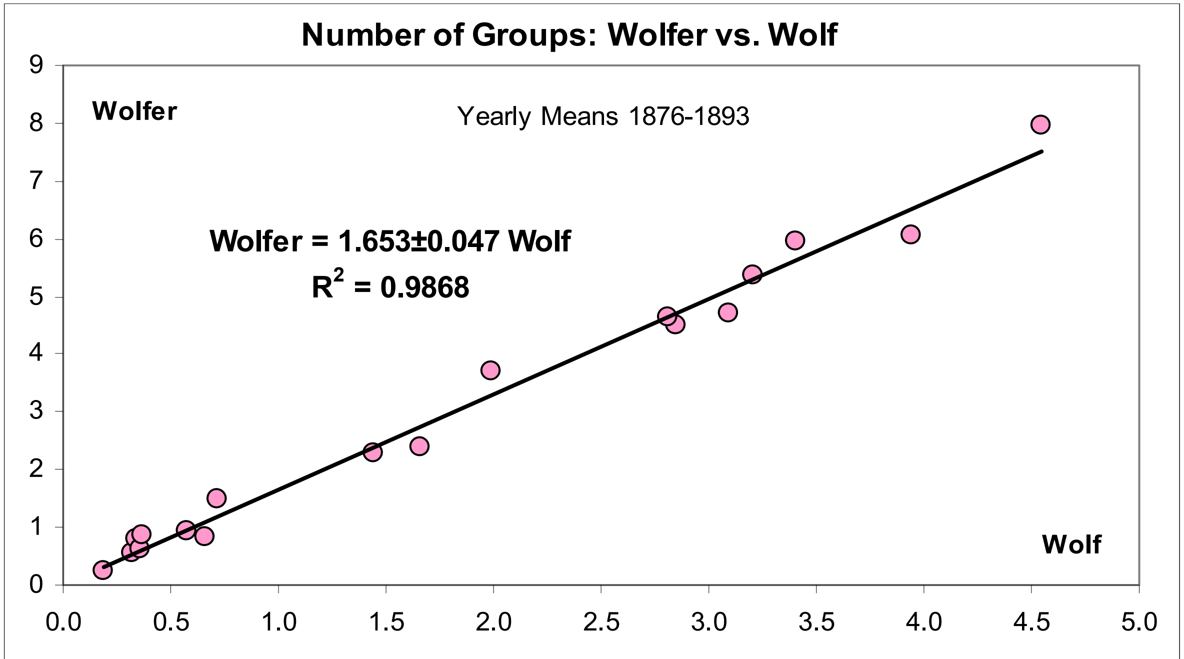
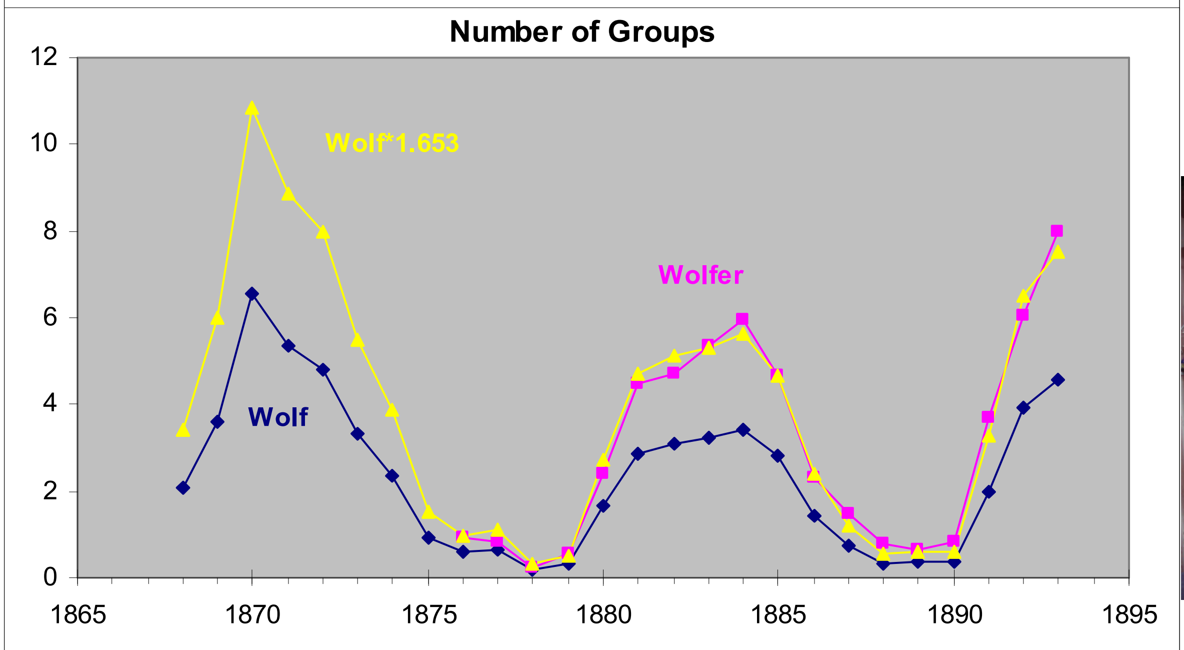
L12

Wolf-Wolfer Groups





Slide 12

L12 Wolfer used the larger 'standard' telescope with 80mm aperture X64 magnification [the grey image]. This telescope still exists and is used every day by Thomas Friedli to continue the Wolf tradition.

From the 1860s Wolf traveled a lot and he started to use exclusively a much smaller telescope [37mmX20] shown at the lower right. As you can see, this telescope also exists today, so we can check what size spots are visible.
For the time when Wolf and Wolfer both observed we can compare how many groups they reported [upper left]. Clearly Wolfer saw 65% more groups as Wolf did, which is reasonable considering the difference in telescopes and Wolf's policy of not counting the smallest spots.

At the lower left we show Wolf's count [blue] and Wolfer's [pink]. Multiplying Wolf's group count by 1.653 yields the yellow curve which is a very close match to Wolfer's, as we would expect from a coefficient of determination of 0.9868. So, 1.653 is the K-factor needed to bring Wolf onto the same scale as Wolfer.

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L13

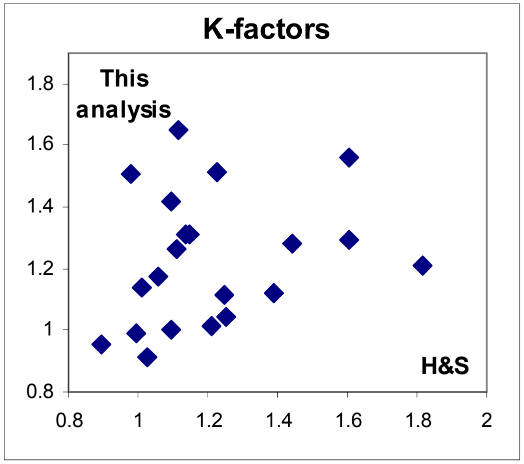
Why are these so different?

This is the main reason for the discrepancy

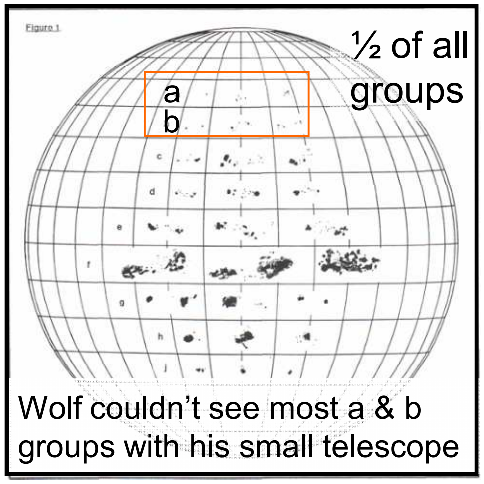
K-Factors

2% diff.

Observer	H&S RGO	to Wolfer	Begin	End
Wolfer, A., Zurich	1.094	1	1876	1928
Wolf, R., Zurich	1.117	1.6532	1876	1893
Schmidt, Athens	1.135	1.3129	1876	1883
Weber, Peckeloh	0.978	1.5103	1876	1883
Spoerer, G., Anclam	1.094	1.4163	1876	1893
Tacchini, Rome	1.059	1.1756	1876	1900
Moncalieri	1.227	1.5113	1876	1893
Leppig, Leibzig	1.111	1.2644	1876	1881
Bernaerts, G. L., England	1.027	0.9115	1876	1878
Dawson, W. M., Spiceland, Ind.	1.01	1.1405	1879	1890
Ricco, Palermo	0.896	0.9541	1880	1892
Winkler, Jena	1.148	1.3112	1882	1910
Merino, Madrid	0.997	0.9883	1883	1896
Konkoly, Ogylla	1.604	1.5608	1885	1905
Quimby, Philadelphia	1.44	1.2844	1889	1921
Catania	1.248	1.1132	1893	1918
Broger, M, Zurich	1.21	1.0163	1897	1928
Woinoff, Moscow	1.39	1.123	1898	1919
Guillaume, Lyon	1.251	1.042	1902	1925
Mt Holyoke College	1.603	1.2952	1907	1925



Zürich Classification:



A still unresolved question is how Hoyt & Schatten got the *K*-factors so wrong

Slide 13

L13 Hoyt & Schatten report a K-factor of 1.021 [=1.117/1.094] as the factor to bring Wolf on the same scale as Wolfer. H&S used the Greenwich photographic data as their 'standard' observer, so the K-factors they report are in relation to that data.

Why such a large difference? As we saw, we expect a large K-factor for Wolf because of telescope differences. Now, the Zurich classification for Groups includes classes a and b consisting of spots without penumbrae. These make up almost half of all groups and cannot be seen with Wolf's small telescope, so no wonder Wolfer saw 65% more groups.

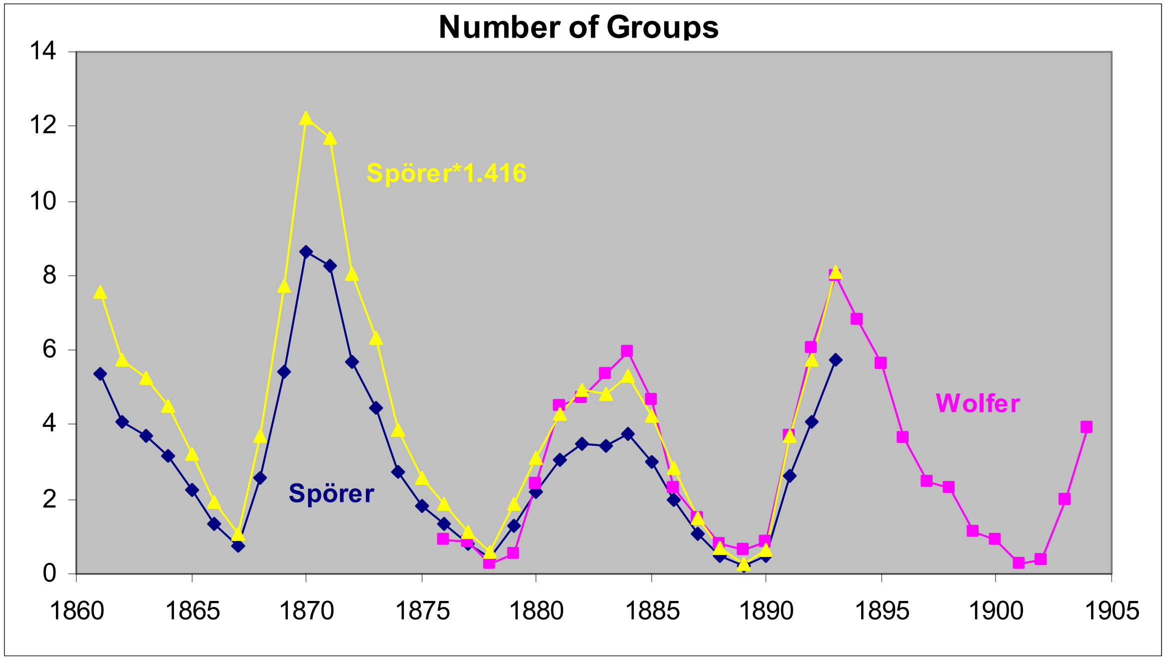
In a similar way we can determine K-factors for all observers covering the critical interval around the 1880s and compare them with what H&S used. There does not seem to be any correlation between our K-factors and H&S's. We do not know why.

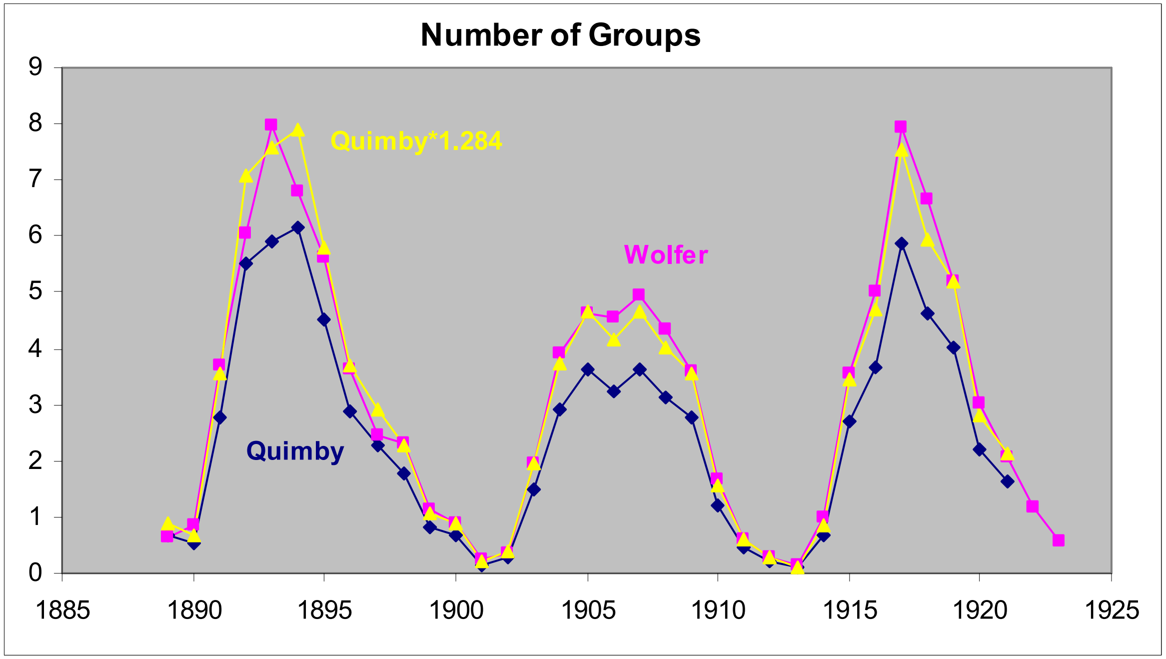
The direct comparison of observers that we show leave no room for doubt about what the K-factors should be. We believe, therefore, that we have uncovered the main reason for the discontinuity in the 1880s.

Leif, 10/19/2012

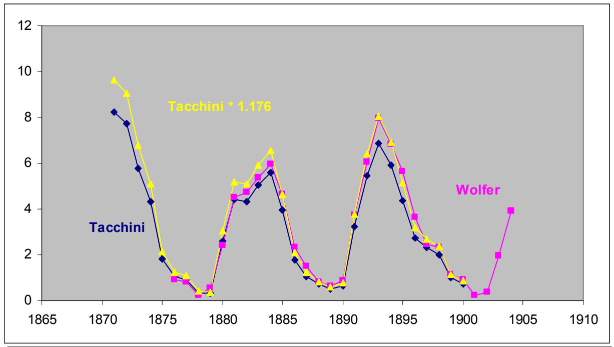
L14

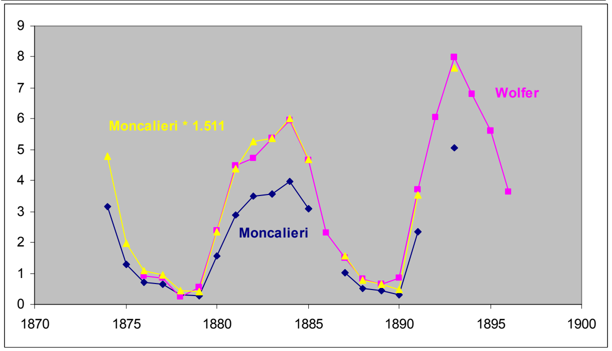
Comparing G. Spörer & Rev. A. Quimby [Philadelphia] to Wolfer





Same good and stable fit, showing that Wolfer's count had not drifted with time





Slide 14

L14 Here we show the comparison of four other observers with Wolfer's group counts for the period around the 1880s. The yellow and pink curves match closely, showing that Wolfer had not changed his counting proficiency over that time, meeting the requirements for a firm, good 'standard' observer. The average of the scaled values for these six observers forms a solid 'backbone' onto which we can hang other observers both before and after Wolfer's tenure.

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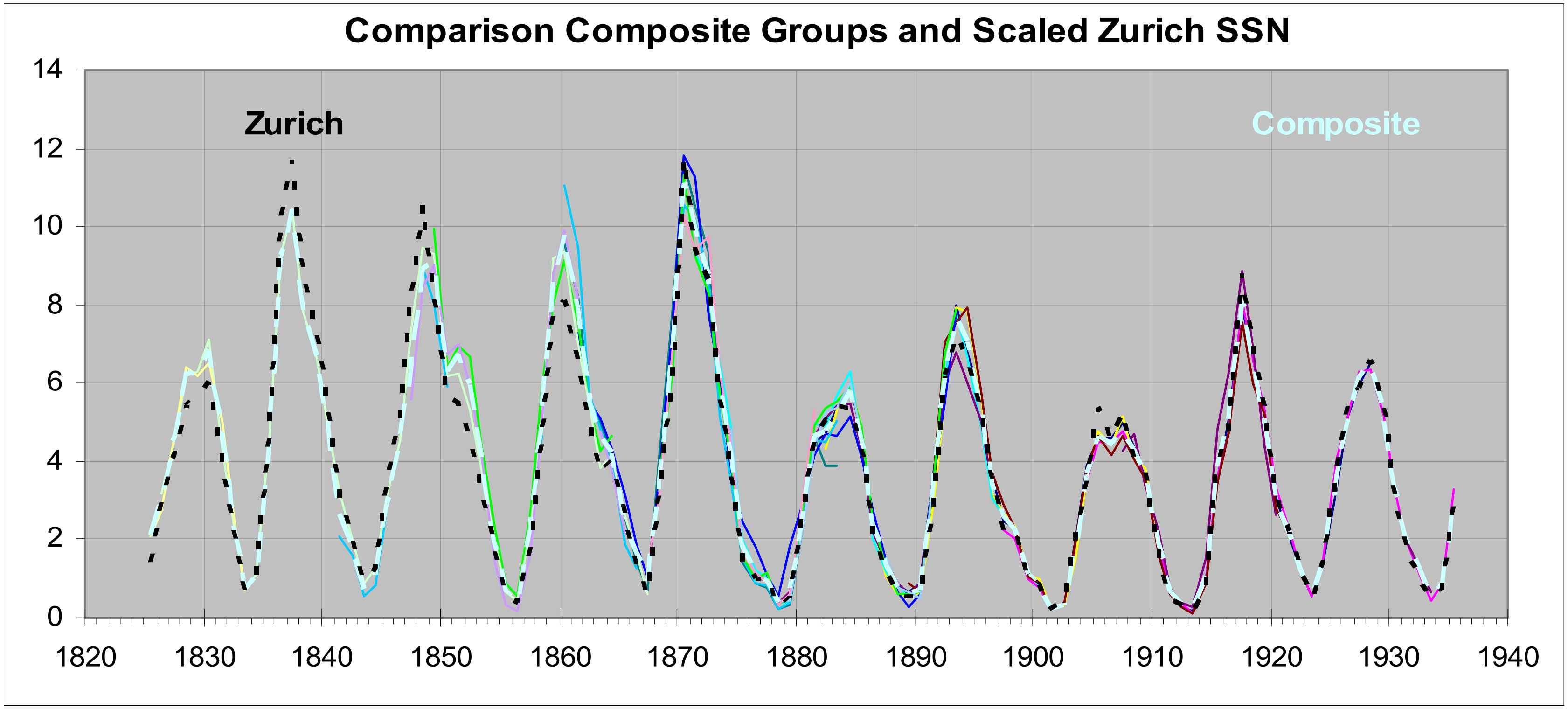
L15

Constructing a Composite

Comparing 22 observers that overlap with each other one can construct a composite group number successively back to Schwabe and up to Brunner:



There is now no systematic difference between the Zürich SSN and a Group SSN reconstructed here by using correct *K*-factors relative to Wolfer.

Slide 15

L15 Using that backbone we can 'daisy chain' all observers back to Schwabe and up to Brunner [just before Waldmeier became the assistant observer], determine K-factors, and construct a composite series as the average for each year of all observers suitably scaled by their K-factors. The dashed bright cyan curve shows the result. The scaled values for each individual observer are also plotted [in different colors]. Those curves are hard to see because the generally fall on top of each other.

Finally, we can convert the Zurich Relative Number to a group count by dividing by 12 [see slide 3]. The result is plotted as the black dashed curve. There is no systematic difference between the two dashed curves.

This resolves the difference between the Wolf Sunspot Number and the Group Sunspot number: there isn't any, when the correct K-factors are employed, and therefore also no steady, secular increase in solar activity in the past 300 years, contrary to common belief.

Leif, 10/19/2012

L16

Geomagnetic Calibration of Sunspot Numbers

Wolf did it…

Slide 16

L16 Solar activity has an impact on the Earth's environment, so by monitoring the latter we can tell something about the former, as Wolf discovered. He marveled: "Who would have thought just a few years ago about the possibility of computing a terrestrial phenomenon from observations of sunspots". This computation can, of course, also be done in reverse, and be used to check the calibration of the sunspot number.

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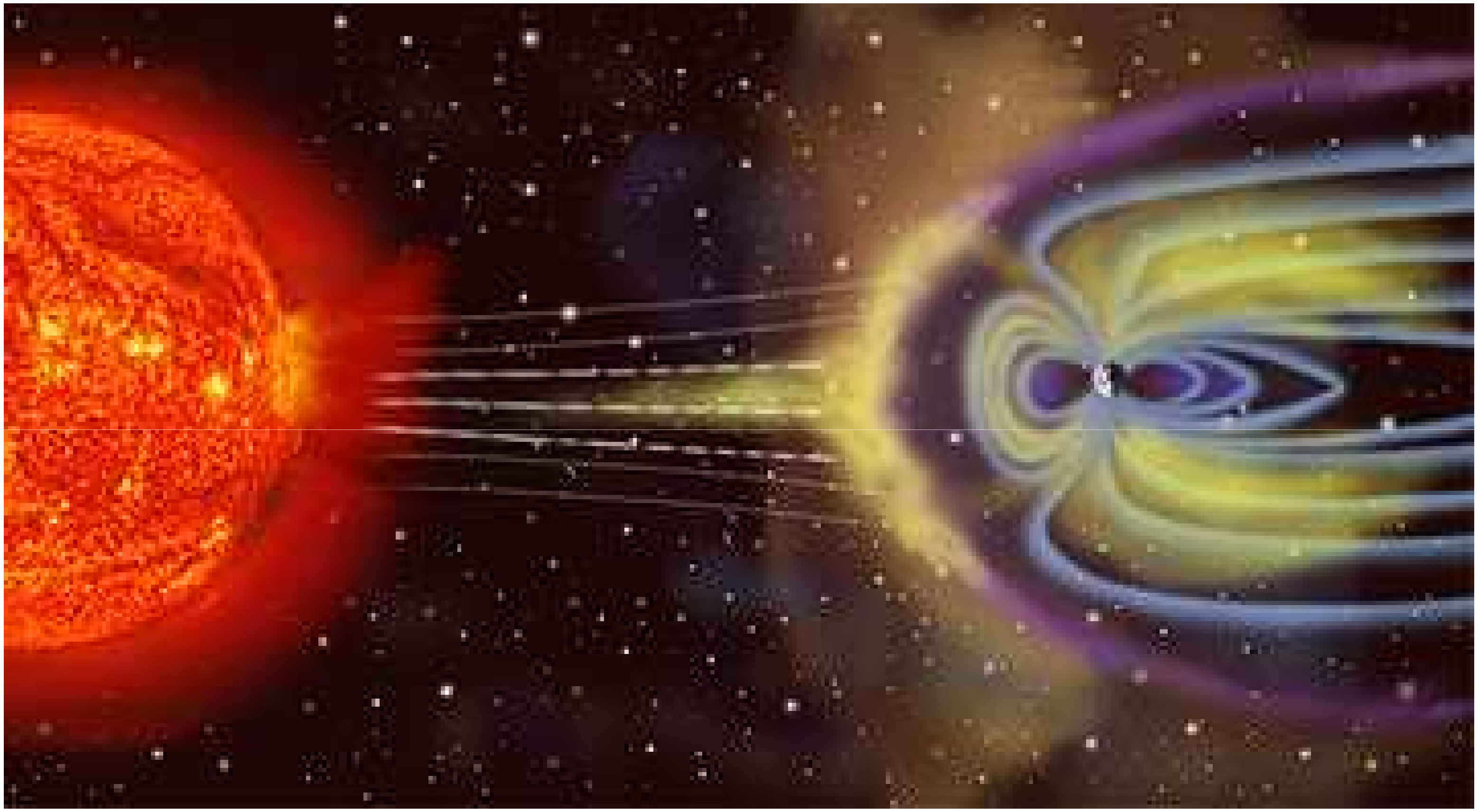
L17

Geomagnetic Regimes



1) Solar UV maintains the ionosphere and influences the daytime field.
2) Solar Wind creates the magnetospheric tail and influences mainly the nighttime field

Slide 17

L17 Solar UV creates and maintains the daytime ionosphere giving us an electrical conductor moving across geomagnetic field lines resulting in a dayside electric current system.
The solar wind drags the geomagnetic field into a long tail. Instabilities in the tail result in intermittent collapse of parts of tail with attendant acceleration of charged particles back towards the Earth, resulting in generally nighttime magnetic disturbances associated with aurorae.

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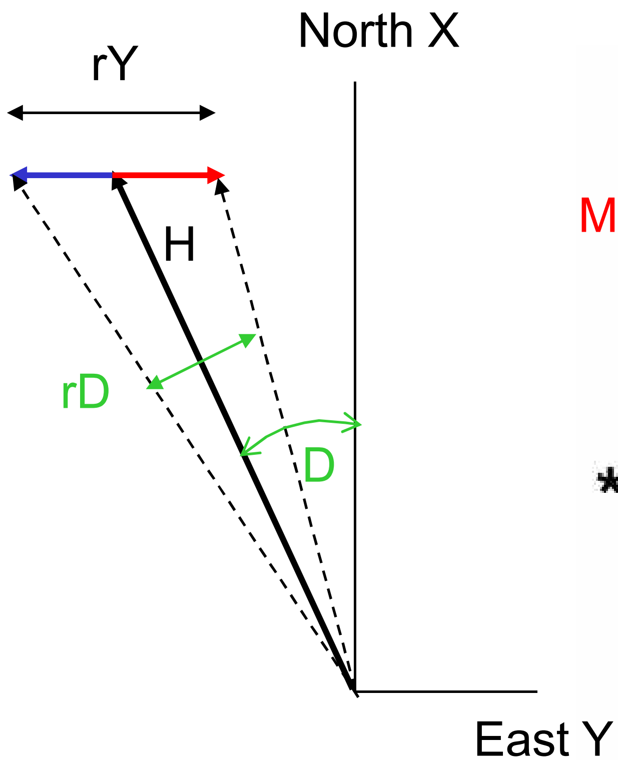
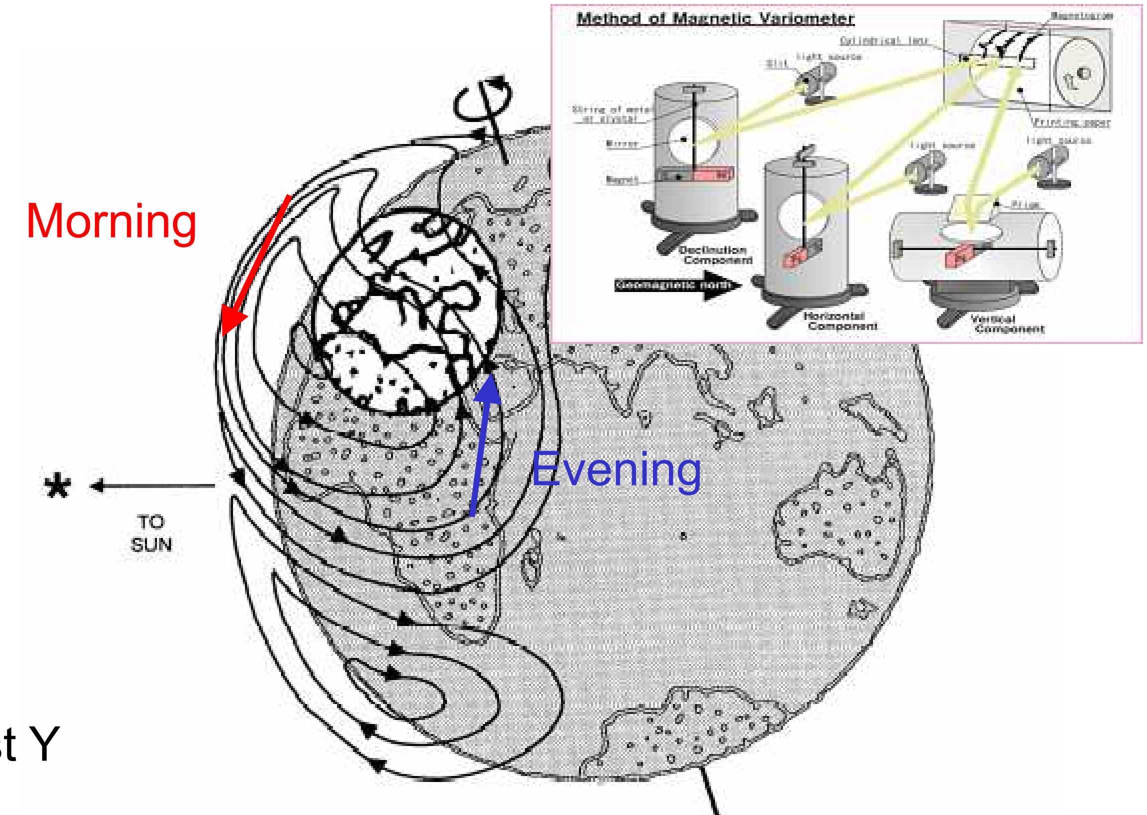
L18

Wolf's Discovery: $rD = a + b\ R_W$





Y = H sin(D)

dY = H cos(D) dD

For small D, dD and dH

A current system in the ionosphere [E-layer] is created and maintained by solar FUV radiation. Its magnetic effect is measured on the ground. (George Graham, 1722)

Slide 18

L18 Perhaps Wolf's greatest discovery was the close relationship between the diurnal variation of the direction [the Declination] of the geomagnetic field and his newly defined Relative Sunspot Number.

The ionospheric daytime current system [two vortices, one in each hemisphere] stays fixed with relation to the Sun while the Earth rotates under it. At mid-latitudes, the direction of the current is North-to-South in the morning [Northern hemisphere] and South-North in the evening. The magnetic effect is perpendicular to the current and the compass needle will thus deviate in the East-West direction, deflected towards the East in the morning and towards the West in the evening. The deflection being linearly dependent on the Sunspot Number. The East-West range of the deflection rY can be easily computed from the observed range of the Declination, rD, as shown.

This effect was discovered as early as 1722 by George Graham in London.
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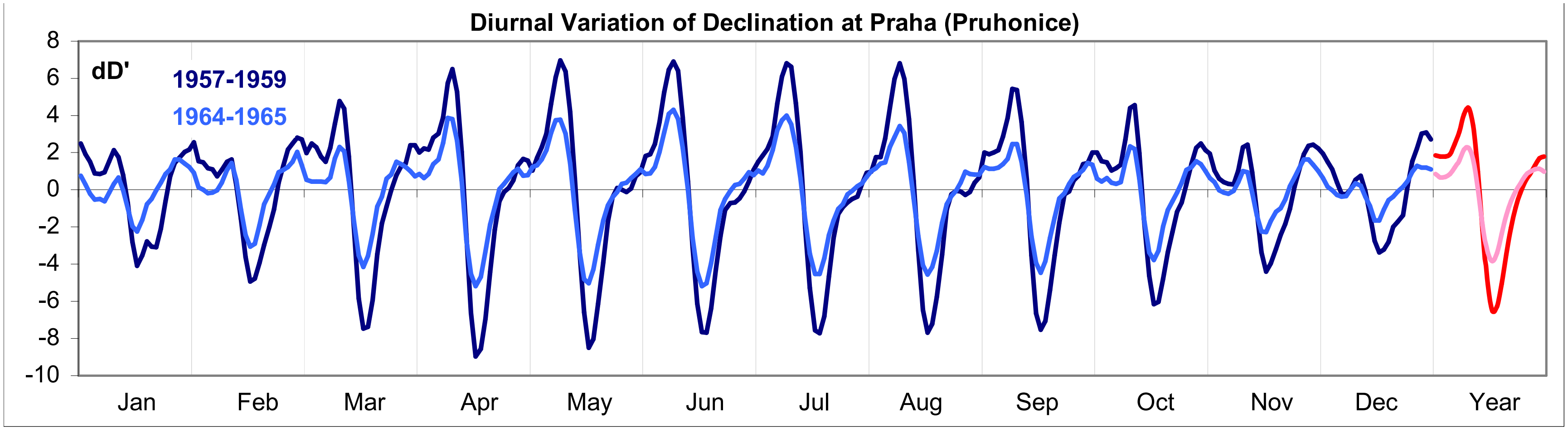
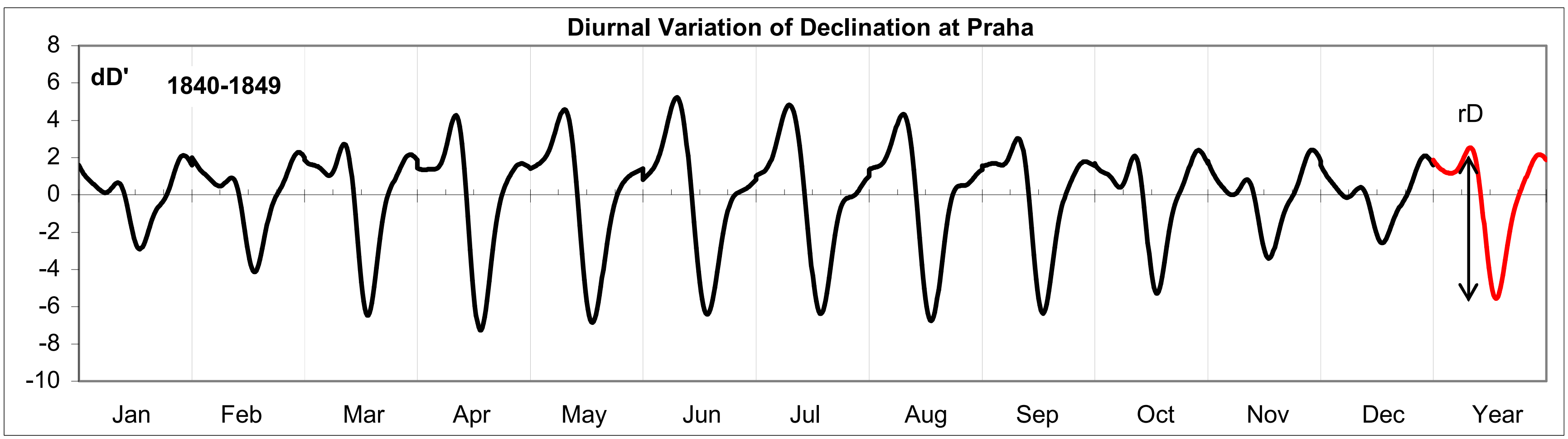
L19

The Diurnal Variation of the Declination for Low, Medium, and High Solar Activity





Slide 19

L19

The solar UV induced ionization obviously depends on the Sun's zenith angle and so has a seasonal variation as well as the diurnal one. The upper panel shows for each month of the year what the diurnal variation of the Declination looks like, for years of high solar activity [1957-1959, dark blue curve] and for years of low activity [1964-1965, light blue]. The average variation for the year is shown in reddish colors at the right. The format is such that the curve for each month shows the variation trough the day, with local noon in the middle.

The lower panel shows the variation at the same location [Praha] for a period of moderate activity 1840-1849. Note how closely the measurements of 170 years ago resemble in form the 20th century data, even in small details. The range of a few arc minutes was easily measurable back then and an angle does not require calibration.

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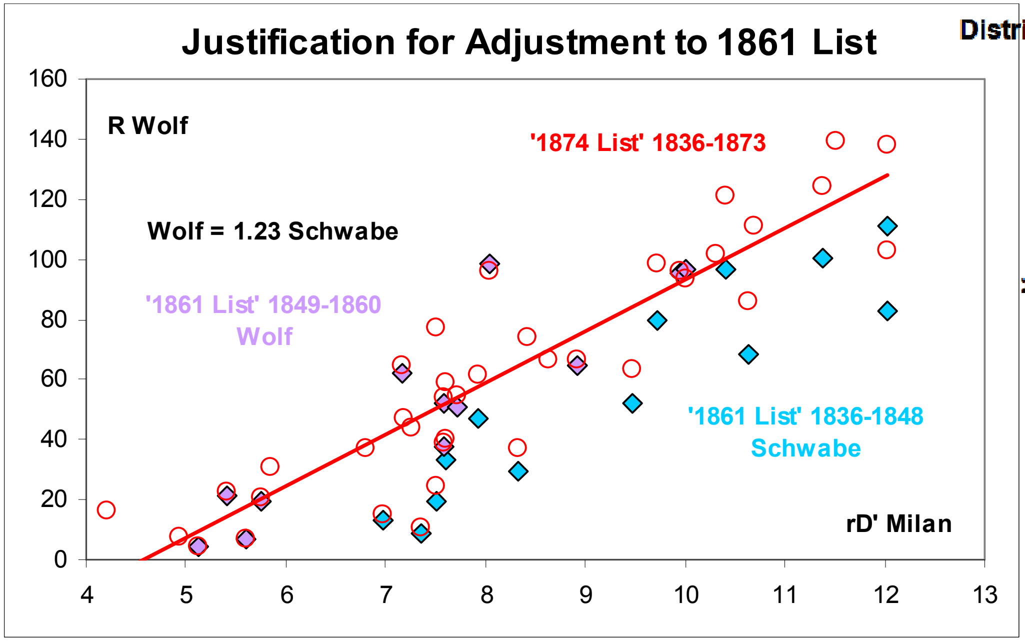
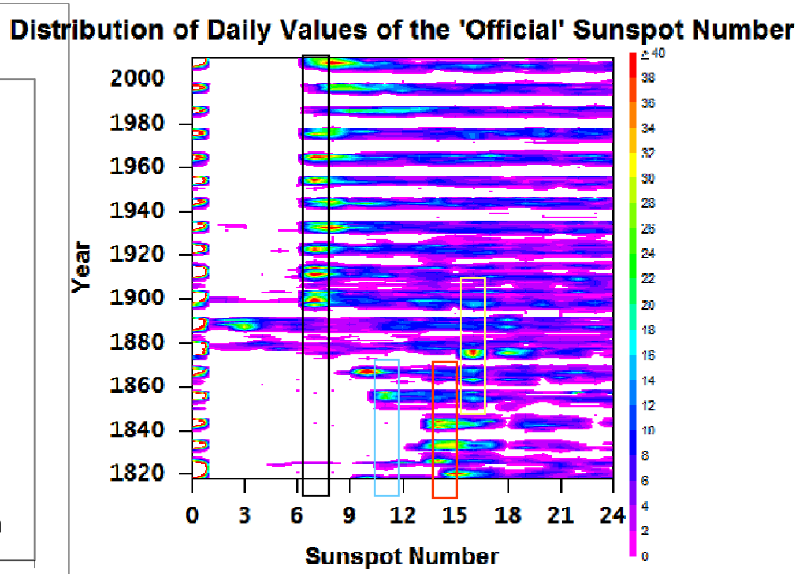
L20

Wolf got Declination Ranges for Milan from Schiaparelli and it became clear that the pre-1849 SSNs were too low





The values for 1836-1848 came from Schwabe. Wolf decided to increase them by 25% to match his own relationship with Milan's Declination

The smallest non-zero SSN should be 11. When it is not, it indicates adjustments were made

The '1874' list included the 25% [Wolf said 1/4] increase of the pre-1849 SSN. Was this a sensible thing to do?

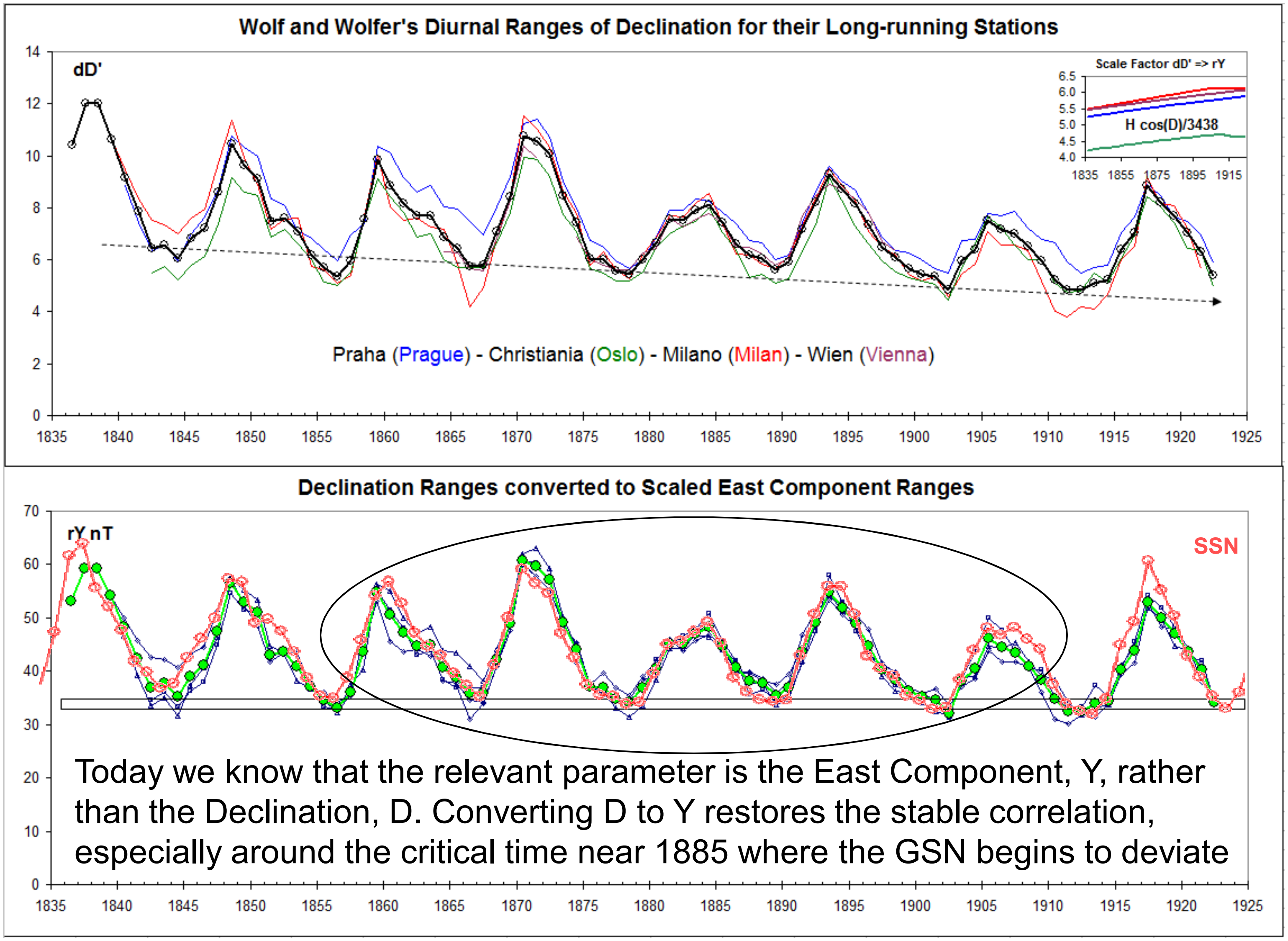
L20 Wolf communicated in 1861 a list of Sunspot Numbers for the interval 1749-1860 to Carrington, who published it. The data for 1826-1848 were mainly based on Henirich Schwabe's observations, while Wolf's own observations, from 1849 on, were the basic material for the list 1849-1860.

in 1874 Wolf got from Schiaparelli data about the diurnal range of the Declination measured in Milan [Italy] since 1836. When Wolf plotted his Sunspot Numbers vs. the Milan data [purple diamonds] and Schwabe's Sunspot Numbers vs. the Milan data [light blue diamonds], he noted that Schwabe's numbers were too low [compared to his own] and decided to increase all the values in the 1861 list by 25% and to release a new list in 1874. That list restored the consistent relation between SSN and the 'Magnetic Needle' [red open circles].

We can see the effect on this 'wholesale' adjustment in the distribution of daily values of the Wolf numbers. The smallest non-zero SSN should be 11 [1 group times 10 plus 1 spot] as can be seen in Wolf's own data from the 1850s [blue box]. Before that all the 11s were increased by 25% to 14, so we see peaks at that value [red box]. In the 1860s Wolf only used his little telescope (see slide 12) with a K-factor of 1.5 [yellow box at 11*1.5=16.5].
When Wolfer decided to count also the smallest spots, his K-factor became 0.6, and the smallest non-zero SSN is then 11*0.6=7, as can be seen from the 1890s until today [black line box]. The strange behavior in the 1870s and 1880s stems from a temporary, unfortunate decision by Wolf to average his and Wolfer's SSNs, rather than to stick with the standard practice of using only ONE observer per day.
Leif, 10/19/2012

L21

Wolf's Original Geomagnetic Data



Today we know that the relevant parameter is the East Component, Y, rather than the Declination, D. Converting D to Y restores the stable correlation, especially around the critical time near 1885 where the GSN begins to deviate

Wolf found a very strong correlation between his Wolf number and the daily range of the Declination.

Wolfer found the original correlation was not stable, but was drifting with time and gave up on it in 1923.

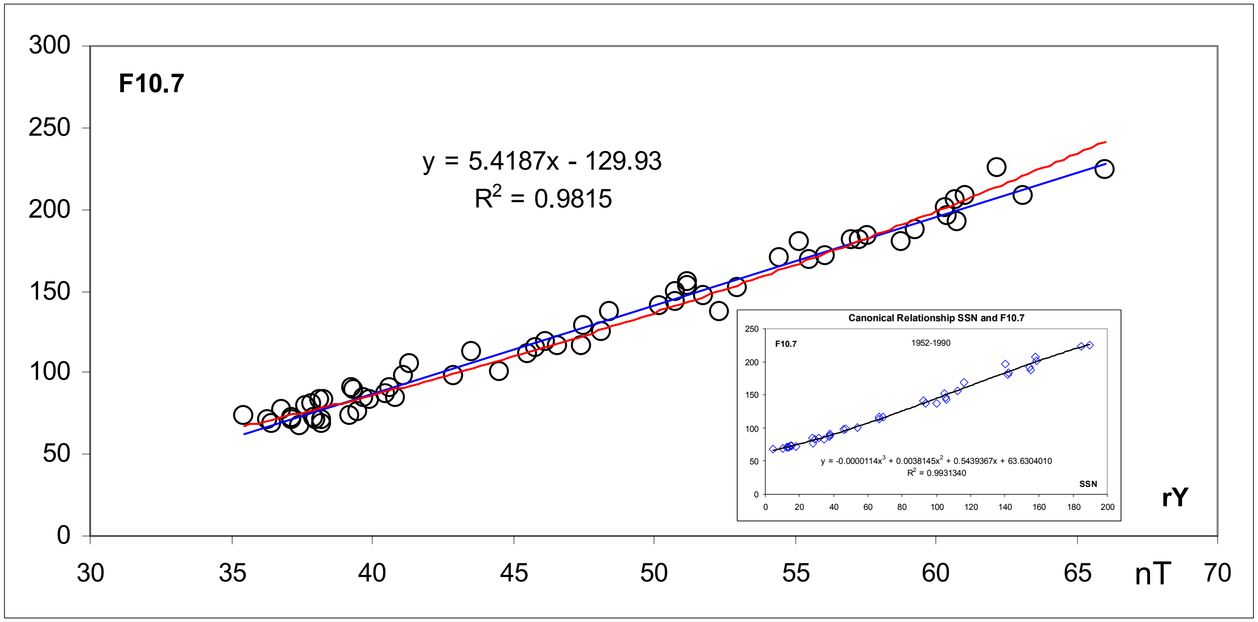
L21

Wolf received Declination from several observatories. Four, in particular, provided long-term records. After Wolf's death in 1893 it became evident that there was a secular drift in the Declination ranges and Wolfer lost heart [and some of the observatories stopped operating] in 1923 and did not continue the comparison with the SSN.

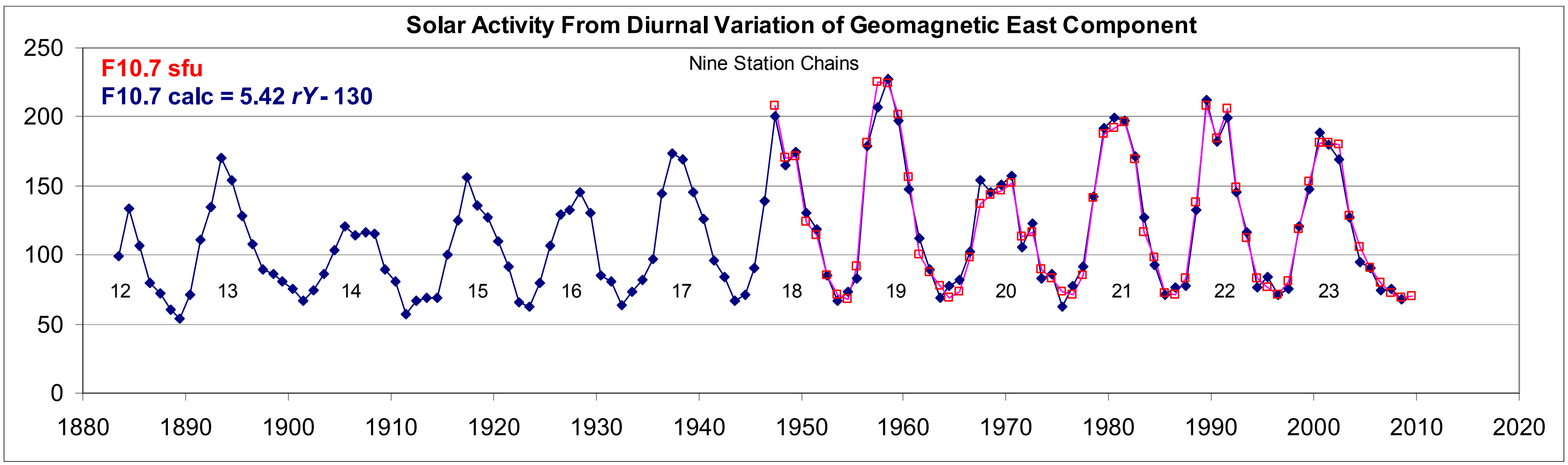
Today we know that the relevant physical quantity is not the range dD of the Declination, but of the East Component rY. The conversion from dD to rY involves a scale factor given by H cos(D)/3438', where H is the Horizontal component. Both H and D have secular changes, so the scale factor also changes with time as shown in the insert. Taking that into account, there is no drift in rY [lower panel] and the correlation with the SSN remains strong [red curve scaled to match]. This is especially important for the critical time around 1885 where the Group Sunspot Number begins to deviate (slide 11).

Leif, 10/19/2012

L22



Using *rY* from nine station ‘chains’ we find that the correlation between *F10.7* and *rY* is extremely good (more than 98% of the variation is accounted for)



This establishes that Wolf’s procedure and calibration are physically sound, and that the diurnal variation gives us a method for calibration of the SSN

L22 We have good geomagnetic data [hourly means] back to the 1880s and can construct a 'daisy chain' of overlapping data [range of East Component] from nine stations from the 1880s until the present. A good proxy for solar UV is the F10.7 cm microwave flux so we'll expect that flux and rY be strongly correlated. The upper panel shows that this expectation is borne out, with more than 98% of the variation accounted for. So, from rY we can calculate F10.7 with precision F10.7 = 5.42 rY - 130. The lower panel shows how well the observed F10.7 flux [red curve] matches the one calculated from the regressionequation. There is little reason to believe that this relation should not hold for the past as well. The insert shows the canonical [and well-known] good relation between F10.7 and the Sunspot number, so it is no wonder that the sunspot number follows the variation of rY.
This establishes that Wolf's procedure and correction are physically sound.
Leif, 10/19/2012

L23

Solar Wind in the Past

The Geomagnetic Record Allows us to Reconstruct the Solar Wind Properties for the Past 180 years

Slide 23

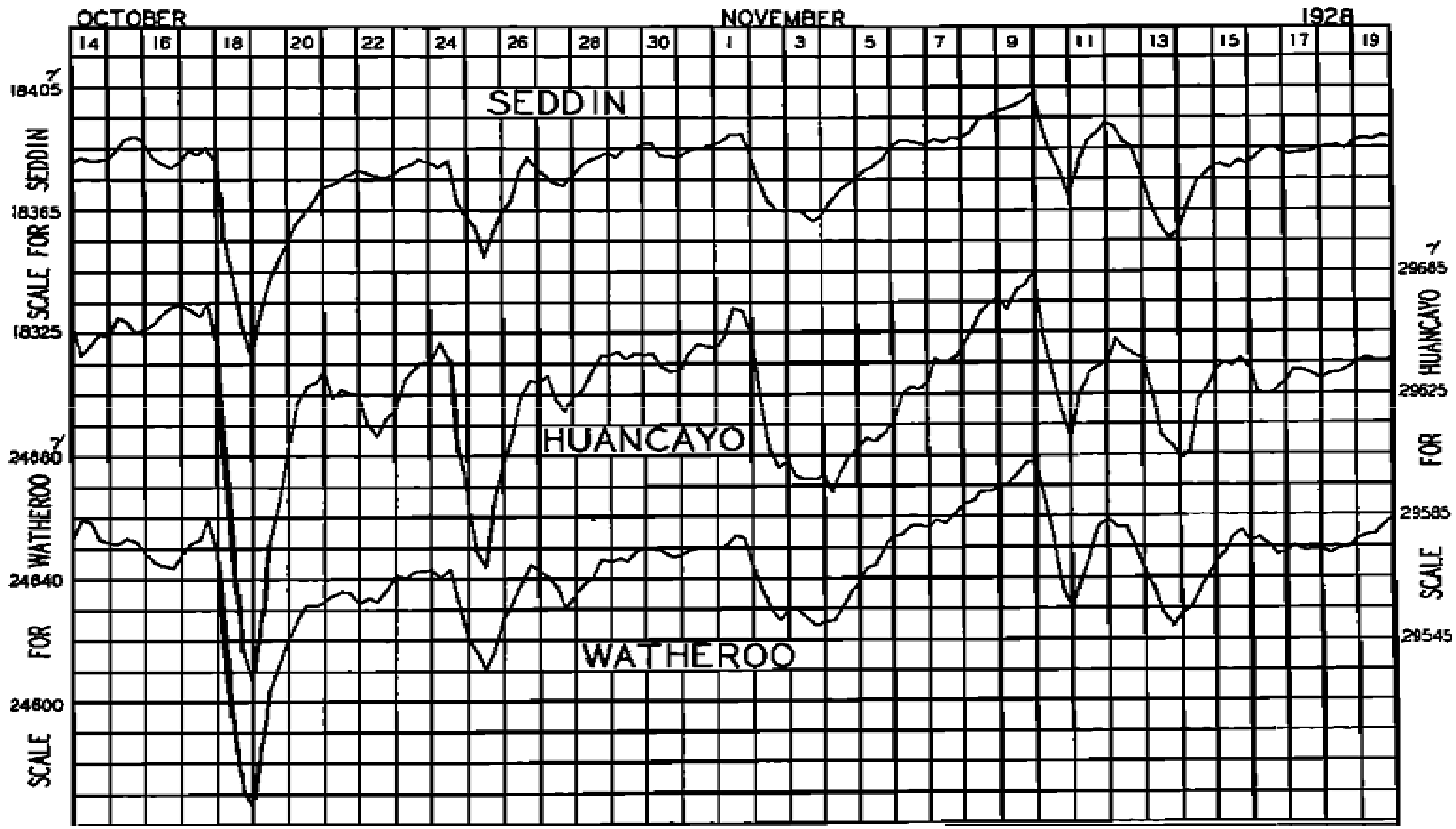
L23 Since the solar wind and its embedded magnetic field is ultimately responsible for generating geomagnetic activity [sometimes of dangerous magnitude] one could surmise that the latter could say something about the former. This suspicion is, in fact, well-founded and it has been possible to quantify geomagnetic activity and the state of the solar wind since the 1830s in detail.

A successful approach has been to device several geomagnetic indices that are sensitive to different combinations of solar wind properties.

Leif, 10/19/2012

L24

24-hour running means of the Horizontal Component of the low- & mid-latitude geomagnetic field remove most of local time effects and leaves a Global imprint of the Ring Current [Van Allen Belts]:



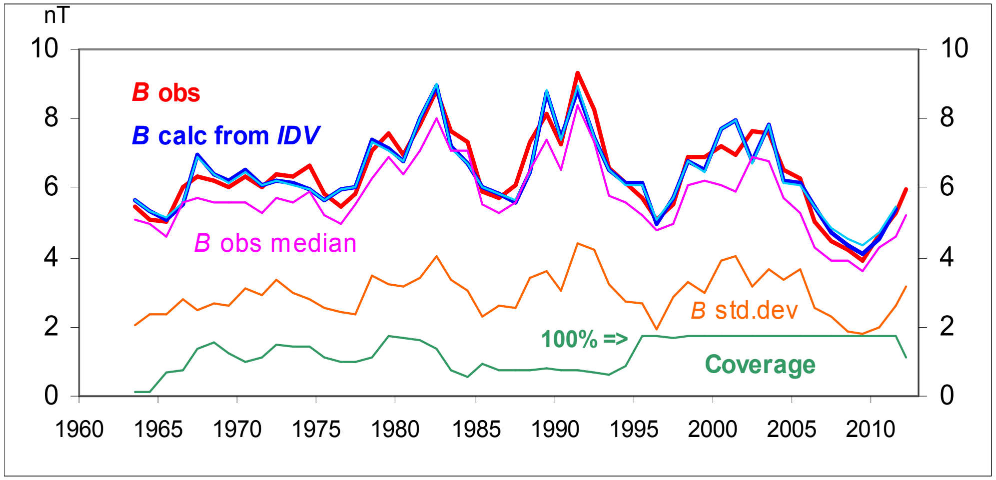
A quantitative measure of the effect can be formed as a series of the unsigned differences between consecutive days: The InterDiurnal Variability, IDV-index. Similar to Bartels' *u*-index and the 'Nachstörung' popular a century ago.

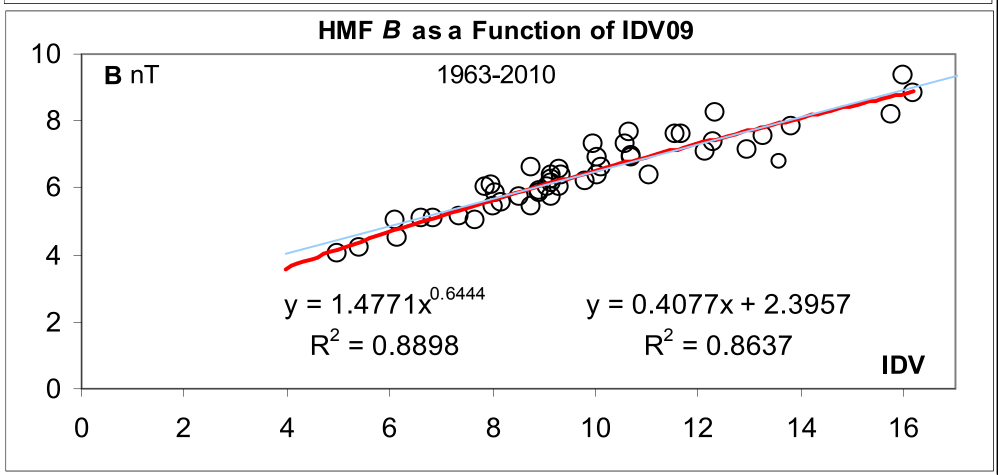
Slide 24

L24 The first such index is the IDV index, defined as the unsigned difference between successive midnight values of the Horizontal Component.
This follows the tradition of Bartels' u-index (1932) and van Bemmelen's Nachstorung (1895).
This is a world-wide effect and can be derived from even a single station.
Leif, 10/18/2012

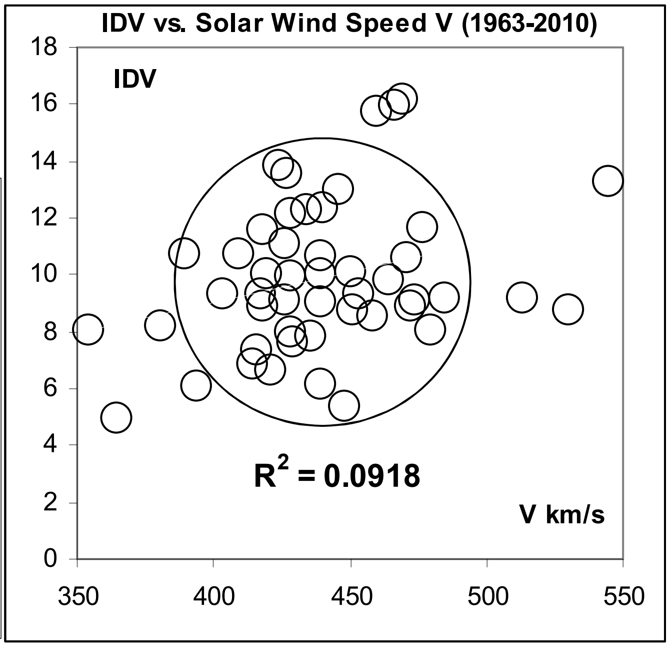
L25

IDV is strongly correlated with solar wind magnetic field *B*, but is blind to solar wind speed *V*





So, from IDV we can get HMF B

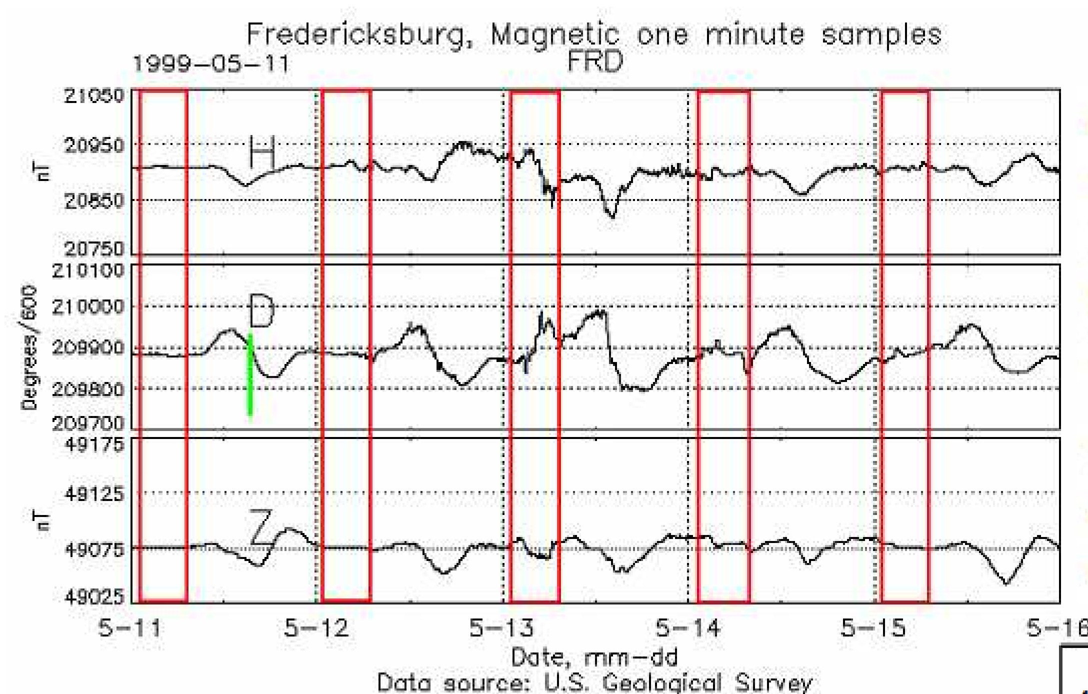


Slide 25

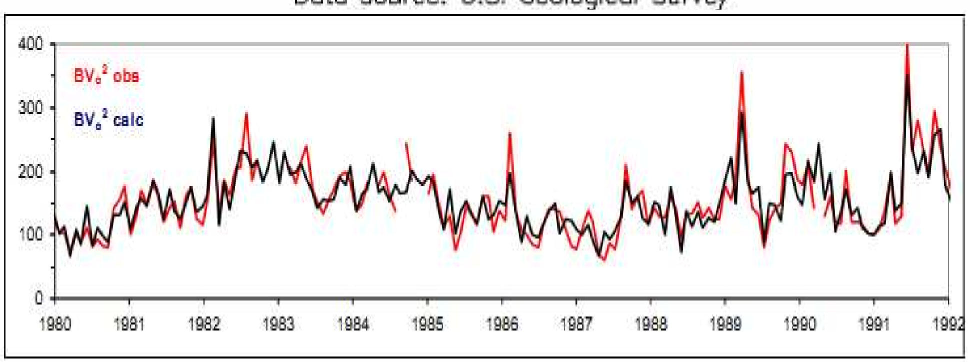
L25 The IDV index has the useful property of not depending on the solar wind speed [unlike most other geomagnetic indices].
There is, however, a strong dependence on the magnitude of the Heliospheric Magnetic Field [HMF] near the Earth (of course, as we use the Earth as our measuring instrument).
It is not really important to use the midnight hour, it turns out that any hour will work. This means that we can derive IDV for any station that at least makes one measurement per day, provided it is always made at the same time from day to day.
Leif, 10/19/2012

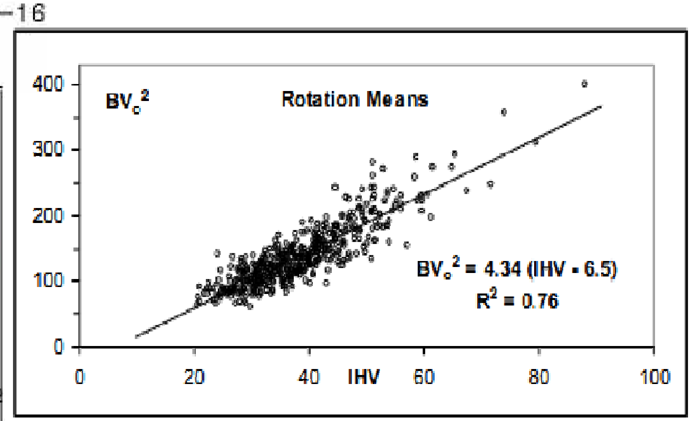
L26

The *IHV* Index gives us BV^2



Calculating the variation (sum of unsigned differences from one hour to the next) of the field during the night hours [red boxes] from simple hourly means (the Interhourly Variation) gives us a quantity that correlates with BV^2 in the solar wind





L26

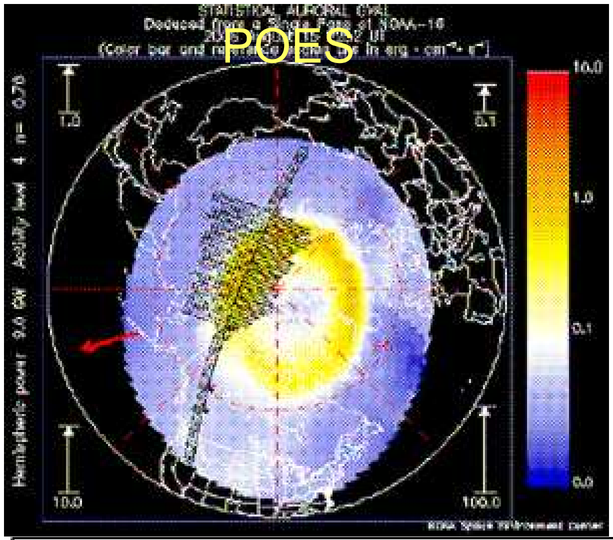
Another index IHV, the InterHour Variability, is defined as the sum of unsigned differences from one hour to the next during the night hours for stations well equatorwards of the auroral zone.
IHV is a close proxy for the quantity BV^2 on time scales of a solar rotation and up.

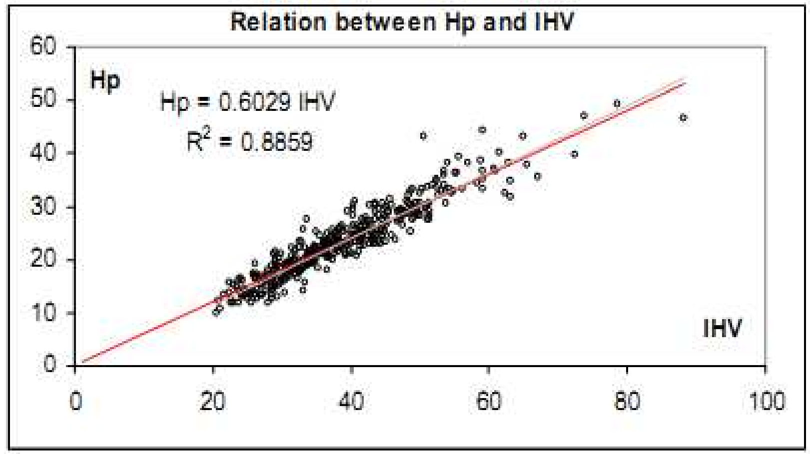
The lower panel shows how well BVo^2 [we use Vo=V/100 km/sec to have more manageable numbers] computed from the regression equation shown [black curve] compares with the quantity observed by spacecraft [red curve] for several years some time ago. The agreement is equally good for any subset of observed data.

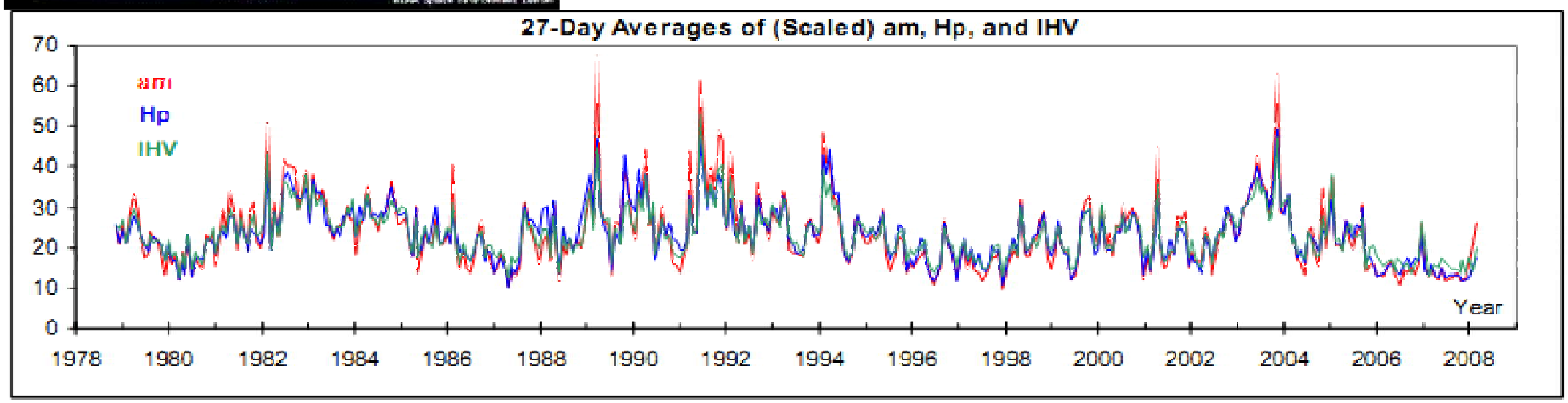
IHV can be computed for any sub-auroral station that reports hourly means [or values] during the night hours.
Leif, 10/19/2012

L27

Physical meaning of IHV: the index is directly proportional to the auroral power input, HP, to the polar regions







Slide 27

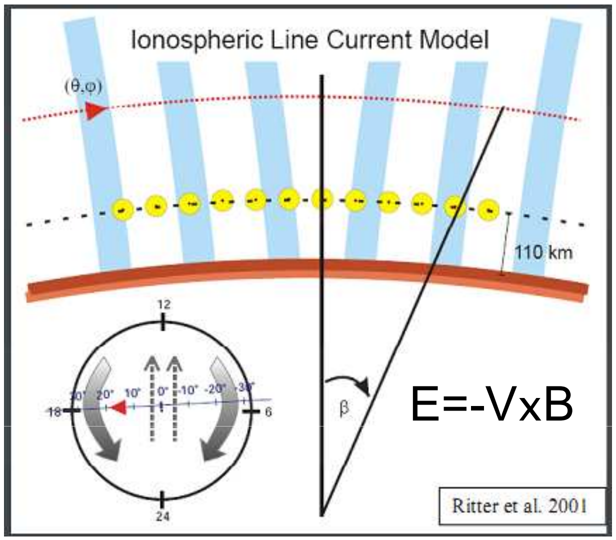
L27 IHV turns out to be directly proportional to the total input of energy of precipitating auroral particles, e.g. as measured by the POES satellites.

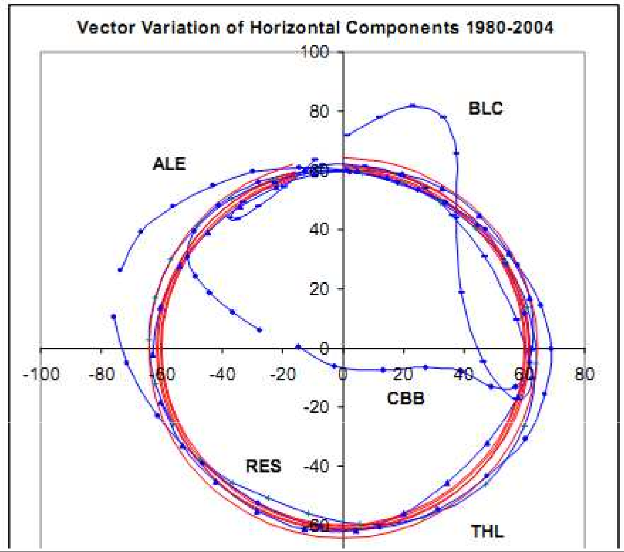
The lower panel shows how well the 'am' geomagnetic index, the 'hemispheric power' input [in GigaWatt], and scaled IHV agree. This close agreement came as a pleasant surprise.

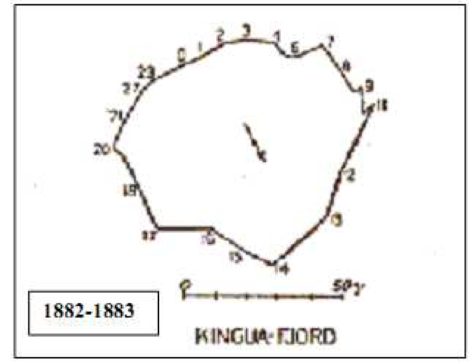
Leif, 10/19/2012

L28

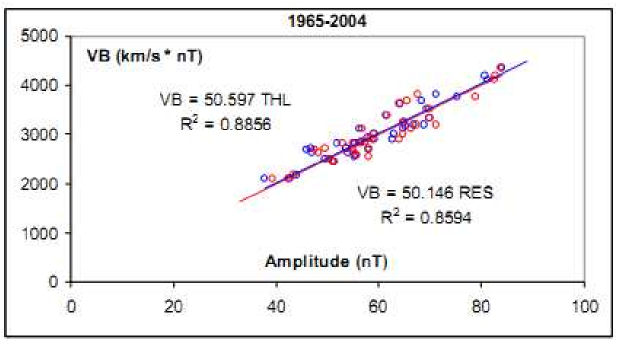
Polar Cap Diurnal Variation gives us V times B

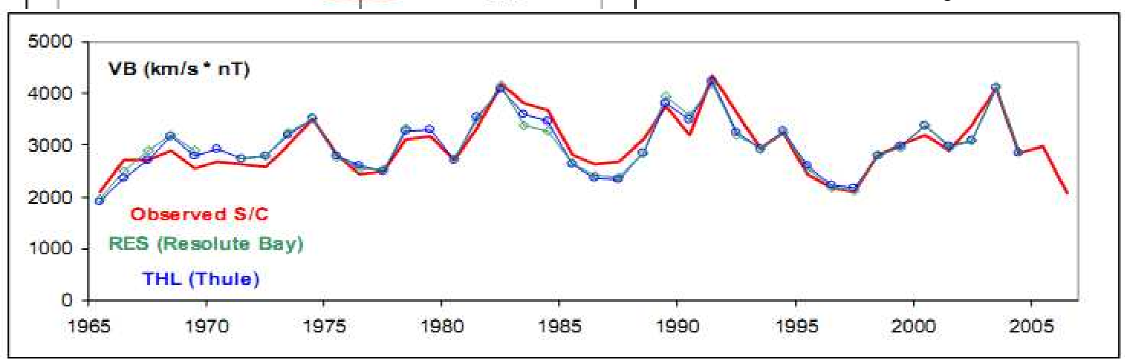






This variation has been known for more than 125 years





L28

Across the polar cap flows a Hall current towards the Sun. As the Earth rotates under this current, the magnetic effect [a vector] from the current rotates in a 24-hour period. The end point of the perturbation vector thus describes a neat circle.

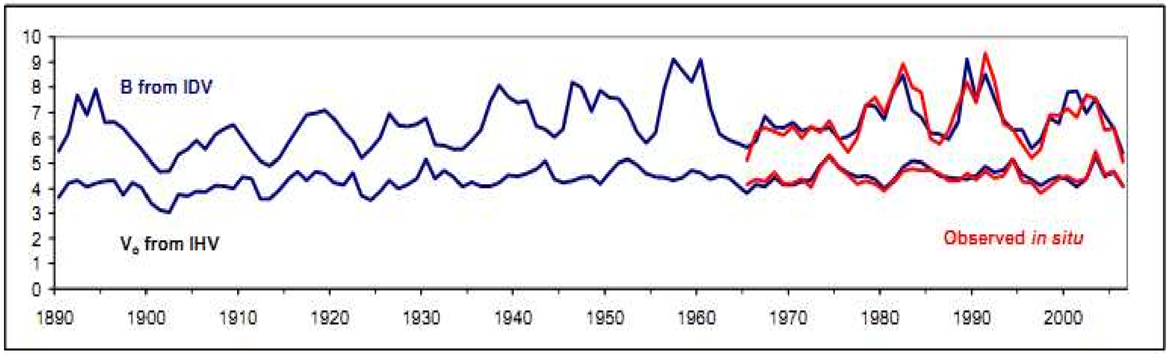
The middle panel shows this circle for polar cap station THL, RES, and ALE. The stations BLC and CBB are only within the polar cap for part of the 24-hour period, but when they are, they too show the same circle. This rotating vector has been knwon for more than 125 years as shown in the upper right for Kingua Fjord back in the first Polar Year 1882-1883.

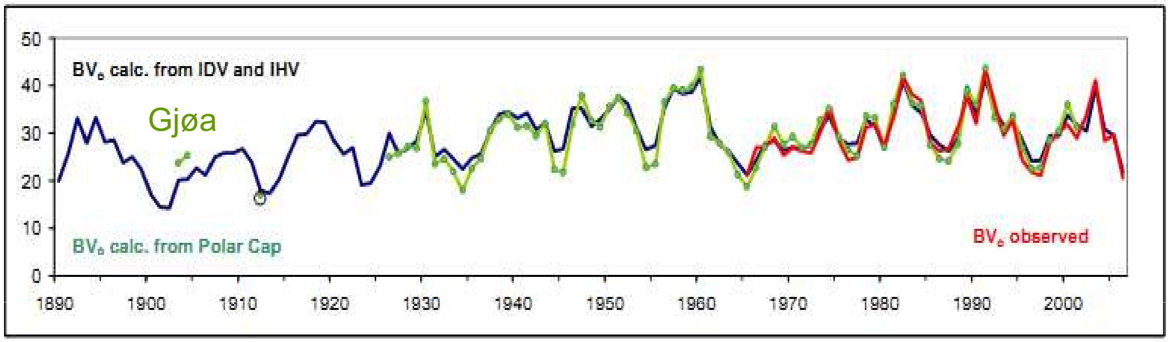
The radius of the circle is the magnetic effect of the current and is essentially proportional to the electric field in the solar wind as seen by the [almost] stationary Earth: -VxB ~ VB. The leftmost lower panel shows how the observed amplitude [radius] at Thule [THL] and Resolute Bay [RES] translates into the quantity VB observed in the solar wind. We have thus here a proxy for VB. The rightmost lower panel shows how well that proxy matches the values of VB observed by spacecraft [yearly averages].

Leif, 10/19/2012

L29

Overdetermined System: 3 Eqs, 2 Unknowns



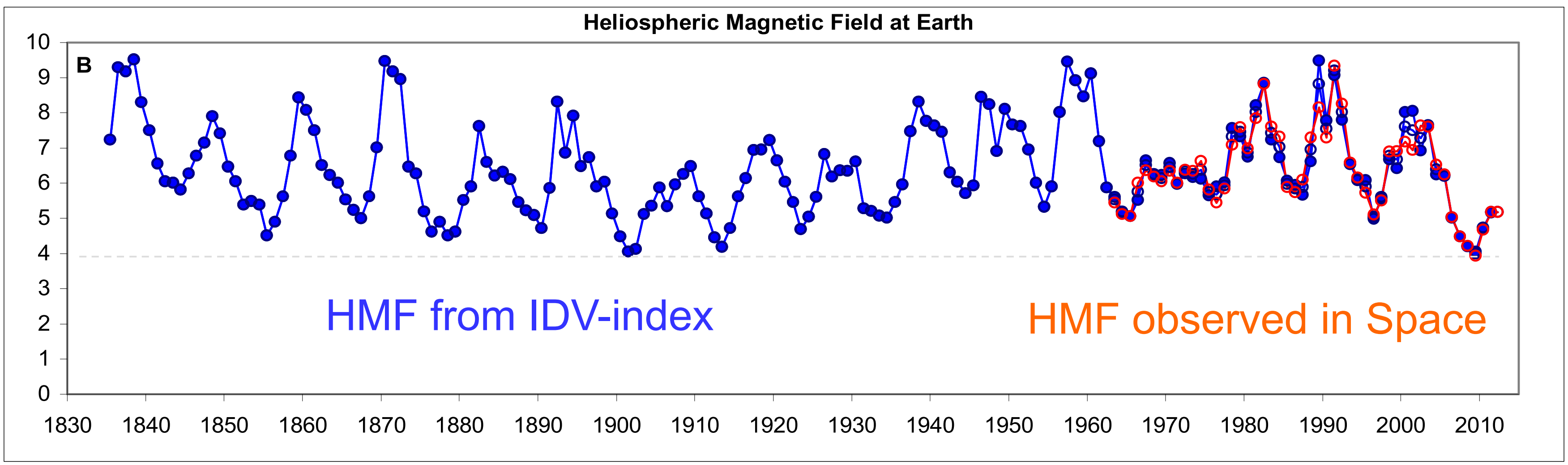


B = p (IDV)

BV^2 = q (IHV)

VB = r (PCap)

Here is B back to the 1830s:



L29

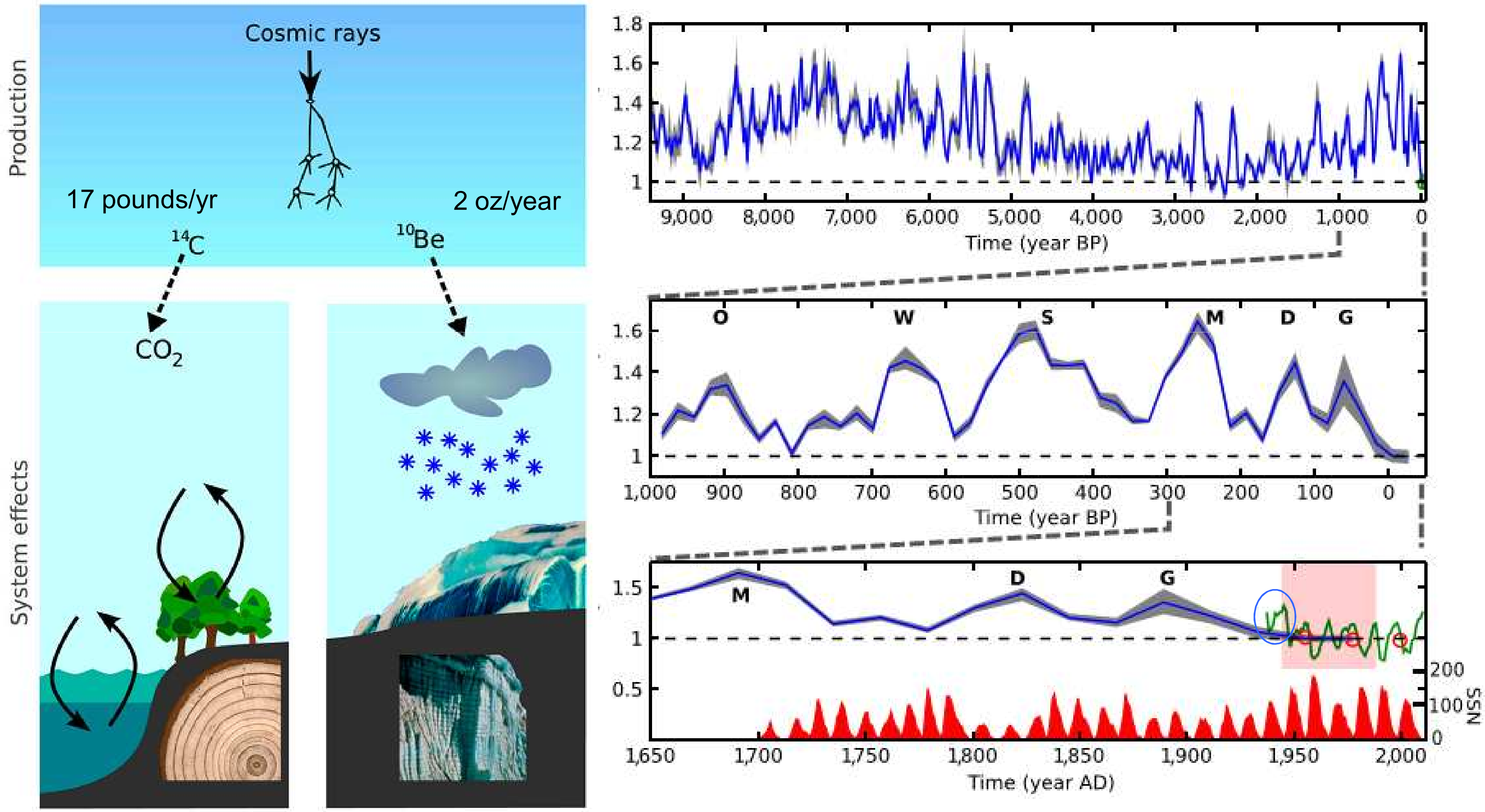
Now we have an over-determined system: 3 equation with but 2 unknowns.
B = p(IDV), BV^2 = q(IHV), and VB = r(PCap).
From the first two we determine B and V. Then multiply them together to get VB and compare that value with VB determined from the third equation [green curve]. For all quantities we compare with in-situ measurements [red curves] and note excellent agreement.

It may be of interest to note the data points for 1904-1905 provided by Roald Amundsen's Gjoea expedition [what else can you do when frozen into the ice than build a magnetic observatory].

The lower panel shows HMF B back to the 1830s. Note that the early part has B-values just as large as the later part.
The very slight increase in V seen in the upper panel is likely due to the decline of the Earth's main field, which tends to increase geomagnetic activity [even when no increase in the solar wind].
Leif, 10/19/2012

L30

The Cosmic Ray Record has Promise, but is not without Problems



Steinhilber et al. 2012

L30

Galactic Cosmic Rays [GCRs] produce by spallation of Oxygen and Nitrogen radioactive nuclei in the Earth's atmosphere. 10Beryllium [2 oz total global yearly production] and 14Carbon [17 pounds] eventually enter reservoirs at ground level [ice cores and tree rings]. From those, researchers have sought to deduce the solar activity responsible for the solar cycle modulation of GCRs.

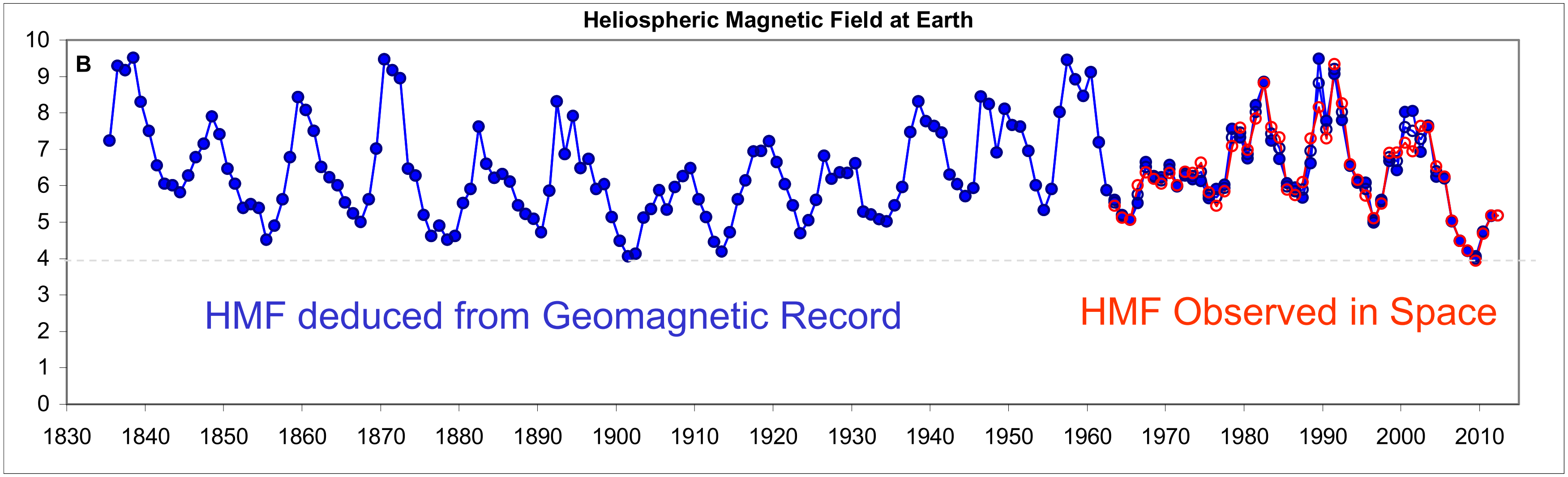
The observable is really the deposition rate rather than the production rate. The deposition is also controlled by the strength of the Earth's magnetic field, and by circulation of air and moisture [i.e. by climate]. The effects of these factors are difficult to remove and the influence of the unknown [but guessed at] flux outside the Heliosphere is not well-known. Nevertheless, progressis being made and preliminary results exist for the past ~10,000 years.

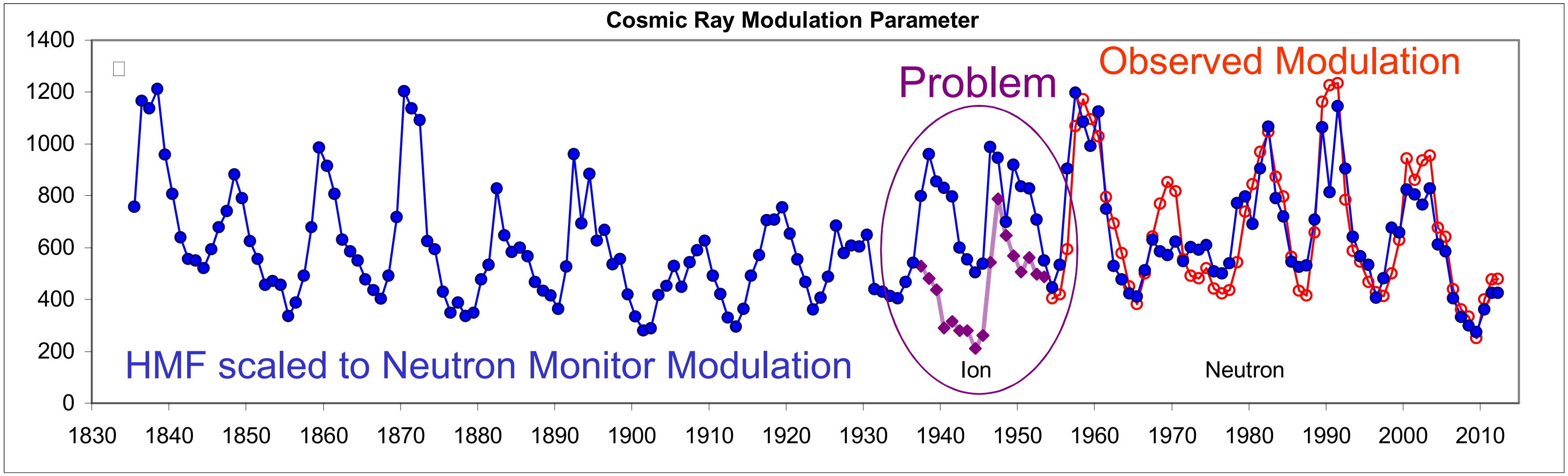
The higher flux at solar Grand Minima stands out, but there are problems. Solar activity at present is on par with what it was a century ago, yet the cosmic rays flux back then seems to announce a grand minimum [marked G] which we are not seeing repeated now.

Leif, 10/19/2012

L31

Cosmic Ray Modulation as Governed by Strength of Magnetic Field in Heliosphere





Slide 31

L31

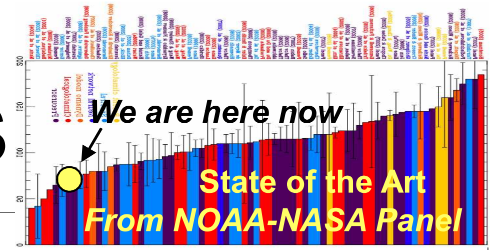
It is often assumed that the GCR production, M, is controlled by the HMF B [upper panel] following a relation of the form M ~1/ B^n where n is of the order of 2. Since [absolute instrument] neutron monitors were introduced in the 1950s this relation has worked reasonably well [lower panel].

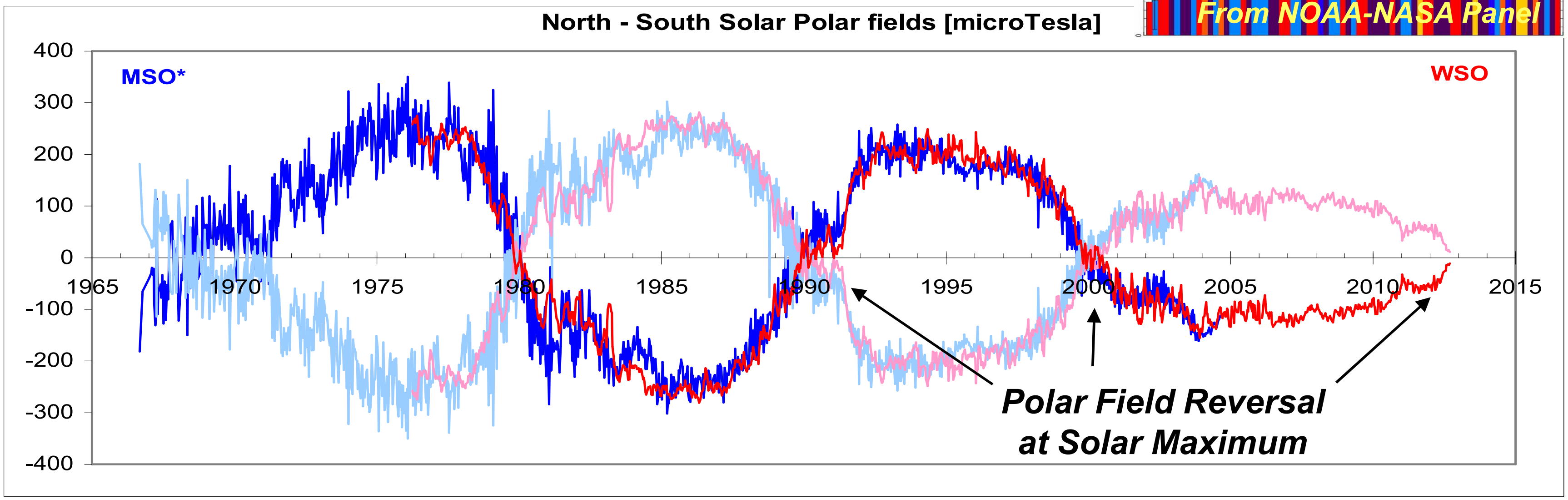
The data from [relative instrument] ion chambers from the 1930s to early 1950s have been spliced to the neutron monitor data, but do not seem to have the same calibration relative to HMF B [oval in lower panel]. This discrepancy feeds into the calibration of the entire 9,300 years before the present and makes the record difficult to interpret. Resolution of this problem is a high-priority ongoing research effort [ISSI workshop 233, co-chaired by me] and the end is not yet in sight.

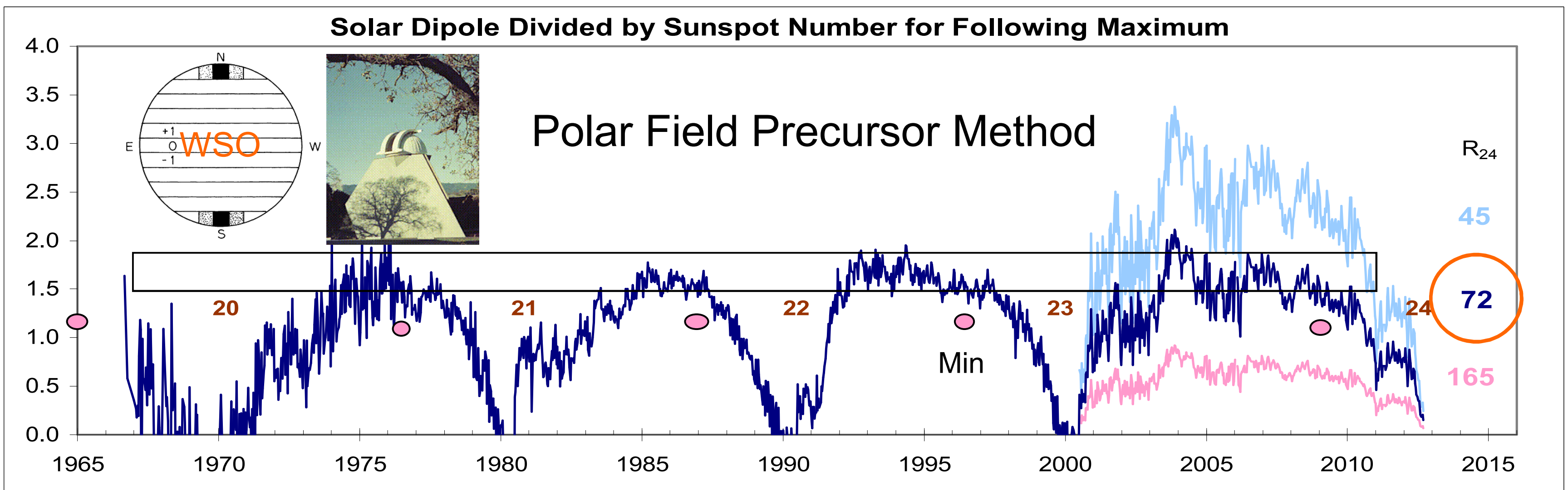
Leif, 10/19/2012

L32

Prediction of Solar Cycles







L32

Among the many 'methods' used to predict the size of the next solar size maximum, the Polar Field Precursor method has proven useful and largely correct the past several cycles since it was proposed in 1978.

It is thought that the polar fields provide the 'seed' for the solar dynamo producing the magnetic fields [solar activity] for the next cycle.

Our definition of the polar fields is the average line-of-sight flux density in an aperture that covers the surface above latitude 55 degrees [the black squares on the insert on the lower panel]. To get a single number [and also eliminate various systematic issues] we compute the 'dipole moment' as the difference between the North and the South polar fields. This is plotted in the upper panel for two observatories [Mount Wilson, blue; Wilcox, red]. A fainter, 'ghost' image is also plotted with reversed sign to make it easier to compare adjacent cycles.

The polar fields disappear and then come back with reversed sign at [or shortly after] solar maximum. They are strongest just prior to solar minimum. At the recent minimum the polar fields were the weakest ever directly observed leading to the prediction of a weak current cycle [number 24].

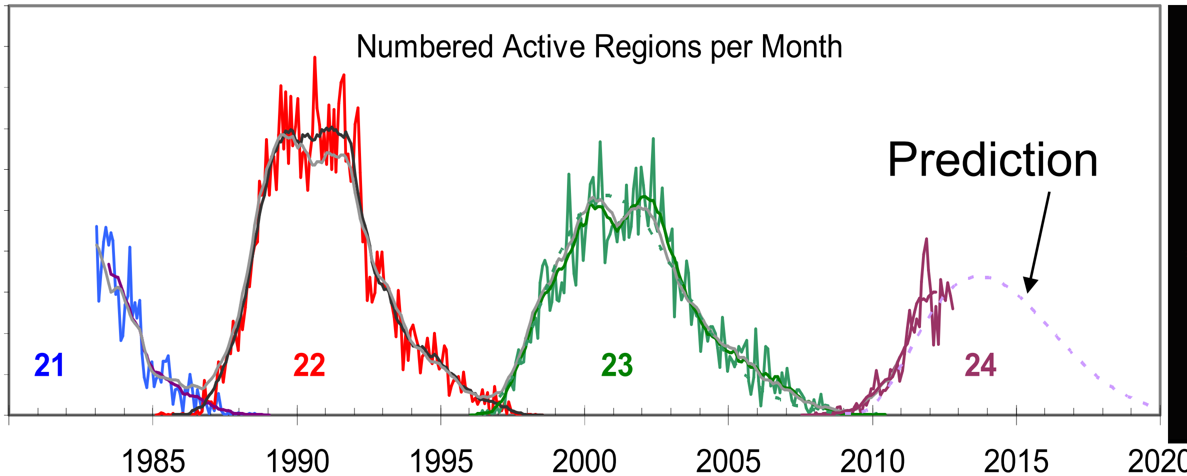
More quantitatively, it was noted that the polar fields divided by the maximum sunspot number for the following cycle seemed to be an invariant [lower panel]. A maximum value of 72 fits the bill for cycle 24.

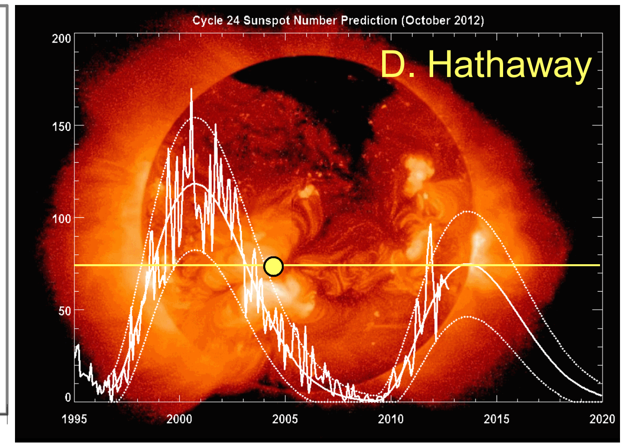
As it is believed that the build up of the polar fields has a strong random element in it, the polar fields cannot be confidently predicted, only observed, so we only claim predictability for one cycle ahead.
Leif, 10/19/2012

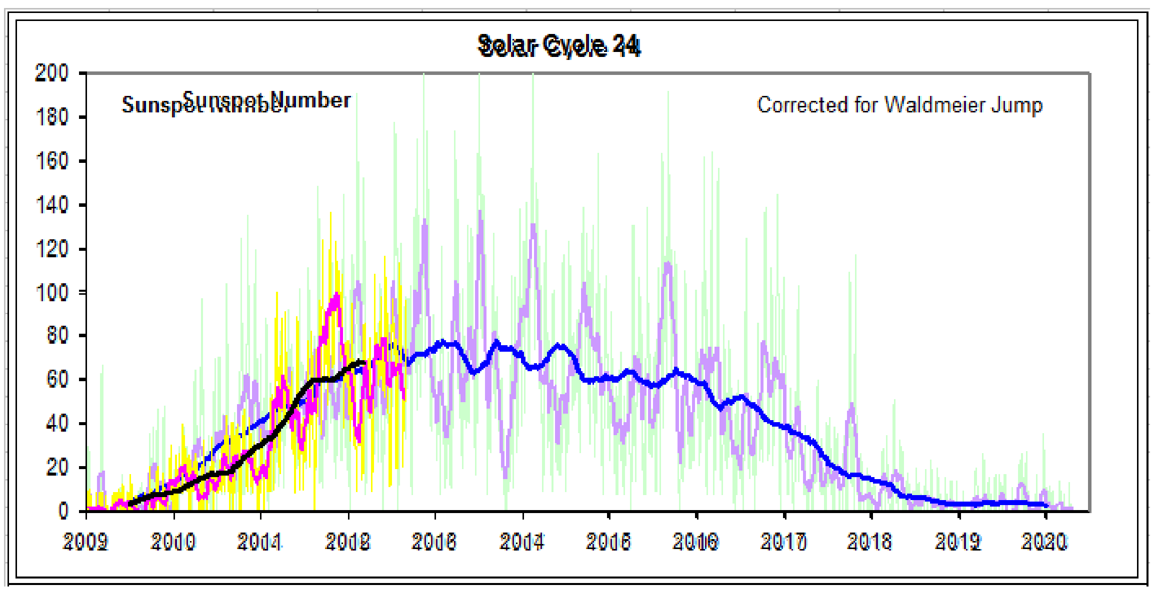
L33

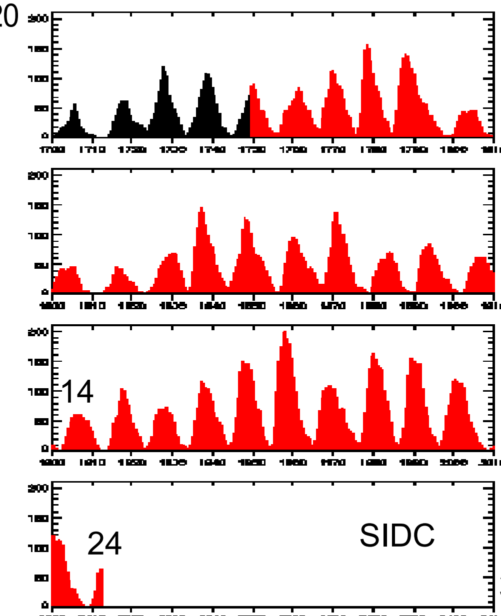
How is Cycle 24 Evolving? As Predicted!

Active Region Count









L33

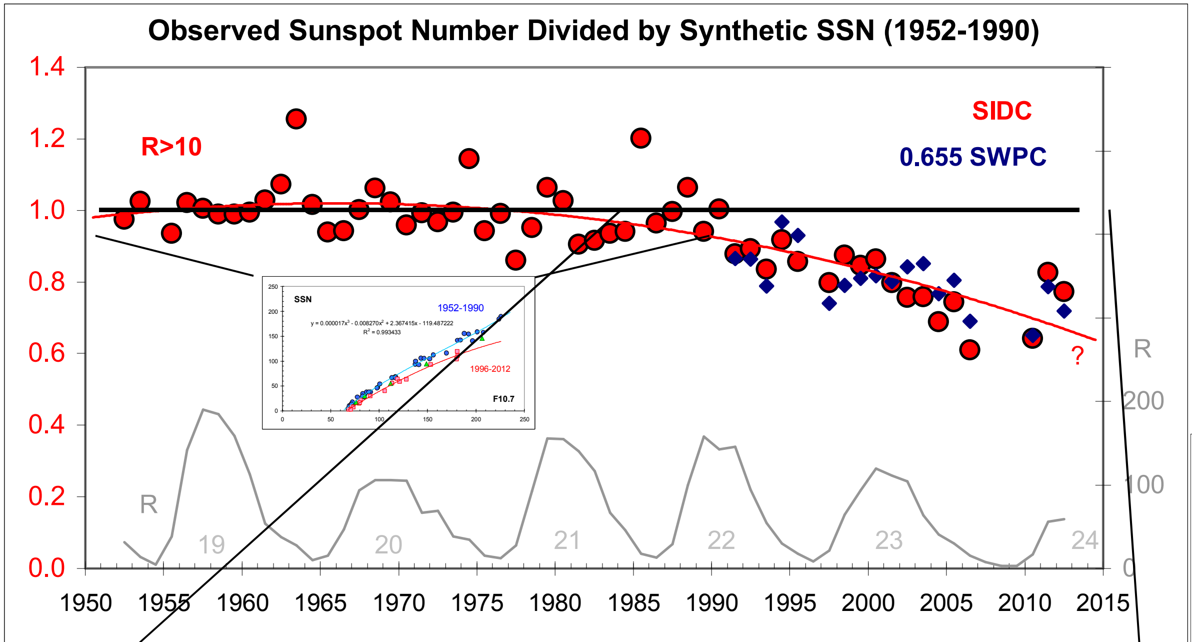
Usually, when we are four years into a cycle, the cycle becomes rather set. So far, the prediction for cycle 24 is holding up well. The colorful Figure from David Hathaway [at NASA] shows his current view. The yellow dot shows when our prediction was made and the line what it was.

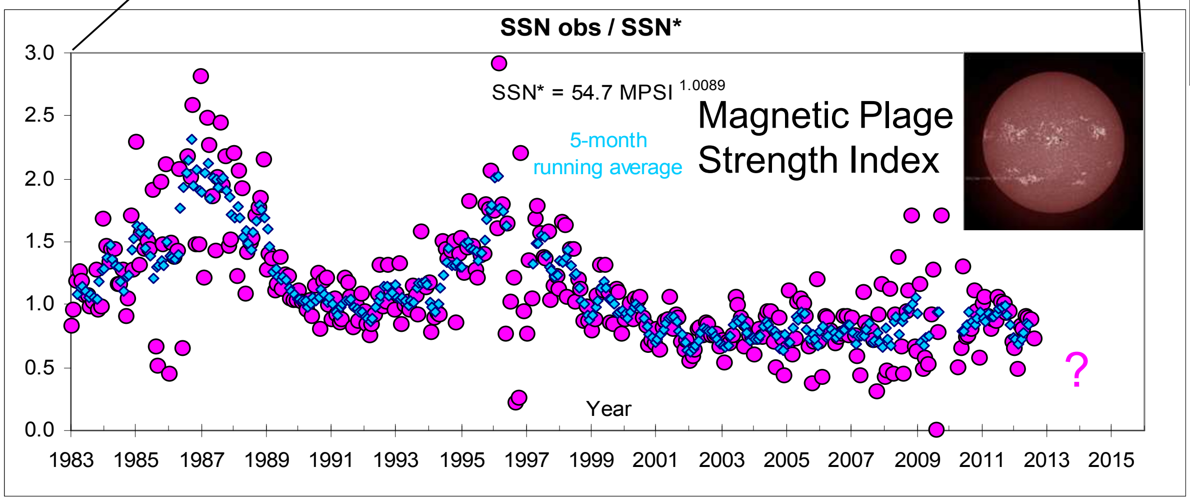
The lower panel shows cycle 24 [yellow] overlain cycle 14 [light green]. The two cycles seem to be a good match, perhaps including some of the wild swings in cycle 14. If the analogy holds, we may look forward to a long drawn-out solar maximum.

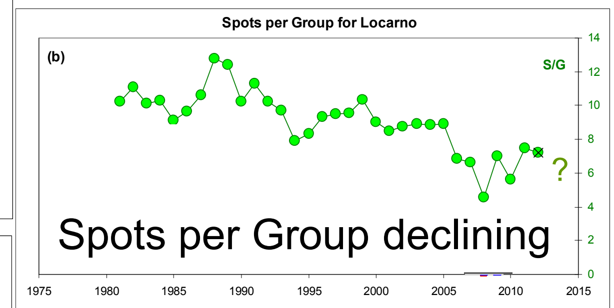
In the lower right panel we show the run of the [official, uncorrected] sunspot number since 1700. A 100-year 'cycle' may be present, but since we don't know what causes that long cycle, we cannot with confidence predict that the 21st century will be like the 20th.
Leif, 10/19/2012

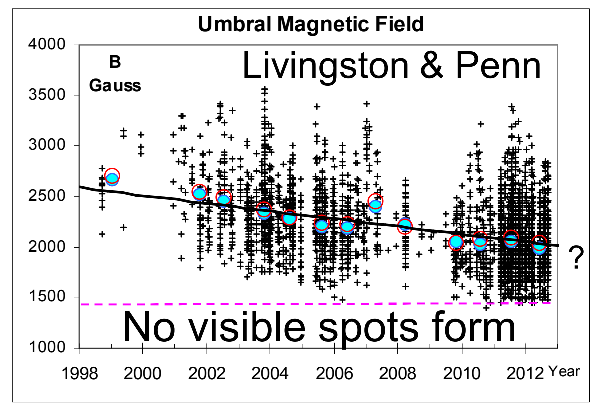
L34

Something *is* happening with the Sun









We don’t know what causes this, but sunspots are becoming more difficult to see or not forming as they used to. There is speculation that this may be what a Maunder-type minimum looks like: magnetic fields still present [cosmic rays still modulated], but just not forming spots. If so, exciting times are ahead.

L34 And something is happening with the Sun. The F10.7 flux has from the beginning of the data [in 1947] had a firm and consistent relationship with the sunspot number, so that one could use one as a proxy for the other [we used that in Slide 22]. Using that relationship we can calculate what sunspot number to expect for a given F10.7 flux and compare it with observations. The ratio between the observed and the synthetic sunspot numbers should scatter a bit around unity, as it does nicely up to about 1990. From then on, the observed SSN falls progressively below the expected values. This using both the SIDC and the SWPC [NOAA] numbers [upper left panel].

Mount Wilson Observatory calculates for each day the fraction [called the Magnetic Plage Strength Index, MPSI] of the solar disk covered with magnetic fields outside of spots [socalled 'plages']. That fraction has a strong solar cycle variation; on average the SSN is a function MPSI: SSN = 55 MPSI. As for F10.7, we can calculate the expected SSN for a given MPSI and form the ratio between the observed and the calculated numbers [lower panel, left]. That fraction has been falling significantly during the same time when the SSN and F10.7 deviated from each other.

Ever since Wolf, there has been on average about 10 spots per sunspot group. This is the reason for the 10 appearing in the sunspot number formula SSN = 10*Groups + Spots. Over the past couple of cycles the number of spots per group has dropped by about a third, so groups are losing the smaller spots.

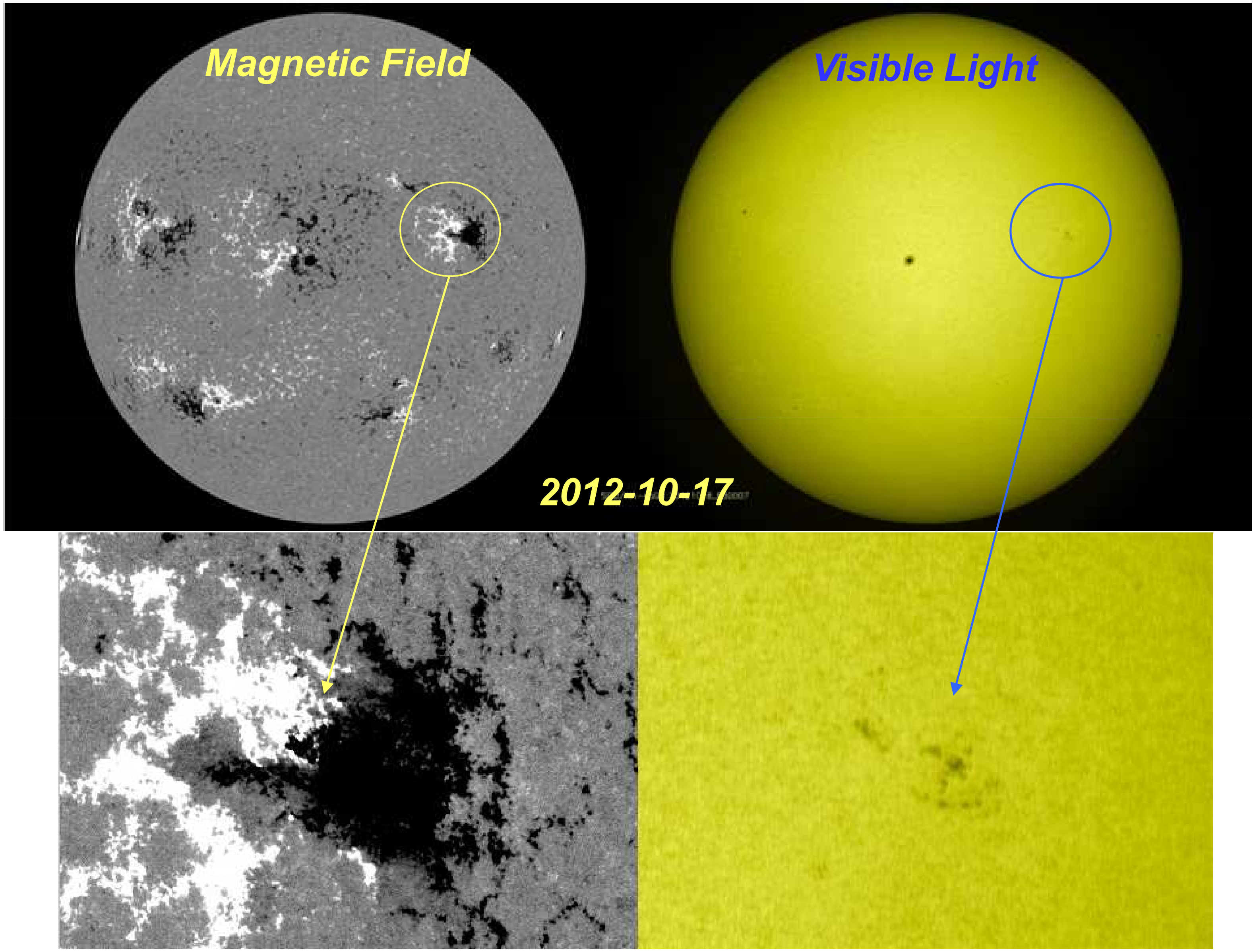
Livingston & Penn have observed the magnetic field at the darkest point in every sunspot [within their observing time window] and find that the average field has decreased by 20% over the same time as the other effects we have been describing. The 'bottom' of the distribution seems to be cut off at 1500 Gauss, below which sunspots do not seem to form.

All of these effects are unprecedented in the observational data and tells us that the Sun is changing in ways not seen before. Or have we seen this before? During the Maunder Minimum cosmic rays were still modulated, the spicule 'forest' in the chromosphere was still observed, so there were healthy magnetic fields, yet few spots were visible. Perhaps they just didn't form as they used to, being an extreme example of the trends we are seen now...

Leif, 10/19/2012

L35

Perhaps like this:



Slide 35

L35 All this is speculation, of course, but instead of fighting a rear-guard action against such heretic ideas we should perhaps better be proud of having identified something unusual, and exploit what we see.

Here is an example [from a few days ago] of an area of extensive magnetic fields [circle on magnetogram] and the very weak and insignificant spots that formed in this area.

If this is a sign of things to come, exciting times are ahead, and our forecasting techniques may require significant revision and adaptation. We shall see.

Leif, 10/19/2012

L36

Conclusions

- The historical (official) ‘Wolf’ sunspot record has been re-assessed and need revision
- The Group Sunspot Number is flawed and should not be used anymore
- There likely was no Modern Grand Maximum
- The Cosmic Ray record calibration is uncertain
- The polar field precursor method for prediction of a low solar cycle 24 has worked well
- The Sun may be entering a new regime of very low activity

Slide 36

L36 In conclusion we note that
1) the historical [and official] sunspot number series must be revised to remove the effect of the weighting of sunspots.
2) the Group Sunspot Number is flawed and should not be used in its present form. Rather the very valuable historical observations uncovered by H&S should be incorporated in the standard SSN.
3) The support for the notion of a Modern Grand Minimum seems to have evaporated and comparable levels of activity has been observed in each of the past three centuries.
4) The Cosmic Ray record calibration problem must be resolved before we can fully exploit that immensely valuable truly long-term record of solar activity.
5) The polar field precursor method for prediction of solar cycles seems to have worked quite well. Cycle 24 is close to the predicted track. We await, of course, the rest of the cycle before we can declare victory.
6) There are several indications that sunspots are becoming weaker, or don't form as readily, and one can speculate that a Maunder-type minimum [the Eddy Minimum] may be in store for us. If so, and that is a big IF, we shall learn a lot and times will be exciting and tumultuous.
Leif, 10/19/2012