Consensus Heliospheric Magnetic Field during the last ~120 years

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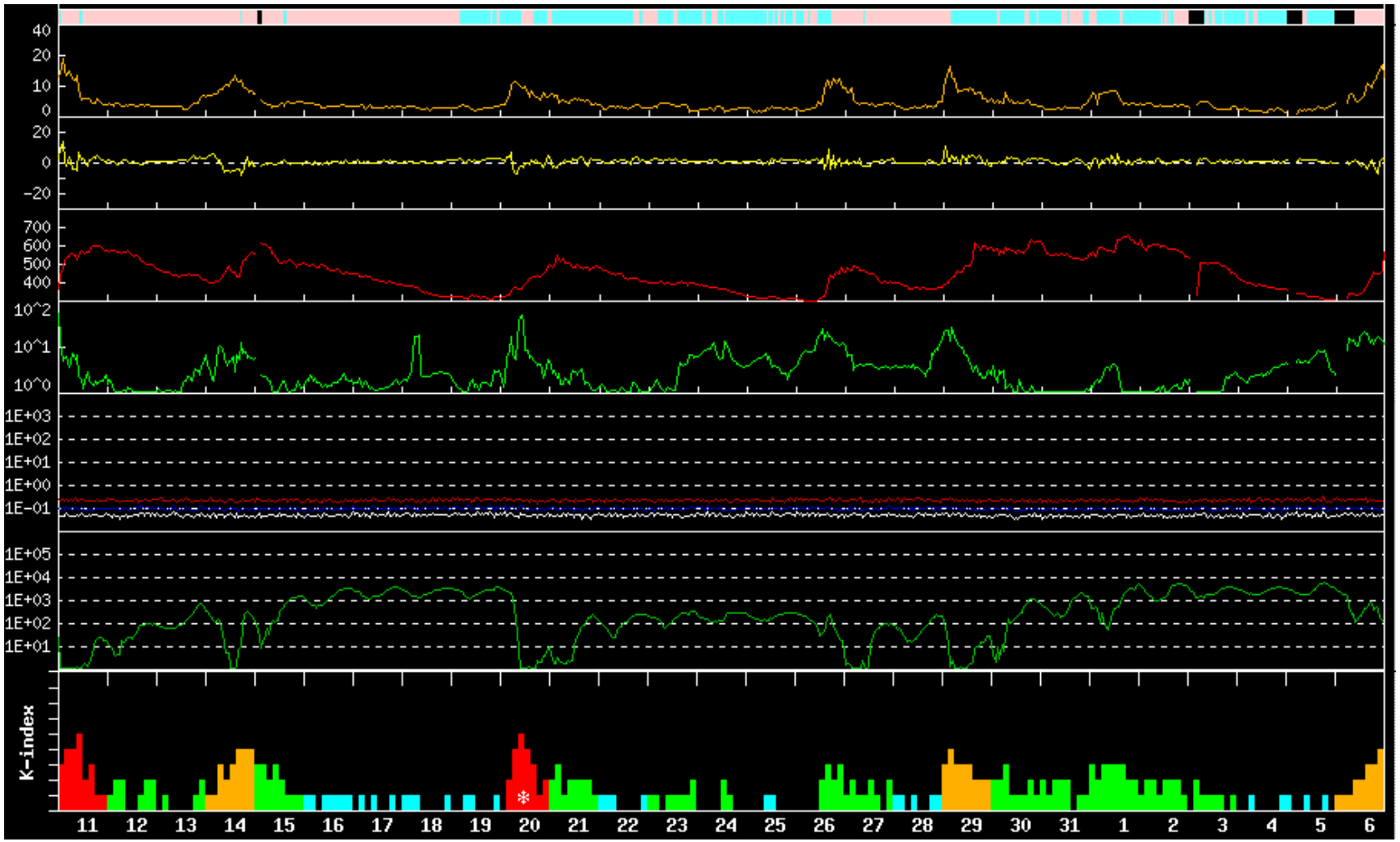
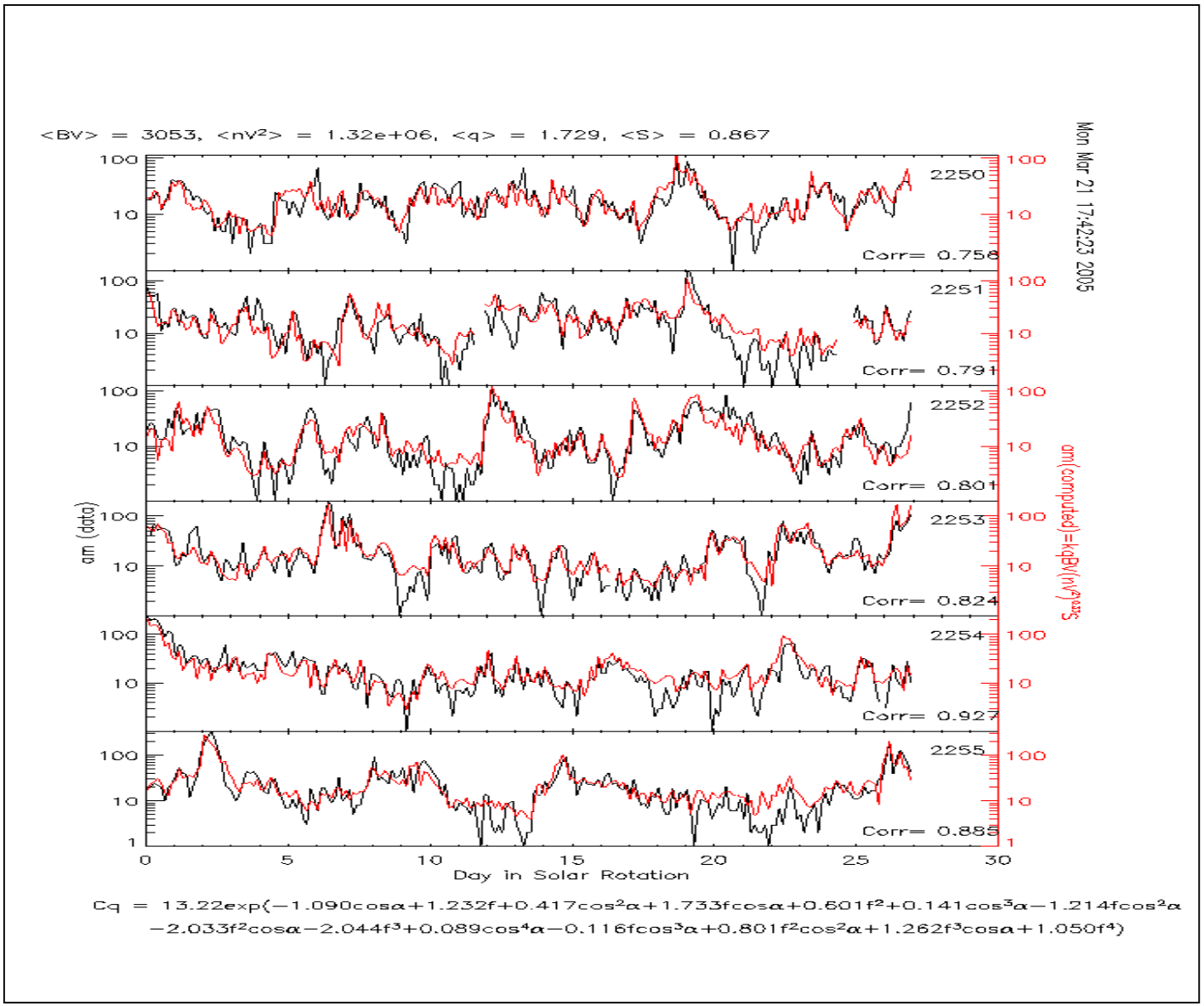
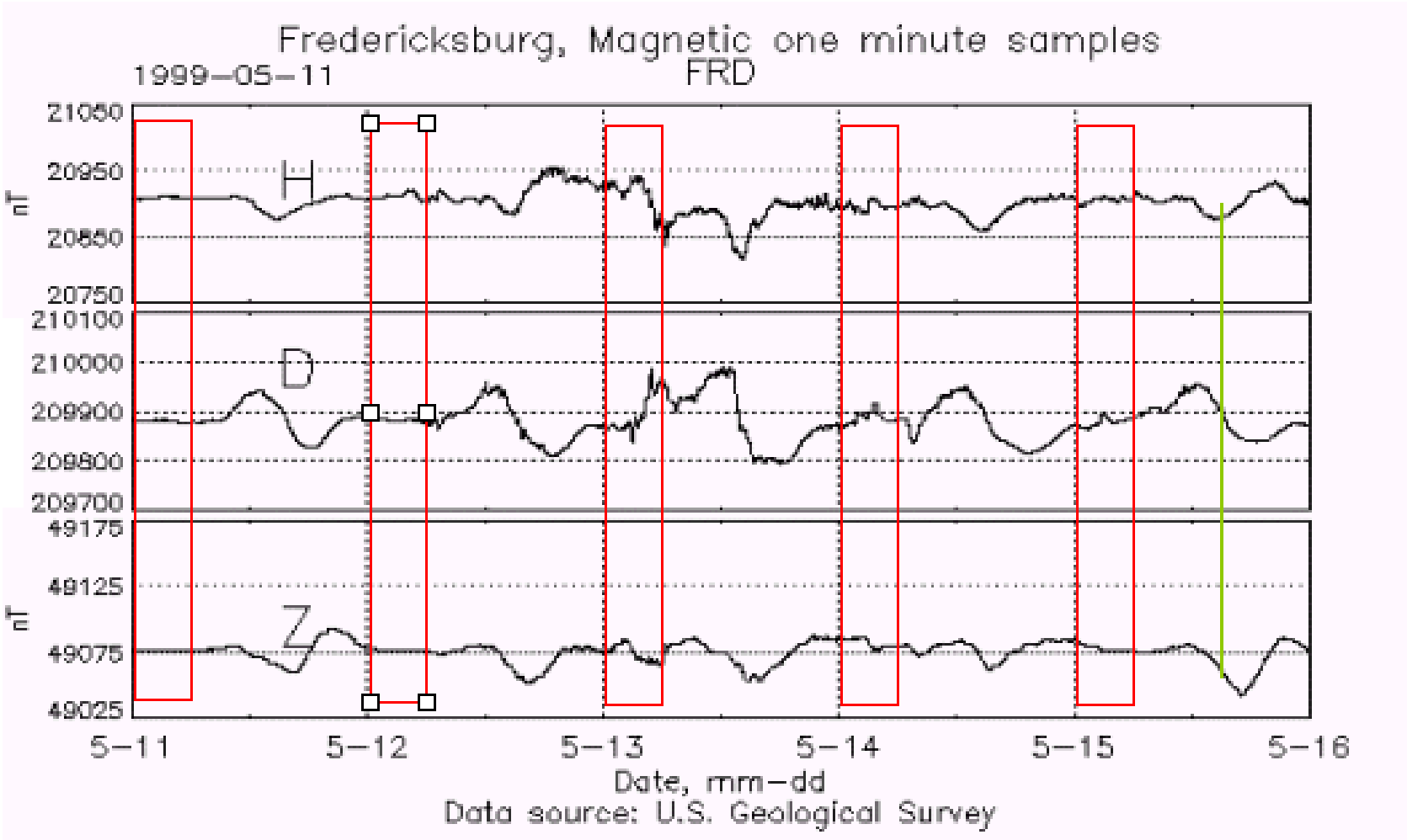
Abstract: Geomagnetic activity has been used to infer the HMF [or the "open" solar magnetic flux] before the Space Age. Earlier, these inferences were discordant and controversial. In the last couple of years, the sources of these disagreements have been uncovered and corrected and a remarkable consensus is now emerging, with the result that the heliospheric magnetic field and the solar wind speed can now be considered to be well constrained to a level of ~10% or better. We describe the work that has led to this consensus and discuss the implications of the consensus for several areas of research, including estimates of Total Solar Irradiance and Cosmic Ray modulation.

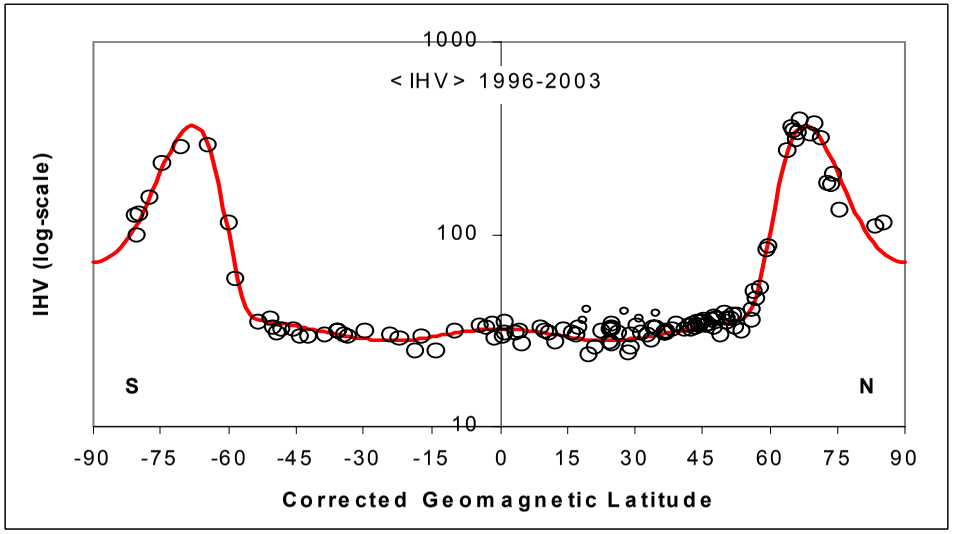


$$A = k\, q(a, f(V))\, (B\, V)\, (n\, V^2)^{1/3} \sim B\, V^2$$

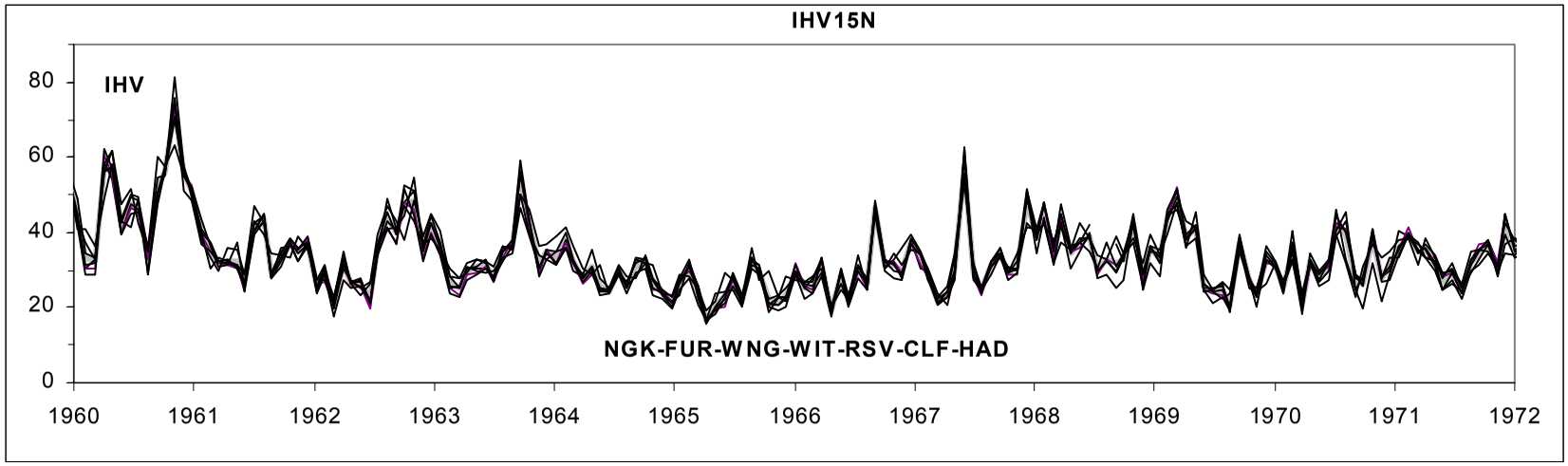

<BV> = 3053, <nV²> = 1.32e+06, <q> = 1.729, <S> = 0.867
Mon Mar 21 17:42:23 2005
2250
Corr= 0.758
2251
Corr= 0.791
2252
Corr= 0.801
2253
Corr= 0.824
2254
Corr= 0.927
2255
Corr= 0.885
am (data)
am(computed)=kqBV/(nV)^2/3S
Day in Solar Rotation
Cq = 13.22exp(−1.090cosα+1.232f+0.417cos²α+1.733fcosα+0.601f²+0.141cos³α−1.214fcos²α
−2.033f²cosα−2.044f³+0.089cos⁴α−0.116fcos³α+0.801f²cos²α+1.262f³cosα+1.050f⁴)

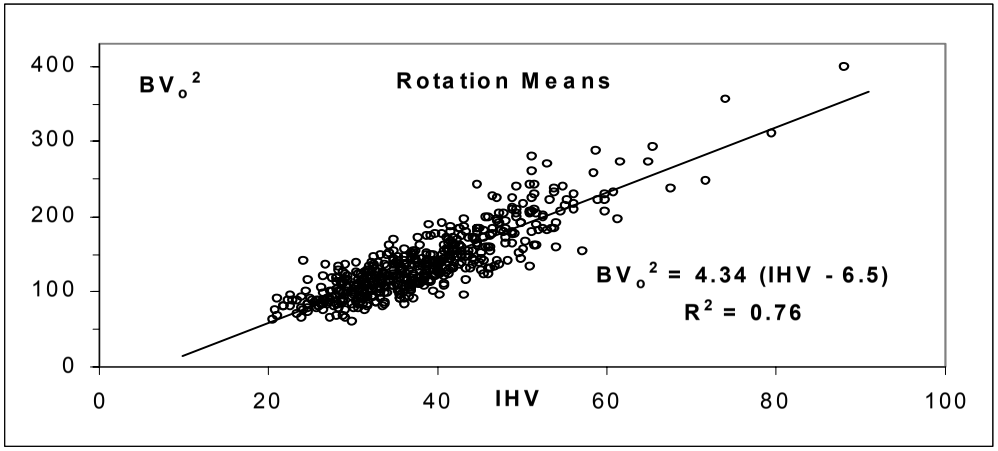


IHV = sum of unsigned differences between 7 hourly means centered at midnight

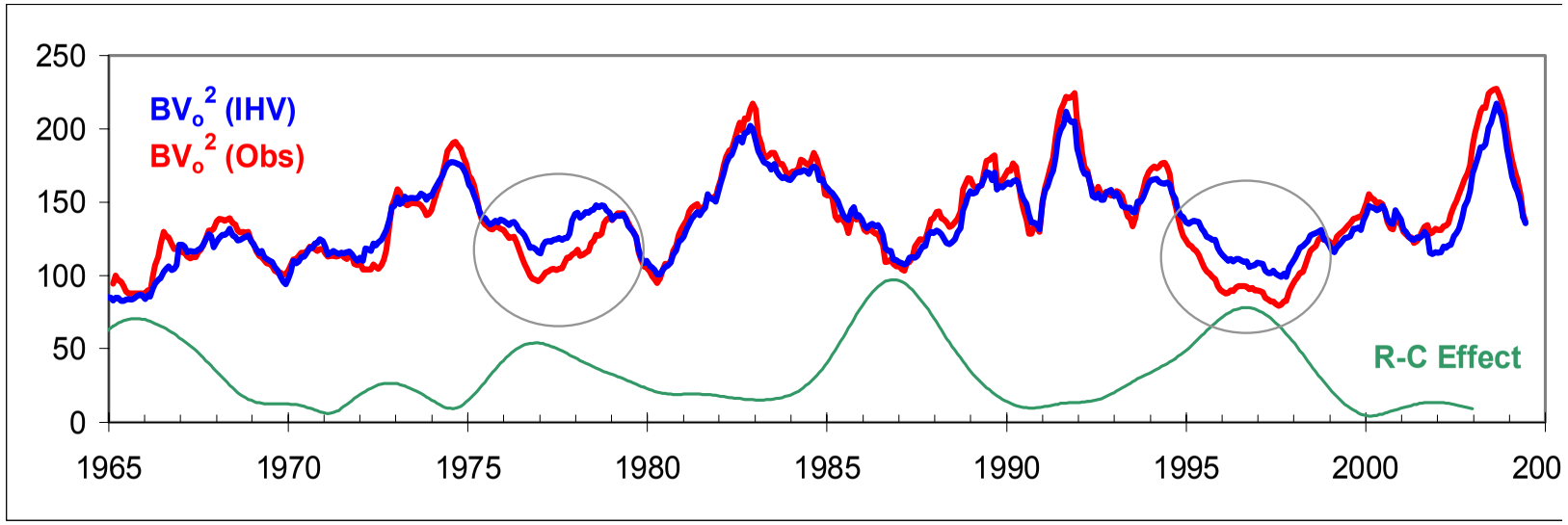


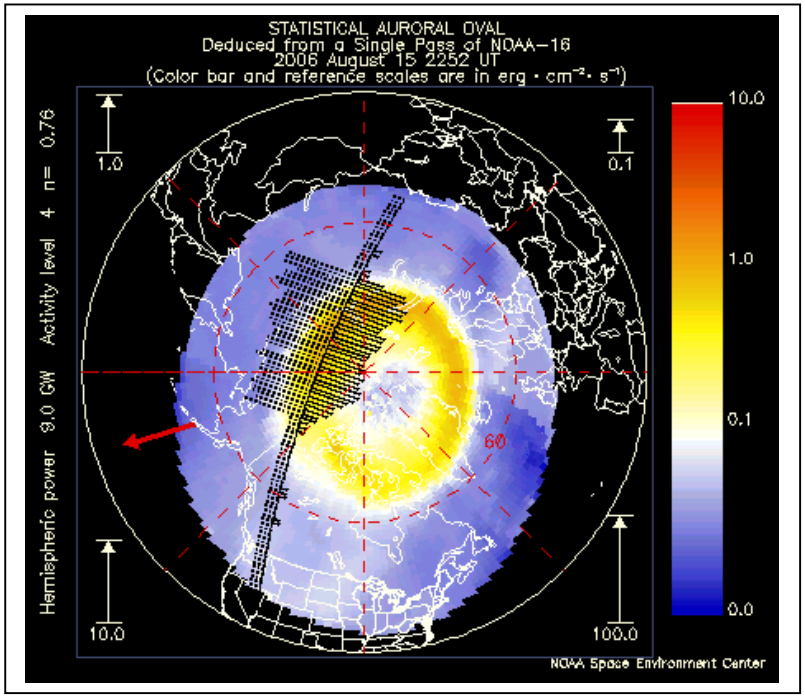
IHV-index is well-determined below 55 degrees geomagnetic latitude. For these mid-latitude stations the index is not very sensitive to secular changes in the geomagnetic field, e.g. the position of the poles.



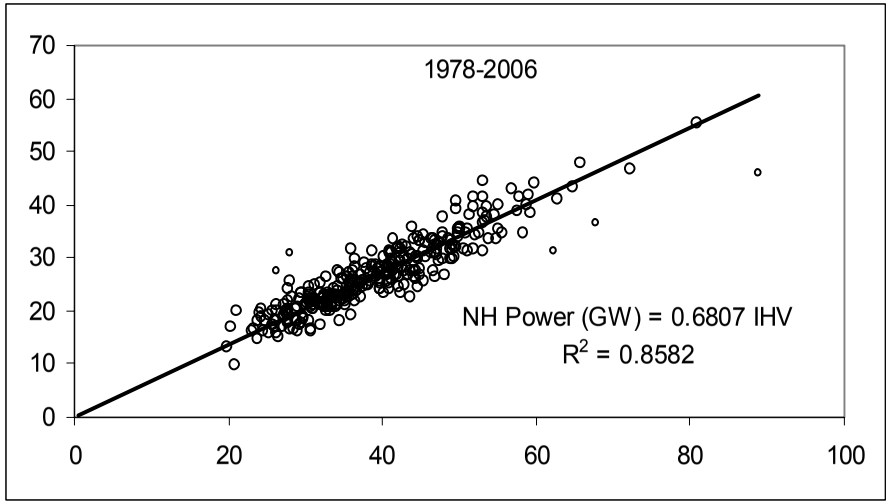


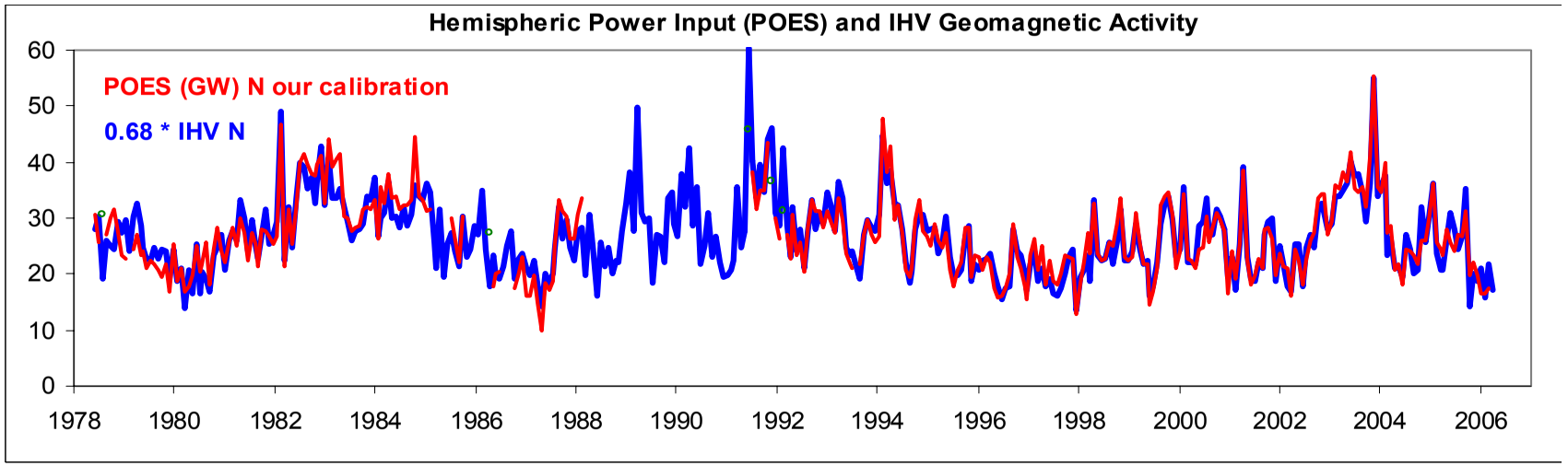
The IHV-index is strongly correlated with BV^2 on a 27-day rotation basis.
There are some second-order effects that we can either ignore (they are small) or correct for. Note high-speed streams in 1974 and 2003.



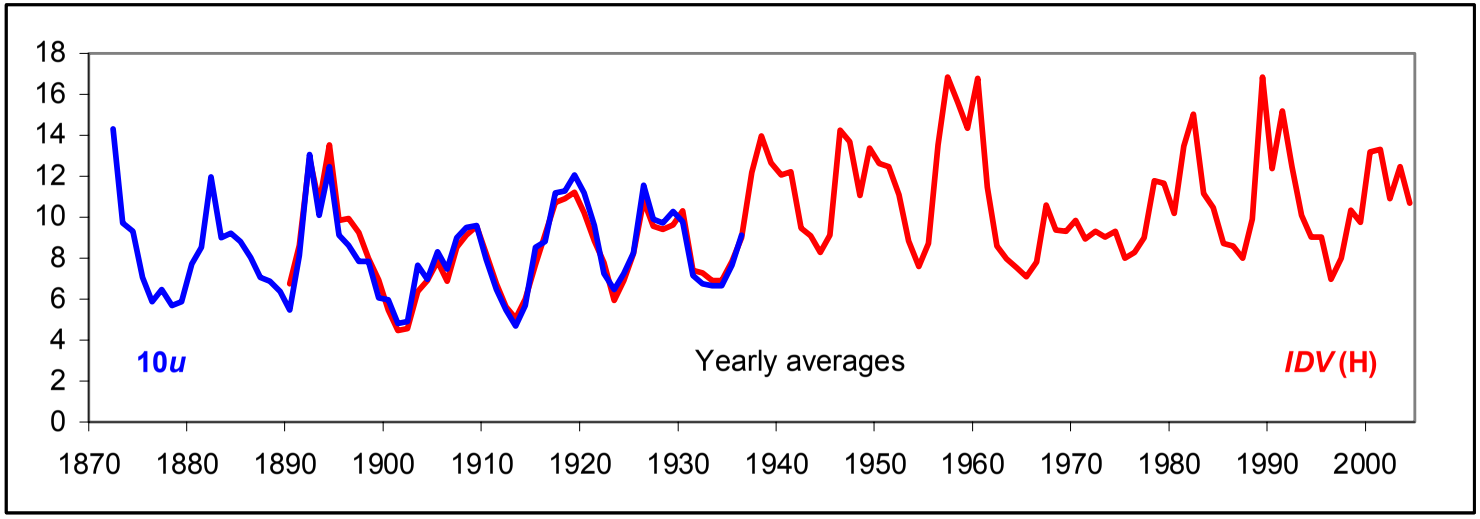


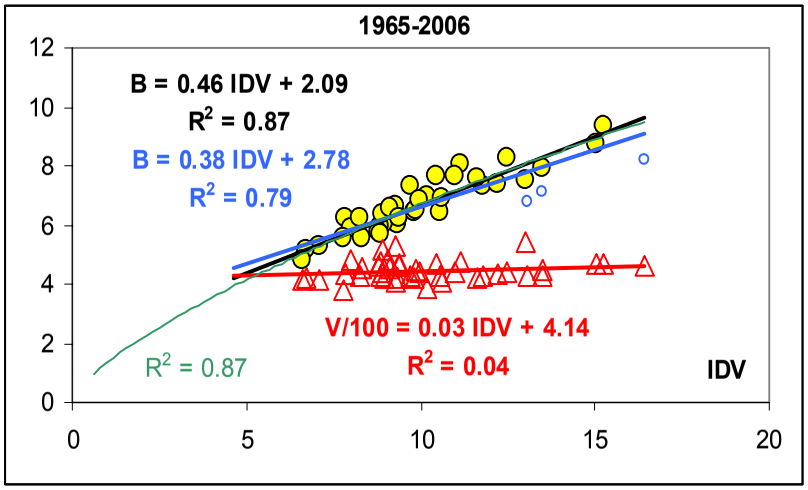
Physical meaning of the IHV-index = Energy input to upper atmosphere

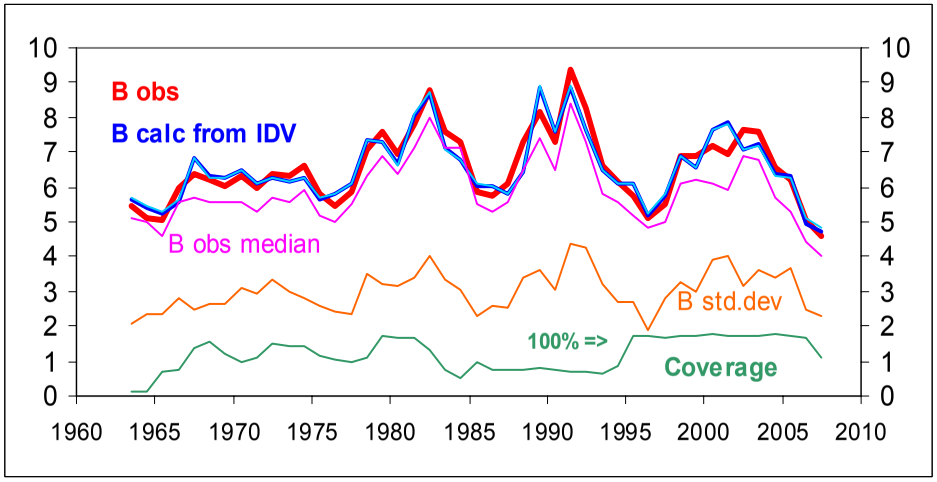




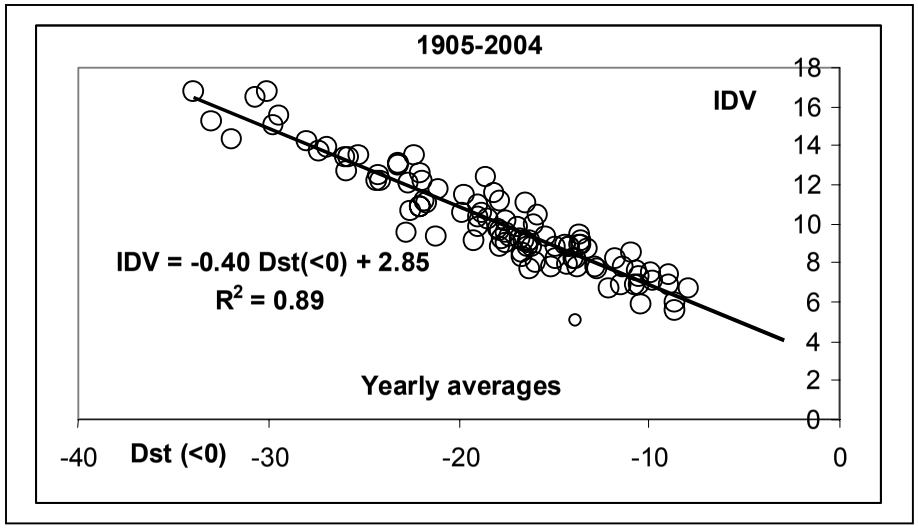
IDV = Average unsigned difference between the midnight hourly means from one day to the next.



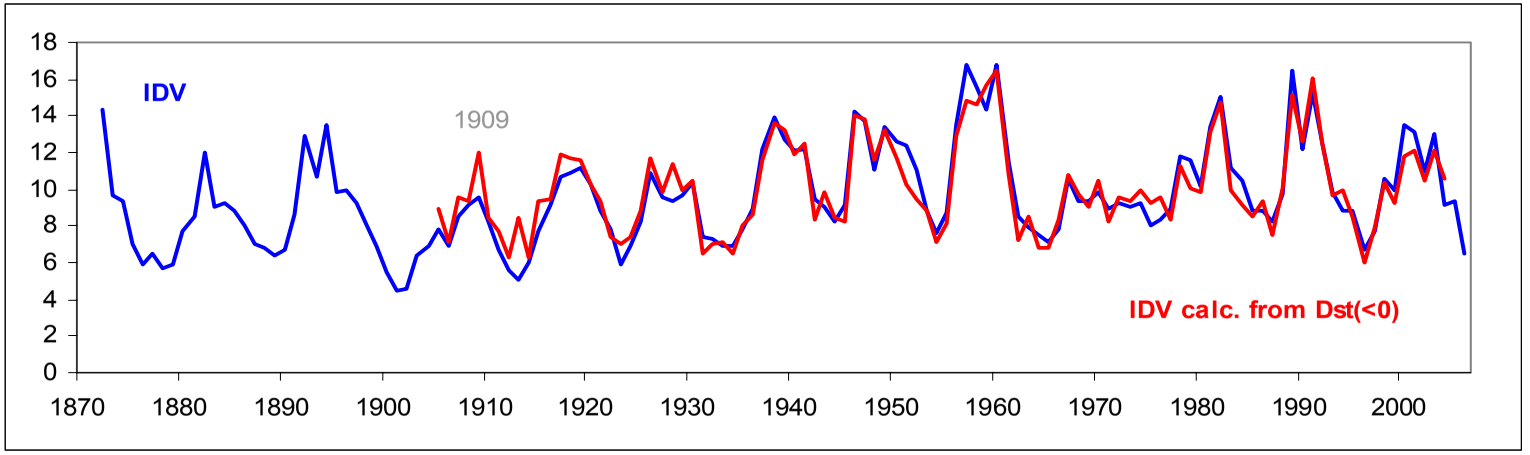




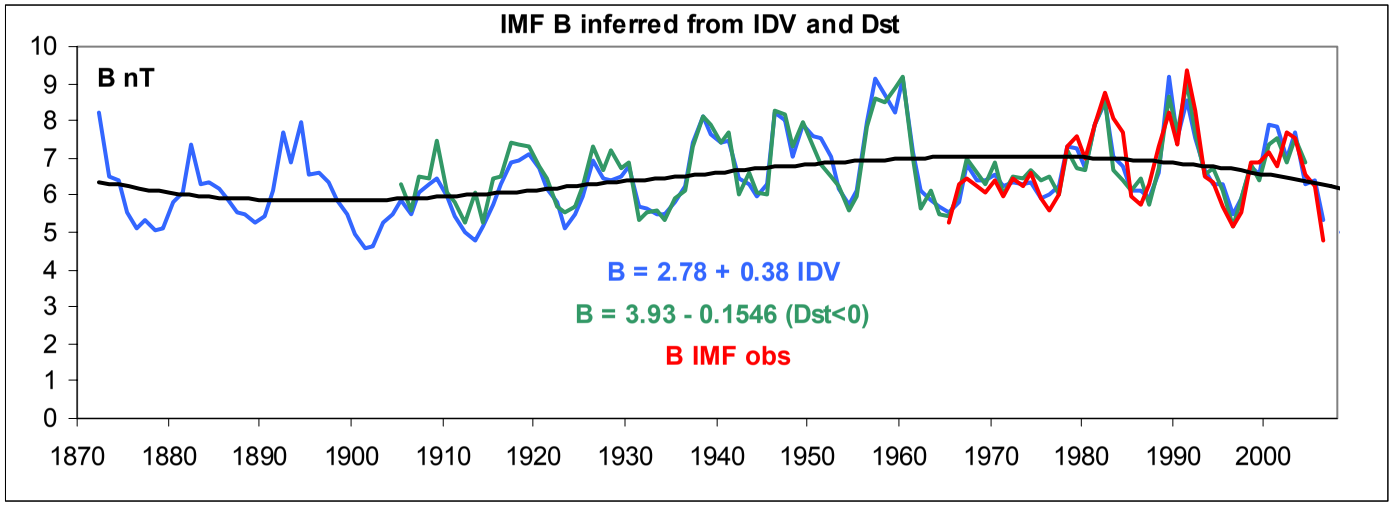
IDV is closely related to negative values of Dst:

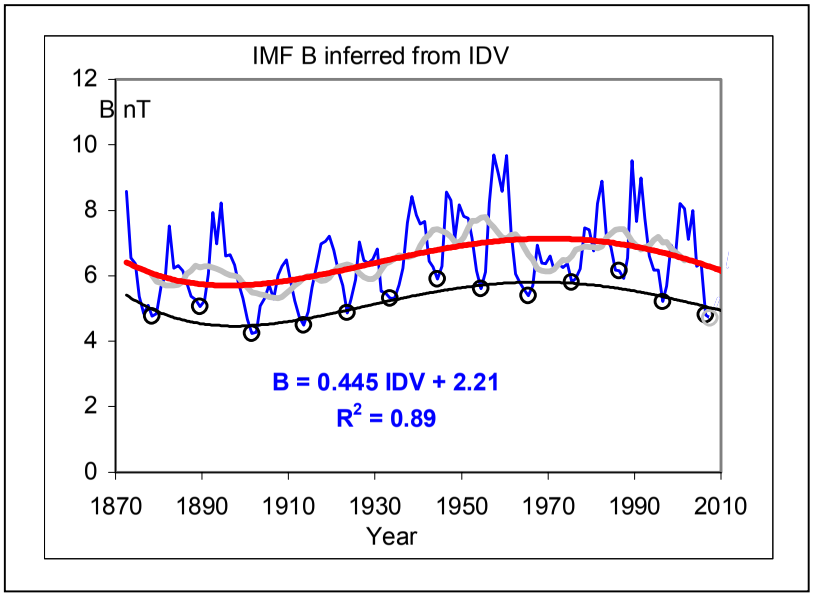


The difference in geomagnetic effect from one large storm to the next is largely due to different IMF strength (as the solar wind speed often follows almost the same pattern from storm to storm). So it is not a surprise that IDV is almost "blind" to the solar wind speed.

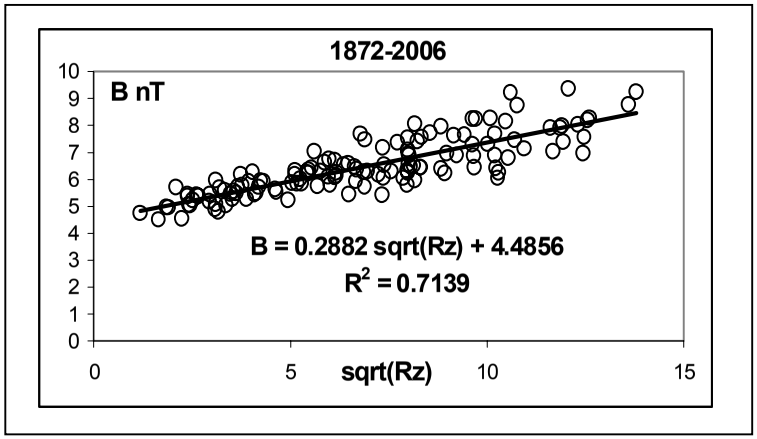


J. Love has calculated Dst back to 1905.

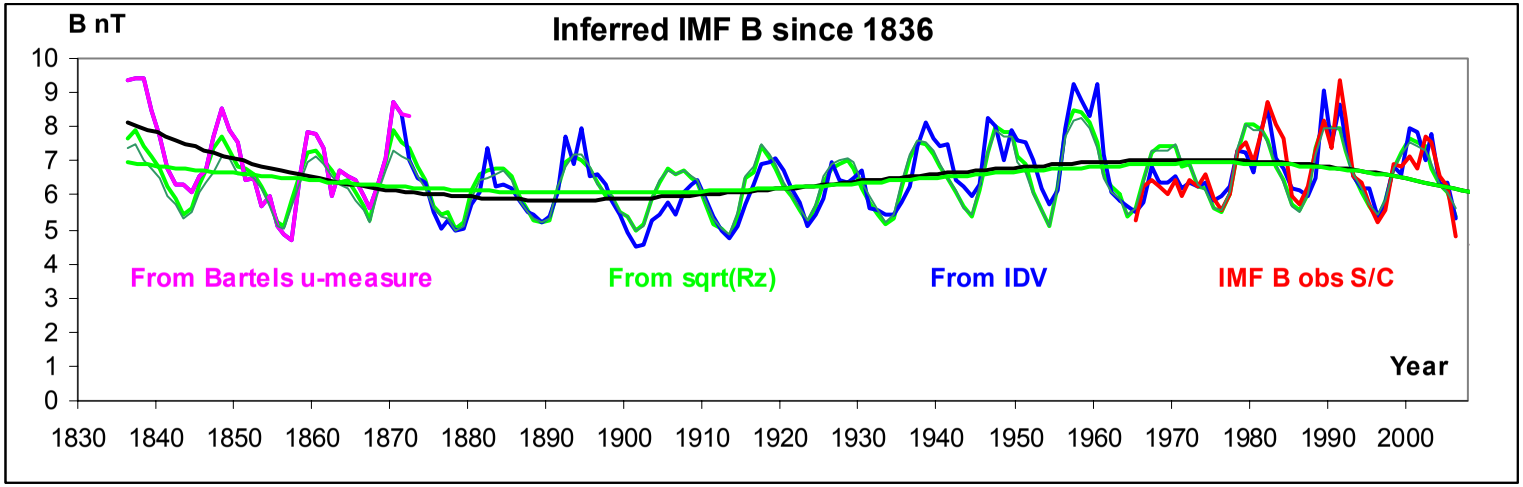




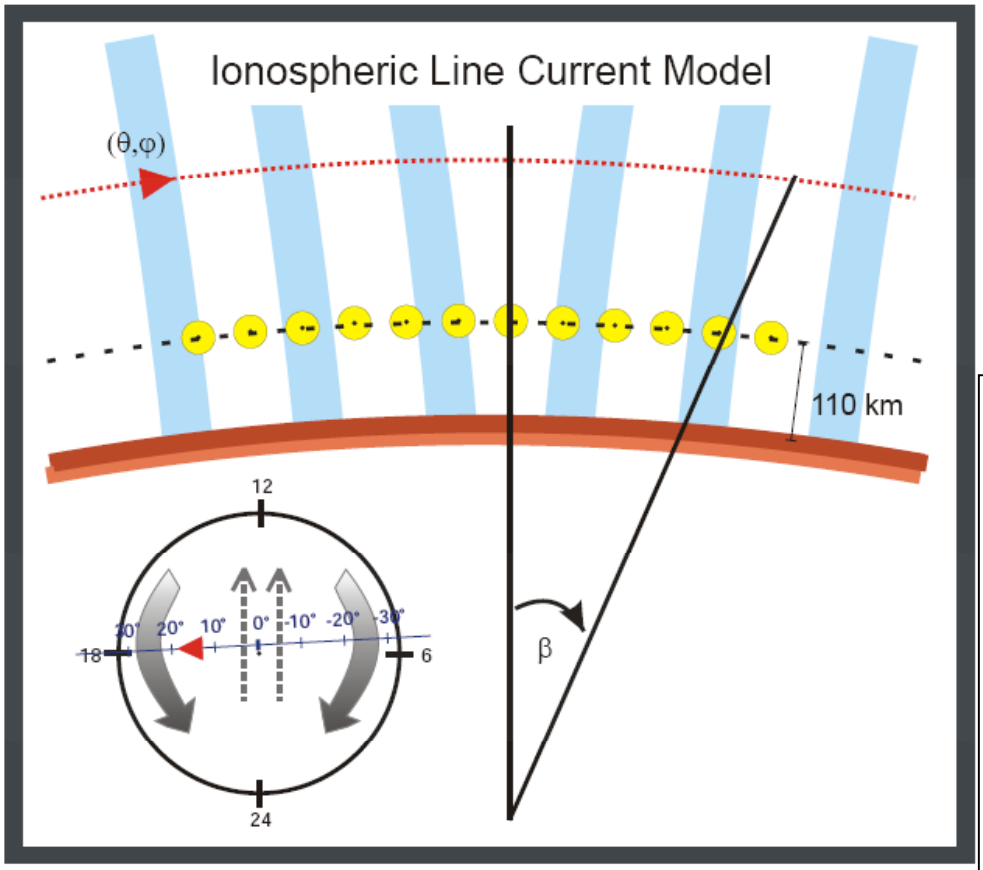
Using u-measure and IDV we can infer IMF B directly back to 1872. There seems to be a "Gleissberg"-type wave in IMF B. This is not a surprise because the sunspots show a similar wave. The IMF at solar minimum varies between 4.5 nT and 5.5 nT. Note that at present the IMF is close to what it was 100 years ago.

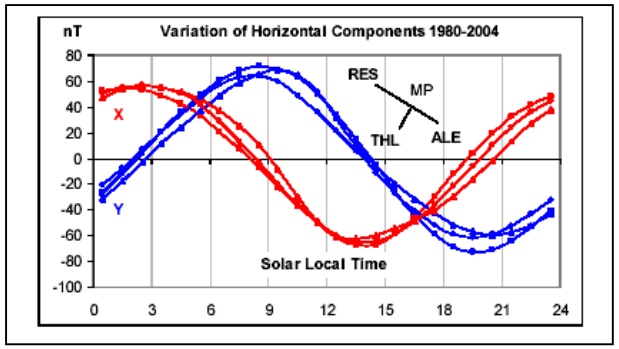


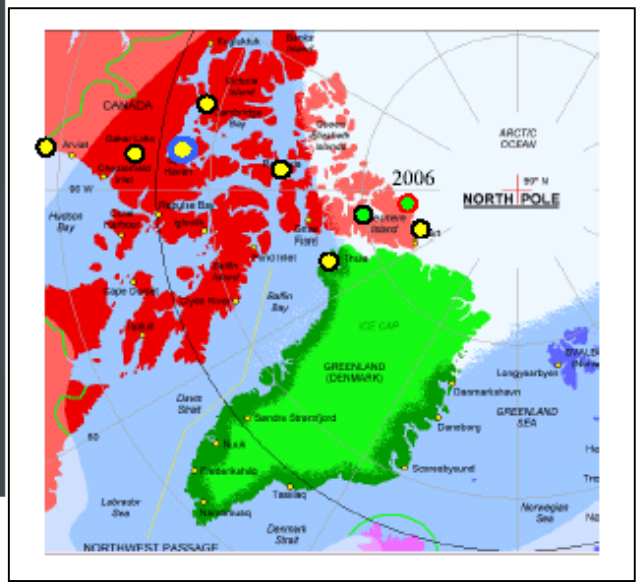
The main sources of the equatorial components of the Sun's large-scale magnetic field are large active regions. If these active regions emerge at random longitudes, their net equatorial dipole moment will scale as the square root of their number. Thus their contribution to the average IMF strength will tend to increase as $SSN^{1/2}$ which is precisely as observed.

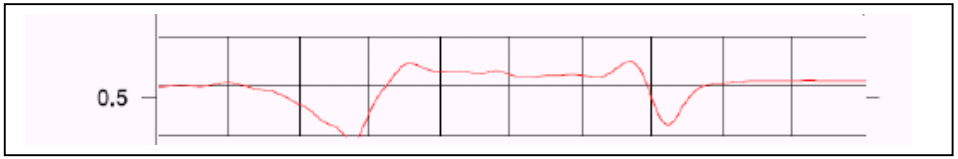


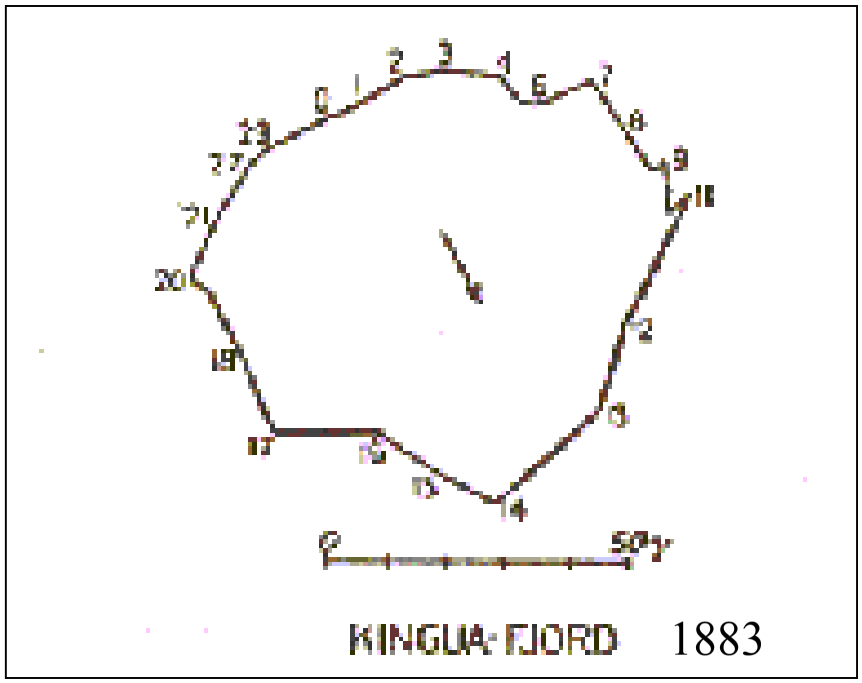
Polar Cap Current Sheet

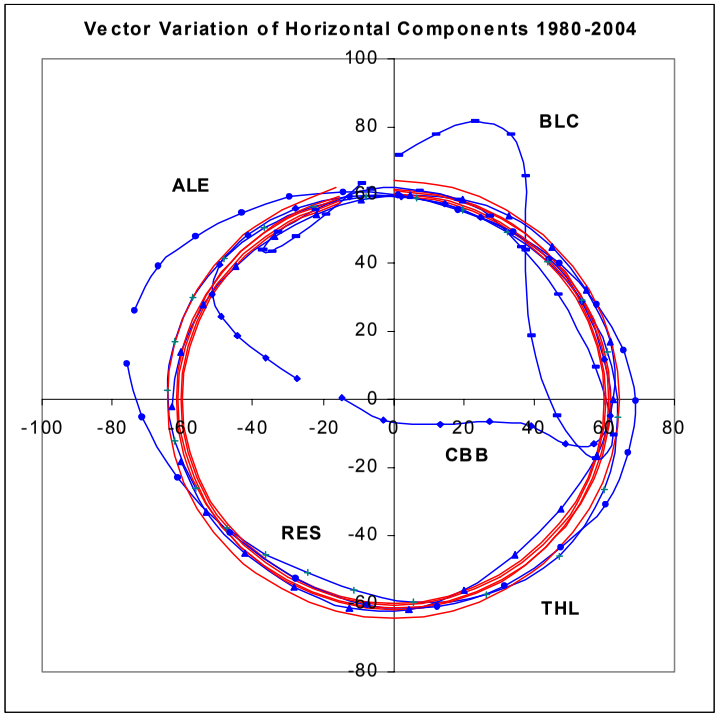


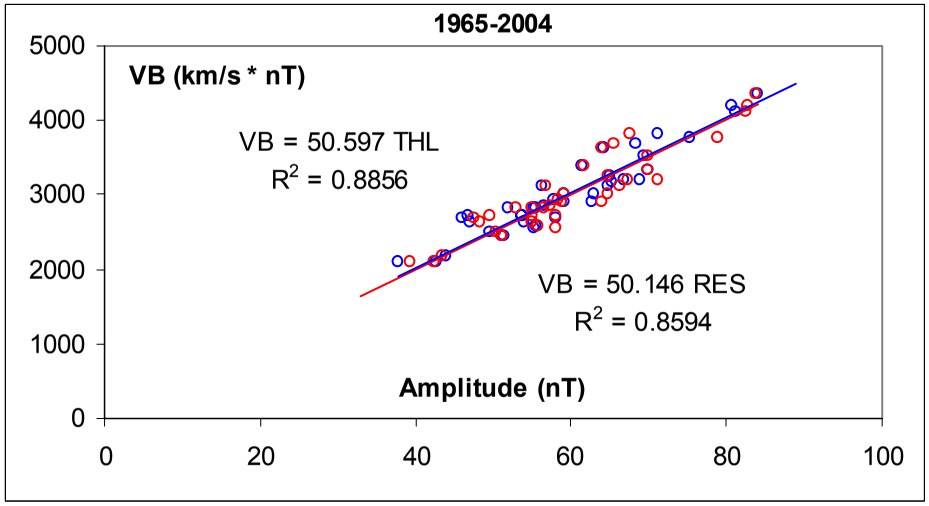




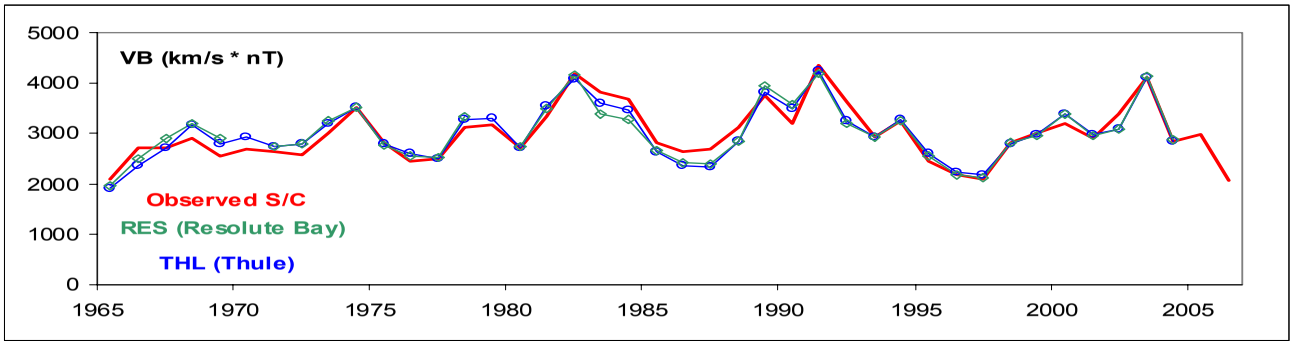




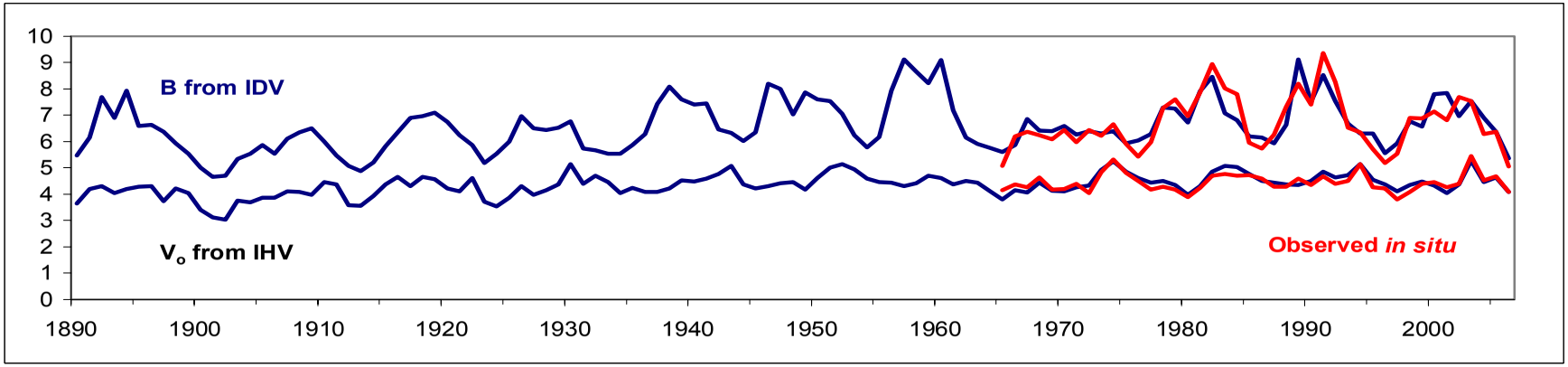


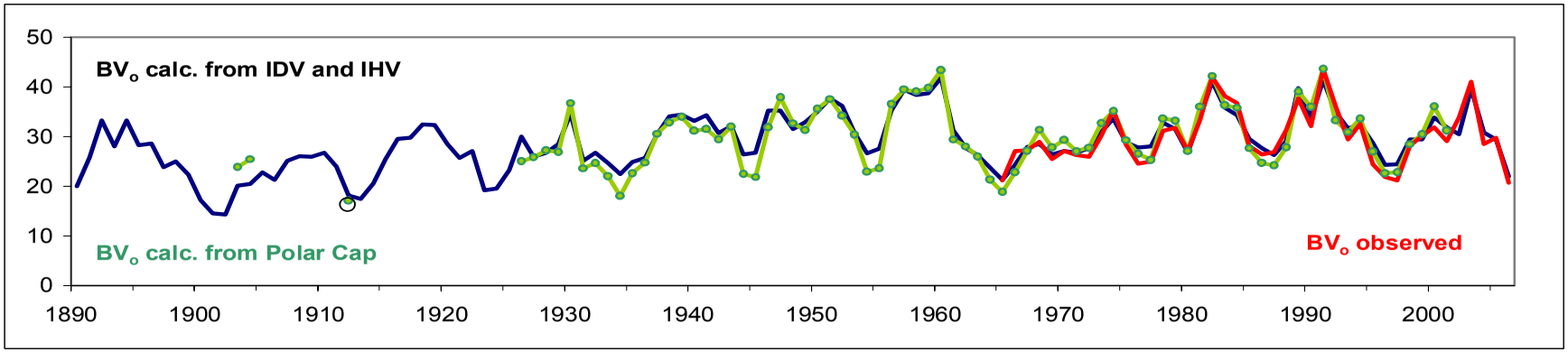


The Polar Cap Current is driven by the Polar Cap Electric Potential which in turn is given by the product of the solar wind speed V and the IMF B. There is a very direct relationship.

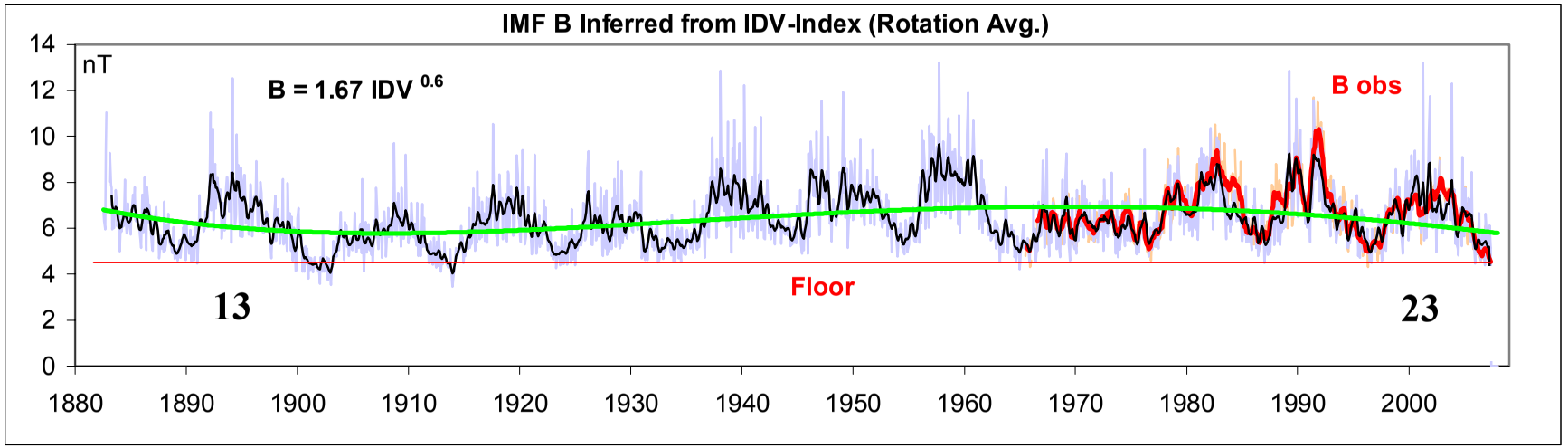


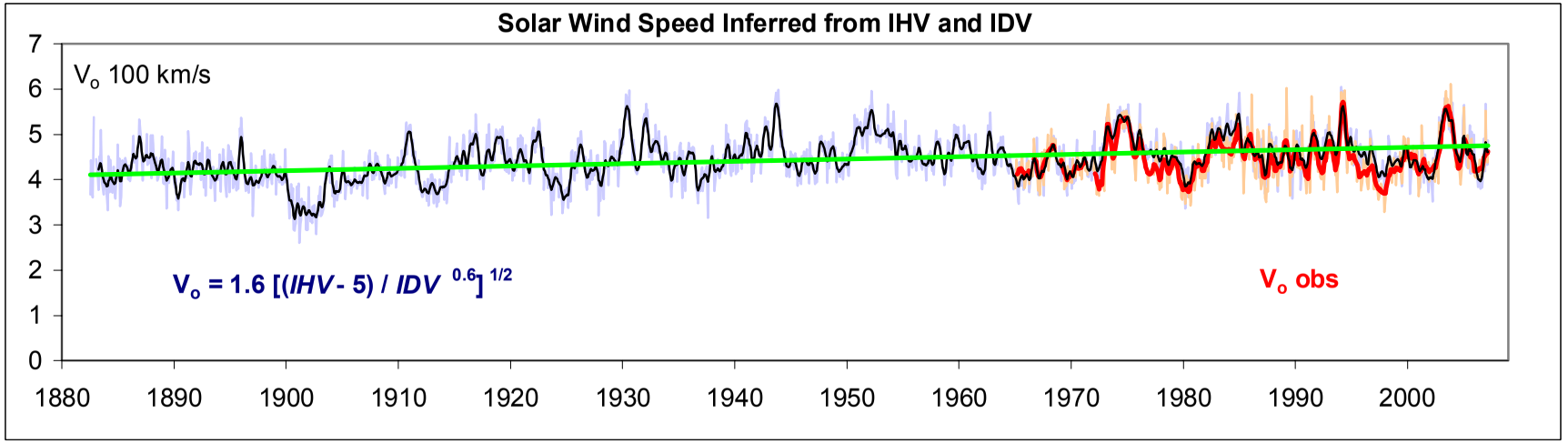
IDV gives us B, and IHV gives us BV^2, hence we can compute V, then BV and compare with polar cap BV.



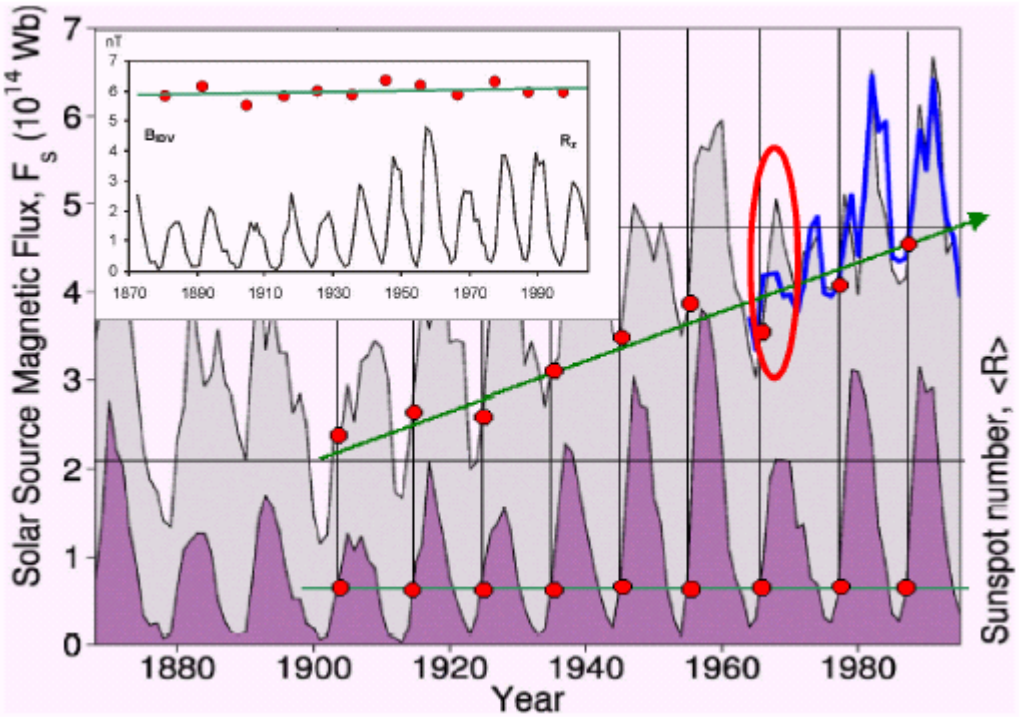


We can even do this on a 27-day rotational basis:


IMF B Inferred from IDV-Index (Rotation Avg.)
nT
B = 1.67 IDV 0.6
B obs
Floor
13
23
14
12
10
8
6
4
2
0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

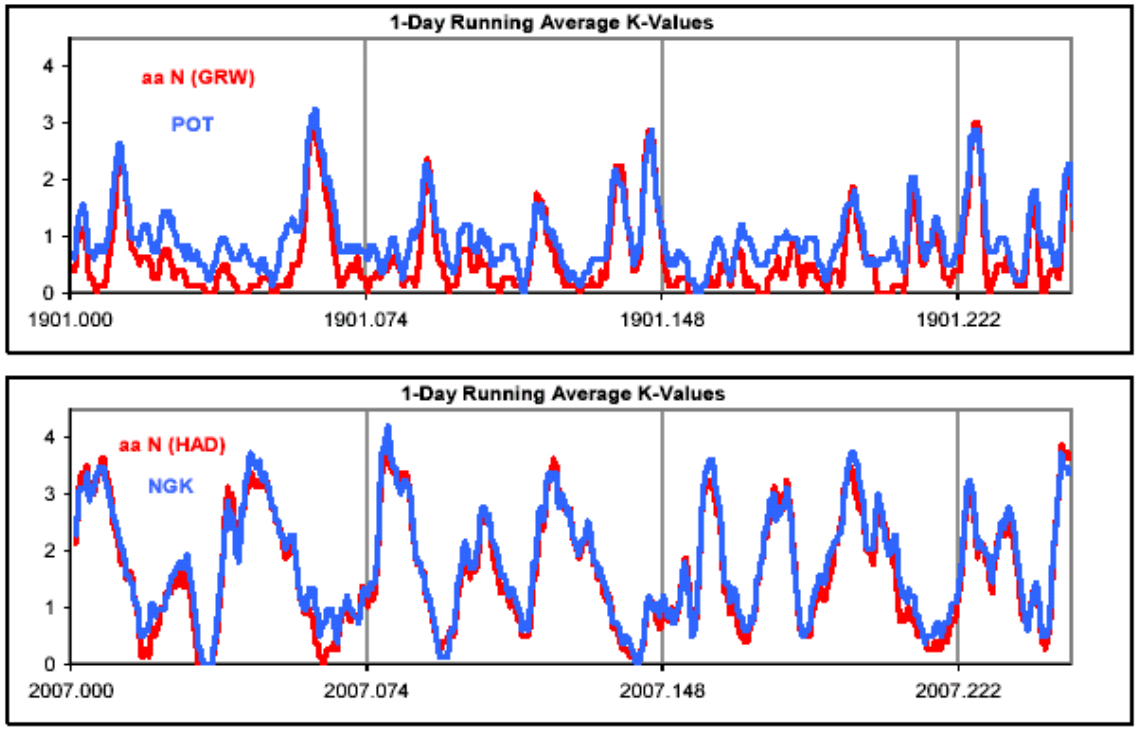

Solar Wind Speed Inferred from IHV and IDV
Vo 100 km/s
Vo = 1.6 [(IHV - 5) / IDV 0.6] 1/2
Vo obs
7
6
5
4
3
2
1
0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

Back in 1978 I proposed that the Sun's "open" flux had doubled since the 1900s. Lockwood et al. in a famous 1999 paper extended the analysis to 1995 and inferred an increase by a factor of 2.3 independent of the sunspot number:



The analysis was based on the geomagnetic aa-index. Subsequent work by several groups has shown that the calibration of aa is too low before 1957. In addition, there is an inhomogeneity in about 1937. Before that time Mayaud [who constructed the aa-index] had himself scaled all the geomagnetic records, after that he used existing scalings by others.

The most difficult K-value to scale is K = 0 [no activity at all] because it requires the correct removal of the [ever changing] daily variation due to solar FUV generated currents. Mayaud was the great expert at this and dared classify many intervals as K = 0 where other people conservatively opted for K = 1:



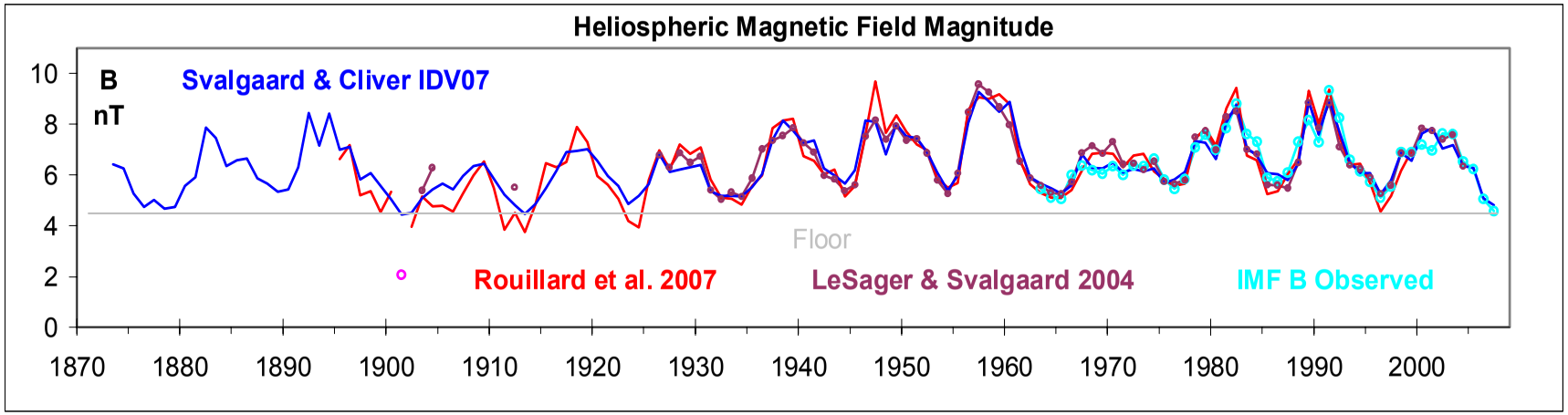
The net result was that aa was on the average 3-5 nT too low during the early years, which for the solar minima years 1901 and 1912 would amount to about 40%, so no wonder we all miscalculated the IMF B and the open flux.

Several new indices of geomagnetic activity have recently been introduced.

Geomagnetic index	**Function of**	$B\,V^{\alpha}$	**Proponents**
IDV, [D_{st}<0]; u	B	$\alpha = 0$	Svalgaard & Cliver; Bartels
m	$B\,V^{0.5}$	$\alpha = 0.5$	Lockwood et al.
PCP	$B\,V$	$\alpha = 1$	Le Sager & Svalgaard
IHV	$B\,V^{2}$	$\alpha = 2$	Svalgaard & Cliver
aa, am; ap	$B\,V^{2}$	$\alpha = 2$	Mayaud; Bartels

Because these depend on different functions of B and V, we can infer both B and V in the past.

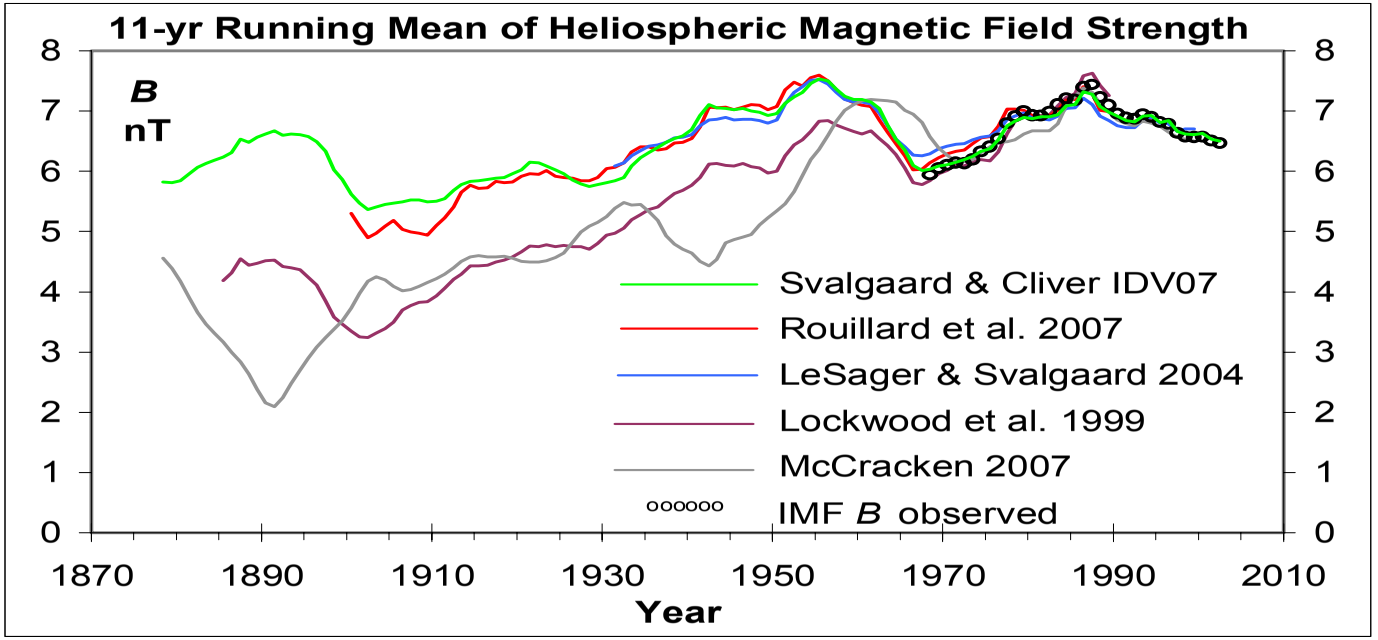
Using their new ‘m-index’ and the corrected aa-index, the Lockwood group (Rouillard et al.) has recently recalculated IMF B and obtained results that are very close to ours, although Lockwood still maintains that the 1999 result is valid [c.f. Solanki at SORCE, 2008]…

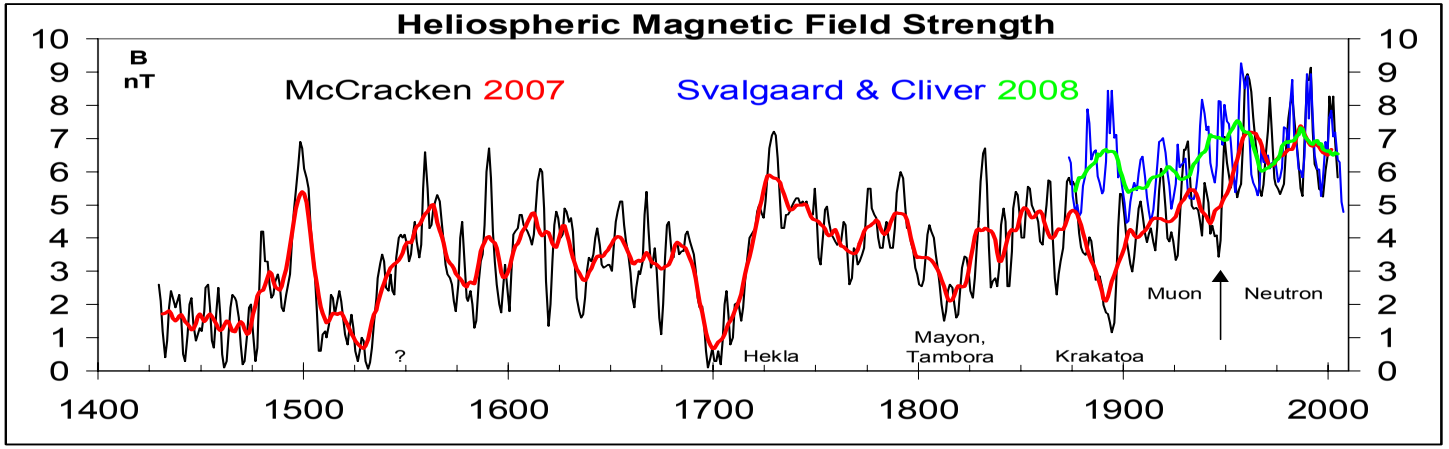


The point for 1901 is in error (Rouillard, Pers. Comm., 2007) and their result before 1910 is based on very few stations with resulting large error bar. Apart from such details, the various groups trying to reconstruct B and V are converging on a common position that should be taken into account now by other researchers, rather than relying on the superceded earlier results.

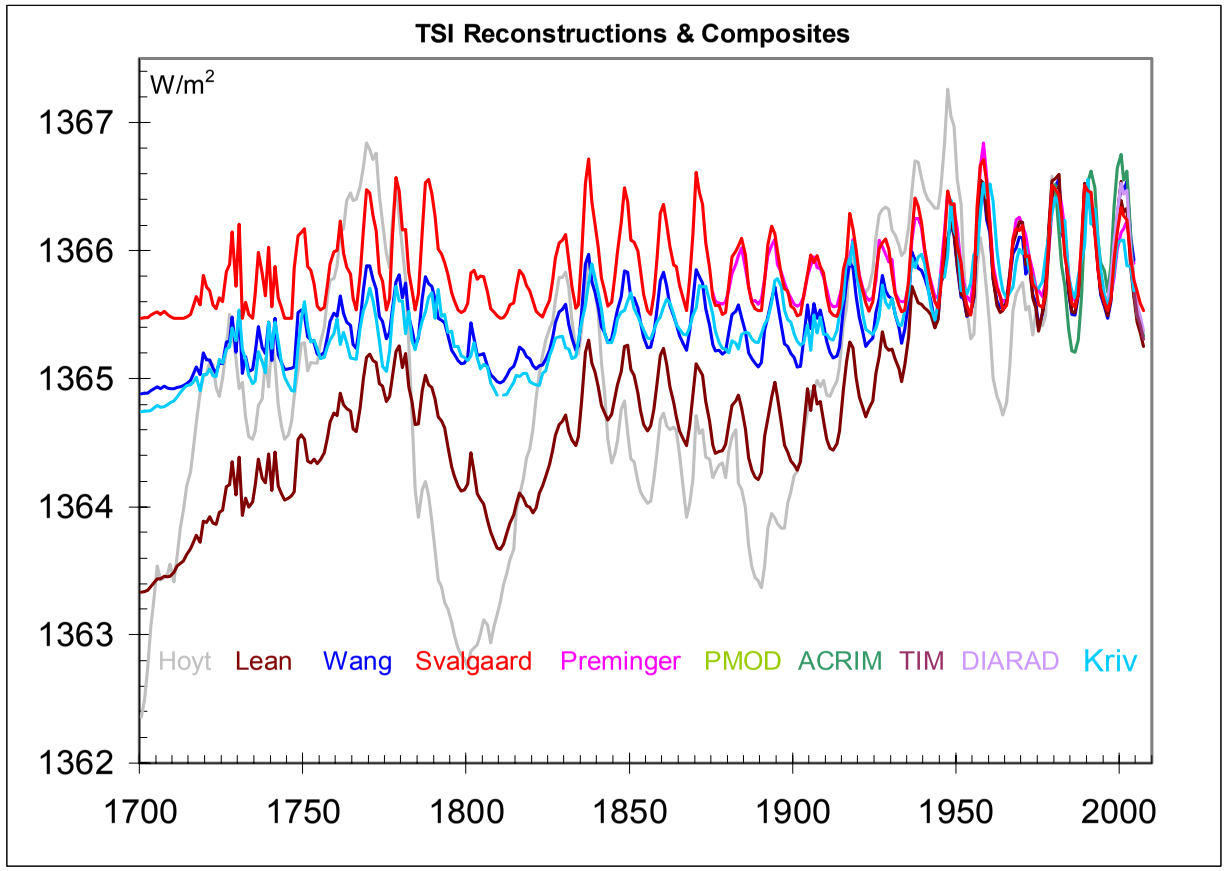
This re-assessment of the “open” flux has implications for reconstructions of various solar proxies that postulate a secular increase of the “open” flux.

One example is McCracken [2007] who inverted the cosmic ray flux (inferred from ^{10}Be fitted to the secular change) to calculate the IMF B (or the HMF as he calls it):





Another example is reconstructions of TSI (Total Solar Irradiance) which often rely on an "open flux background":



Without the background "rise" 1900-1960, the TSI seems to have varied less than commonly assumed.

The end