IDV09 and Heliospheric Magnetic Field 1835-2009

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Abstract. We use recently acquired archival data to extend the *IDV*-index of long-term geomagnetic activity. The new *IDV* series (IDV09) includes the years 1835-2009, vs. 1872-2004 for IDV05, with improved early data coverage, substantiating our earlier work. Comparison of the IDV09-based HMF strength with other recent reconstructions of solar wind *B* yields a strong consensus between series based on geomagnetic data, but lack of support for a discordant series based on ^{10}Be cosmic ray data.

1. Introduction

In *Svalgaard and Cliver* [2005] we introduced the InterDiurnal Variability (*IDV*) index for a given geomagnetic observatory ('station') as the average absolute difference of hourly mean values of the Horizontal Component, H, from one day to the next, measured one hour after midnight. The average should be taken over a suitably long interval of time, such as one year, to eliminate various seasonal complications.

IDV has the useful property of being independent of solar wind speed and is highly correlated with the near-Earth Heliospheric Magnetic Field (HMF) strength *B*. Thus once *IDV* is determined, solar wind *B* is known as well. *Svalgaard and Cliver* [2005] used *IDV* augmented with *Bartels*' [1932] *u*-measure to reconstruct the HMF strength for the years 1872-2004.

Here we report on an extension of the *IDV* index for a longer time interval (1835-2009), using many more stations. The inclusion of more data is particularly important for the years from 1872-1902 for which the initial version of the index (IDV05) was based on observations from one or two stations only. An important aspect of IDV09 is that it includes recent years with index values at the same level as the very low values in 1901-1902, thus allowing the correlation between *IDV* and the magnitude of the near Earth HMF to be extended to such low values without extrapolation. With this correlation, we infer HMF *B* for years prior to the space age and compare our *B* values with those obtained by other investigators using geomagnetic or cosmic ray data.

2. Analysis

2.1 Derivation of IDV09

Our determination of IDV09 is essentially identical to that of IDV05 except for the inclusion of more data. Since 2005, we have been collecting and creating more electronic digitized hourly geomagnetic data. Here we use these newly-acquired data to substantiate the *IDV*-index, which is especially important for the first ~30 years of the time series (1872-1902), during which IDV05 was based solely on *Bartels*' [1932] *u*-measure from 1872-1889, on Potsdam observations from 1890-1902, plus Cheltenham for 1901-1902, and Honolulu for 1902. In contrast, IDV09 is based on four times as many "station years" (135 vs. 34) for this 31-yr interval. We free the *u*-measure from contamination by the Declination (see section 2.1.3) and treat the *u*-measure itself as a station (1835-1937) giving it equal weight to each of the other stations. Finally, we update the time series by adding the index values for 2005-2009. These latter years are significant because the yearly-averages of *B* observed in 2007-2009 are the lowest observed during the space age. They lie at the lower endpoint of the correlation between yearly averages of observed *B* and *IDV*.

Table 1 contains a list of the 72 stations used to compute IDV09 (versus 14 for IDV05). A comprehensive list of the data coverage and the data values for the individual stations used in this study is given in Table E1 in the Electronic Supplement.

2.1.1. Latitude Normalization

For IDV05, we normalized *IDV* values for a given station with corrected geomagnetic latitude, *M*, to those of Niemegk (NGK) [as Bartels did for the *u*-measure] using

$$IDV_{\mathrm{norm}} = IDV_{\mathrm{raw}} / (1.324 \cos^{0.7}(M)) \qquad (1)$$

Here we have retained this relationship for stations with $|M| < 51°$. At higher latitudes, the index becomes strongly contaminated by auroral zone activity, and we recommended not using such stations, *e.g.*, the long-running station Sodankylä, SOD (used by *Lockwood et al.* [2009]). For IDV09, we relax this restriction slightly [by a few degrees for a few stations, indicated in Table 1] using an empirical normalization divisor of 1.1 instead of the divisor in equation (1). We do this to accommodate changes in *M* with time which for some stations can exceed several degrees[1]. Figure 1 shows the adopted normalization divisor as a function of *M* for the 72 stations used in the present study. Different symbols denote the divisor values for the years 1800, 1900, and 2000, showing the sensitivity of *IDV* to changes in latitude. The normalization divisor was calculated for the centroid of the time of the actual data used for each station.

2.1.2. Effect of Hourly Means versus Hourly Values on *IDV*

Early magnetometer data were taken [and/or reported] as readings once an hour rather than as the hourly mean that Adolf Schmidt advocated in 1905 and that was widely and rapidly adopted. In *Svalgaard & Cliver* [2005] we showed that although the variance of single values is larger than for averages, the overall effect on *IDV* was small[2]. The two long-running series POT-SED-NGK and PSM-VLJ-CLF afford a convenient additional test of this: POT changed from values to means with the 1905 yearbook, but CLF

[1] We expect only a very weak influence in the basic response of the Ring Current [see section 2.1.5] to the change of the Earth's magnetic dipole moment [*Glassmeier et al.*, 2004] over the interval in question, and so have not attempted to correct for this.

[2] This effect is significant for the *IHV* index but in that case, correction of the effect is straightforward [*Svalgaard and Cliver*, 2007b].

changed much later, with the 1972 yearbook, so we can directly compare the (raw – uncorrected in any way) *IDV*-values for the two series (Figure 2). It is evident that the change from hourly instantaneous values to hourly means did not introduce any sudden changes in *IDV* at the times of the transitions.

2.1.3. The *u*-measure Before 1872

Julius *Bartels* [1932] compiled the *u*-measure from the interdiurnal variability of the Horizontal Component, H, from hourly or daily values from several observatories operating from 1872 onwards as described in his paper. He wrote, "Before 1872, no satisfactory data for the calculation of interdiurnal variabilities are available", but "more for illustration than for actual use", he attempted to extend the series backwards to 1835. For this he used the "Einheitliche Deklinations-Variationen", *E*, of *Wolf* [1884] and the "summed ranges", *s*, derived from the mean diurnal variation of H at Colaba (Bombay) due to *Moos* [1910]. He derived regression formulae relating *E* and *s* to *u* for times after 1872 and used them to synthesize values of *u* for the earlier years, giving *s* double the weight of *E*. We have re-derived *u* for 1847-1871 using only the summed ranges based on H as it is better not to introduce the Declination for times when H is available. Figure 3 shows a comparison between the various measures and indices. The good agreement justifies use of the *u*-measure derived from the summed ranges as a proxy for *IDV* back to 1847, and use of Bartels' original *u*-measure ("for illustration only") before 1847 based on sufficient data from the 'Magnetic Union' initiated by Gauss, followed by the 'Magnetic Crusade' of the 1840s. The summed ranges will be contaminated slightly by the day-time regular variation as they are calculated over the full 24 hours. Judging from Figure 3 this contamination does not appear to have a large effect.

2.1.4. The Composite *IDV*-index 1835-2009

From the 1,342,294 daily differences [3675 station-years] derived from the stations in Table 1 we construct the composite *IDV*-index shown in Figure 4, with individual station curves in grey. The composite (red curve) is the mean of the median and average values for each year. Also shown (blue curve) is the number of stations contributing to the mean. The large number of stations from 1957 on does not add further significance to the composite, but only serves to establish the range of scatter of the values.

It is evident that *IDV* from only a single station (provided that not too much data is missing either because the recording went off-scale or as a result of other problems) does not differ much from the mean of many stations; the standard deviation of *IDV*-values for all stations for a given year is less than 1 nT or about 9%. This means that only a few [good] stations are needed for a robust determination of *IDV*. This conclusion, of course, only emerges after the spread of *IDV*-values has first been shown to be small. The standard error of the mean of more than fifty stations is 0.1 nT.

Figure 5 shows that the differences between IDV05 and IDV09 are slight, and mainly due to the additional data for 1872-1889, including the improved *u*-measure. During the period of overlap (1872-2003, 2004 was only partial), the two time series agree within an RMS of 0.45 nT or 5%. The coefficient of determination for the correlation between IDV09 and IDV05 is $R^2 = 0.975$. *IDV* is a robust index.

2.1.5. Physical Interpretation of *IDV*: Measure of the Energy in the Ring Current

In *Svalgaard and Cliver* [2005] we reported that *IDV* is closely correlated with the negative part of the D_{st}-index based on data back to 1932 [*Karinen and Mursula*, 2005].

In *Svalgaard and Cliver* [2006] we extended that relationship back to 1905 using the 100-year D_{st}-series derived by *J. Love* [2006, 2007], and confirm it here using IDV09. Yearly averages of D_{st} when the hourly value [adjusted to Kyoto D_{st}] was negative were computed and found to be strongly correlated with *IDV* [$R^2 = 0.91$]: $IDV = -0.45\ (D_{st}<0)$. Figure 6 compares IDV09 and *IDV* computed from D_{st}. The good match suggests that the *IDV* is a measure of the same physical reality as negative D_{st}, namely the energy in the Ring Current, which then in turns seems to be controlled by HMF *B*: $(D_{st}<0) = 4.81\ B - 9.41$ [$R^2 = 0.84$], and we can also use D_{st} to determine the HMF strength: $B = 2.70 - 0.1736\ (D_{st}<0)$.

2.2. Using IDV09 to Calculate HMF Strength, 1835-2009

Since the 2005 definition paper, lower values of HMF strength, *B*, have improved the dynamic range (and thus the statistical significance) of the correlation between *IDV* and *B*. An approximate linear correlation was found, but there is no *a priori* reason the relationship would be strictly linear. In addition, it has been argued [*Lockwood et al.* 2006] that *B* should be taken as the independent variable instead of *IDV*. We showed in *Svalgaard and Cliver* [2006] that it does not make much difference which way the correlation is evaluated. In the end, the RMS difference [0.4 nT or less than ~10%] between HMF *B* observed *in situ* near the Earth and inferred from *IDV* is what matters. The average coefficients for the linear correlation performed four ways (average, median, and for each: direct and inverse) are

$$B\ (\mathrm{nT}) = (2.07 \pm 0.21) + (0.448 \pm 0.020)\ IDV \quad (R^2 = 0.868) \qquad (2)$$

The equivalent power law dependence comes to

$$B \text{ (nT)} = (1.34\pm0.08)\, IDV^{\,0.686\pm0.025} \qquad (R^2 = 0.904) \qquad (3)$$

The adopted values for *B* inferred from IDV09 given in Table 2 are the mean values calculated using these two relationships.

Figure 7 shows the values for HMF *B* inferred from *IDV* from 1835 to the present (blue curve) and *B* measured by spacecraft (red curve). A 4th-order polynomial fit suggests a ~100 year Gleissberg cycle. Cycle 23 looks remarkably like cycle 13, including the very deep solar minimum following both cycles, likely presaging a weak cycle 24 as predicted from the solar polar fields [*Svalgaard et al.*, 2005; *Schatten*, 2005]. It is clear that we are returning to conditions prevailing a century ago. It seems likely that other solar parameters such as Total Solar Irradiance [*Fröhlich*, 2009] and cosmic ray modulation [*Steinhilber et al.*, 2009] are reverting to similar conditions.

2.3. Comparison of IDV09-based *B* with Other Recent Reconstructions

2.3.1. Consilience of Reconstructions Based on Geomagnetic Data.

Reconstructions of HMF *B* have been discordant in the past [e.g. *Lockwood et al.*, 1999, 2006; *Svalgaard and Cliver*, 2005, 2006, 2007b]. The realization [*Svalgaard et al.*, 2003] that geomagnetic indices can be constructed that have different dependencies on *B* and solar wind speed (*V*) has enabled robust determinations of both *V* [*Svalgaard and Cliver*, 2007b; *Rouillard et al.*, 2007; *Lockwood et al.*, 2009] and *B* [*Svalgaard and Cliver*, 2005, 2006; *Lockwood et al.*, 2009] that have converged to a common, well-constrained dataset. Progress has been swift and Figure 8 shows the convergence of HMF *B* determined by *Lockwood et al.* [2009] to the values determined from *IDV* [*Svalgaard and Cliver*, 2005, this paper]. The *Lockwood et al.* [2009, and references therein] reconstruction still differs from ours for a few years during solar cycle 14, but apart from that, the agreement is quite remarkable and the issues seem resolved.

Figure 9 details the evolution of the various determinations of *B* since the seminal, but now superseded, *Lockwood et al*. [1999] paper. It is clear that we now possess the methodology to infer B with good accuracy as far back as continuous geomagnetic records of H reach. A concerted effort of digitization of 19th Century yearbook records promises to further improve our knowledge of the magnetic field in the heliosphere.

Svalgaard and Cliver [2007a] argued for a floor in the solar wind *B* of 4.6 nT which was approached at every 11-yr minimum and represented the ground-state of the Sun during extended minima such as the Maunder Minimum. With the larger dynamic range afforded by the current minimum, we can refine the value of the floor to the ~4 nT observed during 2008 and 2009 [see also *Owens et al.*, 2008], returning to the values inferred for 11-yr minima during the previous Gleissberg minimum at the turn of the 20th century.

2.3.2. Discordance with a ^{10}Be-based Reconstruction

McCracken [2007] spliced together ^{10}Be data, ionization-chamber cosmic ray data (calibrated with balloon flight data), and neutron monitor cosmic ray data to produce an 'equivalent' neutron monitor count series covering the entire interval 1428-2005, and inverted the series for *B* in order to express the data in terms of the HMF *B*. In Figure 10 we compare his series for HMF *B* with the 'consensus' *B* from geomagnetic data.

In McCracken's time series for *B*, a large step-like change (1.7 nT; from 3.5 nT to 5.2 nT; the largest jump in the entire ~600-year record) occurs between the 1944 and 1954 sunspot minima flanking cycle 18. No such corresponding change is observed in the concordant reconstructions of *Svalgaard and Cliver* [2005; this paper], *Rouillard et al.* [2007] and *Lockwood et al.* [2009], nor in B calculated from the quantity BV deduced by *Le Sager and Svalgaard* [2004] using either V of *Svalgaard and Cliver* [2006] or of *Rouillard et al.* [2007], or in B deduced from D_{st}.

Muscheler et al. [2007] discuss the uncertainties with the balloon-borne data that form the basis for McCracken's calibration of the composite equivalent neutron monitor data before 1951. The strong geomagnetic evidence argues that the calibration of the pre-neutron monitor cosmic ray reconstruction is not on a firm footing. We suggest that part of the reason for the disagreement might lie with the calibration and splicing together of the disparate cosmic ray datasets.

3. Summary and Discussion

We have extended and substantiated the annual *IDV-index* of long-term geomagnetic activity [*Svalgaard and Cliver*, 2005]. The new *IDV* series, given in Table 2 and designated IDV09, is based on four times as many station-years of data for the interval from 1872-1902 than the initial IDV05 series (135 station-years from 11 geomagnetic observatories vs. 34 station years from four observatories). In addition we have used a modification of Bartels' *u*-measure to extend the *IDV-index* back in time from 1872 to 1835 and updated the index from 2005 to 2009. This forward extension is important because the years 2007-2009 witnessed the lowest annual averages of *IDV* during the space age. For the time of overlap between the re-evaluated *IDV-index* (IDV09) and IDV05, the difference is very small, testifying to the robustness of the index.

A comparison of IDV09-based HMF strength with those obtained by other investigators using various combinations and permutations of geomagnetic indices revealed a pleasing agreement in what had been previously a contentious field of research. The technique proposed by *Svalgaard et al.* [2003] and adopted by *Rouillard et al.* [2007] to use indices with different dependencies on B and V to separate these variables has proven out and allowed the vast storehouse of hourly and daily data to be brought to bear. In particular, the B values deduced and cross-checked [*Le Sager and Svalgaard*, 2004] by this method has substantiated the approach made possible by the *IDV*-index and, as we suggested in *Svalgaard and Cliver* [2005] and have substantiated here, the negative component of the D_{st}-index. We conclude that the long-term variation of heliospheric B is firmly constrained [to better than 10%] and that current values at the solar minimum between cycles 23 and 24 are back to where they were 108 years ago at the solar minimum between cycles 13 and 14.

The lack of support from the various robust geomagnetic-based reconstructions of B for the cosmic-ray-based reconstruction of *McCracken* [2007] needs to be resolved. It is possible that the differences arise because geomagnetic measurements are made in the ecliptic plane while ^{10}Be isotope production depends on cosmic ray modulation, a heliospheric phenomenon. As a counter-argument, however, a reasonable correlation exists between the cosmic ray intensity and the HMF strength measured in the ecliptic at 1 AU [*Cane et al.*, 1999]. Differences between V values deduced (geomagnetic activity yields essentially BV^2) from the McCracken B series before ~1950 and those obtained by other investigators (*Rouillard et al.*, 2007; *Svalgaard and Cliver*, 2007b) are even more egregious than those seen for B in Figure 9. We note that other reconstructions of B based on the ^{10}Be and ^{14}C isotopes [*Caballero-Lopez et al.*, 2004; *Muscheler et al.*, 2007] more closely match the time series obtained by *Svalgaard and Cliver* [2005], *Rouillard et al.* [2007], and *Lockwood et al.* [2009] (see Figure 2 in *Svalgaard and Cliver*, 2007a).

Acknowledgements

Geomagnetic data has been downloaded from the World Data Centers for Geomagnetism in Kyoto, Japan, and Copenhagen, Denmark [now defunct], and from INTERMAGNET at http://www.intermagnet.org/Data_e.html. The research results presented in this paper rely on the data collected at magnetic observatories worldwide, and we thank the national institutions that support them. We also recognize the role of the INTERMAGNET program in promoting high standards of magnetic observatory practice. We thank the many people worldwide who have helped us with collection of data and metadata. We also thank Vladimir Papitashvili for the program to calculate corrected geomagnetic coordinates using the GUFM1 coefficients (courtesy of Catherine Constable). The OMNI dataset was downloaded from http://omniweb.gsfc.nasa.gov/.

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Captions

Figure 1. Adopted divisors (blue circles) to normalize *IDV* to the NGK-scale as a function of average corrected geomagnetic latitude for each station over the time of operation. The variation of the divisor with time is shown by different symbols (Year 1800, pink plus; 1900, orange triangles; 2000, red diamonds).

Figure 2. *IDV* calculated without any normalization or adjustments for the long-running German series (Potsdam POT–Seddin SED–Niemegk NGK; reddish curves) and the long-running French series (Parc Saint-Maur PSM–Val Joyeux VLJ–Chambon-la-Forêt CLF; greenish curves). Vertical lines show when the replacement stations went into operation and the ovals show when the yearbook values changed from being instantaneous hourly spot values to hourly means. There are no clear indications of changes in *IDV* due to the change in recording/reporting practice.

Figure 3. *IDV* calculated without using the *u*-measure (pink squares); ten times the *u*-measure, i.e., now in units of nT, as given by *Joos et al.* [1952] (blue diamonds); and the *u*-measure calculated from the summed Colaba H-ranges [*Moos*, 1910; *Bartels*, 1932] (purple open circles). The coefficient of determination R^2 = 0.88 is for the linear correlation between *u* and *IDV*.

Figure 4. Yearly *IDV*-indices derived for individual stations (as given in Table 1) shown as grey curves. The red curve is a composite index calculated as the mean of the median and average values of the individual station values. This procedure may be justified by the very small difference between medians and averages (0.16 nT on average, see Figure 5). The number, *N*, of contributing stations is shown by the thin blue curve. The *u*-

measure is considered a single station. A few station values differing more than five standard deviations from the average for a given year were omitted in calculating the average for that year.

Figure 5. Average yearly values of IDV09 (dark blue curve) compared with median yearly values (light blue curve) and compared with published IDV05 (red curve).

Figure 6. Yearly average values of *IDV* and of D_{st} when it was less than zero (based on D_{st} from Kyoto WDC and on D_{st} from *Love* [2006] scaled to Kyoto levels). The 'spike' in 1909 is due to the extremely strong storm on 25 September 1909 causing loss of data at all but one station (API), giving that one data point undue influence. To guard against the influence of such sporadic extreme values, the daily values of *IDV* were capped at 75 nT.

Figure 7. Yearly average values of the HMF *B* inferred from the *IDV*-index (blue curve) compared with in situ measurements (red curve). There is a hint of the ~100 year Gleissberg cycle.

Figure 8. Comparison of HMF *B* determined from *IDV* [blue curve], by *Lockwood et al.* [2009, green curve], and observed by spacecraft [red curve].

Figure 9. Comparison between HMF *B* derived by *Svalgaard and Cliver* [2005] (light blue curve and open circles), this paper (dark blue curve and open circles) and HMF *B* derived by *Lockwood et al.* [1999] (orange curve and plus-symbols), *Rouillard et al.* [2007; the point for 1901 is in error, A. Rouillard, Personal comm. 2007] (pink curve and plus symbols), and *Lockwood et al.* [2009] (red curve and plus-symbols), matched to *in situ* observations of *B* (black dots).

Figure 10. Yearly averages of near-Earth HMF *B* inferred by *Svalgaard and Cliver* [this paper] (blue curve $B_{S\&C}$), by *Lockwood et al.* [2009] (green curve $B_{LR\&F}$), observed by spacecraft (red curve B_{OBS}) compared to *B* inferred by *McCracken* [2007] (purple curve B_{McC}). The large arrow marks the beginning of the neutron monitor-based part of the record. One might speculate that the extremely low values during 1883-1895 are caused by the explosion of Krakatoa ejecting sulfur-rich aerosols into the stratosphere influencing the deposition of ^{10}Be.

Table 1. Stations used for IDV09, including replacement stations due to relocation of original stations. The Corrected Geomagnetic Latitude for the year 2000 is given for illustration, but the centroid of the latitudes for the time of operation was used to estimate the Normalization Constants. Constants in *italics* were determined by an empirical fit to time-overlapping stations. For a few observatories (marked with an asterisk) weakly non-linear relationships have been used to normalize directly to NGK.

Table 2. IDV09: The *IDV*-index for each year since 1835. The year 2009 is only partial as not enough data since August is available for processing. The HMF strength *B* at the Earth is derived from *IDV* as per section 2.2. The field observed in situ [OMNI dataset] is given for comparison. A few years had very incomplete data coverage and missing data were derived by linear interpolation across data gaps to avoid uneven coverage skewing the average. Those values are in *italics*.

Tables

Stations (IAGA Abbrev.)	Geodetic Latitude	Geodetic Longitude	Corrected Geomagnetic Latitude 2000	Divisor
HLS*	60.2	25.0	*56.5*	*1.00*
BOX	58.0	39.0	*53.9*	1.10
ESK*	55.3	356.8	*52.9*	*1.00*
SVD,ARS	56.4	58.6	*52.1*	1.10
RSV,BFE	55.6	11.7	*52.1*	1.10
MOS	55.5	37.3	*51.3*	1.10
NVS	55.0	82.9	50.5	0.97
WLH,WNG	53.7	9.1	50.1	0.97
MNK	54.1	26.5	49.9	0.98
CLH,FRD	38.2	282.6	49.7	0.97
BOU	40.1	254.8	49.2	0.99
BAL	38.8	264.8	49.0	0.99
DBN,WIT	52.1	5.2	48.4	0.98
10u	52.4	13.1	48.3	1.00
POT,SED,NGK	52.1	12.7	48.0	1.00
ABN,HAD	51.0	355.5	47.8	0.99
BEL	51.8	20.8	47.5	1.01
IRT	52.2	104.5	47.0	1.02
TKT	41.3	69.6	46.5	1.08
PET	53.1	158.6	46.3	1.02
DOU	50.1	4.6	46.0	1.02
LVV	49.9	23.8	45.3	1.04
PSM,VLJ,CLF	48.0	2.3	43.6	1.04

FUR	48.2	11.3	43.4	1.05
HRB	47.9	18.2	43.0	1.06
THY	46.9	17.9	41.8	1.08
YSS	47.0	142.7	39.9	1.10
TUC	32.3	249.2	39.9	1.10
AAA	43.3	76.9	38.4	1.12
TFS	42.1	44.7	37.2	1.14
MMB	43.9	144.2	36.7	1.13
AQU	42.4	13.3	36.3	1.13
BJI,BMT	40.3	116.2	34.2	1.16
SFS,EBR	40.8	0.5	34.2	1.14
COI	40.2	351.6	34.1	1.15
LNP,LZH	36.1	103.9	30.1	1.20
VQS,SJG	18.4	293.9	29.2	1.20
KAK	36.2	140.2	28.9	1.20
KNZ	35.3	140.0	27.9	1.21
HTY	33.1	139.8	25.7	1.23
SSH	31.1	121.2	24.4	1.24
KNY	31.4	130.9	24.3	1.24
HON	21.3	202.0	21.7	1.26
GUI	28.3	343.6	15.7	1.29
PHU	21.0	106.0	13.7	1.30
API	13.8	188.2	12.8	1.30
ABG	18.6	72.9	11.8	1.31
KOU	5.1	307.4	10.8	1.30
MBO	14.4	343.0	3.2	1.31
ANN	11.4	79.7	3.1	1.32
TAM	22.8	5.5	3.1	1.32

HUA	-12.1	284.7	2.1	1.32
GUA	13.6	144.9	1.0	1.32
TRD	8.5	77.0	0.4	1.32
AAE	9.0	38.8	-1.3	1.32
BNG	4.4	18.6	-2.2	1.32
ASC	-7.5	345.6	-7.9	1.32
BTV	-6.2	106.8	-15.8	1.29
PPT	-17.6	210.4	-16.4	1.29
VSS	-22.4	316.4	-16.5	1.30
PIL	-31.7	296.1	-18.6	1.28
TAN	-18.9	47.6	-29.1	1.20
TSU	-19.2	17.7	-30.0	1.20
HBK	-22.9	27.7	-33.6	1.17
CTO,HER	-34.4	19.2	-42.3	1.09
WAT,GNA	-31.8	116.0	-44.4	1.05
TOO,CNB	-35.3	149.4	-45.8	1.04
TRW	-43.3	19.0	-47.8	1.02
AMS*	-37.8	77.6	-49.1	1.00
AIA	-65.2	295.7	-49.8	*1.20*
AML,EYR	-43.4	172.4	-50.3	0.97
CZT	-46.4	51.9	*-53.1*	1.10

Table 1

Year	IDV09	IDV HMF *B*	Obs HMF *B*
1835.5	11.60	7.24	
1836.5	16.30	9.24	
1837.5	16.00	9.11	
1838.5	16.80	9.44	
1839.5	14.00	8.27	
1840.5	12.20	7.50	
1841.5	10.10	6.57	
1842.5	9.00	6.08	
1843.5	8.90	6.03	
1844.5	8.50	5.85	
1845.5	9.50	6.30	
1846.5	10.60	6.80	
1847.5	11.40	7.15	
1848.5	12.87	7.79	
1849.5	11.89	7.36	
1850.5	9.39	6.26	
1851.5	9.35	6.24	
1852.5	7.35	5.32	
1853.5	8.56	5.88	
1854.5	6.59	4.96	
1855.5	6.03	4.68	
1856.5	7.73	5.49	
1857.5	8.56	5.88	
1858.5	11.51	7.20	
1859.5	15.29	8.81	
1860.5	14.23	8.37	
1861.5	12.91	7.80	
1862.5	11.28	7.10	
1863.5	9.73	6.41	
1864.5	8.48	5.84	
1865.5	7.88	5.56	
1866.5	7.50	5.39	
1867.5	7.18	5.24	
1868.5	8.96	6.06	
1869.5	12.27	7.53	
1870.5	17.39	9.68	
1871.5	15.90	9.07	
1872.5	15.12	8.74	
1873.5	11.84	7.34	
1874.5	9.16	6.15	
1875.5	7.54	5.41	
1876.5	7.76	5.51	
1877.5	7.27	5.28	
1878.5	6.64	4.98	
1879.5	6.54	4.93	
1880.5	8.42	5.81	
1881.5	9.58	6.34	
1882.5	11.35	7.13	
1883.5	10.67	6.83	
1884.5	9.51	6.31	

1885.5	9.79	6.44	1913.5	5.05	4.20
1886.5	9.09	6.12	1914.5	5.90	4.62
1887.5	7.60	5.43	1915.5	7.89	5.57
1888.5	6.97	5.13	1916.5	9.01	6.08
1889.5	6.95	5.13	1917.5	10.85	6.91
1890.5	6.69	5.00	1918.5	10.74	6.86
1891.5	8.58	5.88	1919.5	11.29	7.10
1892.5	13.81	8.19	1920.5	10.23	6.63
1893.5	10.46	6.73	1921.5	8.79	5.98
1894.5	12.81	7.76	1922.5	7.55	5.41
1895.5	9.83	6.45	1923.5	6.02	4.68
1896.5	10.07	6.56	1924.5	6.76	5.04
1897.5	8.63	5.91	1925.5	7.95	5.60
1898.5	8.22	5.72	1926.5	10.66	6.82
1899.5	6.94	5.12	1927.5	9.22	6.18
1900.5	5.75	4.55	1928.5	9.58	6.34
1901.5	4.89	4.12	1929.5	9.54	6.32
1902.5	5.05	4.20	1930.5	10.14	6.59
1903.5	6.88	5.09	1931.5	7.28	5.28
1904.5	7.26	5.27	1932.5	7.20	5.25
1905.5	8.51	5.85	1933.5	6.88	5.10
1906.5	7.40	5.34	1934.5	6.81	5.06
1907.5	8.83	6.00	1935.5	7.70	5.48
1908.5	9.54	6.32	1936.5	8.76	5.97
1909.5	9.90	6.48	1937.5	12.05	7.43
1910.5	8.05	5.64	1938.5	13.83	8.20
1911.5	6.97	5.14	1939.5	12.55	7.65
1912.5	5.61	4.48	1940.5	12.47	7.61

1941.5	12.19	7.49		1969.5	9.37	6.25	6.05
1942.5	9.49	6.30		1970.5	10.13	6.59	6.35
1943.5	9.03	6.09		1971.5	8.84	6.00	6.00
1944.5	8.18	5.70		1972.5	9.49	6.30	6.38
1945.5	8.72	5.95		1973.5	9.27	6.20	6.35
1946.5	14.33	8.41		1974.5	9.13	6.14	6.63
1947.5	13.79	8.18		1975.5	8.10	5.67	5.82
1948.5	10.80	6.88		1976.5	8.71	5.94	5.45
1949.5	13.45	8.04		1977.5	8.95	6.05	5.85
1950.5	12.43	7.60		1978.5	12.31	7.54	7.08
1951.5	12.28	7.53		1979.5	11.77	7.31	7.59
1952.5	10.96	6.95		1980.5	10.50	6.75	6.98
1953.5	8.89	6.03		1981.5	13.77	8.17	7.84
1954.5	7.48	5.38		1982.5	15.24	8.79	8.81
1955.5	8.60	5.89		1983.5	11.59	7.23	*7.61*
1956.5	13.29	7.97		1984.5	10.44	6.72	*7.32*
1957.5	16.54	9.34		1985.5	9.04	6.10	5.89
1958.5	15.37	8.85		1986.5	8.79	5.98	5.74
1959.5	14.32	8.41		1987.5	8.20	5.71	6.09
1960.5	15.86	9.05		1988.5	10.21	6.62	7.30
1961.5	11.44	7.17		1989.5	16.72	9.41	8.15
1962.5	8.59	5.89		1990.5	12.83	7.77	7.29
1963.5	8.06	5.64	5.45	1991.5	15.74	9.00	9.34
1964.5	7.17	5.23	5.12	1992.5	12.85	7.78	8.25
1965.5	6.92	5.11	5.06	1993.5	10.08	6.57	6.59
1966.5	7.87	5.56	*6.00*	1994.5	9.05	6.10	6.15
1967.5	10.28	6.66	6.36	1995.5	9.07	6.11	5.72
1968.5	9.46	6.29	6.19	1996.5	6.74	5.03	5.11

1997.5	8.04	5.64	5.51	2004.5	9.35	6.23	6.53
1998.5	10.35	6.69	6.89	2005.5	9.40	6.26	6.25
1999.5	9.82	6.45	6.91	2006.5	7.22	5.25	5.03
2000.5	13.35	7.99	7.18	2007.5	5.95	4.65	4.48
2001.5	13.41	8.02	6.94	2008.5	5.25	4.30	4.23
2002.5	10.89	6.92	7.64	2009.3	5.04	4.19	4.10
2003.5	12.31	7.54	7.60				

Table 2

Figures

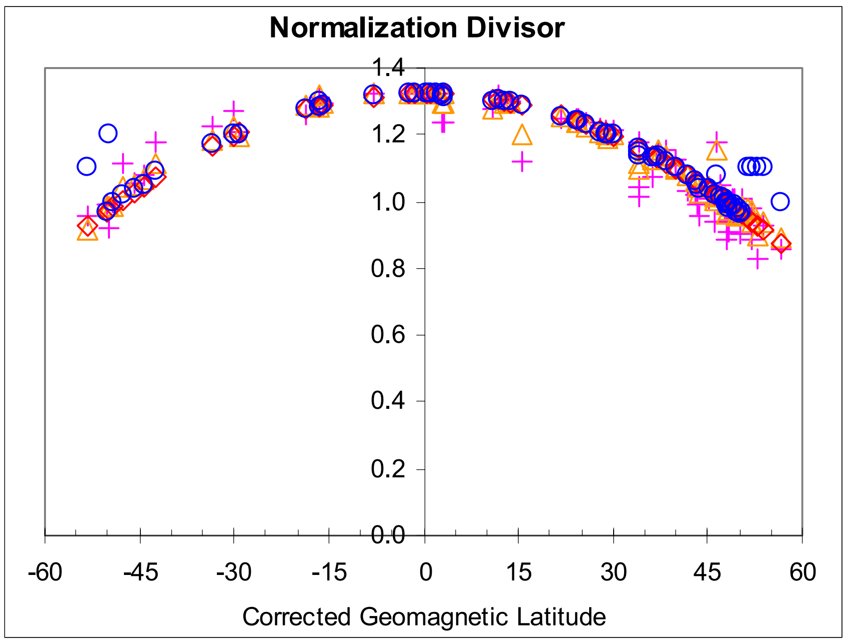

Figure 1

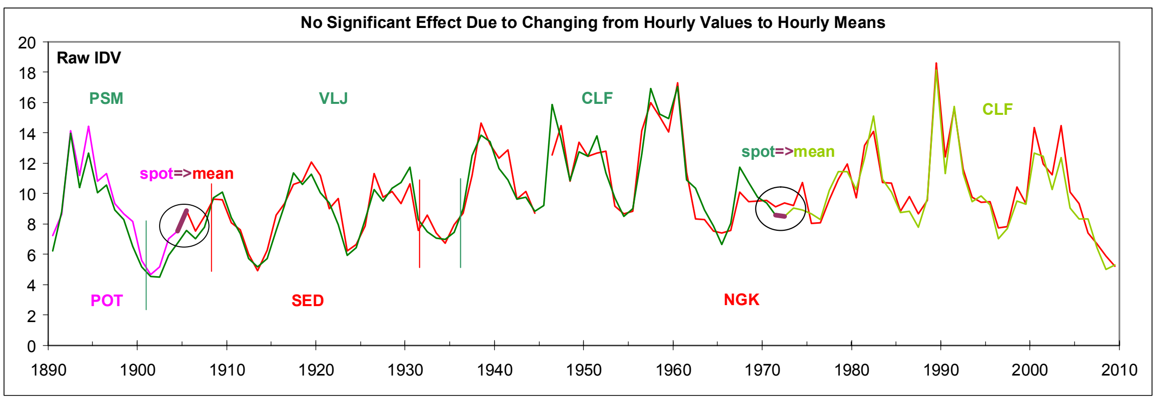
No Significant Effect Due to Changing from Hourly Values to Hourly Means
Raw IDV
PSM
VLJ
CLF
CLF
spot=>mean
spot=>mean
POT
SED
NGK
20
18
16
14
12
10
8
6
4
2
0
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Figure 2

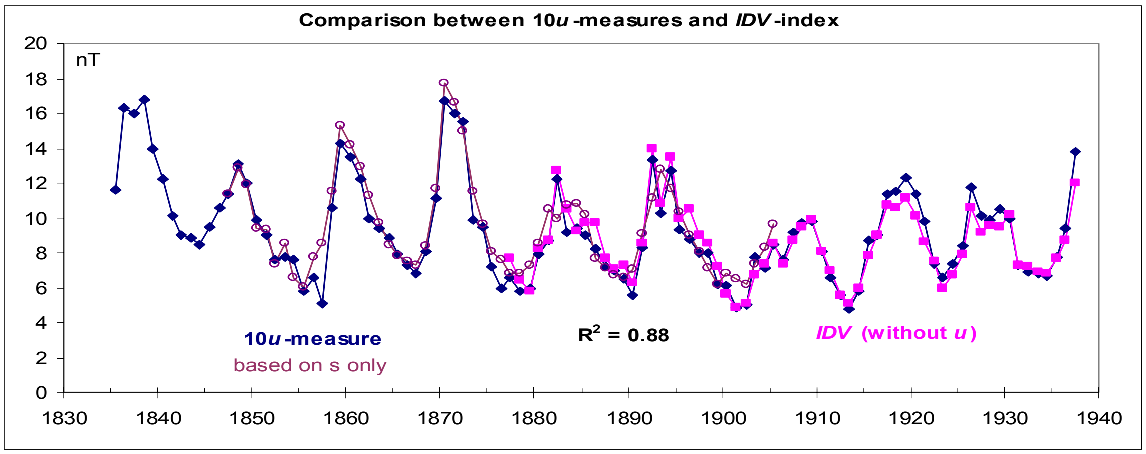
Comparison between 10u-measures and IDV-index
nT
20
18
16
14
12
10
8
6
4
2
0
10u-measure
based on s only
R^2 = 0.88
IDV (without u)
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940

Figure 3

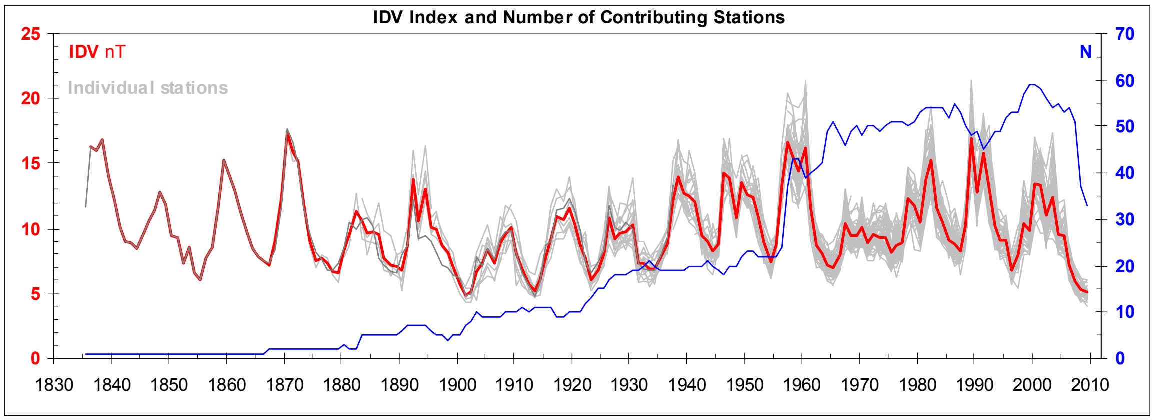
IDV Index and Number of Contributing Stations
IDV nT
Individual stations
N
25
20
15
10
5
0
70
60
50
40
30
20
10
0
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Figure 4

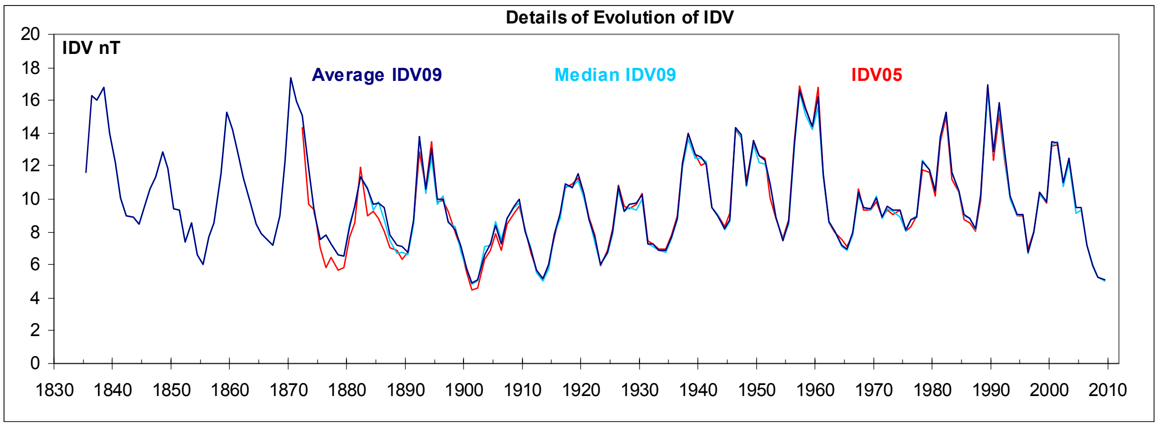
Details of Evolution of IDV
IDV nT
Average IDV09
Median IDV09
IDV05
0
2
4
6
8
10
12
14
16
18
20
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Figure 5

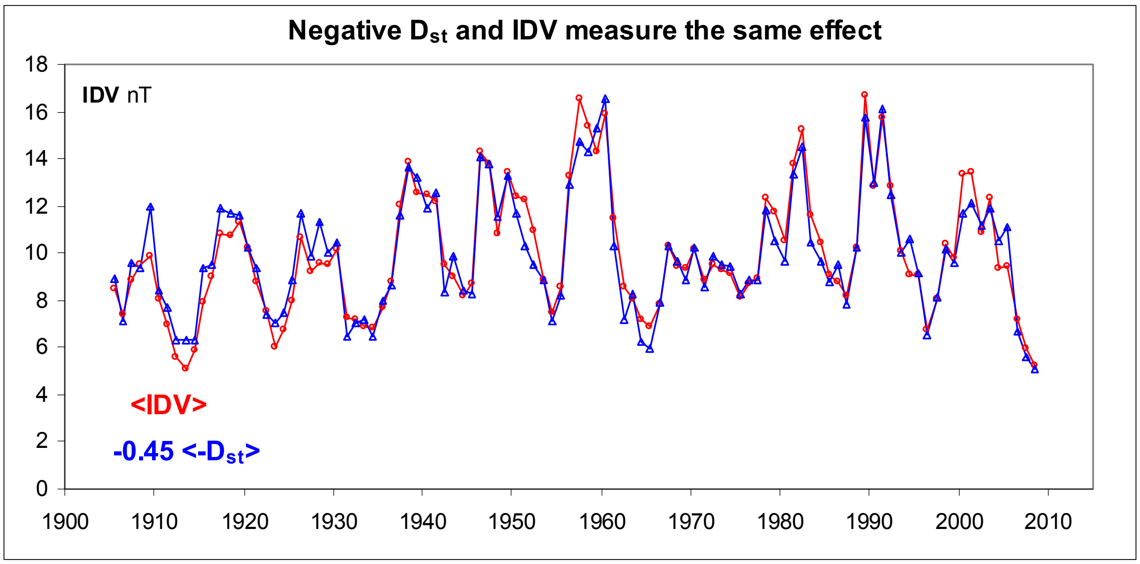
Negative D_{st} and IDV measure the same effect
IDV nT
<IDV>
-0.45 <-D_{st}>
18
16
14
12
10
8
6
4
2
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Figure 6

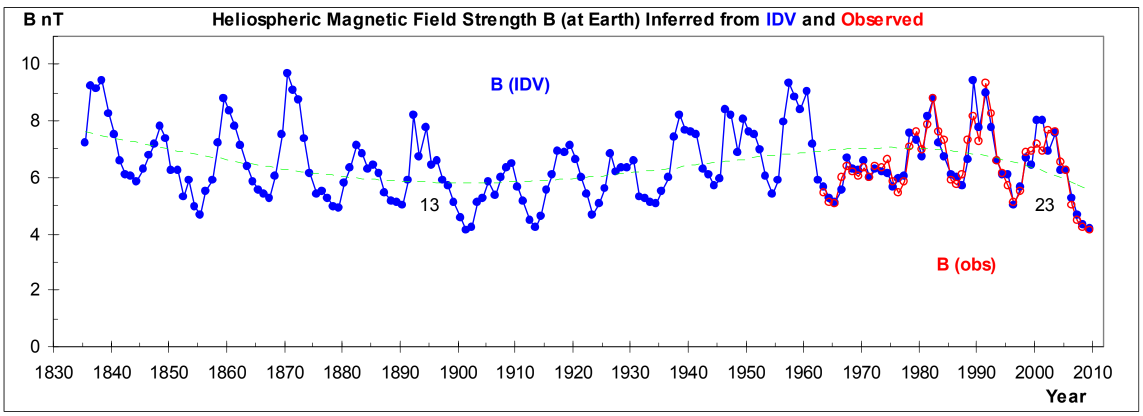
B nT
Heliospheric Magnetic Field Strength B (at Earth) Inferred from IDV and Observed
B (IDV)
B (obs)
13
23
0
2
4
6
8
10
1830 1840 1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Year

Figure 7

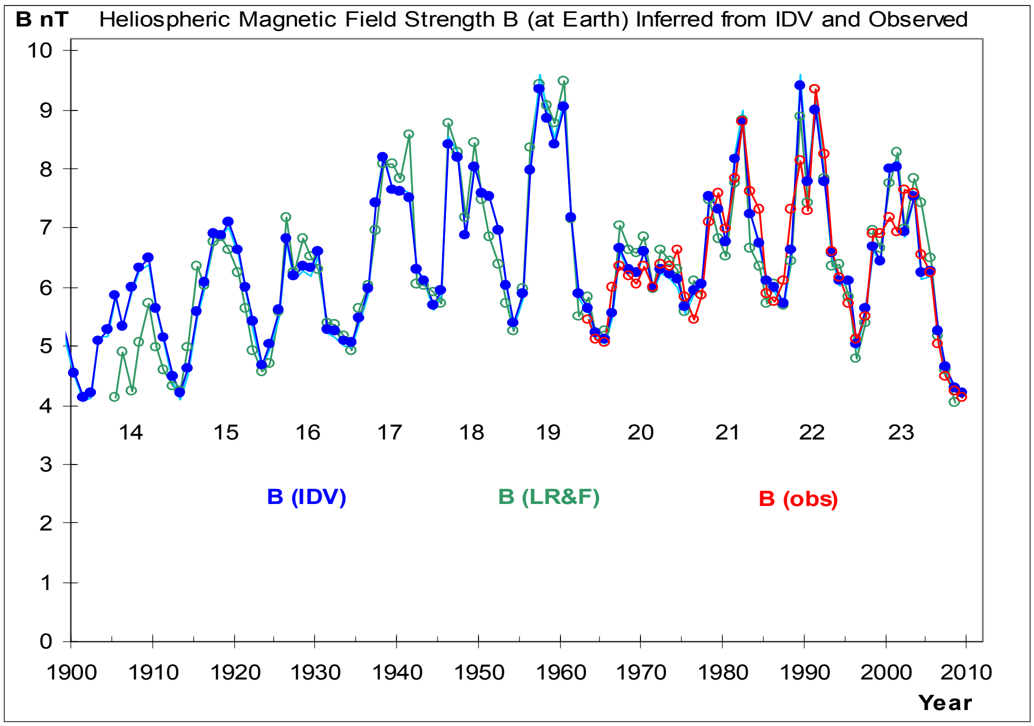
B nT
Heliospheric Magnetic Field Strength B (at Earth) Inferred from IDV and Observed
10
9
8
7
6
5
4
3
2
1
0
14
15
16
17
18
19
20
21
22
23
B (IDV)
B (LR&F)
B (obs)
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year

Figure 8

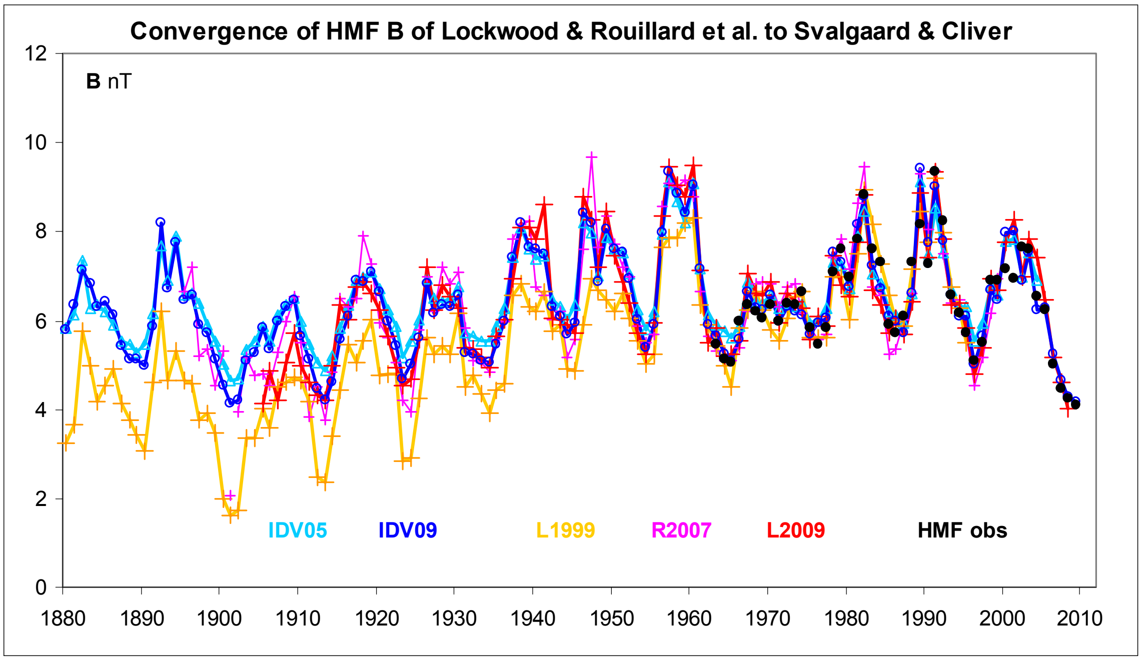
Convergence of HMF B of Lockwood & Rouillard et al. to Svalgaard & Cliver
B nT
12
10
8
6
4
2
0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
IDV05
IDV09
L1999
R2007
L2009
HMF obs

Figure 9

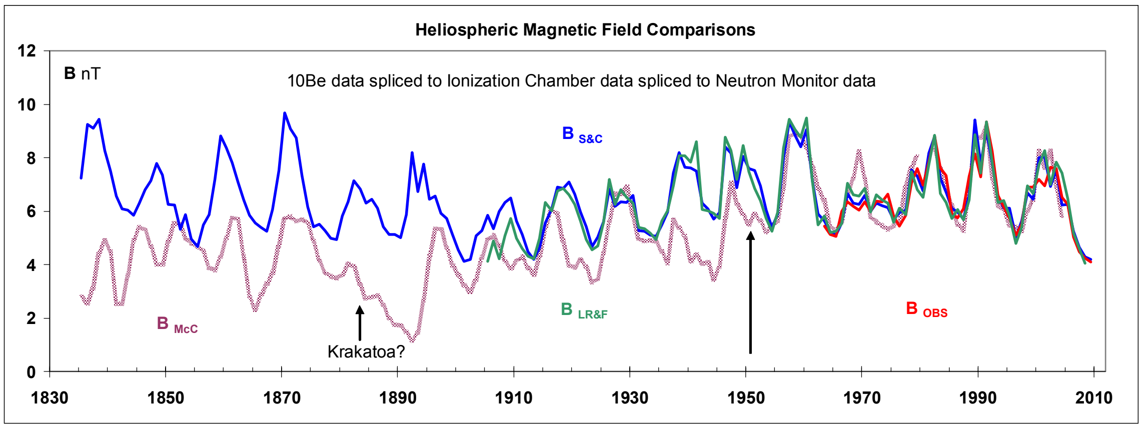
Heliospheric Magnetic Field Comparisons
B nT
10Be data spliced to Ionization Chamber data spliced to Neutron Monitor data
B S&C
B LR&F
B OBS
B McC
Krakatoa?
0
2
4
6
8
10
12
1830
1850
1870
1890
1910
1930
1950
1970
1990
2010

Figure 10