# The *IDV*-Index: a Proxy for the Interplanetary Magnetic Field Strength

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**Abstract**

Based on a consideration of Bartels' historical *u*-index of geomagnetic activity, we devise an equivalent index that we refer to as the InterDiurnal Variability (*IDV*). The *IDV*-index has the interesting and useful property of being highly correlated with the strength of the interplanetary magnetic field ($B$; $R^2 = 0.75$) and essentially unaffected by the solar wind speed ($V$; $R^2 = 0.01$). This enables us to obtain the variation of $B$ from 1872 to the present, providing an independent check on previously reported results for the evolution of this parameter. We find that average $B$ increased by ~20% from ~1900 to ~1960 and since then has been decreasing. If predictions for a small solar cycle 24 bear out, solar cycle average $B$ will return to levels of ~100 years ago during the coming cycle.

## 1. Introduction

### 1.1 Motivation

How does the solar wind vary over time scales of a century or more? The question bears on topics ranging from the nature of the solar dynamo to the effect of the Sun on climate change. Various authors [*e.g.*, *Feynman and Crooker*, 1978; *Cliver et al.*, 1998; *Lockwood et al.*, 1999] have used *Mayaud's* [1973, 1980] geomagnetic *aa* index to constrain or deduce the variation of solar wind parameters over extended intervals. In particular, *Lockwood et al.* suggested that the interplanetary magnetic field (IMF) more than doubled during the twentieth century. In the present paper, we revisit *Bartels*' long-abandoned *u*-measure and show that it can be used to obtain a check on *aa*-based studies of the long-term evolution of the solar wind. This is particularly important now that the calibration of *aa* has been called into doubt [*Svalgaard et al.*, 2004; *Lockwood et al.,* 2005].

### 1.2. The *u*-Measure and the *IDV*-Index

*Bartels* [1932] introduced the *u*-measure of geomagnetic activity as a station-weighted mean of the interdiurnal variability $U$ of the horizontal intensity ($H$) at each station, calculated as the absolute value of the difference between the mean values for a day and for the preceding day. The weight-factor took into account the dipole-latitude of the station by dividing by the cosine of the latitude. The *u*-index was computed using only low to midlatitude stations and was normalized to the German station Niemegk (IAGA-code: NGK) and its predecessor stations Seddin (SED) and Potsdam (POT). Bartels' goal in deriving the *u*-index was to establish "*a homogeneous series for all the time since consistent terrestrial-magnetic observations were begun* (italics in the original)". The basic concept of the interdiurnal variability can be traced to Moos (1910).

*Mayaud* [1980] evaluated the degree of contamination of the *u*-index by the regular daily variation $S_R$ by using only the first and the last six hours of the local day instead of all 24 hours. This elimination of the daytime hours should remove most of the effect of $S_R$. [For a 35-day solar minimum interval examined, Mayaud was "astonished" by just how small a contribution $S_R$ made to the *u*-index (~2 nT out of 7 nT).] We take Mayaud's lead, but further limit the time interval to only one hour (taken to start one hour after the UT-hour closest to local midnight), and construct the InterDiurnal Variability index (*IDV*) for a given station as the unsigned difference between two consecutive days of the average value of a field component measured in nT (usually, and in the present paper, *H*, although, in principle, we can do this for any of the components) for that hour and assigned to the first day. The individual daily values are then averaged over longer intervals, *e.g.,* one year (minimizing various geometric and seasonal effects). The *u*-measure was expressed in units of 10 nT. We have chosen to use 1 nT units for IDV.

*Van Dijk* [1935] criticized the *u*-measure because it failed to register the very high activity in 1930, resulting from extensive recurrent storms and clearly shown in the daily character-figure, the $C_i$ index [see *Feynman*, 1980]. This problem was so severe that Bartels (after some struggle [*Bartels*, 1950]) abandoned the *u*-measure and went on to invent the very successful *K*-index [*Bartels et al.*, 1939] that we use to this day. As we shall see, the lack of sensitivity of the *u*-index to recurrent activity caused by high-speed streams (also noted by *Nevanlinna* [2004]) from coronal holes [*e.g.*, *Neupert and Pizzo*, 1974; see also *Crooker and Cliver*, 1994] is an unexpected advantage of the index.

Figure 1 shows yearly averages of the *u*-measure (in 1 nT units) from 1872 through 1936 [*Joos et al.*, 1952], and of the *IDV*-index since 1890. The *IDV*-index was derived as described below. It is clear that the *IDV*-index also does not register the recurrent, high-speed solar wind streams that were so prevalent in 1930, 1952, 1974, 1994, and 2003. In fact, for the years of overlap (1890-1936) the two indices agree closely (as should be expected) with a linear cross correlation coefficient of 0.95. It is instructive to compare Figure 1 with Figure 1 of *Bellanger et al.* [2002], who investigated the spatial (and, as a by-product, the temporal) behavior of similar daily differences.

[Fig. 1]

## 2. Details of Derivation of the *IDV* Index

### 2.1. Choice of Local Time Interval

The choice of a one-hour interval was dictated by the desire of being able to derive *IDV* indices from old geomagnetic data for which discrete values may be available for only certain hours of each day. Experimentation showed that little is gained by using longer spans of night time hours. This conclusion is implicit in Figure 1 that compared the *u*-measure (based on 24 hours) and the one-hour *IDV*-index. We have chosen the interval one hour after local midnight but it does not make much difference precisely which night-hour is used. A fine point is the distinction between an hourly *mean* and an hourly (instantaneous) *value*. Early magnetometer records often consist of hourly values which, having more variance than hourly means, result in a slight (few per cent) increase of *IDV* compared to the same index derived from hourly means. We shall ignore this effect in the present study.

### 2.2. Missing Data

If either of the two values needed to calculate a daily *IDV* is missing, the *IDV*-value for that day is missing. Similarly, if more than half of the *IDV*-values needed for a long-term average are missing, the *IDV*-value for the averaging interval is not computed. The ideal way of dealing with missing data when combining or comparing several datasets is to limit the study to times where all contributing datasets have simultaneous high-resolution data. We did not do this, but assumed that the distribution of missing data was random enough to make the averages comparable. This assumption is reasonable for modern data, but is somewhat problematic with older data where recordings often go off-scale at times of large storms, resulting in an underestimation of the index.

### 2.3. Dependence on Latitude

For each of the 34 stations in Table 1 we computed yearly averages of *IDV* for 1965-2003. As noted above, if data for over half of the days for a given station/year were unavailable (a relatively rare occurrence), we did not compute an average for that station/year. For each year for each station, we formed the ratio between the yearly-averaged *IDV* for that station and for NGK. By considering ratios, we largely eliminate the effects of the placement of missing data caused by solar cycle and longer term trends in the geomagnetic records. The average of the individual yearly *IDV*-ratios for the 1965-2003 interval was determined for each station and is plotted in Figure 2 as a function of corrected geomagnetic latitude (CGML) which organizes the data better than does the dipole latitude.

[Table 1]
[Fig. 2]

*IDV* is smallest at |CGML| = 45º, increases slightly towards low latitudes, and increases dramatically above |CGML| of ~ 50º. At higher latitudes, the magnetic effects of the auroral electrojets begin to overwhelm the effect due to the ring-current, which is the physical quantity measured primarily by *IDV*. We therefore only included stations with |CGML| less than 51º (see below for the reasoning behind this precise choice). This requirement reduces the number of stations used to 22. Empirically, the dependence on latitude for a given Station "A" is somewhat weaker than the "theoretical" 1/cos(CGML) dependence that Bartels assumed for the *u*-measure (and used today for the *Dst* index), namely:

$$IDV\text{ (normalized to NGK)} = IDV\text{ (Station A)} / (1.324 \cos^{0.7}(\text{CGML(Station A)})) \quad (1)$$

Physically, it would have made more sense to normalize to the equator, but we retain the historical choice of NGK [in any event, there is just a constant factor involved: 1.324 = $1/\cos^{0.7}$(CGML (NGK))].

## 2.4. Averaging over Stations

The final step is to (arithmetically) average the normalized *IDV*-values over all stations with CGML between 51º North and 51º South. These boundaries were chosen to include the stations WNG and FRD (important because of their long series of observations). Figure 3 shows the result for 1965-2003, as well as the run of values for each individual station to allow assessment of the standard deviation (average 0.9 nT or 9%). The average standard error of the mean of the 22 stations is 0.2 nT.

[Fig. 3]

## 3. Correlation with Interplanetary Magnetic Field Strength

Figure 4 contains scatter plots of yearly averages of solar wind magnetic field strength (*B*) and speed (*V*) vs. annual IDV indices for 1965-2003. Although the *IDV* index seems to be "blind" to *V*, there is a robust correlation with *B*.

[Fig.4]

The interplanetary data was obtained as hourly values from the OMNI-2 dataset [*King and Papitashvili* (2005); http://nssdc.gsfc.nasa.gov/omniweb/ow.html]. Because significant amounts of interplanetary data are missing for certain years, we adopted the following procedure to deal with missing data: the (UT) daily mean was calculated from available hourly data (even if only one); the 27-day Bartels rotation mean was calculated from available daily means (even if only one); if there was no data for a rotation, its mean was linearly interpolated from surrounding rotations. The average for a year was then calculated from the Bartels rotations spanned by the year. Table 3 contains these averages.

The linear regression fit ($R^2$ = 0.74) for yearly averages of *B* is

$$B\text{ (nT)} = (3.04\pm0.37) + (0.361\pm0.035)\ IDV \quad (2)$$

The linear fit has an offset that limits *B* from below to ~ 3 nT for *IDV* = 0. The equally good power-law fit has *B* going to zero with *IDV*. We do not have values of *IDV* low enough to decide among the two cases. As always, it is problematic to extrapolate regression fits beyond their input data range. We opt in the present analysis for the simple linear fit and reconstruct $B$ from $IDV$ using (2) as shown in the lower panel of Figure 4. The average reconstruction error is about 5%. The reconstruction appears good enough to permit a reconstruction of $B$ for times before the availability of *in situ* interplanetary measurements. Thus the $IDV$-index may be considered to be a proxy for the interplanetary magnetic field strength under the usual assumption that the response of the Earth's magnetosphere to solar storms has remained the same over time (at least over the last few centuries).

## 4. Average *IDV*-Index since 1890 (and 1872)

The World Data Centers archive machine-readable hourly means (or values) of the geomagnetic elements for several stations back in time. Fewer and fewer stations have data available as we go to earlier and earlier years. Before 1901, only a single station (POT) has data readily available (back to 1890). Using the stations given in Table 2, we compute yearly values of the $IDV$-index with the result shown in Figure 5. This directly derived $IDV$-series starts in 1890. Because of the very high correlation ($R^2 = 0.908$) with the $u$-measure (the $IDV$-index is really nothing more than a revived $u$-measure), we can with some confidence extend the series back to 1872 (as shown in Figure 1) by setting $IDV = 10u$. The $u$-measure is available back to 1836, but values before 1872 are unreliable as they were derived from monthly or yearly values, rather than from daily values [*Mayaud*, 1980].

[Table 2]
[Fig. 5]

## 5. Comparison with $D_{st}$ (and $D_{xt}$)

As we would expect, (yearly averages of) the $IDV$-index and the $D_{st}$ index [*Sigiura*, 1964; *Karinen and Mursula*, 2005, and references therein] are moderately correlated ($R^2 = 0.65$ for the years 1957-2002). The fact, that positive and negative values of $D_{st}$ are due to different physical processes (controlled roughly by solar wind pressure and magnetic reconnection, respectively) makes a simple yearly average of $D_{st}$ a somewhat suspect physical quantity. If we include only negative values of $D_{st}$ in the average, the correlation improves markedly to $R^2 = 0.89$. We conclude that the same physical processes are responsible for the correlation between $B$ and both the $IDV$- and $D_{st}$-indices. *Karinen and Mursula* [2005] have reconstructed $D_{st}$ back to 1932. Their reconstruction, called $D_{xt}$, corrects several errors (*e.g.,* in 1971) and inhomogeneities in the index. The regression equation $IDV_{xt} = 1.142 + 0.4078\ |D_{xt}{<}0|$ ($R^2 = 0.89$ for negative values only over 1957-2002) can be used to calculate IDV from $D_{xt}$ using only negative values of $D_{xt}$. Figure 6 shows the result.

[Fig. 6]

## 6. Inferred Interplanetary Magnetic Field Strength since 1872

Using the regression equation (2) we can convert the yearly averages of the *IDV*-index to inferred interplanetary *B*. The result is shown in Table 3 and in Figure 7.

[Table 3]
[Fig. 7]

It has been suggested that the coming solar cycle 24 will be a small cycle (possibly the smallest in a 100 years [peak sunspot number (SSN) = 75; *Svalgaard et al.*, 2005 and references therein]). If so, we might speculatively plot the field strength inferred for cycle 14 as a guess of what the field might be during cycle 24 (shown as a purple curve on Figure 7). This places the long-term trend in perspective. Over the 150 years covered there is no discernible linear, secular trend ($R^2 = 0.01$). A $4^{th}$-order polynomial fit to the variation of *B* over the period suggests evidence of a ~100-year wave (±10%), so often seen in solar activity and proxies thereof (*Gleissberg*, 1939). In addition, there is a strong ~11-year modulation of *B*, generally following the sunspot number. That *IDV* at sunspot minima also shows the ~100-year modulation is a simple consequence of the fact that larger (and often, shorter) cycles have significant overlap during minima so clearly evidenced in the sunspot Butterfly Diagram.

## 7. Correlation between *B* and Sunspot Number (SSN)

Although it came as a surprise that there was no clear solar cycle dependence of IMF *B* during the first decade of spacecraft measurements [*King,* 1976], data from later cycles do show a strong solar cycle relationship. Having 13 cycles worth of *B* (inferred and observed) permits a study of this relationship with much improved statistics. 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 $SSN^{1/2}$ [for a detailed discussion, see *Wang and Sheeley*, 2003]. We find, indeed, that there is a linear relation between *B* and the square root of the SSN as shown in Figure 8.

[Fig. 8]

The best-fit ($R^2 = 0.71$) regression equation is

$$B\ (\text{nT}) = (4.62 \pm 0.16) + (0.273 \pm 0.015)\, R_z^{1/2} \qquad (3)$$

Where $R_z$ is the Zürich (International) Sunspot Number. Using the Group Sunspot Number gives essential the same result. Using eq.(3) we can then calculate *B* from $R_z$ for comparison with *B* derived from the geomagnetic record (Table 3). The result is shown in Figure 9. Although there are areas of minor disagreement (e.g. for cycle 20, possibly due to ecliptic-only sampling of a global solar property), the overall fit is encouraging. As will be explored elsewhere, eq.(3) permits the possibility of estimating *B* back to the beginning of the sunspot time series.

[Fig. 9]

## 8. Conclusion

It is pleasing that the *u*-measure introduced by *Bartels* nearly 75 years ago as a long-term measure of geomagnetic activity is capable, in the light of modern knowledge, of providing insight on the variability of the solar wind for periods preceding the space age. The equivalent *IDV*-index that we have derived indicates that the IMF *B* seems to be the sum of a fixed amount and a component that varies with the square root of the sunspot number. We find that average *B* increased by ~20% between 1900 and 1960 and declined thereafter. This behavior stands in contrast to the more than doubling of *B* during the 20$^{th}$ century suggested by the analysis of the *aa*-index by *Lockwood et al.* [1999]. If the coming cycle 24 is as small as predicted (peak SSN = 75; *Svalgaard et al.*, 2005), the long-term average of *B* should be approaching its value circa 1900 of ~ 6 nT by ~2015. The *IDV* and *B* variation we obtain during the 20$^{th}$ century are consistent with the results of *Le Sager and Svalgaard* [2004] who found that there was no increase of the interplanetary near-earth electric field since 1926. In contrast to the *IDV* index, mid-latitude range indices such as *aa* are dependent on both solar wind speed (squared) and IMF, enabling one to determine *V* once *B* is known. Investigation of the evolution of *V* over time will be the subject of a future report.

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**Captions**

Table 1. Observatories (Stations) use for normalization of *IDV*. Geographic latitude, geomagnetic latitude (epoch 1985) and corrected geomagnetic latitude (CGML epoch 1985) as shown are used. The average ratios (over 1965-2003) of yearly average *IDV* for each station to that of NGK as shown are used in Figure 2.

Table 2. Observatories with long series of data (as covered by available hourly means from the WDCs) used for Figure 5. More data exists (even for these stations), but is not yet available in digital form.

Table 3. Yearly averages of *IDV* (10*u* before 1890) and the inferred near-earth interplanetary magnetic feld strength calculated using eq. (2). The IMF *B* as observed by spacecraft is given for comparison.

Figure 1. 10 times the *u*-measure (blue curve) for 1872-1936 compared to the *IDV*-index (red curve, derived as described in the text) for 1890-2004). For the time of overlap, the linear cross correlation coefficient is 0.95. Yearly averages of both indices are plotted.

Figure 2. (Upper panel) Mean ratios between yearly average *IDV* for the 34 observatories listed in Table 1 and yearly average *IDV* for NGK over the interval 1965-2003 as a function of corrected geomagnetic latitude (CGML). (Lower panel) Expanded lower part of the above panel. Filled circles show the observed ratios. The dashed-line curve is the function cos(CGML) normalized to go through the datapoint for NGK (*IDV* ratio = 1.0000 at CGML = 47.95º). A better fit to the observed ratios is the somewhat flatter function $\cos^{0.7}$(CGML) also normalized to go through NGK and shown by the full-line curve. The squares show the result of dividing the ratios by the better fit: (*IDV* ratio) / $\cos^{0.7}$(CGML). For a useful normalization these points should cluster on a horizontal line at an ordinate value of 1.0.

Figure 3. Yearly averages of normalized *IDV* for the stations with |CGML| < 51º for the interval 1965-2003 (thin blue lines). The (arithmetic) average over all stations is shown

by the heavy red line. A (hard to see) thin pink line shows the run of the median value for each year. It does not make a significant difference which of the two means is chosen.

Figure 4. (Upper panel) Scatterplots of yearly average *IDV* and the strength of the total interplanetary magnetic field, *B* (open blue circles), and the solar wind speed, *V* (red crosses) for each year of the interval 1965-2003. There is no correlation (square of linear cross correlation $R^2$ effectively zero) beween *IDV* and *V*. There *is* a robust correlation ($R^2 \approx 0.75$) between *IDV* and *B*. There is no significant difference between a simple linear fit (blue regression line) and a power-law fit (green curve) within the range of the data. (Lower panel) Comparison between observed yearly averages of *B* (red curve) and reconstructed values of *B* (blue curve) using eq.(2). The thin green curve shows the observed solar wind speed in units of 100 km/s.

Figure 5. Combined *IDV*-index (yearly averages) for the stations given in Table 2. The run of *IDV* for individual stations are shown as thin blue lines. The average *IDV*-index for each year over all stations with data is shown as a heavy red line. Before 1901, only one station (POT) has data available from the WDCs. The average standard deviation is 0.7 nT.

Figure 6. Yearly means of the *IDV*-index (blue line) compared to $IDV_{xt}$ computed from negative $D_{xt}$ only using the regression equation given in section 5.

Figure 7. Inferred (reconstructed) near-earth interplanetary magnetic field strength, *B* since 1872 (blue curve). Before 1890, *B* is calculated using the *u*-measure. After 1890, *B* is calculated from *IDV* using eq.(2). The observed field strength is shown by the red curve. The purple curve shows a guess of what *B* might be during the coming solar cycle 24. Thin green lines show (dashed) a negligeble linear secular trend and (full) a 4th-order polynomial fit suggesting a ~100-year wave.

Figure 8. Yearly means of *B* derived from *u* and *IDV* (blue) and observed by spacecraft (red) as a function of the square root of the Zürich (International) sunspot number. Regression line is computed from a combined dataset (*B* inferred for 1872-1964 and observed thereafter -marked with open circles).

Figure 9, Variation of yearly averages of IMF *B* inferred from geomagnetic records (blue) and from sunspot numbers (green). Observed *B* is shown in red, while *B* predicted for cycle 24 is shown in light purple.

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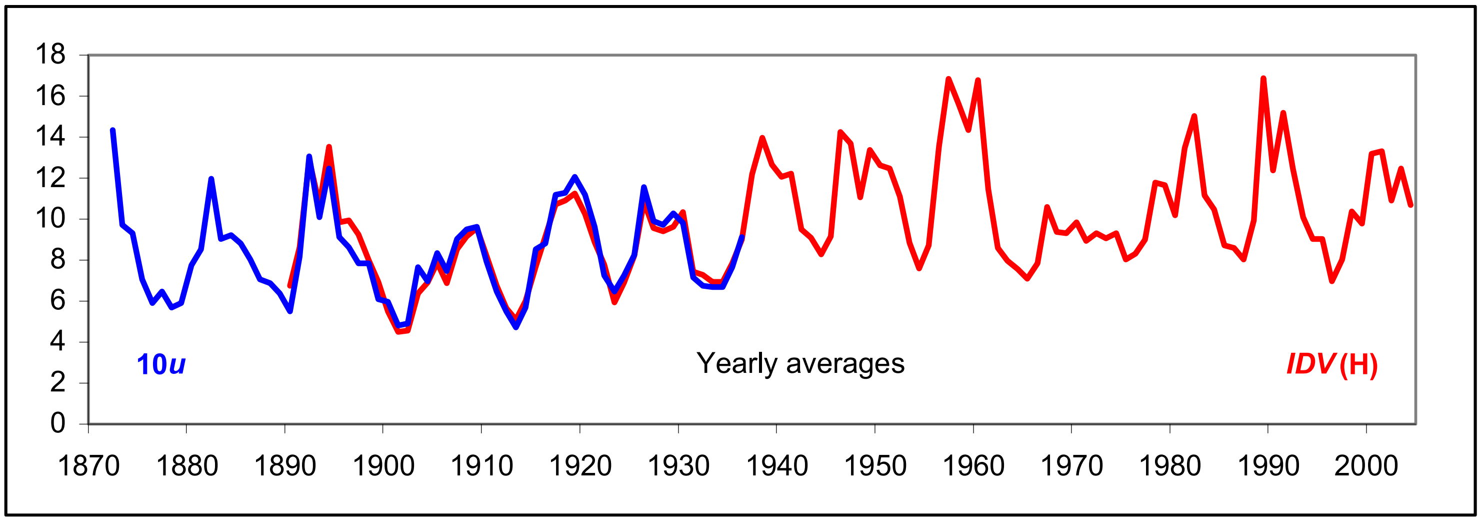
18
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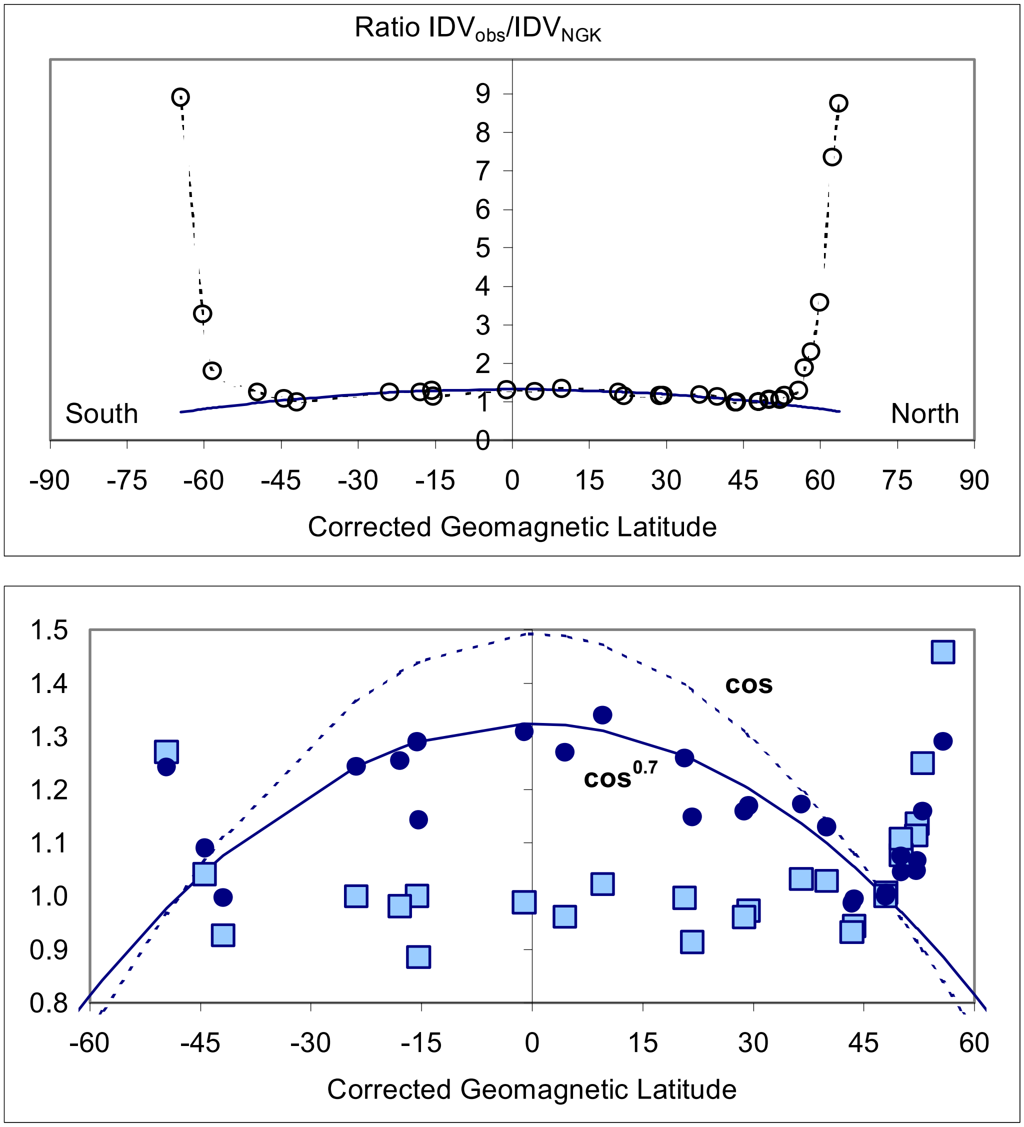
Yearly averages
IDV(H)

Figure 1.

| Observing Station | Geographic Latitude | Geomagnetic Latitude | Corrected Geomagnetic Latitude | Ratio IDV OBS/NGK 1965-2003 |
|---|---|---|---|---|
| SOD | 67.37 | 63.68 | 63.63 | 8.7422 |
| MEA | 54.62 | 61.88 | 62.40 | 7.3532 |
| SIT | 57.07 | 60.31 | 59.85 | 3.5731 |
| LER | 60.13 | 62.15 | 58.18 | 2.2992 |
| OTT | 45.40 | 56.37 | 56.96 | 1.8796 |
| LOV | 59.35 | 57.84 | 55.78 | 1.2901 |
| ESK | 55.32 | 58.04 | 53.00 | 1.1592 |
| RSV/BFE | 55.85 | 55.56 | 52.25 | 1.0668 |
| SVD/ARS | 56.73 | 48.64 | 52.12 | 1.0476 |
| WNG | 53.75 | 54.22 | 50.08 | 1.0454 |
| FRD | 38.20 | 49.13 | 50.04 | 1.0755 |
| HAD | 50.98 | 54.17 | 48.03 | 1.0054 |
| NGK | 52.07 | 51.94 | 47.95 | 1.0000 |
| CLF | 48.02 | 50.06 | 43.74 | 0.9947 |
| FUR | 48.17 | 48.48 | 43.42 | 0.9868 |
| TUC | 32.25 | 40.37 | 39.96 | 1.1301 |
| MMB | 43.90 | 34.61 | 36.54 | 1.1728 |
| SJG | 18.38 | 29.36 | 29.36 | 1.1693 |
| KAK | 36.23 | 26.62 | 28.75 | 1.1594 |
| HON | 21.32 | 21.46 | 21.74 | 1.1488 |
| MBO | 14.40 | 20.68 | 20.68 | 1.2591 |
| ABG | 18.63 | 9.64 | 9.64 | 1.3397 |
| BNG | 4.43 | 4.45 | 4.45 | 1.2697 |
| HUA | -12.05 | -1.06 | -1.06 | 1.3079 |
| VSS | -22.40 | -12.53 | -15.38 | 1.1430 |
| API | -13.80 | -15.61 | -15.61 | 1.2900 |
| PIL | -31.67 | -20.73 | -17.92 | 1.2536 |
| TAN | -18.92 | -23.85 | -23.85 | 1.2433 |
| HER | -34.42 | -33.73 | -41.94 | 0.9975 |
| GNA | -31.78 | -42.71 | -44.36 | 1.0901 |
| AIA | -65.20 | -54.20 | -49.57 | 1.2422 |
| PAF | -49.35 | -57.31 | -58.37 | 1.7935 |
| SNA | -70.30 | -64.23 | -60.20 | 3.2781 |
| MCQ | -54.50 | -60.50 | -64.51 | 8.9059 |

Table 1



Ratio IDVobs/IDVNGK
South
North
Corrected Geomagnetic Latitude
cos
cos0.7
Corrected Geomagnetic Latitude


Figure 2

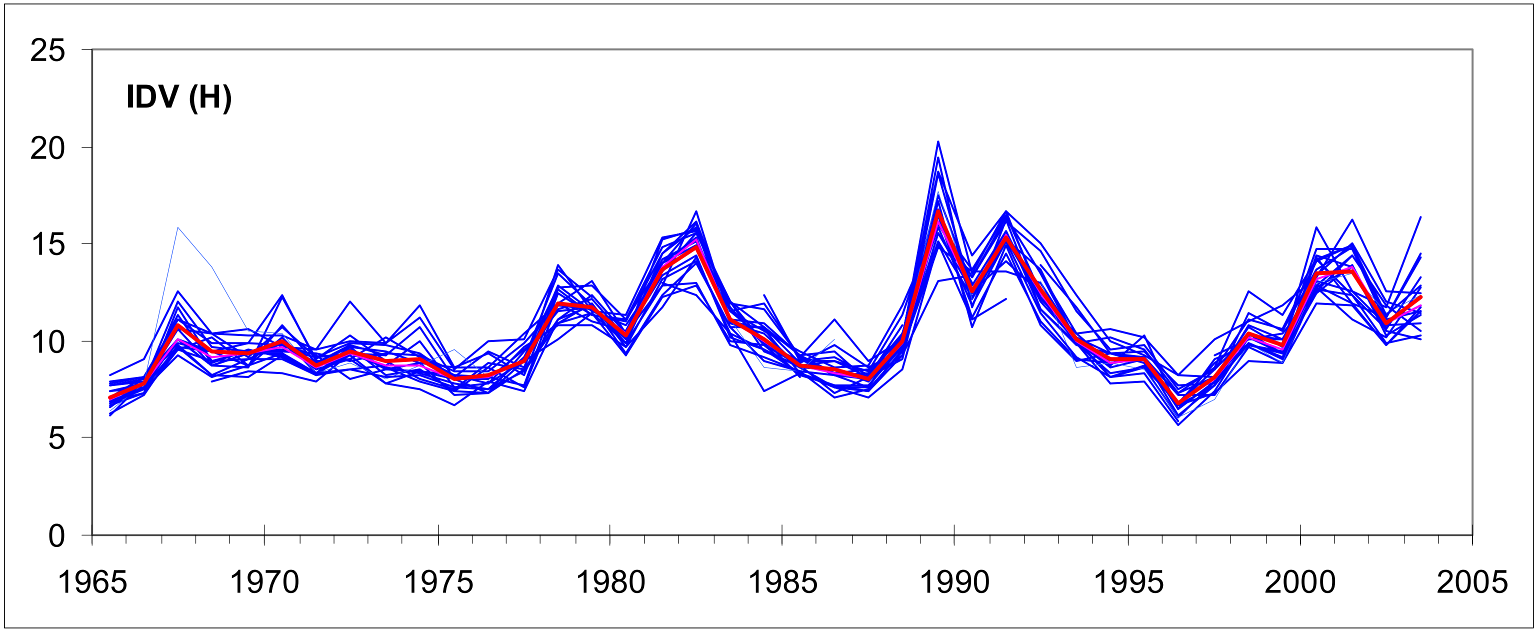
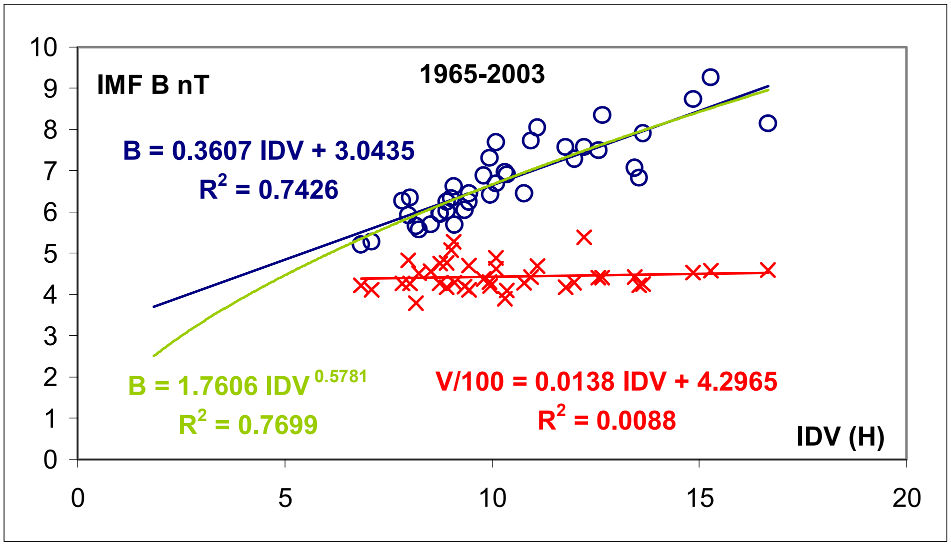

IDV (H)
25
20
15
10
5
0
1965
1970
1975
1980
1985
1990
1995
2000
2005

Figure 3


IMF B nT
1965-2003
B = 0.3607 IDV + 3.0435
R2 = 0.7426
B = 1.7606 IDV 0.5781
R2 = 0.7699
V/100 = 0.0138 IDV + 4.2965
R2 = 0.0088
IDV (H)

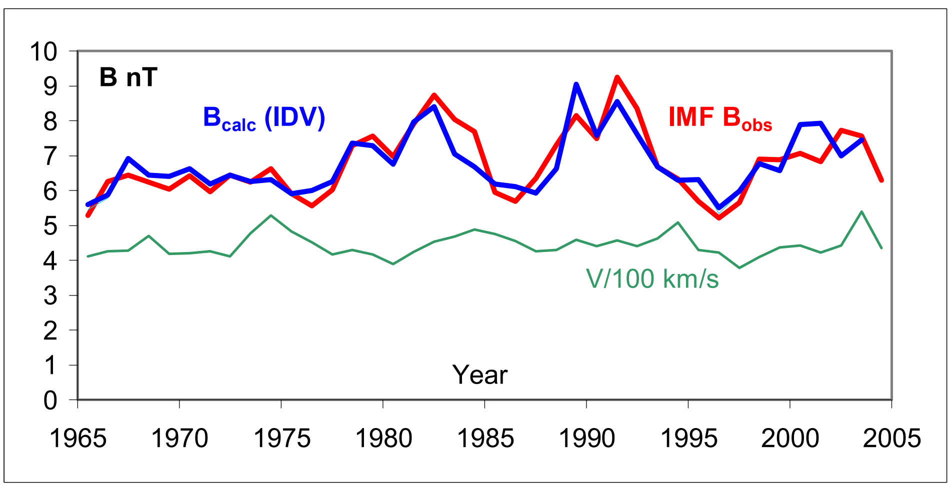

B nT
Bcalc (IDV)
IMF Bobs
V/100 km/s
Year

Figure 4

| Observatories | Coverage |
|---|---|
| POT/SED/NGK | 1890-2003 |
| CLH/FRD | 1901-2003 |
| HON | 1902-2003 |
| DBN/WIT | 1903-1984 |
| VQS/SJG | 1903-2003 |
| TUC | 1910-2003 |
| KAK | 1913-2004 |
| WAT/GNA | 1919-2003 |
| VLJ/CLF | 1923-2003 |
| ABG | 1925-2003 |
| ABN/HAD | 1926-2003 |
| CTO/HER | 1933-2003 |
| FUR | 1940-2003 |
| WNG | 1943-2003 |

Table 2

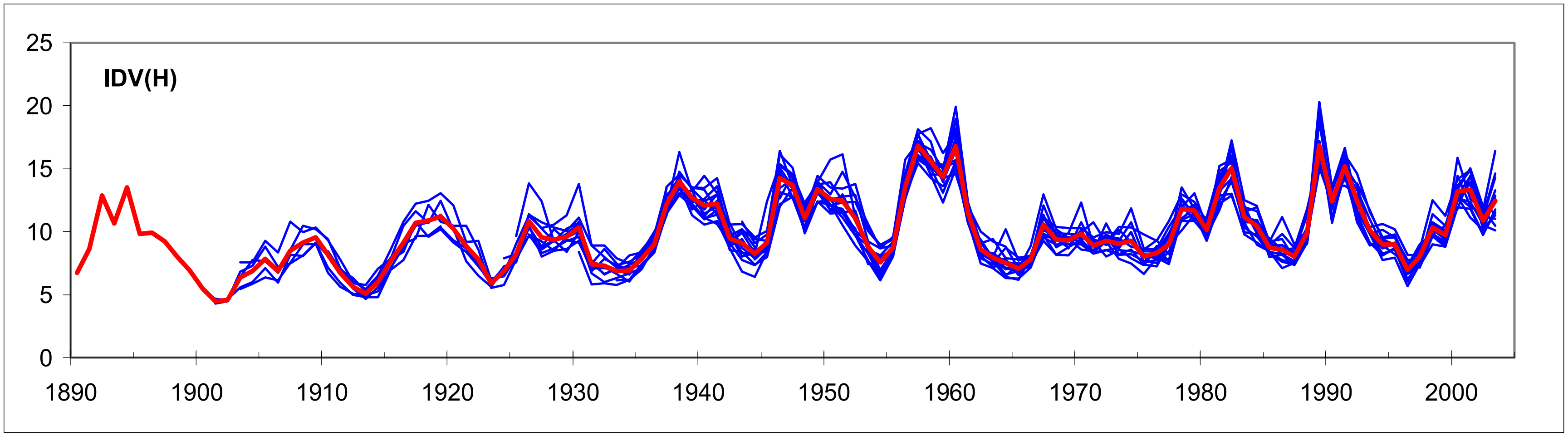

IDV(H)
25
20
15
10
5
0
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

Figure 5

| Year | <10u,IDV> | $B_{calc}$ | $B_{obs}$ |
|---|---|---|---|
| 1872.5 | 14.308 | 8.21 | |
| 1873.5 | 9.702 | 6.54 | |
| 1874.5 | 9.310 | 6.40 | |
| 1875.5 | 7.056 | 5.59 | |
| 1876.5 | 5.880 | 5.16 | |
| 1877.5 | 6.468 | 5.37 | |
| 1878.5 | 5.684 | 5.09 | |
| 1879.5 | 5.880 | 5.16 | |
| 1880.5 | 7.742 | 5.83 | |
| 1881.5 | 8.526 | 6.12 | |
| 1882.5 | 11.956 | 7.36 | |
| 1883.5 | 9.016 | 6.29 | |
| 1884.5 | 9.212 | 6.37 | |
| 1885.5 | 8.820 | 6.22 | |
| 1886.5 | 8.036 | 5.94 | |
| 1887.5 | 7.056 | 5.59 | |
| 1888.5 | 6.860 | 5.52 | |
| 1889.5 | 6.370 | 5.34 | |
| 1890.5 | 6.736 | 5.47 | |
| 1891.5 | 8.622 | 6.15 | |
| 1892.5 | 12.876 | 7.69 | |
| 1893.5 | 10.682 | 6.90 | |
| 1894.5 | 13.507 | 7.92 | |
| 1895.5 | 9.834 | 6.59 | |
| 1896.5 | 9.925 | 6.62 | |
| 1897.5 | 9.235 | 6.37 | |
| 1898.5 | 7.993 | 5.93 | |
| 1899.5 | 6.938 | 5.54 | |
| 1900.5 | 5.479 | 5.02 | |
| 1901.5 | 4.485 | 4.66 | |
| 1902.5 | 4.561 | 4.69 | |
| 1903.5 | 6.377 | 5.34 | |
| 1904.5 | 6.903 | 5.53 | |
| 1905.5 | 7.854 | 5.88 | |
| 1906.5 | 6.876 | 5.52 | |
| 1907.5 | 8.512 | 6.11 | |
| 1908.5 | 9.137 | 6.34 | |
| 1909.5 | 9.575 | 6.50 | |
| 1910.5 | 8.198 | 6.00 | |
| 1911.5 | 6.753 | 5.48 | |
| 1912.5 | 5.641 | 5.08 | |

| | | |
|---|---|---|
| 1913.5 | 5.080 | 4.87 |
| 1914.5 | 6.012 | 5.21 |
| 1915.5 | 7.688 | 5.82 |
| 1916.5 | 9.142 | 6.34 |
| 1917.5 | 10.697 | 6.90 |
| 1918.5 | 10.894 | 6.97 |
| 1919.5 | 11.230 | 7.09 |
| 1920.5 | 10.230 | 6.73 |
| 1921.5 | 8.857 | 6.24 |
| 1922.5 | 7.793 | 5.85 |
| 1923.5 | 5.928 | 5.18 |
| 1924.5 | 6.891 | 5.53 |
| 1925.5 | 8.204 | 6.00 |
| 1926.5 | 10.833 | 6.95 |
| 1927.5 | 9.553 | 6.49 |
| 1928.5 | 9.390 | 6.43 |
| 1929.5 | 9.626 | 6.52 |
| 1930.5 | 10.322 | 6.77 |
| 1931.5 | 7.427 | 5.72 |
| 1932.5 | 7.276 | 5.67 |
| 1933.5 | 6.906 | 5.53 |
| 1934.5 | 6.911 | 5.53 |
| 1935.5 | 7.834 | 5.87 |
| 1936.5 | 8.992 | 6.29 |
| 1937.5 | 12.165 | 7.43 |
| 1938.5 | 13.960 | 8.08 |
| 1939.5 | 12.665 | 7.61 |
| 1940.5 | 12.062 | 7.39 |
| 1941.5 | 12.220 | 7.45 |
| 1942.5 | 9.480 | 6.46 |
| 1943.5 | 9.081 | 6.32 |
| 1944.5 | 8.274 | 6.03 |
| 1945.5 | 9.137 | 6.34 |
| 1946.5 | 14.254 | 8.19 |
| 1947.5 | 13.690 | 7.98 |
| 1948.5 | 11.059 | 7.03 |
| 1949.5 | 13.382 | 7.87 |
| 1950.5 | 12.603 | 7.59 |
| 1951.5 | 12.455 | 7.54 |
| 1952.5 | 11.084 | 7.04 |
| 1953.5 | 8.839 | 6.23 |
| 1954.5 | 7.598 | 5.78 |
| 1955.5 | 8.714 | 6.19 |
| 1956.5 | 13.533 | 7.93 |

| | | | |
|---|---|---|---|
| 1957.5 | 16.825 | 9.11 | |
| 1958.5 | 15.574 | 8.66 | |
| 1959.5 | 14.327 | 8.21 | |
| 1960.5 | 16.766 | 9.09 | |
| 1961.5 | 11.460 | 7.18 | |
| 1962.5 | 8.590 | 6.14 | |
| 1963.5 | 7.960 | 5.91 | |
| 1964.5 | 7.542 | 5.76 | |
| 1965.5 | 7.090 | 5.60 | 5.28 |
| 1966.5 | 7.826 | 5.87 | 6.27 |
| 1967.5 | 10.583 | 6.86 | 6.45 |
| 1968.5 | 9.362 | 6.42 | 6.25 |
| 1969.5 | 9.308 | 6.40 | 6.05 |
| 1970.5 | 9.832 | 6.59 | 6.42 |
| 1971.5 | 8.919 | 6.26 | 5.97 |
| 1972.5 | 9.297 | 6.40 | 6.45 |
| 1973.5 | 9.044 | 6.31 | 6.25 |
| 1974.5 | 9.299 | 6.40 | 6.62 |
| 1975.5 | 8.016 | 5.93 | 5.92 |
| 1976.5 | 8.298 | 6.04 | 5.57 |
| 1977.5 | 8.983 | 6.28 | 6.02 |
| 1978.5 | 11.786 | 7.29 | 7.29 |
| 1979.5 | 11.638 | 7.24 | 7.57 |
| 1980.5 | 10.177 | 6.71 | 6.97 |
| 1981.5 | 13.468 | 7.90 | 7.91 |
| 1982.5 | 15.021 | 8.46 | 8.74 |
| 1983.5 | 11.162 | 7.07 | 8.05 |
| 1984.5 | 10.456 | 6.81 | 7.69 |
| 1985.5 | 8.719 | 6.19 | 5.95 |
| 1986.5 | 8.593 | 6.14 | 5.70 |
| 1987.5 | 8.017 | 5.93 | 6.35 |
| 1988.5 | 9.924 | 6.62 | 7.31 |
| 1989.5 | 16.846 | 9.12 | 8.15 |
| 1990.5 | 12.381 | 7.51 | 7.50 |
| 1991.5 | 15.182 | 8.52 | 9.26 |
| 1992.5 | 12.443 | 7.53 | 8.35 |
| 1993.5 | 10.093 | 6.68 | 6.69 |
| 1994.5 | 9.022 | 6.30 | 6.33 |
| 1995.5 | 9.023 | 6.30 | 5.69 |
| 1996.5 | 6.972 | 5.56 | 5.21 |
| 1997.5 | 8.019 | 5.93 | 5.66 |
| 1998.5 | 10.352 | 6.78 | 6.91 |
| 1999.5 | 9.753 | 6.56 | 6.88 |
| 2000.5 | 13.186 | 7.80 | 7.07 |

| | | | |
|---|---|---|---|
| 2001.5 | 13.310 | 7.84 | 6.83 |
| 2002.5 | 10.893 | 6.97 | 7.73 |
| 2003.5 | 12.451 | 7.53 | 7.57 |
| 2004.5 | 10.688 | *6.90* | *6.16* |

Table 3

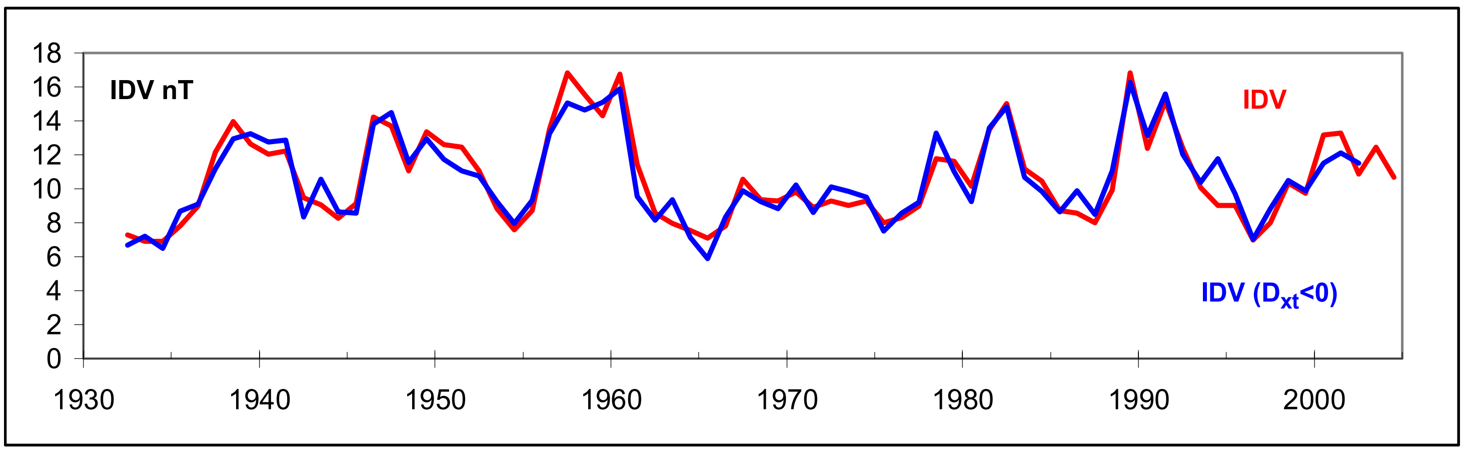

IDV nT
IDV
IDV (Dxt<0)
18
16
14
12
10
8
6
4
2
0
1930
1940
1950
1960
1970
1980
1990
2000

Figure 6

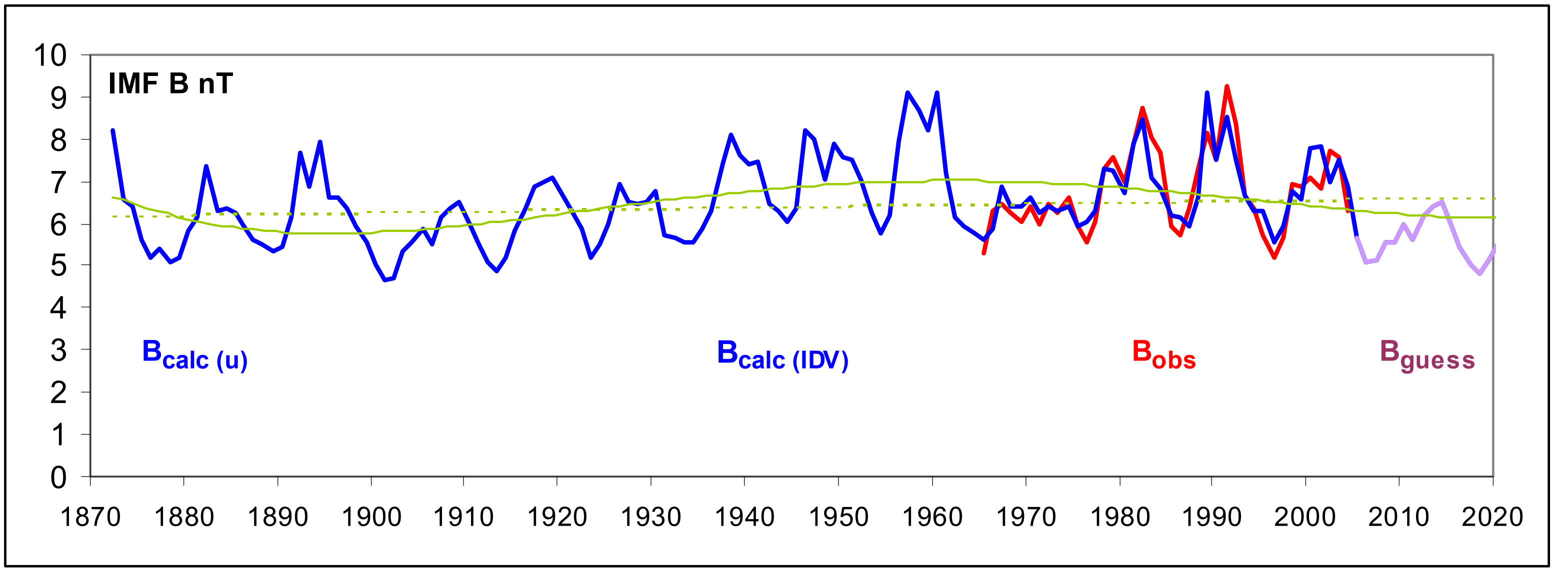
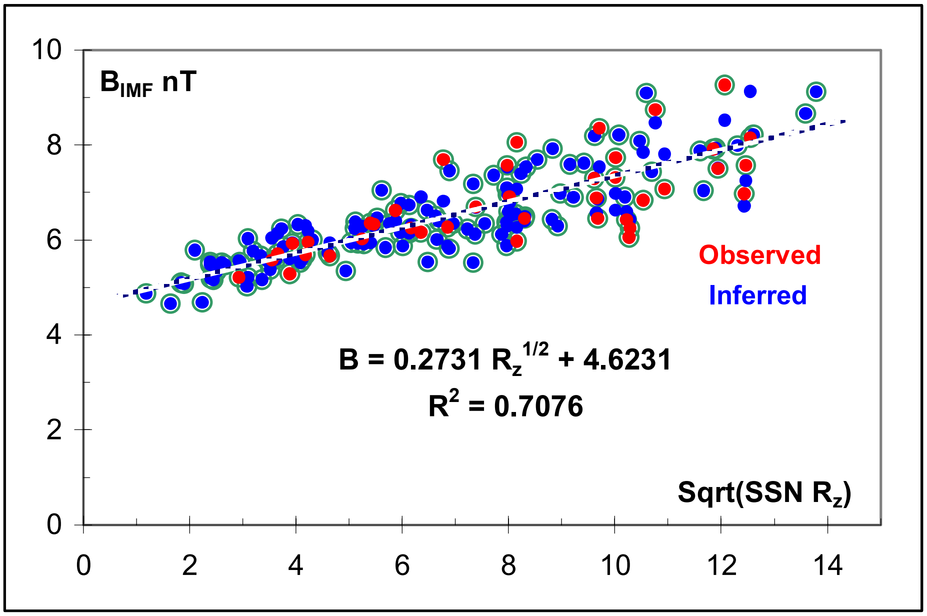

IMF B nT
B calc (u)
B calc (IDV)
B obs
B guess
10
9
8
7
6
5
4
3
2
1
0
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Figure 7



B_IMF nT
Observed
Inferred
B = 0.2731 R_z^1/2 + 4.6231
R^2 = 0.7076
Sqrt(SSN R_z)
0
2
4
6
8
10
12
14


Figure 8

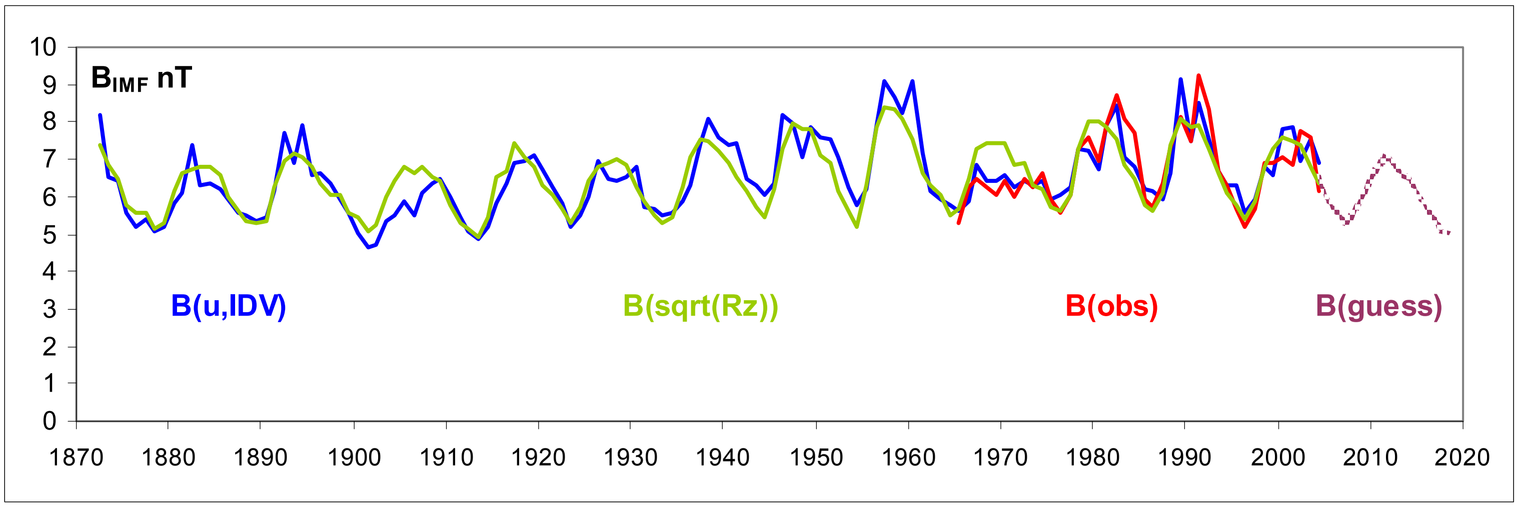

B_IMF nT
B(u,IDV)
B(sqrt(Rz))
B(obs)
B(guess)
10
9
8
7
6
5
4
3
2
1
0
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Figure 9