Comment on "Correcting the *Dst* index: Consequences for absolute level and correlations"
by A. Karinen and K. Mursula

The paper discusses the implications of a correcting the Dst index using a method set forth in a recent paper by the same authors in *GRL* [Mursula and Karinen, Explaining and correcting the excessive semiannual variation in the Dst index, *GRL*, 2005, *32* (*14*) L14107, doi:10.1029/2005GL023132]. The rationale for the paper is the correctness of the method and conclusion of that previous paper:

A) Is there a problem at all ("excessive" semiannual variation) that needs fixing?

B) Is the conception of the "problem" correct?

C) Is the method for fixing the "problem" adequate?

D) Is this the time for yet another index (especially if the new index is premature)?

The answers to these questions and thus the recommendation for acceptance of the paper hinge strongly on that MK [*GRL*, 2005] paper, so our analysis which follows below begins with a critical look at MK [*GRL*, 2005].

Already Bartels, Mayaud, and others have stressed that a geomagnetic activity index ideally should monitor or measure a distinct physical process or relationship [realizing that the process may be complex and in actuality compound]. The classical example of an index that fails this criterion is the "daily range" mixing the effect of solar EUV and of the solar wind. In designing the *K*-index, Bartels attempted [and largely succeeded] to separate out the solar EUV effects as manifested in the regular diurnal variation and thereby eliminate them from the index bringing it closer to a measure of the efficiency of the coupling between the magnetosphere and the magnetized solar wind on a time scale comparable with the time it takes the solar wind to "pass" the extended magnetosphere.

The Dst index is traditionally considered (and was conceived as such) to be a measure of the intensity or maybe even the energy content of the "ring current". A problem here is the time scale. Dst can be defined on any time scale (minutes, hours, days, …). The ring current has "semi-persistence" and decays on a time scale unrelated to the time scale on which Dst is defined or reported. This fact complicates the removal from the raw H-component data of effects not related to the ring current. Since we are not sure exactly what is caused by the "ring current" or even if the classical concept of the ring current is itself valid or useful, it is not easy to determine what should be removed and how.

We shall attempt to argue that the answers to questions A) through D) are all "no". We realize that if MK [2005] is accepted as correct our analysis just stands as a contrary viewpoint. In that case, we will have to recommend the present paper under review as appropriate and have no reservations against it being published basically as it is, with two minor caveats that we would like to have addressed:

1) Figure 6: The color coding should be the same in both panel a and b. Right now, the two panels look very much alike and defeat the purpose of showing that the two distributions are different.

2) Figure 7 (and its discussion). The linear relationship between the u-measure (an early version of Dst) and the square root of the sunspot number was already pointed out by Svalgaard et al. at a symposium in Slovakia in 2003 (ESA SP-535) and should be acknowledged.

In constructing Dst there are three “variations” that need to be removed:

1) Remove the secularly varying main field for each station. The method used by Mursula and Karinen [*AG*, 2005] (MK) is to compute the yearly mean based on the five internationally quiet days (5IQD) each month. Then fit a 2^{nd}-order polynomial to 6 years and use that to interpolate the main field at any time (during the year). A problem with this is that the 5IQDs are not equally quiet from month to month and that seasonal and solar cycle variability of the average level of activity leak into the “quiet” level.

2) Remove part of the seasonal variation of the geomagnetic field *level* at each station. This is not to be confused with the annual or seasonal variation of geomagnetic *activity*. The seasonal variation is not fully understood and has several parts:

> 2a) Intensifications of the “ring current” persist for days. Their magnitude and/or frequency depend on time of the UT-day and on time of year (showing a well-known semiannual variation with minima at the solstices). This part of the seasonal variation we do not want to remove, as it is a part of precisely what we are trying to measure with the Dst index.
>
> 2b) The “quiet” ring current is presumably permanent or declining very slowly (lasts more than a month). This part also depends on UT-time and on time of year, and, again, we presumably want to keep it in the index.
>
> 2c) The location of the Sq current changes with season, being shifted towards the hemisphere having local summer. This part of the variation, which shows up mainly during the local daytime, we do want to remove.
>
> 2d) The Malin-Isikara (M-I) effect may be operating to turn the ring current/magnetospheric tail current away from the summer hemisphere reducing their negative effects thereby increasing the field level (of the H-component) during local summer. If we want Dst to be a measure of the effect of the ring current at the surface of the earth (*e.g.* for assessment of its terrestrial effects) we want to include the M-I effect. If we want Dst to be a measure of the energy in the ring current itself we want to remove the M-I effect. So, we are not even sure if we want to leave in/remove the M-I effect. We shall assume that we want Dst to be a measure of a property of the ring current itself and hence strive to remove the M-I effect. The M-I effect is presumably largest during nighttime hours when the station is closest to the tail current.

3) Remove the regular solar and lunar variations. MK compute a 12 (month) x24 (hour) [total of 288] element matrix of the H-component minus the main field as derived above (using their method) using again the “five quietest days” of each month and for each station. Since the matrix is supposed to be aligned on local time (not UT) one should use local time in selecting quiet days. It is not clear if this was done or if the 5IQDs were used. The matrix is then “smoothed” in a 2-D Fourier transform including only the DC and the first six harmonic components. This approach (apart from its computational complexity) suffers from the same problems as the main field regarding the uneven level of activity from month to month. It also suffers from the additional problem that the conductivity of the ionosphere can easily vary by a factor of two from day to day because of variations of the EUV flux, leading to varying amplitude of the Sq variation from day to day. On top of this, even the shape of the daily variation (the location of the focus) changes from day to day. Using the “iron-curve” of the 288-element matrix forces some of the day-to-day (global) variability of Sq into the Dst index. The lunar variation is commonly ignored, being very small except for stations very close to the “geomagnetic” equator. Such stations are not used for determination of Dst.

If we could identify the various parts of the seasonal variation and remove the parts we did not want, there would be no problem and we could proceed to remove the three portions just mentioned in order: first the main field, then the purely (*i.e.* local Summer time related) seasonal effects, and finally the regular daily variation. Unfortunately, by following the official Dst derivation or the MK procedure this simple scheme is very difficult and clearly has not been executed successfully, to wit: the clamor for corrections - removing the “non-storm” component [Cliver *et al.*], the Dcx-index [MK], etc. The problem has been approached by folding it into the Sq matrix by expressing the elements as $Sq(m,t) = Sq^0(m,t) + L(m,t)$, where the "linear trend" L (not to be confused with the lunar quiet regular variation, Lq) is parameterized by $L(m,t) = a(m)\cdot t + b(m)$, where m is month of year, and t is hour of local time within the day. The a-parameter is historically known as the *non-cyclic variation* and is usually calculated by including one more hourly ("the 25^{th} hour") value after the 24 local time hourly values. Variations of the calculation of a are possible [MK use one] and there are some inherent problems with the calculation if only a subset (*e.g.* the 5IQDs) of all days are used, because the 25^{th} hour would often not belong to a day belonging to the subset.

If the seasonal variation has not been removed before calculation of the Sq matrix, the b-parameter will now contain part of the seasonal variation, so removal of Sq and the seasonal variation are coupled in ways that are not clear and certainly not desirable. Derivation of Dst and Dxt includes both the a- and b-parameters (although the derivations has subtle [but small] differences), while Dcx is characterized by setting $b = 0$. If we look at the seasonal variation (as outlined above) it is evident that variations 2c and 2d would cancel out if we calculated Dst separately for each hemisphere (by averaging over all stations used from each hemisphere) and then averaged the two hemispheres. The 2a and 2b variations (that we want to keep) are not affected by this and the *correct* semiannual variation is retained in the average with the proper amplitude in nT units. MK [*GRL*, 2005] contains the following remarkable statement: "Since the seasonal maximum occurs during the local summer, the maxima in the two hemispheres are in anti-phase […] however, equinoctial minima are in phase in both hemispheres, enhancing the semiannual variation (SA) in the combined curve. Accordingly, the annual variation is reduced and the SA variation is enhanced in the combined ΔH. This leaks into the Dst index, causing excessive SA variation." The statement, as it stands, is an embarrassment to the authors. There is (as we just have seen) no excessive SA variation when you combine the two hemispheres, and hence no reason to correct for it.

To make our argument clear we set out to derive Dst ourselves (Dsv - ***s***torm ***v***ariation), but in a straightforward way that does not involve any attempts to remove anything except the main field. We first explain our procedure, then compare with Dst and derive the magnitude of the various variations and show that there is no excessive semiannual variation.

1) We use an "absolute" level of quietness by selecting all (UT-) days of a year where the *aa*-index did not exceed 12 for *any* of the eight 3-hour intervals. Assuming that the intra-year secular variation can be taken as linear, we compute the yearly averages of the day number within the year and of the geomagnetic component field value for all these "truly" quiet days within the year. A 2^{nd}-order polynomial fit to these yearly pairs of numbers for five years centered on the year within which we wish to derive the main field component values is then used to interpolate the main field for any given day within that year.

2) We use three stations in the Northern Hemisphere (SJG, HON, and KAK) and three stations in the Southern Hemisphere (HER[CTO], API, and VSS[TRW]) and calculate Dsv separately for both hemispheres. CTO and TRW are used to fill holes in HER and VSS coverage.

3) Because of the problems with the proper identification of Sq, we adopt a simpler approach, namely to use only the six hours of the local day centered on local midnight for each station. Since Sq is basically absent during this time interval (or at least reduced to a very small, linear variation) there is no need for an elaborate fitting of Fourier components. To eliminate any residual trend during the 6-hour period, we compute a single average value of Dsv over the six hours. In other words, the time resolution of Dsv is 6 hours. This choice does not significantly alter the amplitude of neither the annual, nor the semiannual variation (MK consider 30-day averages in their analysis!). This step is *a posteriori* justified by the close agreement with Dst, as we shall see.

Figure 1 shows the calculated Dsv for 60 UT-days centered on the UT-day of the vernal equinox in the year 2000. At the equinox the seasonal effects are equal in both hemispheres. The Southern Hemisphere station data are shown as "reddish" colored symbols (VSS - pink circles; API - orange triangles; HER - red diamonds) and the Northern Hemisphere stations with "bluish" (SJG - black circles; HON - blue triangles; KAK - green diamonds). A grey line connects the six symbols per day to form the combined Dsv curve. The occasional gaps are caused by data missing for a station. Let us reiterate that the only processing that was done was to subtract the main field. It is noteworthy how well the data points for the different stations match and join each other, basically validating the procedure so far.

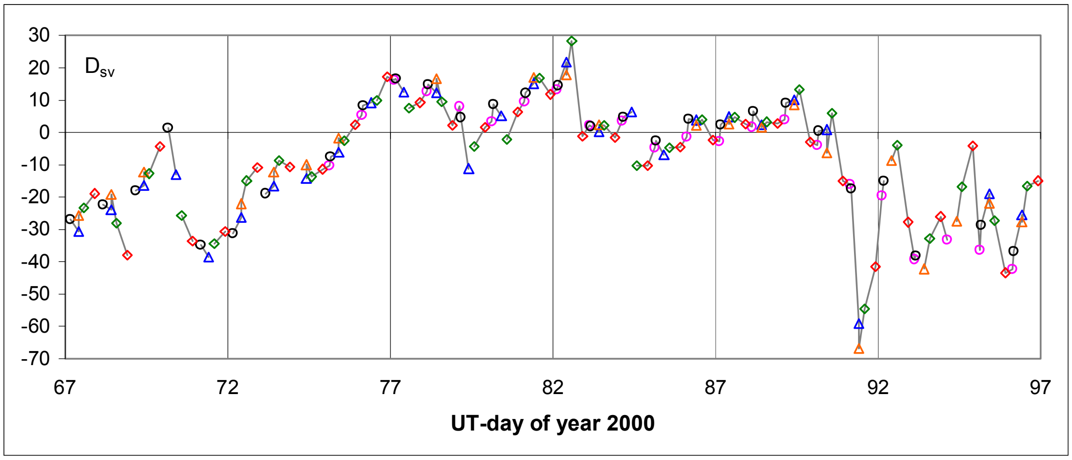


Figure 1

In Figure 2 we compare Dsv (grey curve) with (the official) Dst (red curve) with the same 6-hour time resolution. The agreement is very good (somewhat surprising as Dst is supposed to be inferior to Dxt). We conclude that Dst is not so bad after all.

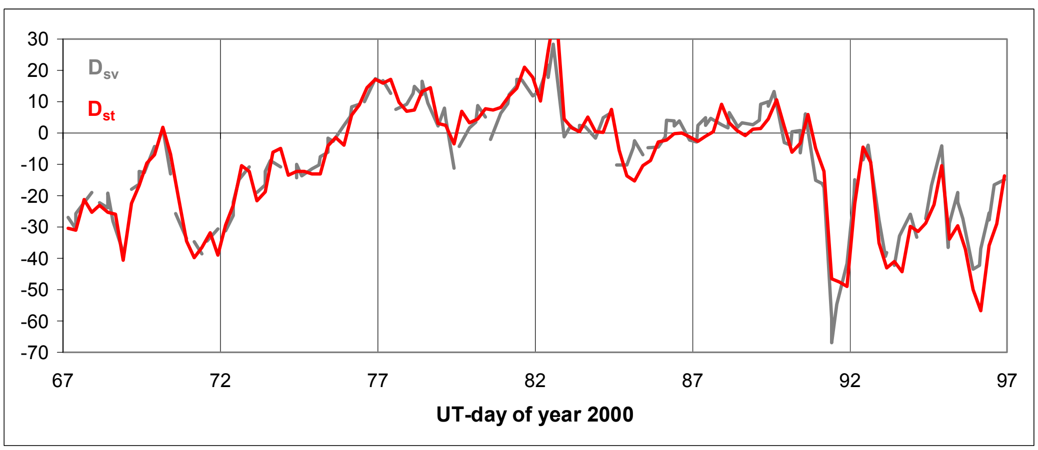


Figure 2

In Figure 3 we show Dsv for the full year of 2000. Dsv for Southern Hemisphere stations are shown as reddish curves and Dsv for Northern Hemisphere stations are shown as greenish-bluish curves. Again, no processing except subtracting the main field (H-component) for each station was done. One can clearly see the annual variation: Dsv for the northern stations lies *above* Dsv for southern stations during boreal summer and *below* for austral summer, while being equal around the equinoxes. Within each hemisphere Dsv for the different stations substantially agree. The agreement is equally good for any other year, including solar minimum years, solar maximum years, and intermediate years. We may note that there does not seem to be a systematic difference between stations reflecting their differing latitude, thus no need to "normalize" with the cosine of the latitude as is customarily done (also by MK). This has recently been pointed out by Campbell as well [Campbell, W., Failure of Dst index fields to represent a ring current, AGU Spring Meeting, 2005, abstract #SM51A-11: "The cosine factor, used to adjust station fields for the magnetospheric ring current effect, typically fails"].

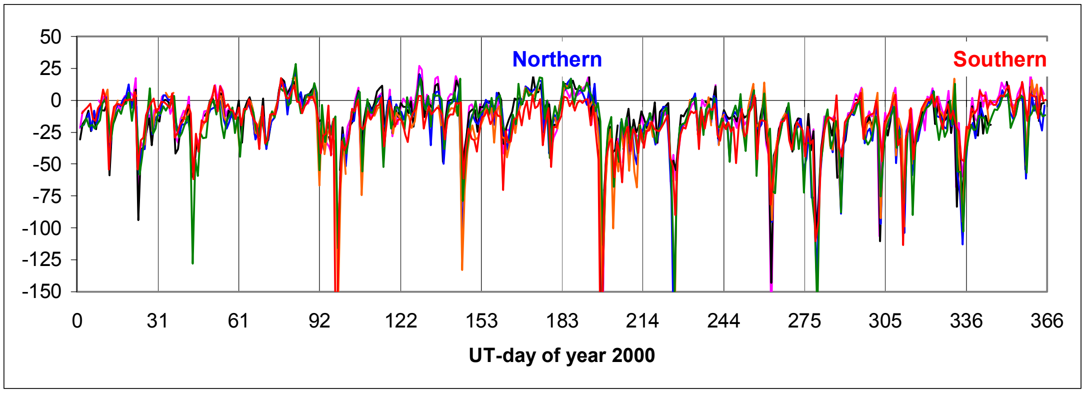


Figure 3

The correct way to eliminate the seasonal (summer) variation is now simply to average the Southern and the Northern Hemisphere data (each being the average of data for stations within that hemisphere). It happens (by design) that there is the same number of stations (three) in each hemisphere, so each station enters with equal weight. The resulting Dsv index has a very high correlation with the Dst index. This is shown in Figure 4:

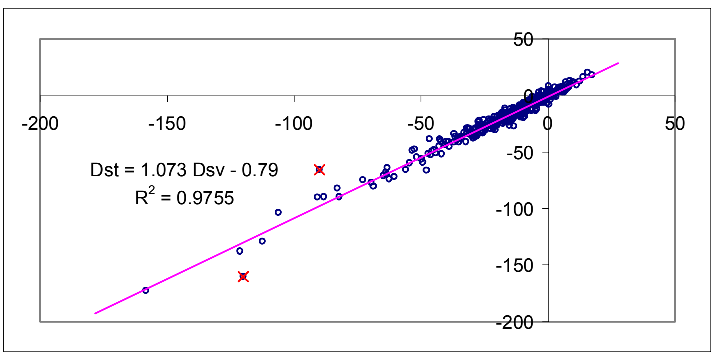


Figure 4.

For ease of comparison, we have computed *daily* averages of the two indices. Dst is numerically larger than Dsv partly because Dst was divided by cos (latitude). Two outliers (red crosses) were not included in the fit.

Using the regression equation from Figure 4, we can now compute a Dsv index adjusted to match the magnitude of the official Dst for the purpose of comparing to the two indices:

$$Dsv^* = (1.073 \pm 0.009)\ Dsv - (0.79 \pm 0.24)$$

Figure 5 shows a comparison of Dsv* (blue curve) and Dst (red curve), They usually agree so well that one curve (the red) is hidden behind the other. There are small, systematic disagreements during the austral summer where the red curve has a tendency to lie below the blue curve. The reason for this is clear: in calculating Dst, the Southern Hemisphere only has 1/3 of the weight (one station only - HER) of the Northern Hemisphere (three stations - KAK, SJG, HON), so the seasonal (summer) variations do not cancel out.

One might suggest calculating the official Dst by first averaging the two hemispheres separately and then averaging the results. This would improve the cancellation of the summer effects. Had this, in fact, been done, there would have been little need for this review ☺.

The offset (0.79 ± 0.24) between Dsv and Dst might be due to the slightly different way of determining the main field to be subtracted, but is in any case small.

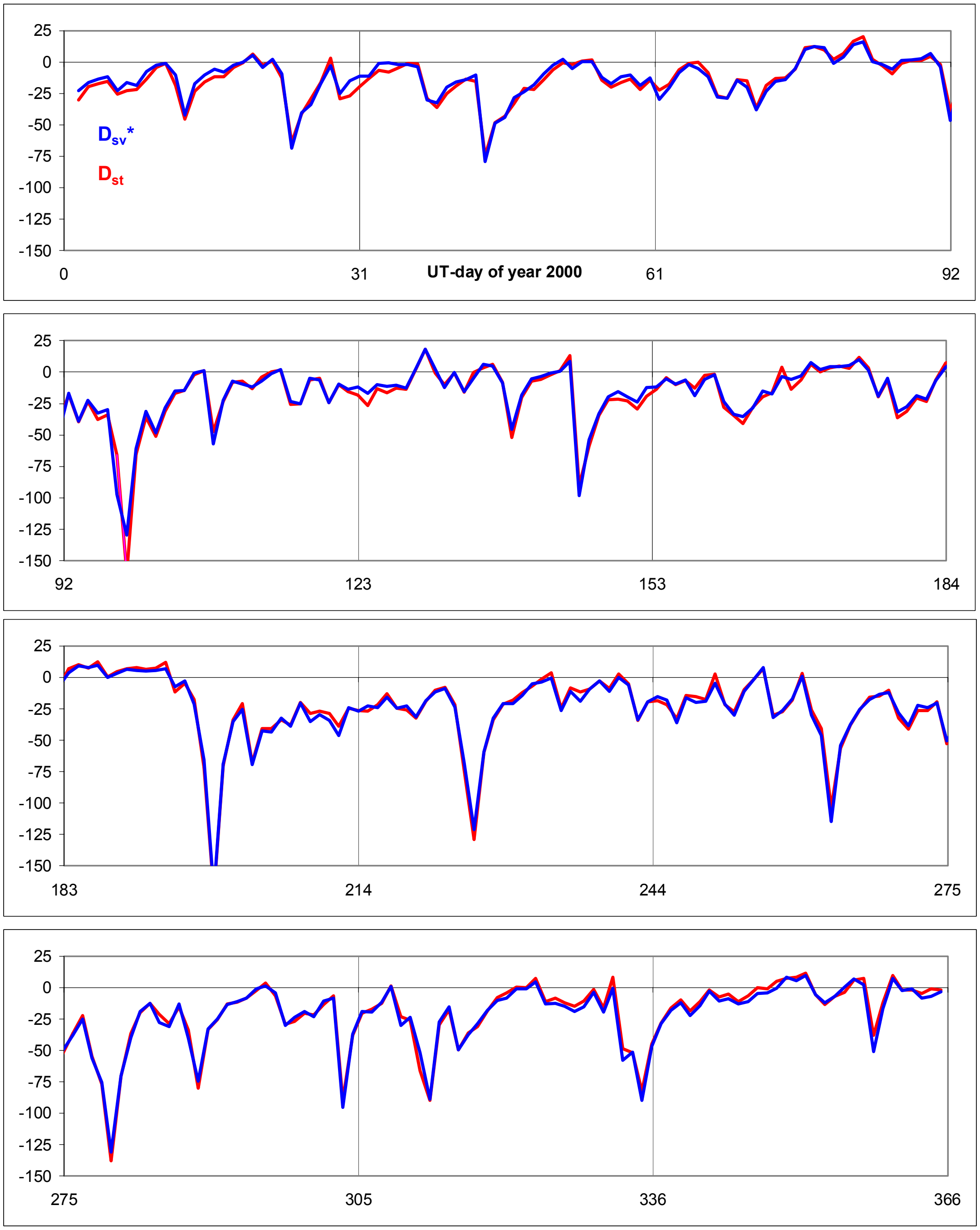


Figure 5

It is now time to look at the seasonal (summer) variation in more detail. Figure 6 shows monthly average Dsv for the interval 1957-2003. Dsv for Northern Hemisphere stations (SJG - diamonds, HON - circles, KAK - triangles) is shown in **blue**, while Dsv for Southern Hemisphere stations (VSS/TRW - diamonds, API - circles, HER - triangles) is shown in **red**. The thin black curve is simply the average of all curves (the "global" Dsv). Due to missing data, VSS is somewhat noisy, but all curves show the characteristic pattern with a local summer maximum in anti-phase between hemispheres. The average curve (**black**), however, is nicely free of the summer effect.

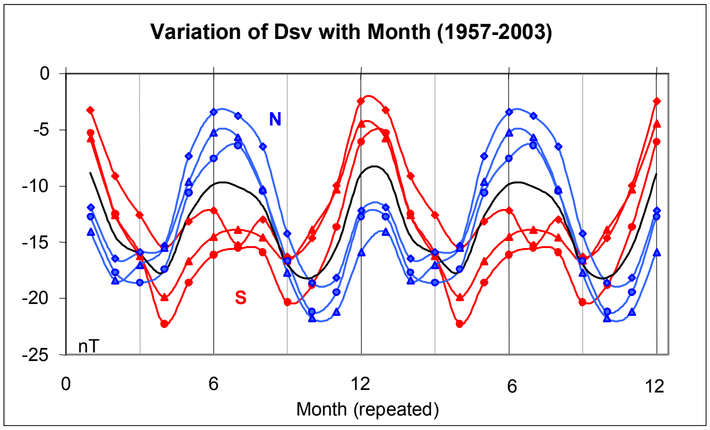


Figure 6.

There are asymmetries: the December maxima are narrower than the June maxima. The main field is not symmetric about the rotation axis either, so such asymmetries are perhaps not too surprising. In the Figure we have repeated the data to show the monthly variation twice in order to show both the boreal and the austral summer peaks "unbroken" by change of year.

Since Figure 6 is quite "busy", we show in Figure 7 just the average curves (blue Dsv_{North} and red Dsv_{South}):

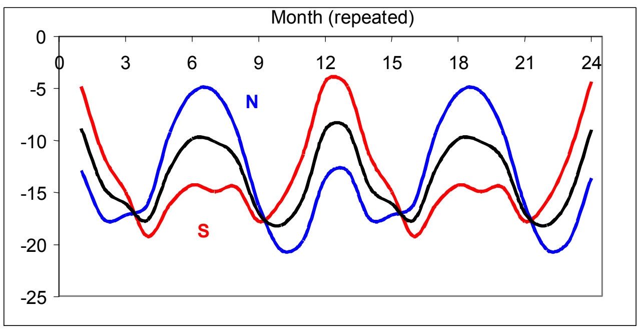


Figure 7.

We can compare more directly with Dst if we compute a weighted $Dsv\# = (3*Dsv_N+1*Dsv_S) / 4$ with the same hemispheric weights as the Dst-index. To get the magnitude right we regress Dst versus Dsv#. The result of this is shown in Figure 8.

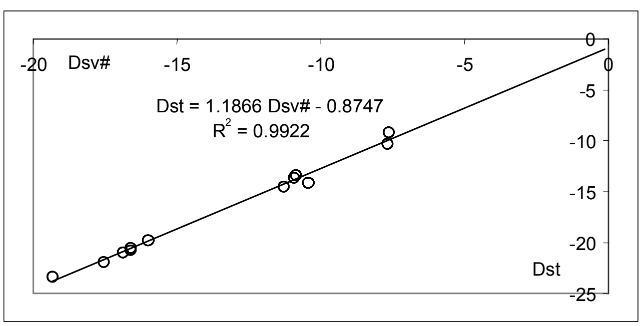


Figure 8.

Using the regression equation of Figure 8 we compute re-scaled monthly averages: $Dsv\#^* = 1.1866\ Dsv\# - 0.8747$

and compare them with Dst in Figure 9.

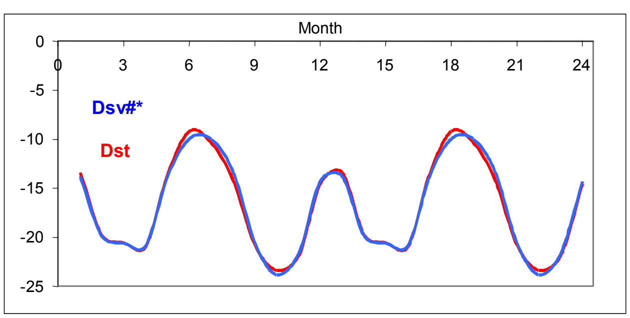
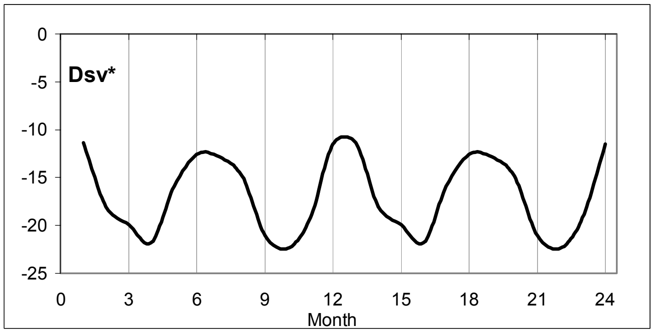


Figure 9.

The agreement between Dsv#* (blue) and Dst (red) is quite remarkable. Where you cannot see the red curve it is because it is just "behind" the blue curve. We remind you that the only processing that was done in deriving Dsv was to subtract the main field. No adjustment for latitude, no 2D Fourier transform, no removal of linear trends.



We now apply the regression equation to the simple average of Dsv_N and Dsv_S (i.e. without the dubious Dst weighting) and compute the average "true" semiannual Dsv* curve with the result shown in Figure 10.

<= Figure 10.

The *am*-index is usually regarded as showing a "correct" semiannual variation because of the good longitudinal and hemispheric distribution of the stations and we shall now compare the SA variation of Dsv* with that of *am* (MK compare with *ap* and *aa*). MK re-scale the indices by their standard deviation before comparing and note that the SA variation of Dst is twice that of *aa* or *ap*, hence the notion of "excessive SA". A similar (but simpler) comparison can be made by reducing the indices by their mean values and comparing D = -Dsv*/<-Dsv*> with A = *am*/<*am*>. This is done in Figure 11 that shows D as the heavy black curve and A as the heavy red curve [Dsv was used with the opposite sign to compare more easily with the always positive *am*]. As MK, we find that indeed the amplitude of the relative variation D is twice as large as the amplitude of A. Because the seasonal (summer) variation has been removed correctly from Dsv we cannot say the D is too large because of a problem in derivation of Dsv. Now, the *relative* variation D is sensitive to an error in the zero-level for Dsv. In Figure 11 we have also plotted (as successive grey curves) the result of (-Dsv* + 5*n*)/(<-Dsv*> + 5*n*) for *n* = 1, …, 6, *i.e.* changing the zero-level by successive steps of 5 nT. It is plain that a suitable value of n (between 5 and 6) makes the variation of D match that of A. One can also see that directly by correlating -Dsv* D versus *am* (Figure 12):

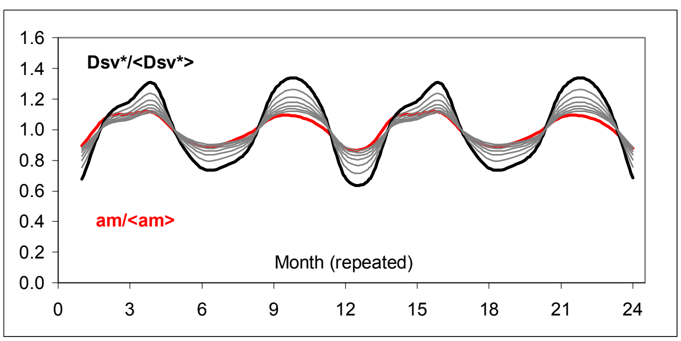


Figure 11

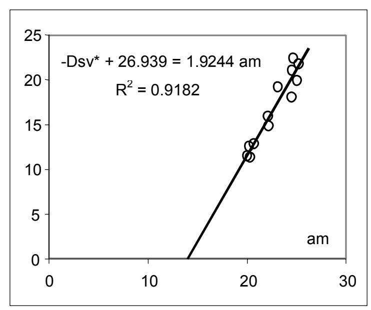


Figure 12

So, it seems that an error in the zero-level of Dsv* (and Dst) of 27 nT would give Dsv* (and Dst) the same *relative* SA variation as *am* (and *aa* and *ap*) although expressed in nT it happened to be 1.9 times as large (there is no *a priori* reason why the scale should be the same). Thus, the 'mystery' of the "excessive" relative SA variation of Dst can be solved by subtracting 27 nT from Dst (and Dsv). The actual magnitude of the SA in nT (≈10) stays the same, of course. There is ample room for confusion of "magnitude" and "amplitude", one being roughly twice the other. The magnitude is the amount by which activity is lower at the solstices. The amplitude is the coefficient of the best sine wave that describes the SA variation of activity around its mean value. Magnitude is the better term as it probably is closer to the physics (there is no anti-activity).

Where does the 27 nT zero-level error come from. The first thing we need to bear in mind is that the main field was determined from "quiet" days, but these days still had *some* (albeit small) activity. "Truly" quiet days are extremely rare. Using our method of selecting days where *no* three-hour interval had activity greater than a given threshold affords a way to extrapolate to zero activity as follows. In our analysis we have used *aa* < 12 as the threshold for selecting quiet days. The average value of *aa* for these days is about 6, (<*aa*> ≈ 6.0 depending weakly on the station used). The main field H-component <H_0> for these days then corresponds to the <*aa*> ≈ 6 for threshold 12. Selecting thresholds 9, 12, 20, 30, 40, 50, 60, and 80 we determine the "main field" <H> and <*aa*> corresponding to these thresholds for each station and for each year as described above. We can now compute the average difference over all years (since 1932) <dh> = <<H> - <H_0>> as a function of <<aa>> for each station and plot the result in Figure 13:

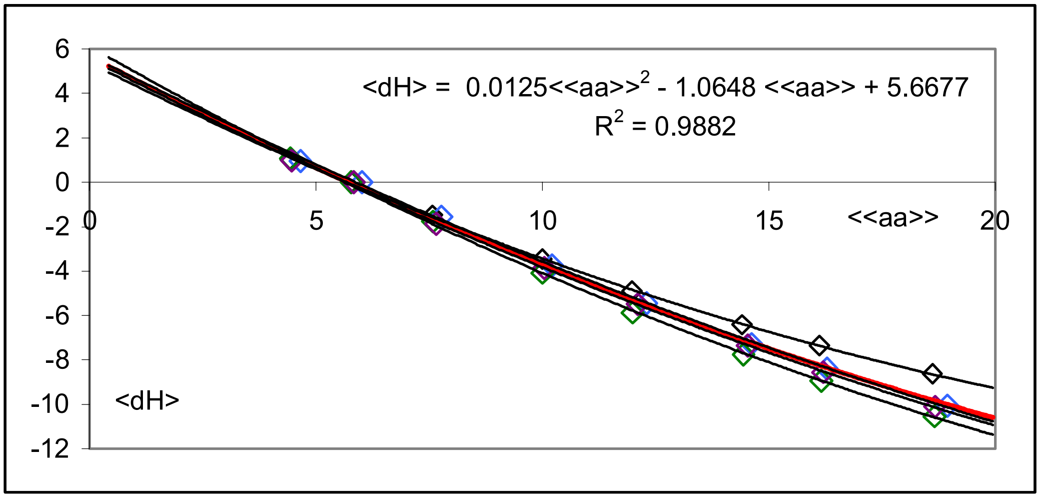


Figure 13

There is a slight curvature to each plot suggesting 2nd-order fits. If we extrapolate each fit to <<*aa*>> = 0, we get a measure of the correction to H_0 to obtain H on the "truly" quiet day. The correction is to within a fraction of a nT the same for the various Dst stations (SJG - black diamond, 5.4 nT; KAK - blue diamond, 5.7 nT; HON - green diamond, 6.1 nT; HER - purple diamond, 5.6 nT). The heavy red line on Figure 13 and the regression equation given are for the average correction, 5.7 nT. This is close to the "non-storm" component suggested by *Cliver et al.*

Thus far we have accounted for 5.7 nT of the 27 nT; where are the remaining 21 nT? Even if geomagnetic activity is extremely low (<<*aa*>> = 0; recognizing that the smallest value obtainable is 2 [because of only two stations], one can still envision a level of activity = 0) the ring current is presumably still there, decaying very slowly, but never really disappearing. Thus there might be a "permanent" 21 nT background contribution from this slowly decaying ring current. *Jorgensen et al.* [2004, A statistical study of the global structure of the ring current, *JGR*, *109*, A12204, doi: 10.1029/20003JA010090] calculate the intensity in the ring current using data from the fluxgate magnetometer on the CRRES satellite and come to a similar conclusion: "there is an offset in the Dst index so that Dst = 0 actually corresponds to a ring current that would create a 20 nT depression."

Figure 14 (from *Jorgensen et al.* [2004]) shows the total current in the ring current region as a function of the Dst index. The total westward (outer) current is plotted as a solid line, while the total eastward (inner) current is plotted as a dotted line. The currents are plotted as a function of the average Dst in each 30 nT wide bin. The straight lines are fits to the current density. The eastward current fit is rather flat and uncertain, but the westward current fit has a well-defined offset at Dst = -23 nT.

The well-known Burton [1975] equation also contains an offset of 20 nT corresponding to the "quiet time" ring current.

Temerin and Li [2002, JGR 107(A12), 1472) conclude that Dst is highly predictable. Their (complicated) empirical model using solar wind input and the dipole tilt angle (and an offset) reproduces Dst (for 1998-2000) with an RMS-error of typically 7 nT. This is another indication that Dst does not need much correction.

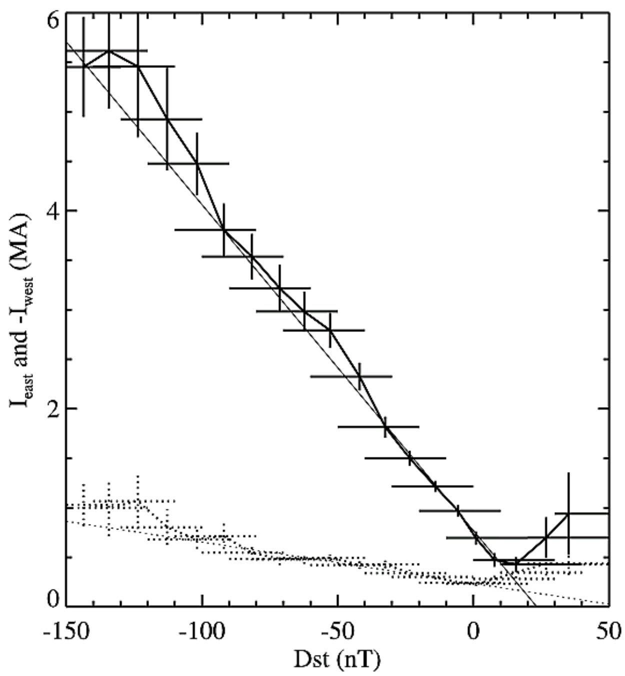


Figure 14.

It is thus quite possible that an offset of 27 nT exists in Dst. The question is if one should correct for it? The offset consists of two parts as suggested above, one part that is a correction to the main field to reduce it to its "truly" quiet value (5.7 nT) and the other part may be the "residual" ring current suggested by *Jorgensen et al.* (≈20 nT). It would be reasonable to correct for the (constant) 5.7 nT as that is just a better determination of the main field, but it would seem better *not* to correct for the second part as it is presumably not constant and is subject to interpretation. We should follow the rule that Dst is a *measured* index, not a theoretical construct.

So, it all comes down to determining the "base level" of Dst. We have identified 14 stations (7 in the Northern Hemisphere - SJG, HON, KAK, SSH, MBO, TKT, ABG; 7 in the Southern Hemisphere - HER(CTO), API, TAN, PIL, PPT, TRW, VSS) in a latitude band suitable for derivation of Dst and with long-term coverage. For all of these we derive Dsv using all available data (there are more data, actually, but not yet in the WDCs) and calculate yearly averages for each station with the result shown in Figure 15:

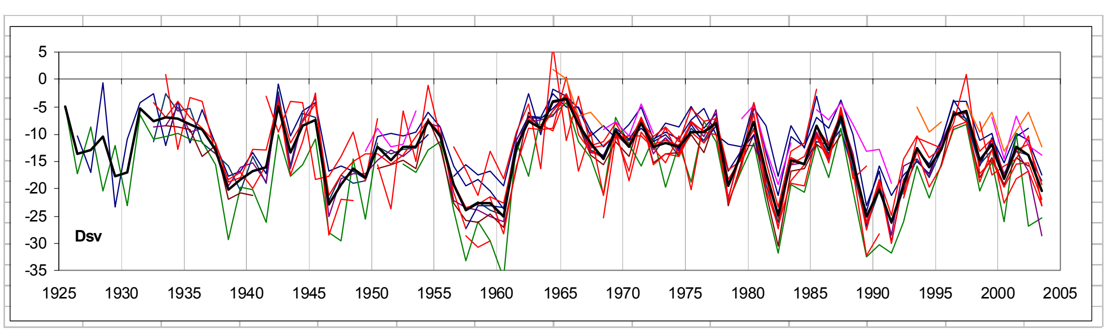


Figure 15

(Northern stations - black or blue curves; southern stations - red or pink curves; average - heavy black)

The standard deviation about the average yearly mean (heavy black curve) is 3.9 nT (a handful of outliers, most caused by incomplete or erroneous data have been omitted). This is quite remarkable considering that no empirical adjustments or corrections (except compensating for changes in absolute values due to station relocation or instrument upgrades) have been performed; this is raw data. The Figure also shows how sensitive Dsv (and Dst) is to good baseline control; any drifts or scatter in baseline feed directly into Dsv. It is instructive to compare the average Dsv with yearly average Dst. This is done in Figure 16:

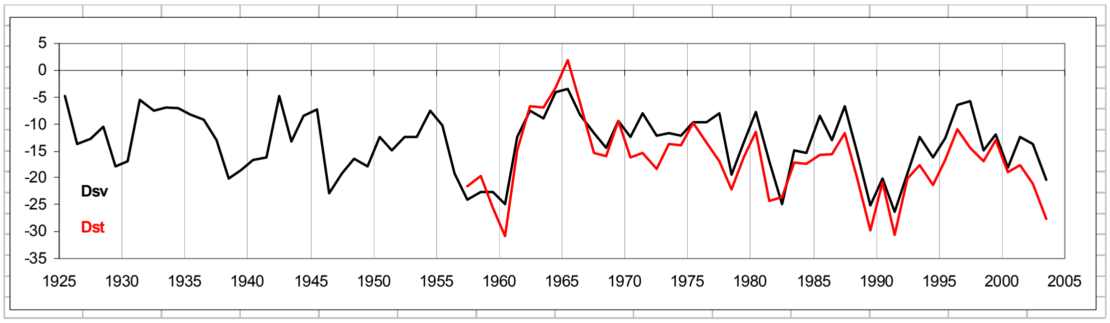


Figure 16

Dst (red curve) is on average 2.8 nT lower than Dsv. This is in good agreement with the regression equation in Figure 8 (observed <Dst> = -16.7; calculated from <Dsv> -17.3).

We also repeated the Superposed Epoch analysis (using Dsv). The result is shown in Figure 15:

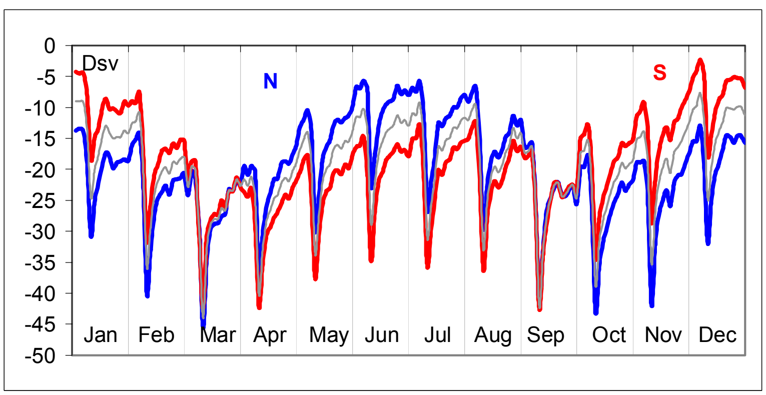


Figure 15.

Dsv (North) is shown in blue, Dsv (South) is shown in red. The interval is 1929-2002. The average is shown in grey. The curves plotted within a month show 15 daily values superposed with the SSC on day four.

Figure 16 shows the difference (red) between north and south and (again) their average (blue):

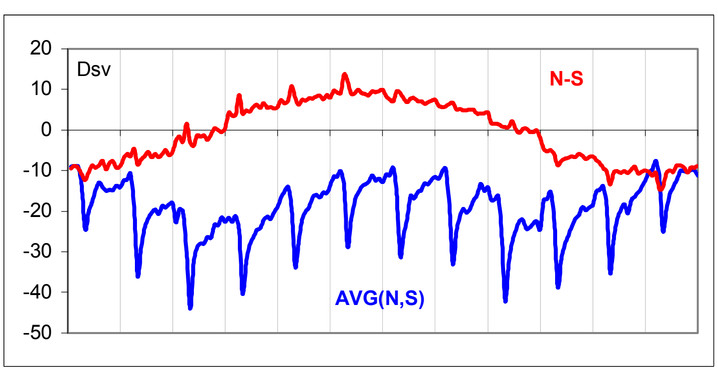


Figure 16.

The annual variation is clearly seen, but it cancels out in the average, so is no longer an issue.

The “sharp dips” on or for a few days after the SCC show the storms proper. The slow recovery thereafter is clearly seen, as is a strong semiannual variation of the “base level” (being the level before the SSC). Some of this is due to overlapping of storm recoveries, but selecting storms that are well separated (by a week or more on both sides of the SSC) leads to the same result. So, it all comes down to a choice: do we wish to include these longer term variations (on a time scale of a week or more) in the Dst index, or do we want to have the Dst index be a measure of “individual storms”? An argument may be made each way.

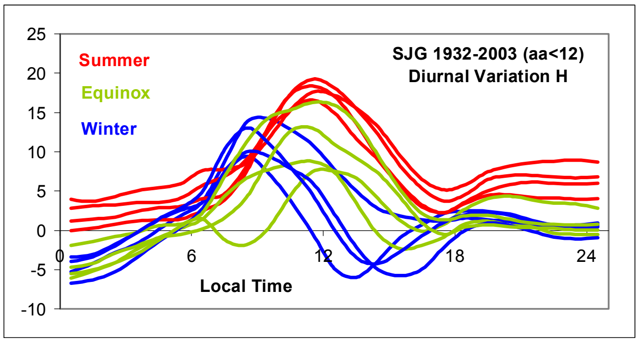
Olsen et al. [2002; ‘Monitoring Magnetospheric Contributions Using Data from Ørsted, CHAMP, and Ørsted-2/SAC-C’, AGU Spring meeting] also found a 20 nT offset and note: “This is due to the quiet level of the magnetospheric ring-current, the absolute level of which can only be determined from satellite data.”

From all the above analysis it seems premature to claim that Dst needs correction to rid it of its “excessive” semiannual variation. If correction is contemplated, the more useful method would be to remove the Northern Hemisphere bias by assigning equal weight to each hemisphere. This may entail using two more stations (that are available) from the Southern Hemisphere.

Notes added later:

The High Energy Neutral Atom (HENA) imager on board the IMAGE S/C shows that the ring current is not smooth, and often does not completely encircle the equatorial zone of the earth. It is more prominent on the night side and as it moves into the dayside it breaks up and vanishes, possibly by losing particles into the magnetopause region. *Le et al.* [*Ann Geo*, *22(4)*, 1267, 2004] found that the ring current is very asymmetric in local time. Some current clearly circles the earth, but much of the energetic particles stays in the night hemisphere. These energetic particles appear not to be able to readily convect into the dayside magnetosphere. During quiet times the peak of the westward ring current is close to local midnight.

Dst is the sum of the magnetopause current (MPC, positive), the tail current (TC, negative) and the ring current (RC, negative). The MPC is largely a daytime current, while the TC is a nighttime current, so our Dsv should see mostly TC and not MPC.



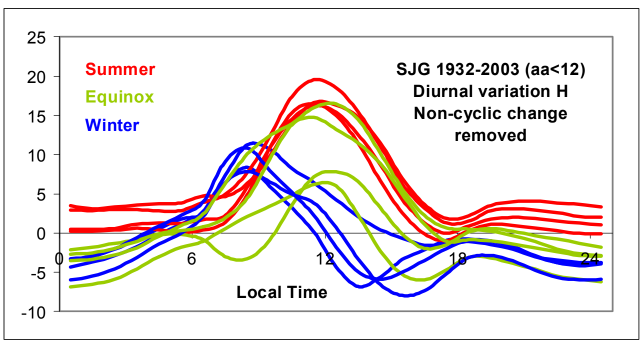


Figure 17.
Shows (top) the diurnal local time variation of the H-component at SJG on all days where not a single 3-hour interval had an *aa*-index value exceeding 12 over the interval 1932-2003. The main field has been removed. An average curve is shown for each month. The curves are color-coded according to season. Note the non-cyclic effect causing the right-hand values (the "25th" hour) to be higher than the left-hand values (the 0th hour). This is the *a*-coefficient of MK. Also note the different levels of the curves during the night where the Sq current system is absent. These correspond to the *b*-parameter of MK. We use the portion of the curves (six hours centered on local midnight) where they are essentially flat. This eliminates the need for estimating the highly variable Sq.

The magnitude of the diurnal variation depends on the conductivity of the ionosphere, which in turn depends largely on solar EUV flux. The F10.7 radio flux is often used as an (imperfect) proxy for the EUV flux. This flux varies over time as the number of active regions on the sun varies and as these are carried into and out of view by solar rotation.

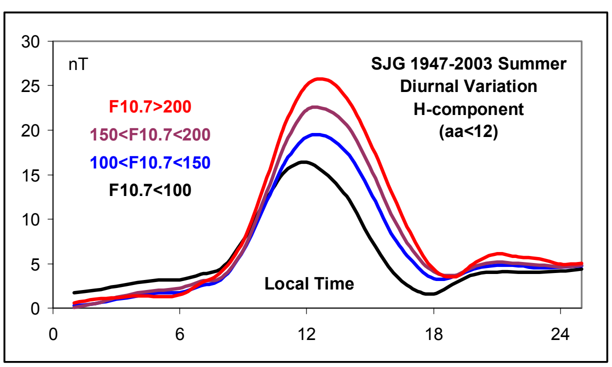


Figure 18

Shown is the effect on varying F10.7 flux on the magnitude of Sq or rather S_R. We show the average S at SJG for local summer months (May, Jun, Jul, Aug) on days when no three-hour interval had *aa* exceeding 12 (the "truly" quiet days) and further subdivided into four groups of increasing F10.7 flux (F<100, 100<F<150, 150<F<200, 200<F).

Variability of the EUV flux (measured by its proxy, F10.7) introduces variability of the day-to-day magnitude of S. Using a "smoothed" curve for each month does not take that variability into account and thus introduces extra noise into Dst. Figure 19 shows the maximum and minimum values for each month of F10.7. It is plain that there are days within each month (away from solar minima) where typically an additional 100 flux units (corresponding to 5-10 nT in Sq) are present. This in turn introduces systematic errors (always positive because we are subtracting an Sq that is too small) of up to 10 nT in daytime Dst-contributions. Since only one of the four Dst stations is near noon at any given time, one might hope that this systematic error might be decreased by a factor of four to about 2-3 nT. This particular systematic error depends on solar cycle phase and local terrestrial season.

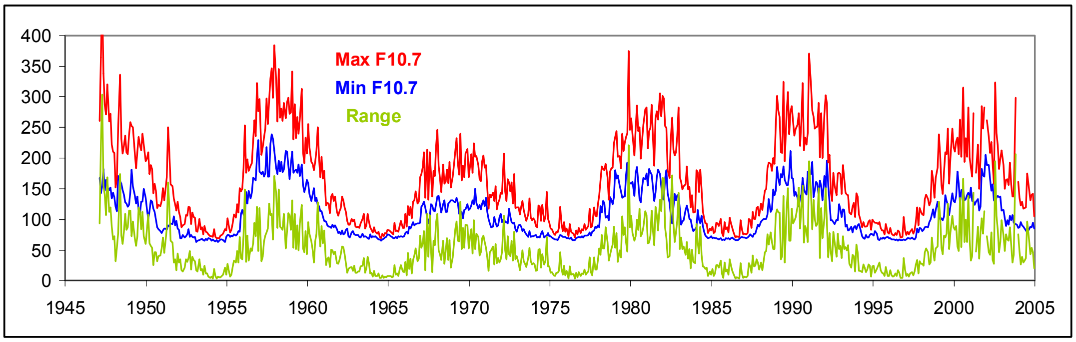


Figure 19

Another problem with determining Sq is day-to-day variations in the position of the Sq-focus (already noted by Hasegawa back in 1936 and even by Bartels in 1932). The magnitude of this effect at stations somewhat removed from the focus (as are the Dst stations) is about the same as the effect of varying EUV flux, but no clear systematic occurrence of short-term variations of the position of the focus have been demonstrated.

It was already clear from Figure 17 that there is a strong seasonal dependence in the shape of the Sq variation. Figure 20 shows this in more detail (for SJG) as a contour plot in month and local time:

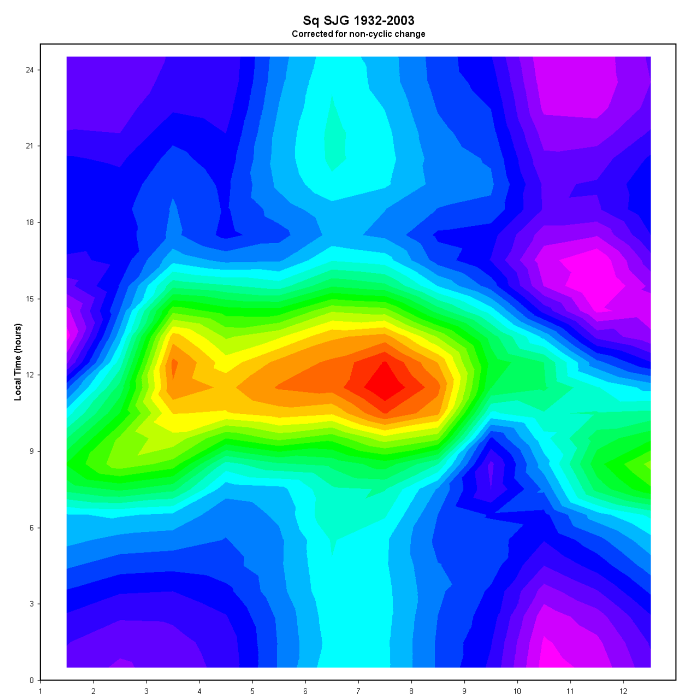


Figure 20.

The non-cyclic change has been removed (the *a*-coefficient), but the annual variation (the *b*-offset) has been left in and is clearly seen as the "ridge" down the middle of the Figure. There is a clear "fine-structure" of the Sq variation. If this fine-structure is a durable and characteristic pattern, then it should not be removed by "smoothing" and the order of the Fourier expansion should be high enough to adequately represent the structure.

We can check if the fine-structure is not merely accidental for this particular dataset by checking if the structure is present for other stations as well and if it persists over time.

SJG and HON have similar Sq patterns. Figure 21 shows Sq for SJG in the left-hand panel and for HON in the right-hand panel. We find similar fine-structures although the two stations are almost on opposite sides of the globe, thus answering the question affirmatively.

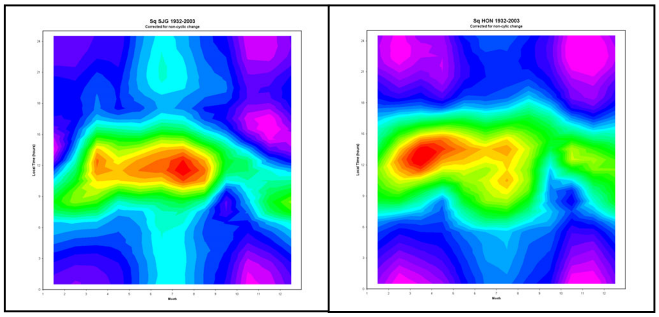


Figure 21

Figure 22 shows Sq for SJG separately for the intervals 1932-1956 and 1957-2003. The non-cyclic change has been left in, so this is raw data not distorted by any processing. In deriving the diurnal variation we only subtract the main field component. The structures in the two panels are virtually identical, showing that the fine-structure is permanent and reproducible. It is thus important not to remove the finer aspects of the Sq-variation by overly aggressive smoothing.

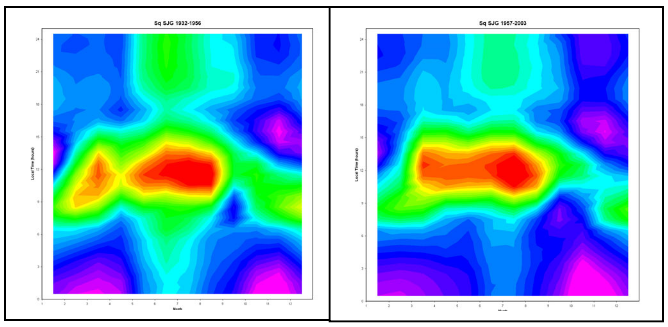


Figure 22

It would be of interest to see similar contour plots of MK’s smoothed 24x12-element Sq-matrix.

Because of all these problems with the proper identification and removal of Sq and because there is growing evidence that the ring-current is very asymmetric and is largely confined to the nightside, it seems advisable to only use nightside data in the construction of Dst.

The existence of the day-to-day (DTD) variability in S has been known for a long time. A recent study by *Xu and Kamide* (*JGR*, vol. *109*, A05217, doi: 10.1029/2003JA010216, 2004) also shows clearly that the DTD variability is as large as the diurnal variation itself (up to tens of nT). Accordingly, it should be taken into account in separating the quiet background and disturbance events, if dayside data is to be used at all..