Astrophys. Space Sci. Trans., 4, 41–45, 2008
www.astrophys-space-sci-trans.net/4/41/2008/

Astrophysics and **S**pace Sciences
Trans**a**ctions

Correct normalization of the *Dst* index

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Received: 5 December 2007 – Revised: 20 May 2008 – Accepted: 20 May 2008 – Published: 18 July 2008

Abstract. The *Dst* index has been one of the most important solar-terrestrial indices for decades, and it is used in numerous studies as a measure of the temporal development and intensity of magnetic storms and the ring current. Here we discuss two issues related to the relative and absolute normalization that are problematic to the *Dst* index. We show for the first time quantitatively that the magnetic disturbances at the four *Dst* stations are ordered according to the latitudinal projection of an equatorial disturbance upon the local horizontal component of the geomagnetic field. Therefore, the disturbances observed at each station should be first normalized by the cosine of the geomagnetic latitude of the station before they are averaged to form the *Dst* index. Perhaps surprisingly, the recipe to calculate the *Dst* index does not include this normalization and, therefore, must be revised on this part. We also discuss the effects of correcting the quiet-time seasonal variation, the so called "non-storm component" in the *Dst* index. This correction is seasonally varying, being largest around equinoxes and smallest at solstices, leading to an average correction (increase) of about 6 nT, i.e. about 25–30%, for annual averages of the *Dst* index. This increase also leads to significantly improved correlations between the corrected *Dst* index, the so called *Dcx* index, and many other indices of solar-terrestrial disturbance. We show here in detail that the correlation between the geomagnetic *Ap* index and the *Dcx* index ($\mathrm{cc} = 0.83$) is much higher than between *Ap* and *Dst* ($\mathrm{cc} = 0.60$). These results give further evidence that the *Dcx* index is a more truthful measure of magnetic storminess than the original *Dst* index.

1 Introduction

The *Dst* index is one of the most important solar-terrestrial indices which is used to study the temporal development and intensity of magnetic storms and the ring current. Major disturbances in the *Dst* index are negative, reflecting the westward drift of the energetic, positively charged ions produced during the storm and carrying a westward directed electric current. The *Dst* index has been calculated at the World Data Center WDC-C2 at Kyoto, Japan, since the International Geophysical Year, 1957, using data from four observatories at low to mid-latitudes (Hermanus, HER; Honolulu, HON; Kakioka, KAK; San Juan, SJG; for coordinates see, e.g. Table 1 in Karinen and Mursula, 2005).

We have recently reconstructed and extended the *Dst* index (Karinen and Mursula, 2005) using the original magnetic observations and following the *Dst* derivation method (see e.g. Sugiura, 1969; Sugiura and Kamei, 1991; WDC-C2, 2004) as closely as possible. The reconstructed *Dst* index (to be called here the *Dxt* index) has a correlation coefficient of 0.987 with the hourly values of the *Dst* index during the overlapping time interval of almost 50 years. As noted in Karinen and Mursula (2005), the *Dxt* index corrects some errors in the original *Dst* index and extends the time span of the *Dst* index by more than 25 years to start in 1932.

One methodological change was adopted in the derivation of the *Dxt* index as a difference to the *Dst* index. Without a detailed analysis, we chose to divide the disturbance $D(t)$ at each station by the cosine of the geomagnetic latitude of the station with the idea of so correcting for the latitude dependent projection of the equatorial disturbance field to the local horizontal component of the geomagnetic field. (We also take the centennial change of the latitude into account according to the varying IGRF models). The *Dst* index is then calculated as the average of these latitude corrected horizontal disturbances. As a comparison, in the original *Dst* recipe the disturbances at the four stations are first averaged and then normalized by the average of the cosines of the four latitude angles. Accordingly, no latitudinal correction is made there to the disturbances at the four stations, only a change to the overall normalization. Here we will show in detail for the

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Published by Copernicus GmbH on behalf of the Arbeitsgemeinschaft Extraterrestrische Forschung e.V.

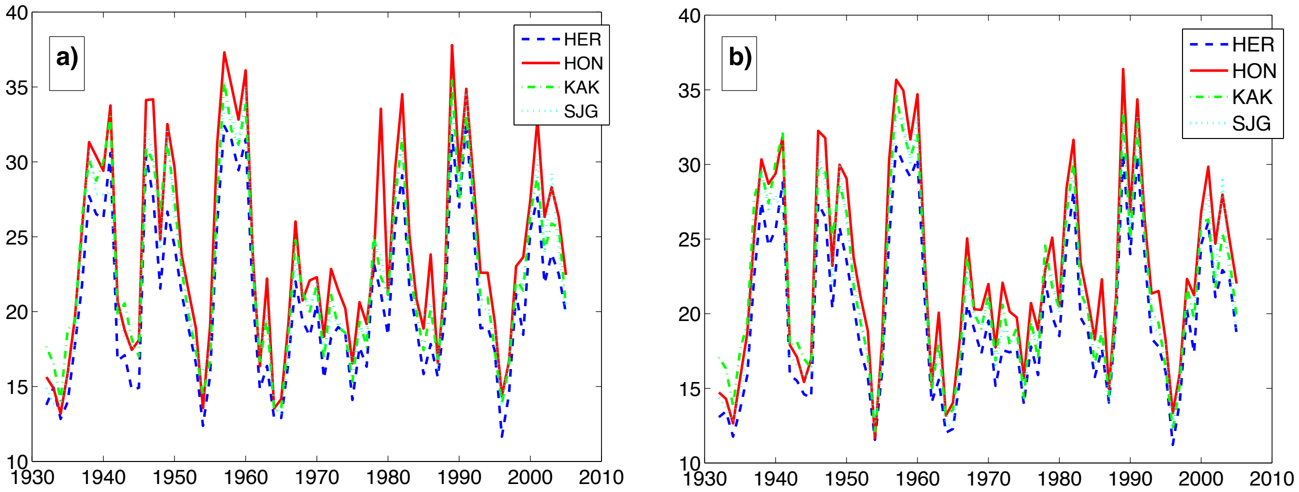

Fig. 1. Yearly standard deviations in 1932–2005 of magnetic disturbances D(t) at the four Dst stations according to **(a)** the *Dxt* index; **(b)** the *Dcx* index.

first time that the latitudinal normalization is indeed needed, and quantify the error included in the *Dst* index when ignoring such a normalization.

Some time ago it was noted (Cliver et al., 2001) that the semiannual variation of the *Dst* index is excessively large, with one half of the variation being completely unrelated to magnetic storms. This "non-storm component" in the *Dst* index arises from the seasonal quiet-time variation of the magnetic field which is erroneously eliminated from the quiet-day curve and, therefore, remains in the *Dst* index (and in the *Dxt* index which follows the *Dst* recipe on this part).

We have suggested a revised treatment of the quiet-day curve (Mursula and Karinen, 2005; Karinen and Mursula, 2006), which removes the excessive seasonal variation. In effect, the absolute level of the *Dst* index is corrected (raised) by a factor which depends on the season, with largest corrections taking place around the equinoxes. However, since the quiet-time variation remains roughly the same during a period of a few days, this correction does not change the temporal evolution of the index during an individual storm, only its overall level. We call the seasonally corrected *Dst/Dxt* index the *Dcx* index (*c* for corrected; *x* for extended). Here we show that this correction of the absolute level of the *Dst* index will greatly improve the correlation of the index with the most reliable measure of geomagnetic activity, the Ap index, which gives strong evidence that the *Dcx* index is a more truthful index of magnetic storminess than the *Dst* index.

2 Cosine normalization of individual disturbances

The *Dst* index is an hourly measure of global magnetic storminess which is calculated from the hourly averages of the magnetic H-component observed at the four *Dst* stations. The derivation of the *Dst* index contains two basic steps, the removal of the secular variation and the removal of the quiet-day variation, both of which are calculated using the five quietest days of each month. As a result, one obtains the hourly values of the local magnetic disturbances $D(t)$ for each station.

According to the original *Dst* recipe the four disturbances are then averaged to attain the global disturbance measure and, finally, the *Dst* index. No correction is made there for the different latitudinal location of the stations. In order to demonstrate the consequences of this recipe, we have calculated the yearly standard deviations of the hourly $D(t)$ values for each station. They are depicted in Fig. 1a for the *Dxt* index (the analogue of the *Dst* index) and in Fig. 1b for the quiet-time corrected *Dcx* index. The standard deviations reflect the annually averaged effect of the (mainly ring current related) disturbances at each station.

Figures 1(a) and (b) show that the standard deviations at all four stations and for both indices vary with the solar cycle and follow roughly each other. Since the $D(t)$ values of the four stations are used to calculate the *Dst* index, they should have the same standard deviations every year. However, Figs 1(a) and (b) show that the standard deviations of the four stations are systematically different. The largest deviations are found at the geomagnetically lowest station, Honolulu, and the smallest deviations at the geomagnetically highest station, Hermanus. This indicates that the differences in deviations are systematically ordered according to the latitude of the stations. Accordingly, the effect of the latitudinal projection is indeed important even over the rather modest latitude range (21.6°–33.9°) covered by the *Dst* stations.

Taking the largest and smallest standard deviation of any of the four stations each year, the annual difference between

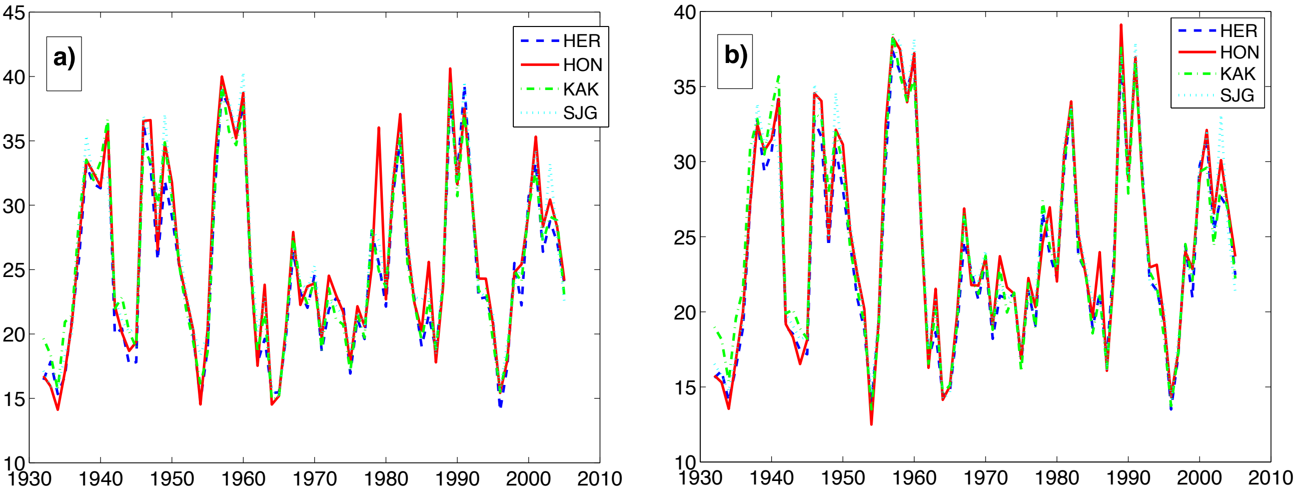

Fig. 2. As in Fig. 1 but the disturbances are normalized by the cosine of the geomagnetic latitude of the respective station.

the two deviations varies from 0.75 nT to 12.4 nT for the *Dxt* indices depicted in Fig. 1(a) (0.91 nT to 6.2 nT for the *Dcx* indices of Fig. 1(b)), with an average of 3.6 nT (3.2 nT, respectively). The fact that the largest differences between the stations are found during largest disturbances verifies that the differences are mostly due to systematic (not random) external disturbances. The relative annual difference varies from a few per cent to more than 30% (about 20%, resp.) with an average of about 15% in both indices.

For most years the largest standard deviation is obtained at HON and the smallest at HER, the HON-HER difference being on an average 3.2 nT (2.9 nT), thus explaining most of the above differences. Therefore, when averaging the disturbances of the four stations, the variability in the *Dst* index will include, on an average, roughly a 15% larger contribution from the HON station than from the HER station. Obviously, this is not a balanced situation.

Figures 2(a) and 2(b) depict the annual standard deviations from the four stations after first normalizing the individual *D(t)*'s by the cosine of the geomagnetic latitude of the respective station. One can see that the four standard deviations are very close to each other and depict no latitudinal ordering. Some differences between the annually largest and smallest standard deviations still exist but they are considerably smaller than in Figure 1, with an average of 2.29 nT for *Dxt* (Fig. 2a) and 1.88 nT for *Dcx* (Fig. 2b). After the cosine normalization, no single station pair has a dominant contribution to this difference. The largest average difference of only about 0.98 nT is found between HER and KAK (0.74 nT between HER and SJG, respectively). Thus, the differences between the normalized standard deviations are mainly random. This good agreement between the normalized disturbances proves that one really has to correct the disturbances by the cosine of the geomagnetic latitude of the respective station before the disturbances are averaged to form the various global indices. This strongly suggests a revision to the official *Dst* recipe on this part.

The good agreement between the normalized disturbances also proves that, at least at the annual resolution, the contribution of all non-equatorial current systems to the *D(t)* values, and therefore to the *Dst/Dxt/Dcx* indices, remains very small. This is obvious since the contribution from such non-equatorial currents like the ionospheric and field-aligned currents, would be inversely ordered in latitude, being strongest at the highest HER station and smallest at the lowest HON station. Note, however, that this argument does not apply to the Chapman-Ferraro or near-tail currents that are mainly equatorial.

3 Absolute level and correlations

As mentioned above, correcting the *Dst* index for its quiet-time seasonal variation raises the absolute level of the index by a factor which is seasonally variable. Figure 3 (analogous to Fig. 2 in Karinen and Mursula, 2006) depicts the averaged evolution of magnetic storms in each month according to the *Dxt* index which includes the excessive quiet-time variation, and to the corrected *Dcx* index which does not. While the temporal evolution of storms remains the same in both indices, the average monthly difference between the two index curves is seen to be largest at equinoxes (about 10–15 nT) and smallest at solstices (about 3–6 nT).

The effect of the quiet-time correction is even relatively larger in annual averages of the index because most index (absolute) values are quite small. Figure 4 (analogous to Fig. 4 in Karinen and Mursula, 2006) depicts the annual averages of the *Dxt* and *Dcx* indices and their differences in 1932–2005. Since the typical annual average is about 20 nT,

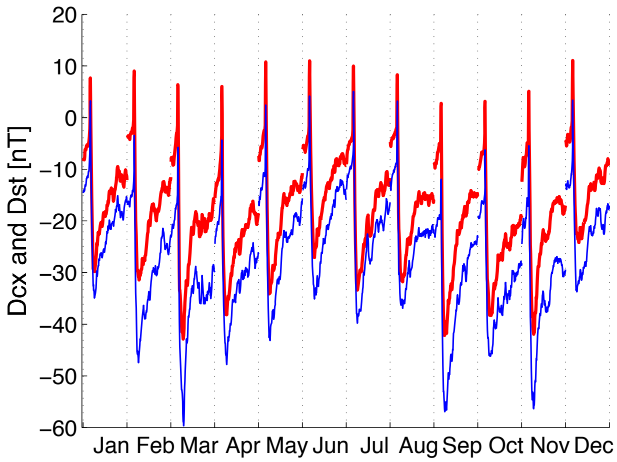

Fig. 3. The average evolution of storms for each month averaged over 1932–2005 according to the *Dxt* index (blue curve) and *Dcx* index (red curve).

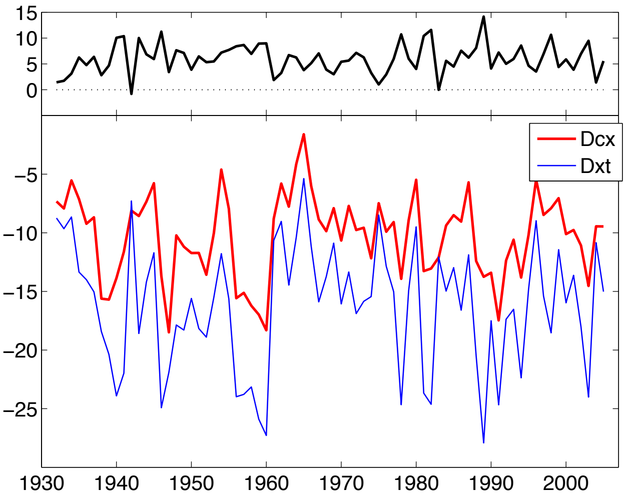

Fig. 4. Bottom panel: the annual averages of the *Dxt* index (thin blue line) and *Dcx* index (thick red line) in 1932–2005. Top panel: the *Dcx-Dxt* difference.

the average correction (rise) of about 6 nT marks a significant relative change of about 25–30%.

Taking into account the size of the quiet-time correction, it is interesting to study whether it affects the correlation of the index with other measures of geomagnetic or, more generally, solar-terrestral disturbance. Figures 5(a) and (b) depict the correlation between the annual averages of the geomagnetic *Ap* index (*Ap* is the linearized version of the Kp index) with the (absolute value of) annual *Dxt* and *Dcx* indices in 1932–2005. Correlation between *Ap* and the *Dcx* index (cc = 0.83) is much higher than with the *Dxt* index (cc = 0.60). This verifies that the correction essentially modifies the *Dst* index and that the (corrected) *Dcx* index is a more truthful presentation of magnetic disturbances and storminess than the original *Dst* index.

Positive *Dst* values are mainly due the compression of the dayside magnetosphere, typical for the initial phase of storm, while strongly negative values are due to magnetic reconnection and the formation of the ring current during the storm main phase. Therefore, positive and negative values of the *Dst* index reflect different physical processes. We have calculated the annual averages of the *Dxt* and *Dcx* indices using only their positive or negative values. These values are called the Dxt^+ and Dxt^- indices (Dcx^+ and Dcx^- indices, correspondingly). We have correlated the positive and negative indices with the *Ap* index separately. The correlation between Dcx^+ and *Ap* (cc = 0.60) is somewhat better than between $Dcxt^+$ and *Ap* (cc = 0.51). However, there is no difference in the correlation between $Dcxt^-$ and *Ap* (cc = 0.79) and Dcx^- and *Ap* (cc = 0.78). Since the range of negative values is larger (and physics simpler, so scatter smaller) than the range of positive values, the correlation of negative values with *Ap* is considerably larger than for positive values. The effect of correction raises a number of slightly negative values to positive values which has little effect upon the large negative values but a relatively larger effect on positive values whose range and correlation are thereby increased.

As shown earlier (Karinen and Mursula, 2006), the quiet-time correction also improves the correlation with sunspot numbers. The correlation coefficient between the square root of annual sunspot numbers with the (absolute values of) annual *Dxt* indices is 0.53 and with the *Dcx* indices 0.61. For positive index values they are 0.67 and 0.81, and negative index values 0.79 and 0.82, respectively. Both positive and negative values separately give a better correlation with sunspots, indicating that the different processes they describe depend differently on solar activity. Anyway, in all cases the correlation of sunspot activity with the *Dcx* indices is better than with the *Dxt* indices.

4 Conclusions

We have discussed here the normalization of the magnetic disturbances at the four *Dst* stations with different latitudes. We have shown for the first time in detail and quantitatively that the disturbances are ordered according to the latitudinal projection of an equatorial disturbance upon the local horizontal component of the geomagnetic field. Therefore, the disturbances at the different stations should be normalized by the cosine of the geomagnetic latitude of the station before the *Dst* index is constructed from them. Otherwise, the four *Dst* stations are weighted differently in the *Dst* index, with contributions to the average annual deviations differing by about 15%. The recipe to calculate the *Dst* index does not include this normalization and should be revised on this part. We have included the normalization in the new *Dxt* and *Dcx* indices. We also noted that the good agreement between

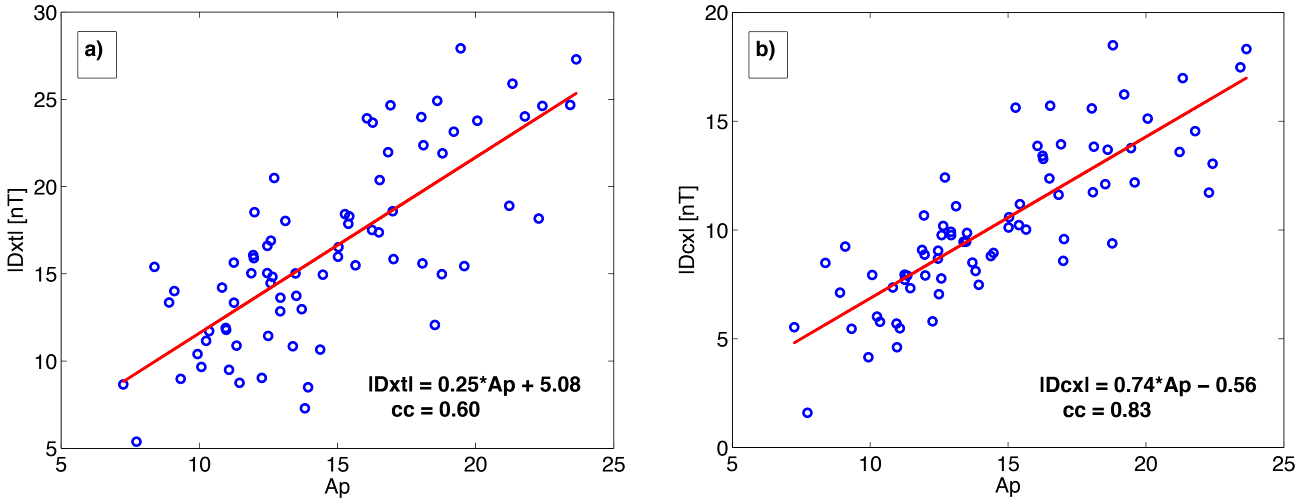

Fig. 5. Scatterplot and best fit line between the annual averages of the geomagnetic *Ap* index and the absolute values of the annual averages of **(a)** the *Dxt* index; **(b)** the *Dcx* index.

the cosine normalized disturbances proves that, at least at the annual resolution, the contribution of any non-equatorial current systems to the *Dst/Dxt/Dcx* indices, e.g. from the ionospheric and field-aligned currents, must remain very small.

We have also discussed the effect of correcting the quiet-time seasonal variation, the so called "non-storm component" in the *Dst* index. As found earlier (Karinen and Mursula, 2006), for annual averages the average correction is about 6 nT, implying a rise of the index by about 25–30%. The correction is seasonally varying, being largest around equinoxes (about 10–15 nT) and smallest at solstices (about 3–6 nT). While the temporal evolution of storms remains the same in both indices, the average level is significantly increased which is also reflected in the various correlations with other indices indicating solar-terrestrial disturbance. We have shown here that the correlation between *Ap* and the *Dcx* index (cc = 0.83) is much higher than between *Ap* and the *Dxt* index (cc = 0.60), verifying that the quiet-time correction essentially modifies the *Dst* index and makes the *Dcx* index a more truthful presentation of magnetic storminess. We showed that this improvement is due to the upward shift of the *Dst* distribution which raises a number of slightly negative values to positive values, thus correcting their classification and improving their correlation with the Ap index.

Concluding, the normalization of the *Dst* index must be revised in two ways. Firstly, it must be constructed from cosine normalized local disturbances. Secondly, the seasonally varying quiet-time level must be removed. The *Dcx* index includes these corrections and is shown to be a considerably improved measure of magnetic storminess than the original *Dst* index.

Acknowledgements. Financial support by the Thule Institute of the University of Oulu is gratefully acknowledged.

Edited by: R. Vainio
Reviewed by: three anonymous referees

References

Cliver, E. W., Kamide, Y., Ling, A. G., and Yokoyama, N.: Semiannual variation of the geomagnetic *Dst* index: Evidence for a dominant nonstorm component, J. Geophys. Res., 106, 21 297–21 304, 2001.

Karinen, A. and Mursula, K.: A new reconstruction of the *Dst* index for 1932–2002, Ann. Geophys., 23, 475–485, 2005.

Karinen, A. and Mursula, K.: Correcting the *Dst* index: Consequences for absolute level and correlations, J. Geophys. Res., 111, A08207, doi:10.1029/2005JA011299, 2006.

Mursula, K. and Karinen, A.: Explaining and correcting the excessive semiannual variation in the *Dst* index, Geophys. Res. Lett., 32, L14107, doi:10.1029/2005GL023132, 2005.

Sugiura, M.: IAGA Resolution 2, in IAGA Bulletin, Madrid, Spain, 27, 123, 1969.

Sugiura, M. and Kamei, T.: Equatorial *Dst* index 1957–1986, in IAGA Bull., 40, edited by A. Berthelier and M. Menvielle, ISGI Publ. Off., Saint-Maur-des-Fossés, France, 1991.

WDC-C2, Definition of the *Dst* index. The World Data Center for Geomagnetism (WDC-C2), http://swdcdb.kugi.kyoto-u.ac.jp, Kyoto, Japan, 2004.