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Uneven weighting of stations in the Dst index

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ABSTRACT

We note in this paper that the average disturbances of the four *Dst* stations are systematically different and, therefore, the stations contribute to the *Dst* index by unequal weights. This is an important problem, e.g., for the estimated longitudinal asymmetries of the ring current and the long-term averages of the *Dst* index where the contribution of the most dominant station (HON) is twice as large as the weakest station (KAK). We use an extended network of stations to demonstrate that the averaged local *Dst* indices are ordered according to the station's geographic longitude, with westernmost stations depicting the largest disturbances and contributions to the *Dst* index and easternmost the smallest. We show that the problem is related to the way that the quiet days are treated in the *Dst* recipe. We modify the recipe so that UT-fixed quiet days are used in all stations, whence the corrected local *Dcx* indices have equal weights at all stations. This gives strong support for using the corrected *Dcx* index instead of the *Dst* index.

1. Introduction

Several magnetic indices have been developed that describe some aspects of the near-Earth space currents, and allow to study the impact of solar wind upon the Earth's space environment over long time intervals. The *Dst* index is one of the most important solar-terrestrial indices, which aims to describe the temporal development of magnetic storms and the intensity of the ring current, although other current systems also have, at least occasionally, a significant contribution to the *Dst* index (see, e.g., Burton et al., 1975; Campbell, 1996, 2004). During magnetic storms the *Dst* index depicts a large negative deflection, reflecting the westward drift of the energetic, positively charged ions produced during the storm and carrying a westward directed electric current. The *Dst* index is being 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 of these and other stations used here, see Table 1).

Although *Dst* index proxies based on other principles have also been developed recently (see, e.g., Love and Gannon, 2009; Xu et al., 2008), we (Karinen and Mursula, 2005) have recalculated the *Dst* index following the original *Dst* derivation method (see, e.g., Sugiura, 1969; Sugiura and Kamei, 1991; WDC-C2, 2004) as closely as possible and using the original data from the above mentioned four magnetic stations. This extended and reconstructed *Dst* index is called the *Dxt* index, and has a correlation coefficient of 0.987 with the hourly values of the *Dst* index during the overlapping time interval of about 50 years. As noted earlier (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.

The *Dst* index is known to include an excessively large seasonal variation which is unrelated to magnetic storms (Cliver et al., 2001) and therefore artificial. This "non-storm component" 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). A modest revision in the treatment of the quiet day curve removes this excessive component (Mursula and Karinen, 2005; Karinen and Mursula, 2006). We call the *Dst*/*Dxt* index without the excessive seasonal variation the *Dcx* index (*c* for corrected; *x* for extended). In effect, the absolute level of the *Dcx* index is raised by a factor which depends on the season, with largest corrections taking place around the equinoxes. However, since the typical time duration of a storm is rather short, the temporal evolution of all the three indices remains quite similar during any individual storm, only the overall levels are different and seasonally varying.

Here we report of another problem in the *Dst* index: The average disturbances of the four *Dst* stations are systematically different. Accordingly, the stations contribute to the *Dst* index by unequal weights. The paper is organized as follows. In Section 2 we present the problem and the level of the difference between the stations and discuss its consequences. Then, in Section 3, using an extended network of stations, we demonstrate convincingly that the disturbances are ordered according to the station's geographic longitude, with westernmost stations

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Table 1
Names, codes and coordinates of stations of the extended network.

Station	Geographic		Geomagnetic	
(IAGA code)	Lat.	Long.	Lat.	Long.
Alma Ata (AAA)	43.25°N	76.92°E	34.29°	152.74°
L'Aquila (AQU)	42.38°N	13.32°E	42.42°	94.50°
Canberra (CNB)	35.32°S	149.4°E	−42.71°	226.94°
Crozet (CZT)	46.43°S	51.86°E	−51.35°	113.27°
Del Rio (DLR)	29.49°N	100.9°W	38.30°	327.31°
Eyerewell (EYR)	43.41°S	172.4°E	−47.11°	253.83°
Gnangara (GNA)	31.78°S	116.0°E	−41.93°	188.84°
Guimar (GUI)	28.32°N	16.44°W	33.78°	60.59°
Hartebeesthoek (HBK)	25.88°S	27.71°E	−27.13°	94.40°
Hermanus (HER)	34.43°S	19.23°E	−33.98°	84.02°
Honolulu (HON)	21.32°N	158.0°W	21.64°	269.74°
Kakioka (KAK)	36.23°N	140.2°E	27.37°	208.75°
Lanzhou (LZH)	36.09°N	103.8°E	25.86°	176.1°
San Juan (SJG)	18.11°N	66.15°W	28.31°	6.08°
Trelew (TRW)	43.25°S	65.32°W	−33.05°	5.62°
Tucson (TUC)	32.17°N	110.7°W	39.88°	316.11°
Vassouras (VSS)	22.40°S	43.65°W	−13.29	26.61°

depicting the largest disturbances and contributions to the *Dst* index, and easternmost the smallest. In Section 4 we discuss how the geographic dependence is related to how the quiet days are treated in the original *Dst* recipe. We correct the *Dst* recipe for this error in Section 5 and show that the seasonally corrected *Dcx* index depicts equal weighting from all stations. In Section 6 we demonstrate how, using UT fixed quiet days, the local *Dcx* indices, but not the local *Dst* indices, of the four stations are practically zero during quiet days. Accordingly, as the final conclusion we note that the original *Dst* index cannot be corrected for this problem, which gives strong support for using the corrected *Dcx* index instead of the *Dst* index.

2. Unequal weighting of Dst stations

The global *Dst* index is an hourly measure of magnetic storminess which is calculated as an average of the local disturbances, or local *Dst* indices, observed in the magnetic H-component of the four *Dst* stations. The derivation of the local *Dst* indices 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. The local disturbances must also be normalized by the cosine of the geomagnetic latitude of the station in order to correct for the latitude dependent projection of the equatorial disturbance to the local horizontal component of the geomagnetic field. We have recently reanalyzed this question in detail and shown that magnetic variability at the four *Dst* stations indeed becomes equal by cosine normalization (Mursula et al., 2008). However, although the need for this normalization is known since long and is even part of the original recipe, no such correction is made at WDC-C2. On the other hand, the *Dxt* and *Dcx* indices do take this latitude correction into account. (The centennial change of the geomagnetic latitude is taken into account according to the varying IGRF models in our 75-year long index series).

Fig. 1 depicts the yearly averaged *Dxt* and *Dcx* indices for the four *Dst* stations. The upper row shows the actual, latitude normalized indices and the lower row shows the corresponding disturbances that have not been normalized by the cosine of station's geomagnetic latitude. One can see in Fig. 1a that the *Dxt* (i.e., *Dst*) indices of the four stations are at completely different levels, HON showing systematically the largest disturbances (lowest index values) and KAK the smallest. If one takes every year the difference between the highest and lowest value, the average difference in 1932–2007 is about 14.8 nT. The mean difference between KAK and HON is 14.2 nT, which shows the systematic ordering of the station disturbances. HER is slightly below KAK, with an average difference of about 2.4 nT, and SJG about 7.8 nT below HER.

Accordingly, Fig. 1a shows that HON registers, on an average, roughly twice larger annually averaged disturbances than KAK, and thereby contributes roughly twice more strongly to the global *Dst* index at time scales longer than a couple of weeks. Obviously, this immediately imposes a problem, since a situation where one station measures the ring current to be, on an average, much stronger than another station in physically untenable. As we will show later, this problem is related to the treatment of the quiet daily variation, and can easily be solved by slightly modifying the *Dst* recipe on this part.

We would like to emphasize that both the *Dst*, *SymH* and *AsyH* indices suffer from this problem. In particular, this problem affects various estimates of the longitudinal asymmetry of the ring current like the *AsyH* index, and studies aiming to estimate (Søraas et al., 2004; Maltsev and Ostapenko, 2004; Shi et al., 2005; Kalegaev et al., 2008) or model the ring current asymmetry (Jordanova et al., 2009). Also, any results based on the long-term evolution of the *Dst* index, like those aiming to extract the long-term evolution of the heliospheric magnetic field from the *Dst* index (Svalgaard and Cliver, 2005) are affected. Although the average difference between the stations is not very large compared to typical disturbances during an intense storm, it is large enough to affect the longer and less intense storms due to high-speed streams, leading to long intervals of moderate activity called HILDCAA (high intensity long duration continuous AE activity; Tsurutani and Gonzalez, 1987; Tsurutani et al., 2006).

Comparing Figs. 1a and b shows that this problem has nothing to do with the latitudinal normalization of indices. In fact, the above mentioned systematic ordering of station averages remains the same and the mean differences between the four stations using unnormalized indices are only slightly smaller than for normalized indices. E.g., the mean maximum–minimum station difference in Fig. 1b is 14.1 nT, and the KAK–HON (HER–SJG; KAK–HER) difference is 13.6 nT (7.2 nT; 1.4 nT, respectively). (Actually, the ratio between the largest unnormalized and normalized differences roughly corresponds to the cosine of a typical station latitude.)

Fig. 1 also shows that this problem is less severe in the *Dcx* index. E.g., in the normalized local *Dcx* indices depicted in Fig. 1c, the average difference between the highest and lowest value is about 5.0 nT, and between KAK–HON (HER–SJG; KAK–HER) about 4.9 nT (2.2 nT; 1.4 nT, respectively). As mentioned above, the seasonal correction adopted in the *Dcx* index raises the absolute level of this index somewhat higher than in the *Dst* index. This correction is seen to most effectively raise the level of the most disturbed stations (HON and SJG), thereby also considerably decreasing the inter-station differences. However, since the absolute level of the global *Dcx* is at about −10 to −15 nT only, the relative contributions of the four stations still differ by some 30–40%. Thus, it is important to try to correct this problem even in the *Dcx* index. (As we will see later, the correction of seasonal variation adopted in the *Dcx* index and the solution of the present problem are connected.) Fig. 1d shows that, as for the *Dxt* index, latitudinal cosine normalization does not much help in alleviating the problem of inter-station differences.

Fig. 2 shows the UT distribution histograms of local *Dcx* indices smaller than −50 nT observed at HON and KAK stations in 1932–2008. The distributions in both cases reproduce the well known fact that the largest disturbances are found in the local