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A model for the diurnal universal time variation of the *Dst* index

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Abstract. Using a simple model for the asymmetric ring current, we show that the main reason for the diurnal universal time (UT) variation of *Dst* index is the uneven distribution of the *Dst* network stations. The model takes into account the four *Dst* stations and the strong disturbance due to the partial ring current in the 1800 LT sector. In agreement with the equinoctial theory the diurnal variation is found to be larger in local summer than winter for Hermanus (HER). However, while Hermanus is the only Southern Hemisphere *Dst* station, this leads to a larger UT variation in the *Dst* index in the Northern Hemisphere summer. Moreover, we find evidence that the diurnal LT minimum is shifted by a couple of hours closer to the midnight during local winter, supporting the Malin-Isikara effect. We also note that the Russell-McPherron (RMP) effect is in phase (out of phase) with the modeled diurnal variation of the *Dst* index around vernal (autumnal) equinox, thus increasing (decreasing) the diurnal variation in the *Dst* index in spring (fall) by 20-30%. However, the RMP effect is not responsible for the overall diurnal UT variation of the *Dst* index.

1. Introduction

The *Dst* index is intended to describe the evolution of the ring current, although there is some influence from other current systems as well [*Campbell*, 1996]. It is calculated from the horizontal component of the magnetic field measured at four low- to midlatitude observatories. (These observatories are listed in Table 1.) It is known since long that the *Dst* index has a diurnal universal time (UT) variation [*Mayaud*, 1978, 1980; *Saroso et al.*, 1993; *Takalo et al.*, 1995; *Siscoe and Crooker*, 1996; *Cliver et al.*, 2000]. We show this variation for the years 1957–1998 in Figure 1. The diurnal UT variation is calculated by a superposed epoch analysis from the hourly *Dst* values. It is seen that the average diurnal UT variation for this 42-year interval is ~2.5 nT. The maximum of this variation (minimum disturbance) is at 1300 UT and the minimum (maximum disturbance) at 2200 UT. There is also a secondary minimum at ~0600 UT and a small secondary maximum at ~0200 UT.

Mayaud [1978] showed that the phase of the diurnal UT variation is independent of season and concluded that this variation is probably due to the uneven local time distribution of the partial ring current and the nonuniform longitudinal distribution of the *Dst* stations. *Saroso et al.* [1993] found the minimum number of large negative values in the 3-hour *Dst* at 1200–1500 UT. They noted that this does not coincide with the diurnal minimum of *ap* index. However, the diurnal variation in the derivative of *Dst* index was found to agree with the variation of the *ap* index. As an alternative explanation, *Siscoe and Crooker* [1996] suggested that the Russell-McPherron (RMP) [*Russell and McPherron*, 1973] effect is the main reason for the diurnal UT variation in the *Dst* index.

In this study we present a model for the diurnal UT variation in the *Dst* index. This model is based on the uneven longitudinal location of the *Dst* stations and on the fact that the horizontal field at each station has a maximum disturbance around 1800 local time (LT) when the effect of the partial ring current to the horizontal magnetic field and to the *Dst* index is largest [*Cummings*, 1966; *Siscoe and Crooker*, 1974; *Mayaud*, 1978]. In section 2 we discuss the diurnal variation in horizontal component at individual stations. The description and predictions of the model are given in section 3. In section 4 we discuss the seasonal differences of the diurnal variation and the long-term change of the UT diurnal variation in the *Dst* index. In section 5 we give our conclusions.

2. Diurnal Variation at *Dst* Stations

Cummings [1966] studied the diurnal variation of magnetic field at *Dst* stations. He analyzed the horizontal field magnitude of the two *Dst* stations, Honolulu (HON) and San Juan (SJG), and showed that the diurnal frequency histogram of values with $-\Delta H = H_{QD} - H \geq 100$ nT is centered at 1800 LT for low-latitude stations.

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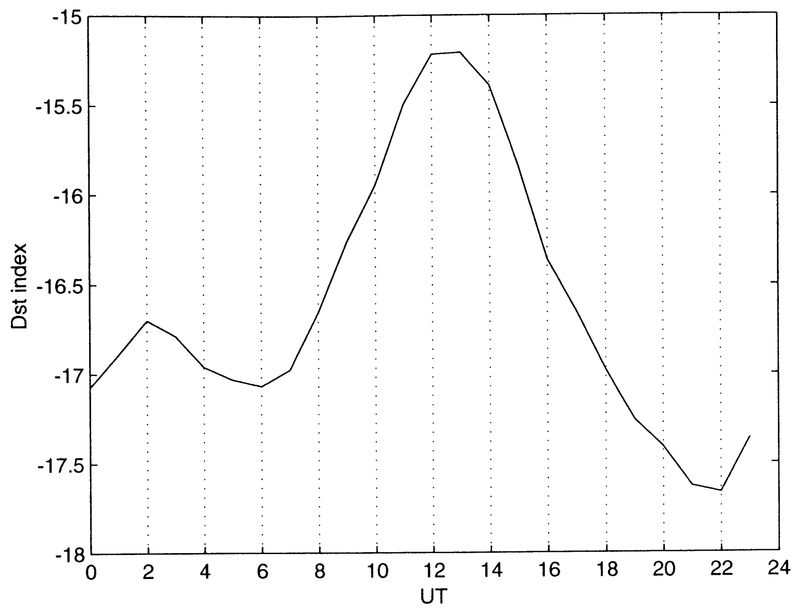

Figure 1. The diurnal UT variation of the *Dst* index in 1957–1998.

The characteristic superposed diurnal UT variation of KAK for the years 1970–1972 is plotted in Figure 2a. The solid curve corresponds to all days in 1970–1972, and the dashed curve to the international quiet days in 1970–1972 (60 days/y). It should be noted that the morning hours in the quiet-day curve are biased such that the H values are too low. This is because the tails of the previous more disturbed days still slightly affect the next, more quiet days. When we subtract the quiet-day curve from the all-day curve, we get the UT variation of the difference ΔH shown in Figure 2b. Note that the biasing effect leads to too high values of during morning hours. There is a clear minimum of KAK at ~0900 UT. Since the LT time at KAK is ~9 hours ahead of the UT time (see also Table 1), this minimum is at ~1800 LT. Accordingly, the maximum disturbance is observed in the early evening LT sector in accordance with *Cummings* [1966]. This result is confirmed by a similar analysis for HER, HON, and SJG in Figures 3a, 3b, and 3c, respectively. The maximum disturbances (ΔH minima) are at 1700–1800 UT for HER at 0600–0700 UT for HON and at 2200–2300 UT for SJG. Taking the time difference between LT and UT for these stations all these minima correspond to the local early evening (1800–1900 LT) at the sites of the stations.

It is now easy to understand some of the features in the diurnal UT variation of the *Dst* (see Figure 1) on the basis of the ΔH curves of the individual *Dst* stations. The absolute diurnal minimum in the *Dst* index at ~2100–2200 UT is caused by the minima of HER and SJG, while the secondary minimum at ~0600 UT is caused by the minima at HON and KAK. The diurnal maximum in the *Dst* index is at 1200–1300 UT because at that time none of the *Dst* stations is located at late afternoon LT sector and two stations (HON and SJG) have their diurnal maxima close to this time.

3. Model of Diurnal Variation

In this section we present a model for the diurnal variation of the *Dst* index which is based on the superposition of the model ΔH of the four *Dst* stations. We model the diurnal variation of the horizontal field at one station with the following formula:

$$\Delta H^m(t) = -k \exp[\cos(t - \mathrm{UT_{LGM}} + D)], \qquad (1)$$

Table 1. Geographic Coordinates and the Universal Times of the Local Geomagnetic Midnight of the Four Magnetometer Stations Used in the *Dst* index

Station	IAGA Code	Geographic Latitude	Geographic Longitude	CGM Latitude	CGM Longitude	LGM UT Time (Epoch 1980)
Hermanus	HER	-34.42°	19.23°	-42.06°	80.96°	23.48
Kakioka	KAK	36.23°	140.18°	28.76°	210.76°	15.06
Honolulu	HON	21.32°	202.00°	21.88°	268.70°	11.13
San Juan	SJG	18.12°	293.85°	29.99°	8.29°	4.12

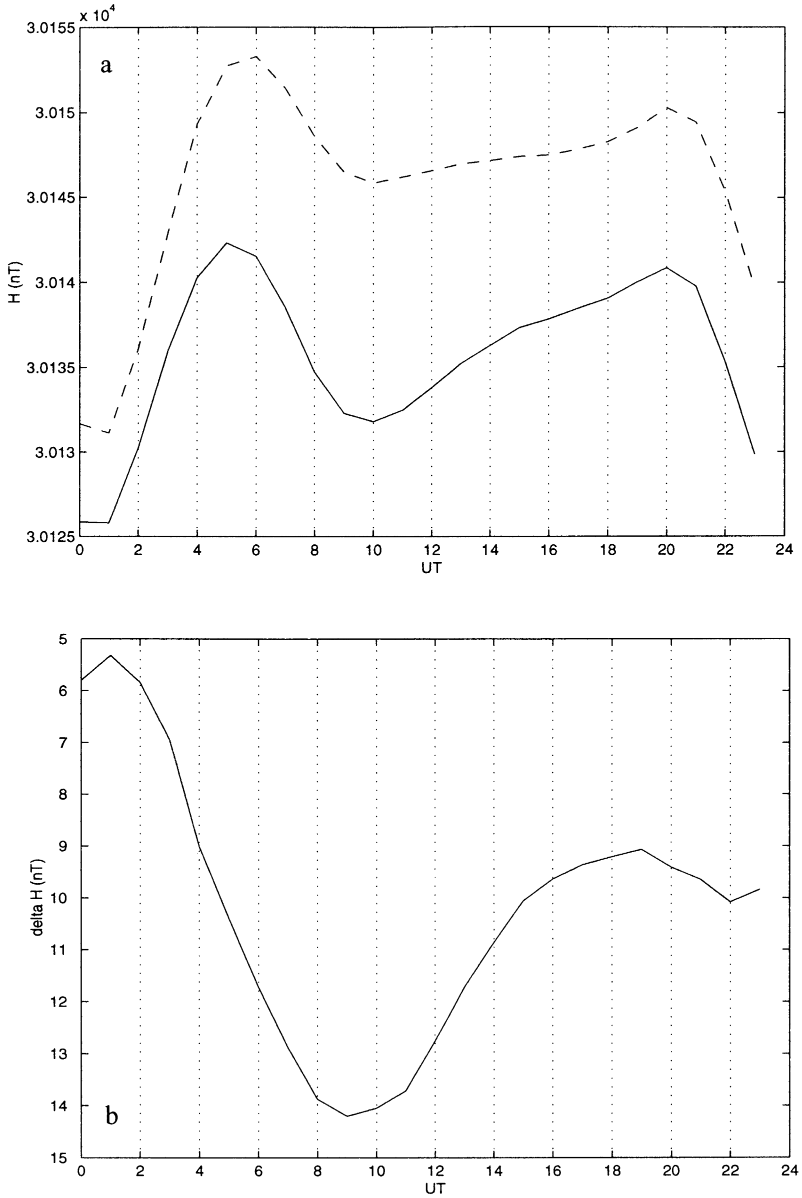

Figure 2. (a) The diurnal UT variation of the H component of the magnetic field at KAK. Solid line represents all days of 1970-72 and dashed line the international quiet days of 1970–1972. (b) Difference ΔH of the curves in Figure 2a.

where UT_{LGM} is the UT time of the local geomagnetic midnight at the site of the station, and D (here D = 6 hours) is the time difference of the diurnal maximum disturbance from the local geomagnetic midnight (LGM). The coefficient k is a normalization factor, including also the reciprocal of the cosine of the station's mean geomagnetic latitude. The form of this function is shown in Figure 4 for KAK with $UT_{LGM} = 15.06$. The diurnal minimum is found at about the same UT time as for the original KAK data (see Figure 2b).

When we superpose the form of (1) for the four Dst stations as a function of UT time, we obtain the diurnal UT variation ΔH (model) depicted in Figure 5. This curve has been scaled to have the same mean and standard deviation as the 42-year averaged diurnal variation of the Dst index shown in Figure 1. The stations are marked in Figure 5 according to the UT time of their 1800 LT sector. We note that the overall form of the diurnal UT variations in Figures 1 and 5 are very similar. However, the morning (0200 UT) maximum is higher and the two diurnal minima more equal in the model curve. We suggest that these differences are mainly due to the hemispheric asymmetry of the Dst index and the seasonal differences to be discussed below.

4. Seasonal Differences in the Diurnal UT Variation

In Figures 6a, 6b, 6c, and 6d we plot the diurnal UT variations of the Dst index for spring (February-

April), summer (May-July), fall (August-September), and winter (November-January) months of 1957–1998, respectively. (Thus the seasons refer to the Northern Hemisphere unless otherwise stated.) We analyze these differences with the help of the above presented model. Note first that the overall diurnal variations in all the four seasons have roughly similar shape in agreement with *Mayaud* [1978]. However, the diurnal variation is smaller (~1.8 nT) in winter than in summer (~ 2.4 nT). Summer-winter differences are also found at individual stations. Figure 7a shows the diurnal variation of Hermanus (HER) during the summer (June-July only, solid curve) and winter (December-January only, dash-dotted curve) for the years 1970–1972. At HER

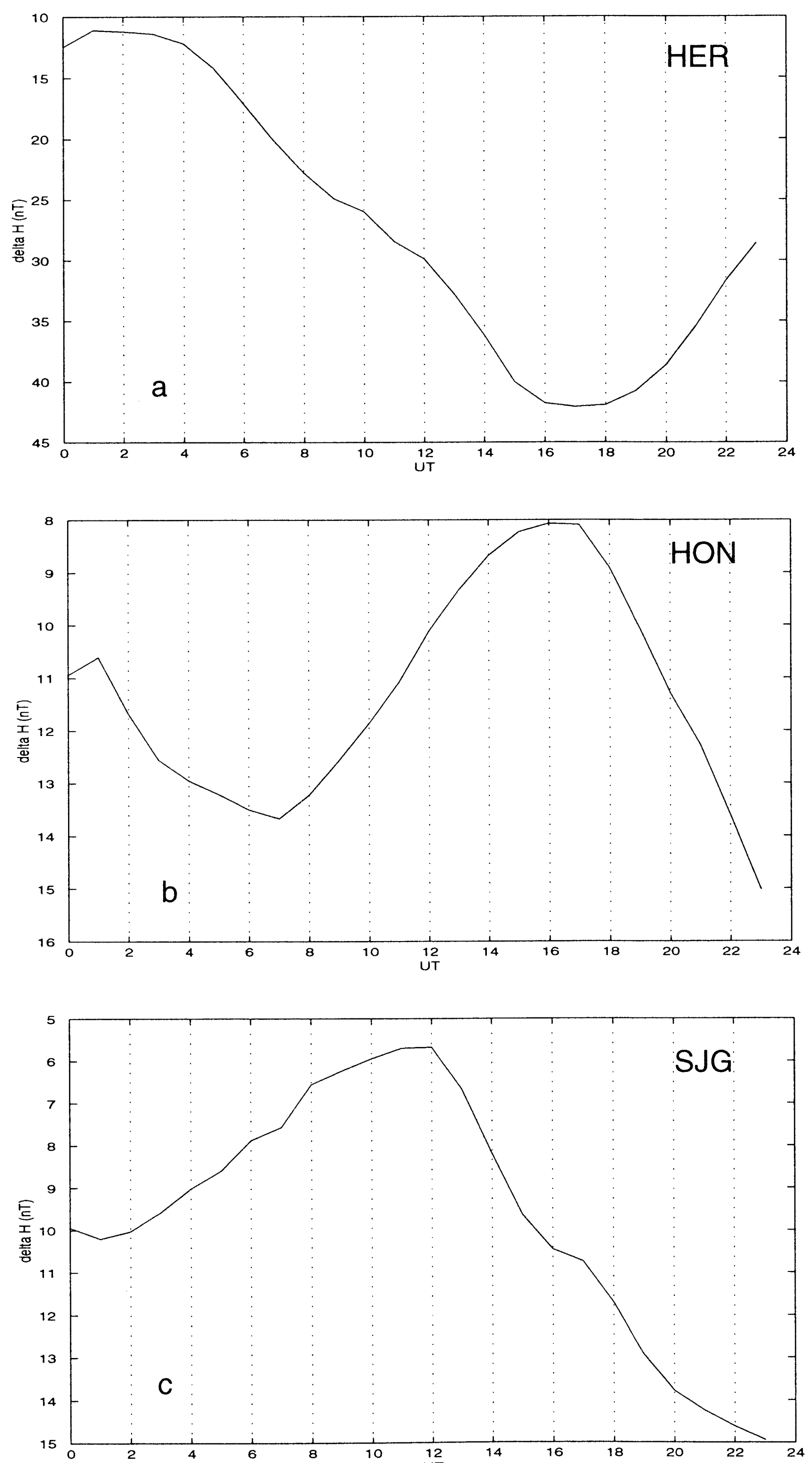

Figure 3. The same difference ΔH as in Figure 2b for (a)Hermanus (HER), (b) Honolulu HON, and (c) San Juan (SJG).

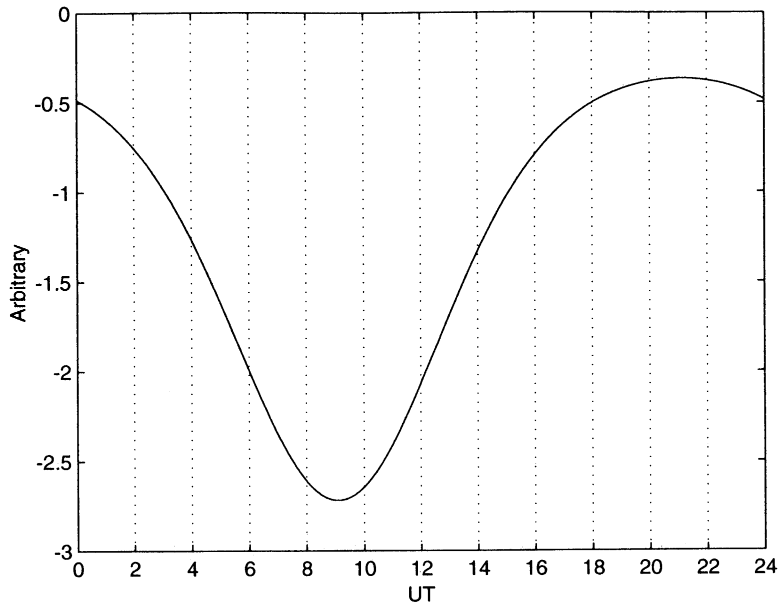

Figure 4. The form of the ΔH^m calculated from (1) for KAK.

the diurnal variation in summer is ~20–30% smaller than in winter. This difference is mainly due to the smaller activity in summer in the early evening sector, in agreement with the effect of the equinoctial mechanism [*McIntosh*, 1959; *Boller and Stolov*, 1970; *Cliver*, 2000]. Similarly, the activity is smaller at HON (see Figure 7b) in summer in the early evening sector at ~1630 UT, the time of the minimum summer activity according to the equinoctial mechanism. (Also, there is evidence that the activity at HON is smaller in winter in the morning sector, close to the 0430 UT winter minimum of the equinoctial mechanism.) Since the UT time of the equinoctial effect roughly coincides with the time of the main disturbance at HER, this leads to a larger diurnal variation in winter than in summer. On the other hand, the two effects are out of phase for HON, leading to a smaller diurnal variation in winter than summer.

Accordingly, the different stations have different weights in the diurnal UT variation of the *Dst* index in different seasons. This must also be taken into account in the model. For example, when modeling the diurnal UT variation of the *Dst* in winter, we weight HER data by a factor 1.25 with respect to the other stations, corresponding to the above mentioned fact (see Figure 7a) that the variation at HER is ~20–30% larger dur-

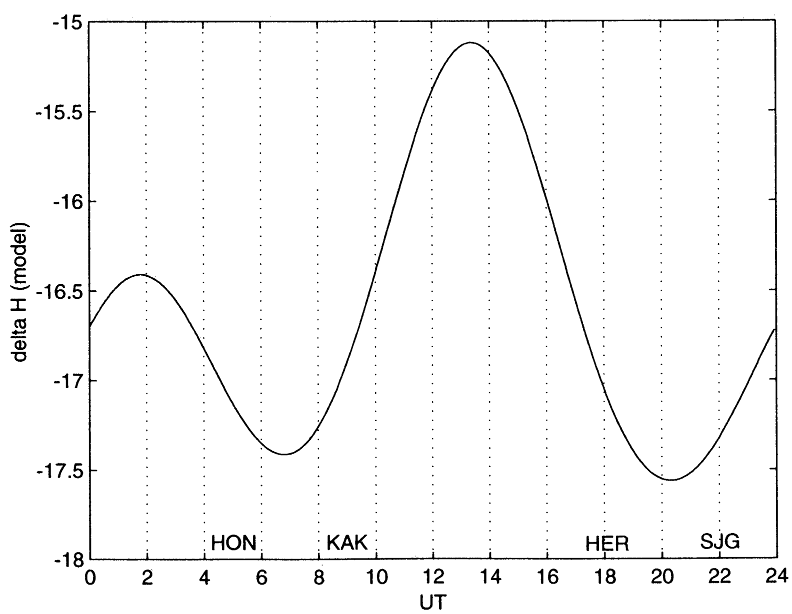

Figure 5. The superposition of the ΔH^m values of all the four *Dst* stations.

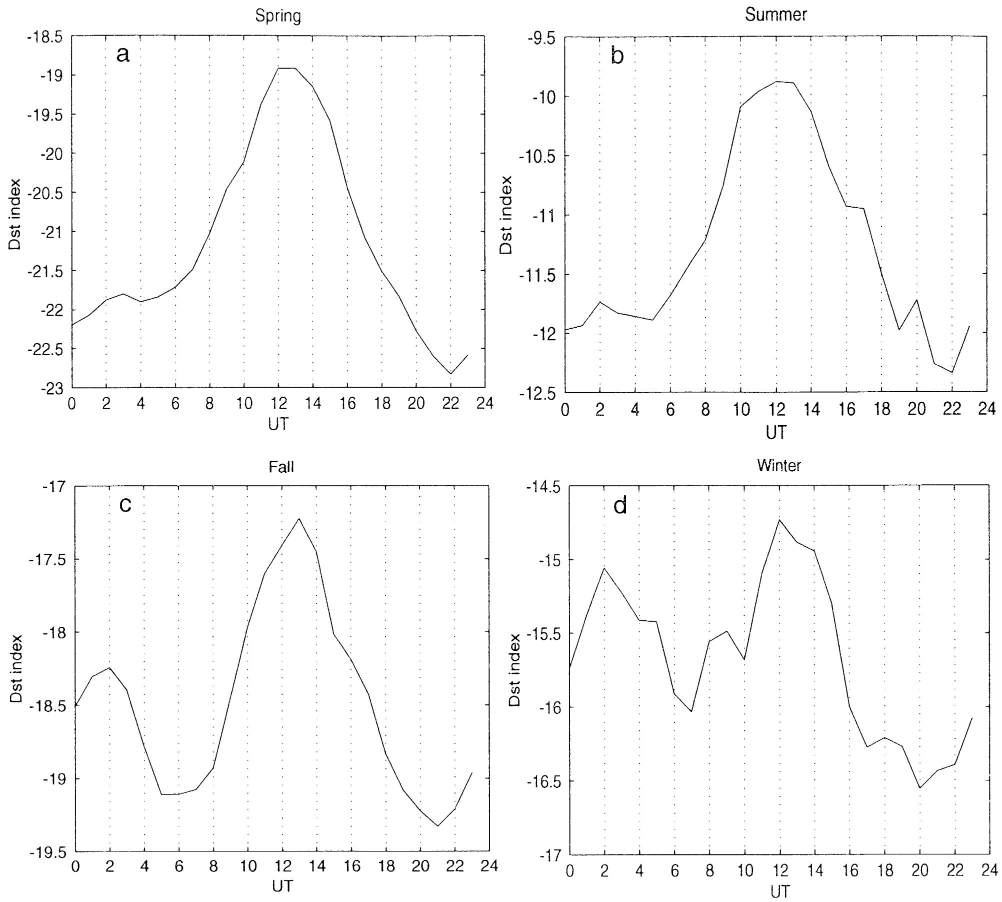

Figure 6. The diurnal UT variation of *Dst* index in 1957–1998 for (a) February-April, (b) May-July, (c) August-October, and (d) November-January.

ing winter than summer. After adjusting this weighted model to the *Dst* index in the same way as described above we obtain a new model diurnal variation, ΔH (weighted) which is depicted in Figure 8a. Comparing Figure 8a with Figure 5 one sees that the new weighted model raises the morning peak at ~0200 UT and the morning minimum at ~0700 UT with respect to the diurnal minimum, making the model curve more winterlike, as depicted in Figure 6d.

Another difference between winter and summer is that the diurnal evening minimum moves later in local winter. At HER the minimum is at ~1900–2000 UT in local winter (northern summer) and at 1700–1800 UT in local summer (northern winter; Figure 7a), and at HON at 0700–0800 UT in winter and 0500–0600 UT in summer (Figure 7b). *Malin and Isikara* [1976] have suggested that during northern summer (winter) the ring current moves southward (northward) from the equator at the nightside of the magnetosphere. This affects the location of the partial ring current and moves the disturbance from 1800 LT toward later LT time in local winter. Note that this effect is slightly smaller for Northern Hemisphere stations (for HON, see Figure 7b) than for HER. The larger effect for HER may be because its absolute corrected geomagnetic latitude (CGM) is bigger than that for the Northern Hemisphere stations (see Table 1).

We have studied the effect of a shift of the diurnal minimum for summer by calculating a model diurnal variation ΔH (shifted) where the constant $D = 4$ was taken for HER, corresponding to the shift of the disturbance closer to midnight by 2 hours. No change was made to other stations. This shifted model is depicted in Figure 8b. In addition to the shift of the evening minimum to later hours, the morning peak is greatly diminished with respect to the unshifted ΔH (see Figures 5 and 8a). With this change the model has now a diurnal variation, which greatly resembles that of the *Dst* index during summer (see Figure 6b).

As seen in Figures 6 the diurnal UT variation in the *Dst* index is largest (~4 nT) in spring. This is probably because the diurnal UT minimum is in phase with and further enhanced by the RMP effect [*Russell and McPherron*, 1973] at the vernal equinox. The evening minimum predicted by our model at 2000–2200 UT (Figure 8) coincides rather well with the diurnal maximum RMP time at 2230 UT for IMF toward sector around vernal equinox. On the other hand, the RMP effect in the IMF away sector around autumnal equinox has its diurnal maximum at ~1030 UT and therefore is in the opposite phase with the prediction of the model, thus reducing the UT variation during fall. If we attribute the difference between spring- and fall-time diurnal variations to the strengthening and reducing effects of RMP, respectively, we estimate ~1 nT of the total diurnal variation of about 4 nT in spring to be due to the RMP effect. However, it is difficult to estimate the contribution of RMP effect more exactly because of the lack of the station at noon UT near the maximum effect of the fall away sector RMP. Accordingly, the RMP effect is not the dominant factor in forming the diurnal UT variation in the *Dst* index but does affect the seasonal differences in this variation. (We have also found an essentially similar diurnal UT variation in the *Dst* index for the away and toward IMF sectors, despite the very different UT distributions of the IMF *Bs* component. These results, to be published separately later, further verify that the RMP effect is not responsible for the overall form of the diurnal UT variation of the *Dst* index.)

The annual average of the amplitude of the diurnal UT variation of the *Dst* index changes considerably over the years, as depicted in Figure 9a. Interestingly, there seems to be, e.g., no clear solar cycle pattern in the variation of the amplitude. A conspicuous feature is the large amplitude of the variation for the year 1971. We did not find any reason for such a special behaviour when studying the data of the original stations for this

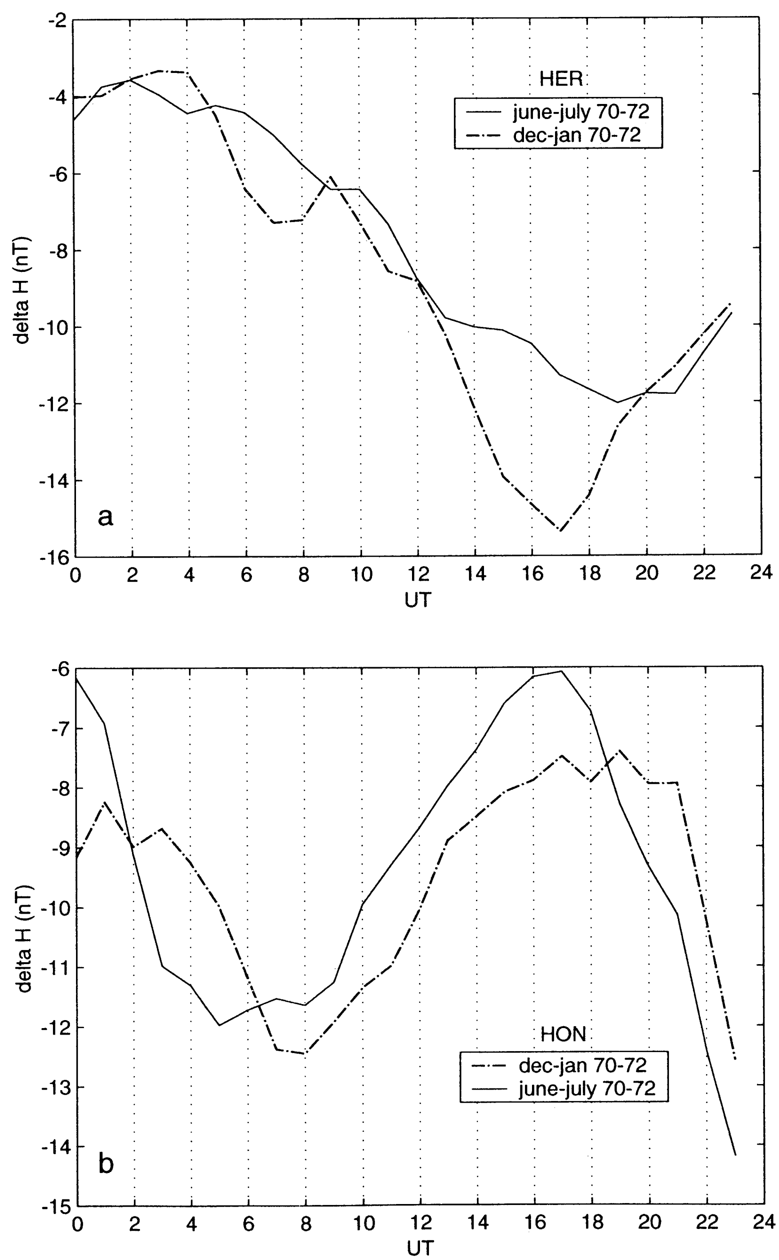

Figure 7. ΔH curves of June-July (solid curve) and December-January (dash-dotted curve) in 1970–1972 for (a) HER and (b) HON.

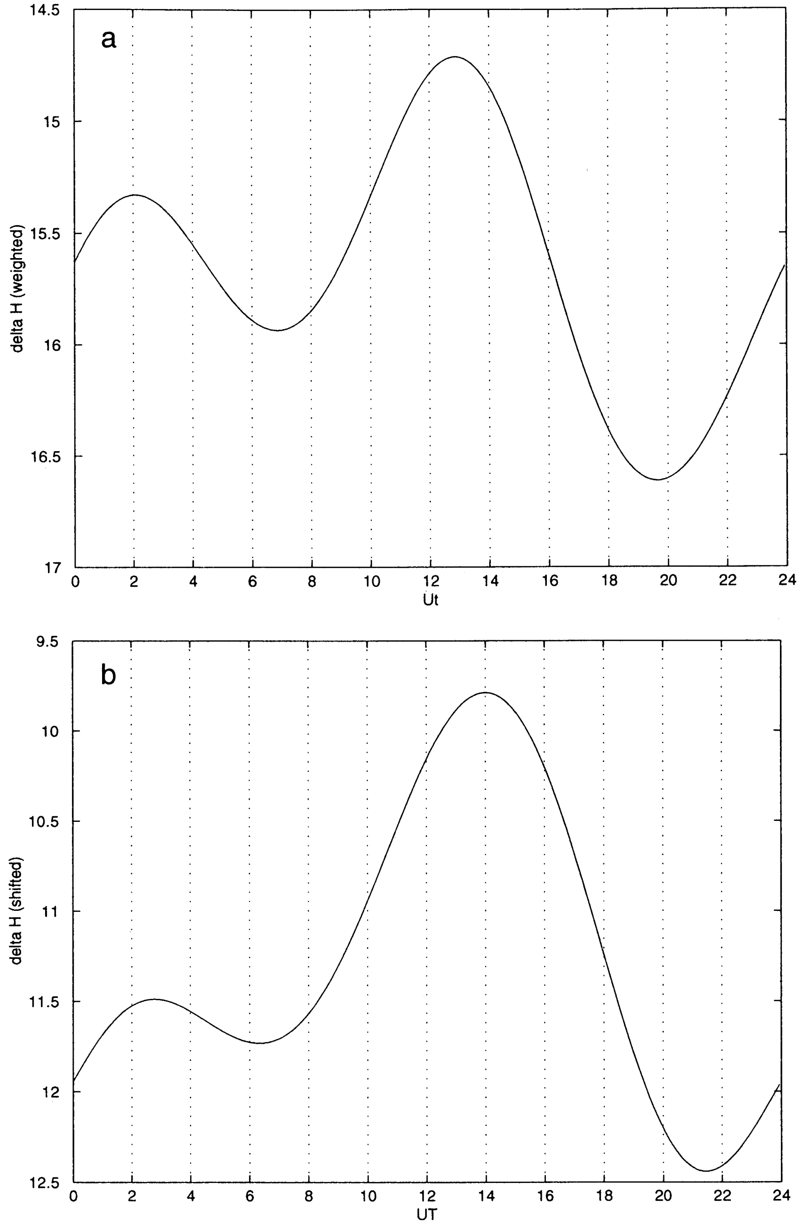

Figure 8. (a) The superposition of the ΔH^m values of all the four *Dst* stations, (a) weighting HER by factor 1.25, (b) lagging the diurnal peak at HER by 2 hours.

year. Instead, the variations at the individual stations in 1971 were very similar as, e.g., in 1970 and 1972. We suspect, after a preliminary analysis using our model, that the extraordinarily large diurnal variation of 1971 results from an erroneous weighting of the stations in the *Dst* index in this year. The spring (February-April) amplitudes (see Figure 9b) are sometimes more than twice as large as the annual average. Again, the year 1971 shows up as an exceptional year but there are five other years (1959–1960, 1977, 1989, and 1994) where the spring variation is more than 8 nT.

5. Conclusions

We have presented a model, in order to quantitatively study the diurnal UT variation of the *Dst* index. Each *Dst* station is located in the model according to the UT time of the local geomagnetic midnight. In addition, the fact that each station observes the strongest diurnal disturbance of the partial ring current at 1800 LT is taken into account in the model. This simple model can explain all the fundamental features of the diurnal UT variation of the *Dst* index.

We have shown that the equinoctial mechanism [*McIntosh*, 1959; *Boller and Stolov*, 1970; *Cliver*, 2000] has an effect on the diurnal UT variation of the disturbance pattern at individual stations. In particular, the equinoctial mechanism decreases the diurnal UT variation at HER in summer by ~20–30% with respect to winter because of the appropriate phasing of this effect with the time of maximum disturbance. On the other hand, the two effects are roughly in antiphase at HON,

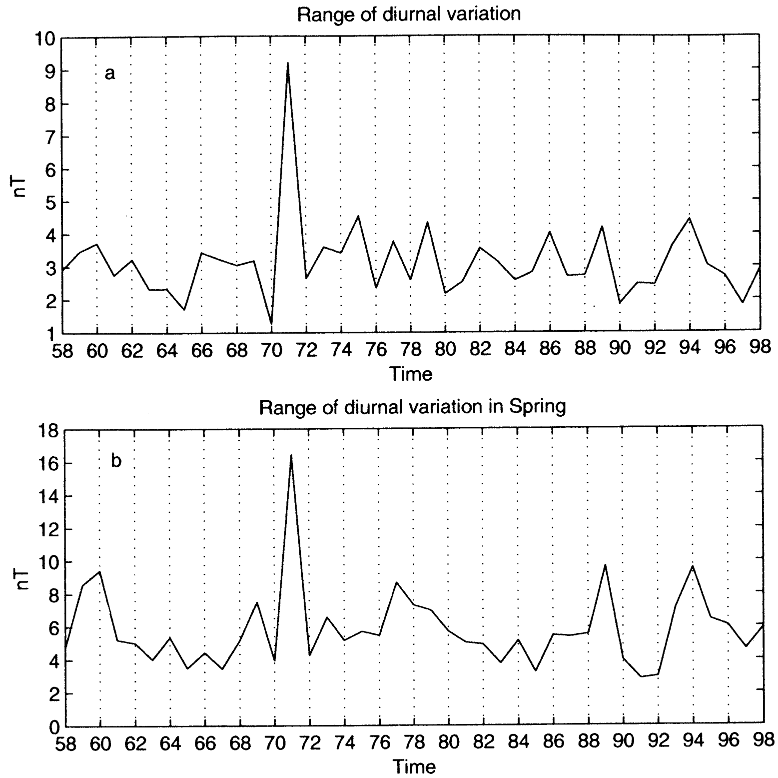

Figure 9. (a) The annual average amplitudes of the diurnal UT variation for the *Dst* index for 1958-1998. (b) The spring-time average amplitudes of the diurnal UT variation for the *Dst* index.

leading to a larger diurnal variation in summer. We have taken this difference into account when modelling the *Dst* index in the two opposite seasons.

We also found that the diurnal minimum at each individual station is shifted during local winter toward midnight by roughly 2 hours from 1800 to ~2000 LT. This supports the idea of the near-Earth tail turning southward in summer and northward in winter, as suggested by *Malin and Isikara* [1976]. Because HER is the only *Dst* station from the Southern Hemisphere, this effect also leads to additional seasonal differences which must be taken into account when modeling the diurnal UT variation of the *Dst* index.

We found that the modeled diurnal UT variation of the *Dst* index has a minimum in the late evening (2000–2200 UT), close to the expected diurnal minimum at 2230 UT of the *Russell and McPherron* [1973] effect in the toward IMF sector during vernal equinox. Accordingly, the RMP effect tends to increase the amplitude of the diurnal variation in spring. On the other hand, the RMP effect tends to decrease the diurnal variation of the *Dst* index in fall. We estimated that the RMP effect is to increase or reduce the diurnal variation by roughly ±1 nT of the average 3-nT variation. However, the main features of the diurnal variation of the *Dst* index (location of the main and subsidiary maxima and minima) are not due to the RMP effect but to the uneven distribution of *Dst* stations. The RMP only causes seasonal differences in the amplitude of this variation.

Although the UT variation of the *Dst* index is not very strong, it is very systematic and attains sometimes quite large amplitudes. We showed that the diurnal UT variation in 1971 is exceptional and suggested this to be due to an erroneous treatment of the *Dst* stations. Moreover, we suggest that the diurnal UT variation should be taken into account when modeling and predicting the behavior of the *Dst* index. The analysis shows the need to increase the number of related magnetic stations, in particular in the Southern Hemisphere, in order to have a better coverage in longitude and latitude.

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