Data Science Journal, Volume 10, 30 August 2011

ANALYSIS ON THE TEMPORAL-SPATIAL DISTRIBUTION OF THE GEOMAGNETIC ACTIVITY INDEX VR

Ya-Hong Yuan[1], Dong-Mei Yang[1*], Hua-Ran Chen[1], Yu-Fei He[1], Chuan-Hua Chen[2]

*[*1] *Institute of Geophysics, China Earthquake Administration, Beijing,* 100081, *China*
*Email:*ydmgeomag@263.net
[2] *Taian Magnetic Observatory, Earthquake Administration of Shandong Province, Taian,* 271000, *China*

ABSTRACT

Based on the analysis of the Vr index from data from geomagnetic observatories in China and four geomagnetic observatories abroad, temporal-spatial distribution characteristics of Vr index were analyzed. The Vr index showed 27-day solar-cycle recurrences and significant seasonal variation. It also increased with latitude. Meanwhile, both local-time dependence and an obvious dusk-dawn asymmetry existed, which might be related to the asymmetric ring current, the partial ring current, and the field-aligned current.

Keywords: Vr index, Temporal-spatial distribution, Local time dependence, Dusk-dawn asymmetry, Partial ring current, Field-aligned current

1 INTRODUCTION

Geomagnetic activities are global or regional temporal variations of geomagnetic fields. They have wide ranges, multi-components, multifarious types, different shapes, wide bands, complicated causes, and so on. To understand the physical essence of all kinds of geomagnetic phenomenon and to review their characteristics and describe their general morphology by convenient classification and simple indicators, various kinds of geomagnetic activity indices have emerged. So far, there are more than fifty kinds of geomagnetic indices that have been applied (Xu, 2009). In ionospheric and magnetospheric studies, Kp and its related index Ap are widely used as indices measuring worldwide geomagnetic activity. However，Kp is not good for describing high frequency magnetic disturbances. Therefore, Yang et al. (2010) introduced a new geomagnetic activity index called Vr, which shows the drastic rate of instantaneous changes in geomagnetic fields. In this paper, we focus on analyzing the temporal-spatial distribution characteristics of the Vr index and discover the physical sources, which can lay the basis for applying the Vr index to monitor geomagnetic activity.

2 DATA AND ANALYSIS

In this paper, the data used are 1-minute values of the geomagnetic horizontal component (H) and the geomagnetic declination (D) in the year 2008 at 41 geomagnetic observatories in China and 4 geomagnetic observatories abroad. We calculated the Vr index according to Yang's method. First, the first order differences of the 1-minute values of H and D were calculated. Second, the hourly standard deviations of the first order differences were calculated. Third, the background noises were subtracted from the hourly standard deviations to get the Vr indices. In practice, the background noises were chosen to be 0.1nT because the resolution of the fluxgate magnetometers used in variation recording of the geomagnetic fields at the observatories was 0.1nT. In case the hourly standard deviation was less than 0.1nT, the Vr value was set to 0.

In this paper, we calculated the hourly and 3-hourly Vr indices of H and D, respectively.

3 THE TEMPORAL DISTRIBUTION CHARACTERISTICS

3.1 27-day solar cycle recurrences of the Vr index

The geomagnetic field has 27-day solar cycle recurrences (Xu, 2003), which can be found from the distribution of the Kp indices in 2008 (Figure 1(a)). The Vr index was used to describe the instantaneous changes of the geomagnetic field. The study also showed it has 27-day solar cycle recurrences.

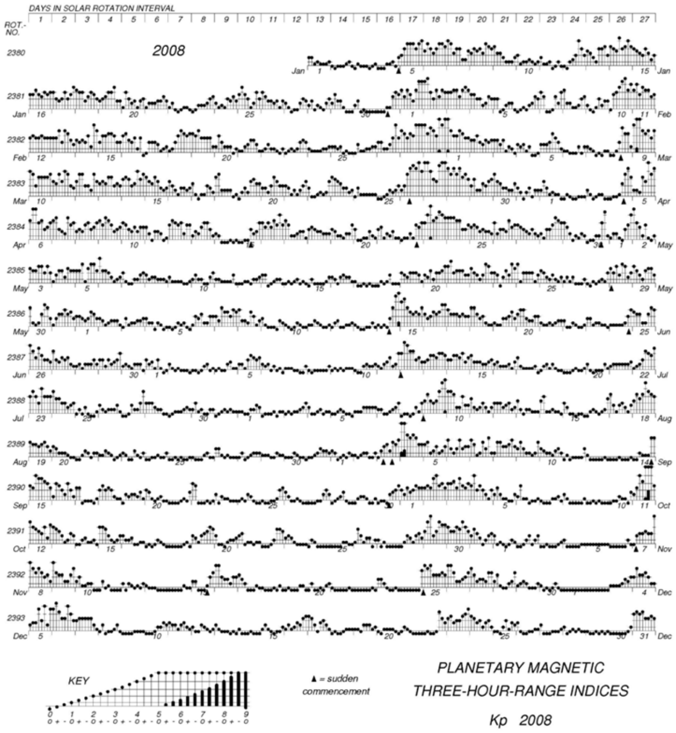


Figure 1(a). The Bartels musical diagram of Kp index in 2008 (Downloaded from http://wdc.kugi.kyoto-u.ac.jp/kp/index.html)

Figures 1(b) and 1(c) show the three-hourly Vr indices of *D* and *H* at Urumchi Observatory (WMQ, as shown in Table 1) in 2008 in a way similar to the Bartels musical diagram. The Vr values regularly changed with time. Longitudinally, most of the changes showed 27-day solar cycle recurrences. For example, the value of the Vr indices of *D* (Vr*D*) increased from January 5 to January 7, which implies magnetic disturbance. Looking downward, in each 27-day solar cycle, larger Vr values appear in corresponding time sections, showing 27-day recurrences. Figure 1(c) illustrates the three-hourly Vr indices of *H* (Vr*H*) in 2008, which also show the same 27-day period.

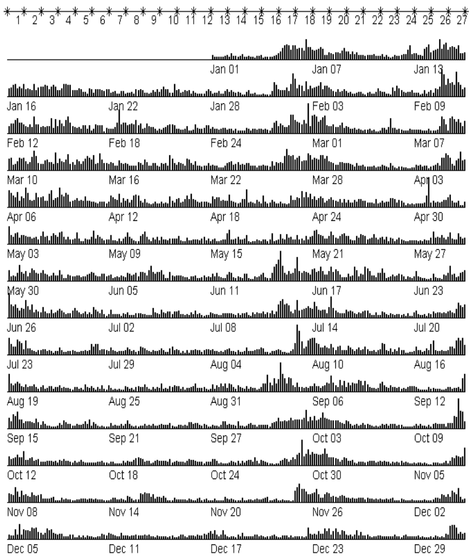


Figure 1(b). The three-hourly Vr indices of declination at Urumchi Observatory in 2008

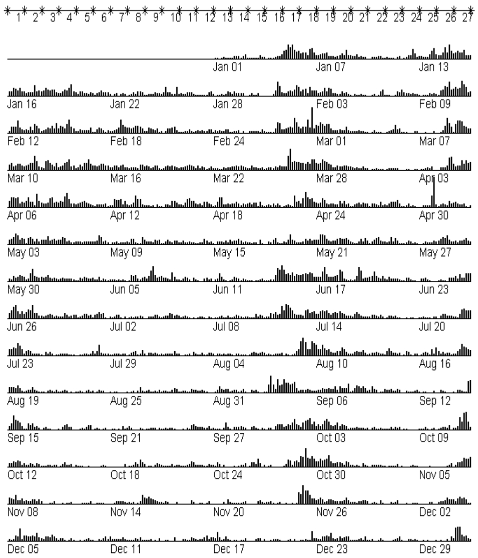


Figure 1(c). The three-hourly Vr indices of *H* component at Urumchi Observatory in 2008

3.2 Seasonal variation of the Vr index

The Vr index also changed with season. Taking data from 2008 to 2010 at Wuhan Observatory (114.5°E, 30.5°N) as an example, we calculated the hourly VrH and VrD and their monthly sum for each hour and converted UT to LT. Figure 2(a) shows the monthly sum of hourly Vr*D* and Vr*H* at Wuhan Observatory in 2008-2010. From the left of Figure 2(a), we can find that from 2008 to 2010 the shapes of the variation were fairly similar every year. If we divide the whole year into three seasons as winter (Nov. - Feb.), summer (May - Aug.), and equinox (Mar., Apr., Sep. and Oct.), we can see that the VrD values declined with summer, equinox, and winter in turn; meanwhile the VrD changes in summer were more drastic than those in winter and equinox. Also the VrD show two peaks and two valleys in every month. The larger peak appeared at 6^h -9^h in the morning, and the smaller peak appeared at 18^h -20^h in the evening. The valleys appeared at 13^h -15^h in the afternoon and at 23^h -1^h in the midnight. Taking the monthly sum of the hourly Vr*D* in July 2008 (Figure 3(a)) for an example, they gradually increased to the first maxima 10.67nT/min at 7^h in the morning, next dropped dramatically to the minima 2.4nT/min at 13^h, and then gradually increased to the second maxima 5.14nT/min at 19^h, finally returned to the night levels. However, the changes in winter and equinox were a bit slower and the peak values appeared at 9^h in winter and at 8^h in equinox in the morning which were two and one hours later than that in summer. The field-aligned current appeared in the morning and evening (Le, Russell, & Takahashi, 2004), and we identified its influence more easily from the *D* component. Therefore, we regard the field-aligned current as the reason for the Vr*D* seasonal variation.

However, the VrH varied differently every year. In 2008, the values during the first half of the year were generally larger than those during the second half. They showed minimum values from 5^h to 8^h in the morning and peak values in the night time. Taking the monthly sum of the hourly Vr*H* in July 2008 (Figure 3(a)) for instance, the VrH dropped dramatically to the minima 3.67nT/min at 5^h in the morning and then gradually increased to a maximum 8.35nT at 16^h, and finally stayed in around the maxima until midnight. In 2009, the overall trend was smooth from month to month. At first the values tended to go up steadily from January to March, but later they declined to the minimum in June and then increased again in July and August while a slight decline happened in the next months. In 2010, the values of VrH also increased in the first three months; later, from April to August, they remained level and then decreased slowly.

To understand the reason for the variation of the VrH, we analyzed it together with the solar wind bulk speed (SWS, downloaded from http://www.srl.caltech.edu/ACE/ASC/level2/policy_lvl2.html). We calculated the monthly means of SWS for each hour in the same way as we did for VrH. And then a peak value normalization processing and a 24-point moving average processing were applied to the monthly means. From Figure 2(b), we could see that the variation trends of VrH and SWS were basically consistent, which revealed that the variation of VrH was responsive to solar wind bulk speed.

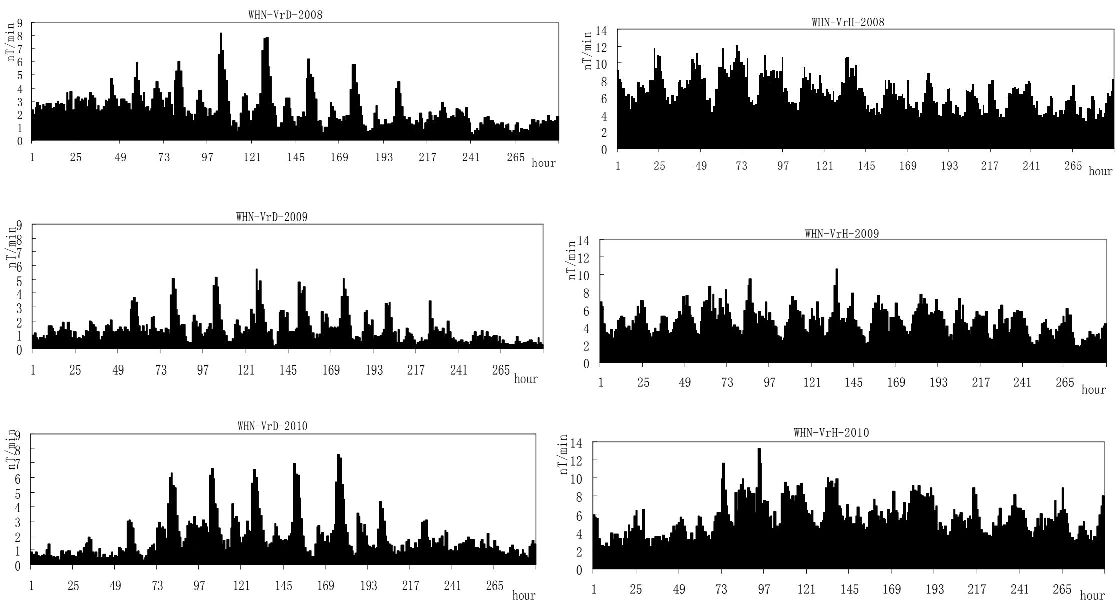


Figure 2 (a). The monthly sum of hourly Vr*D* and Vr*H* values at Wuhan Observatory in 2008-2010

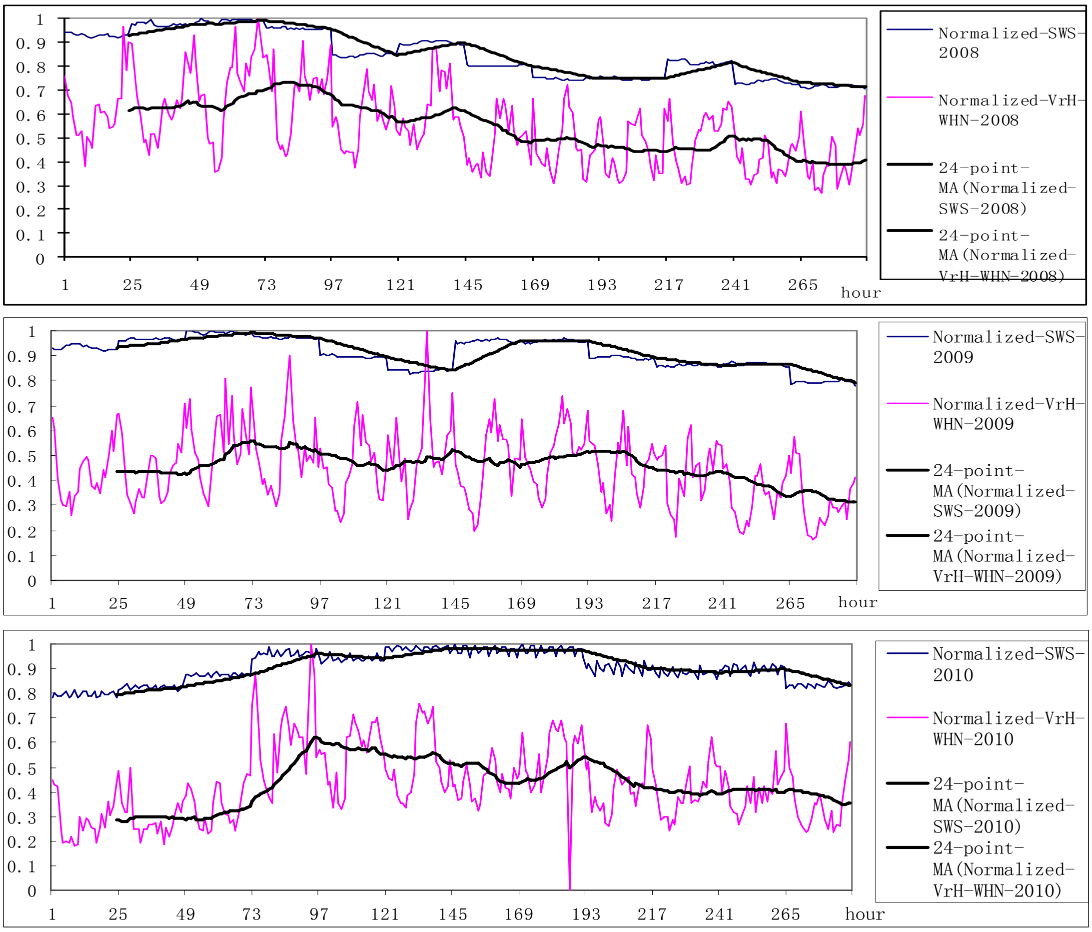
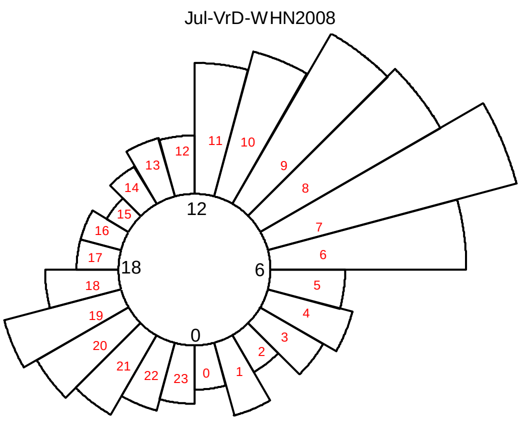


Figure 2(b). The relationship between solar wind bulk speed and the seasonal variation of VrH at Wuhan Observatory in 2008-2010



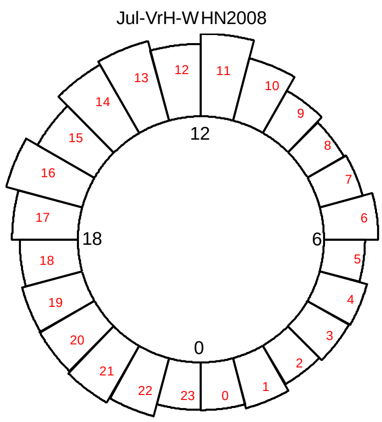


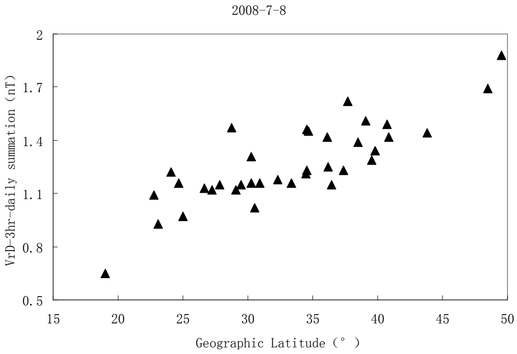
Figure 3(a). The monthly sum of the hourly Vr*D* index at Wuhan Observatory in July 2008

Figure 3(b). The monthly sum of the hourly Vr*H* index at Wuhan Observatory in July 2008

4 SPATIAL DISTRIBUTION OF THE VR INDEX

4.1 Variation of the Vr index with latitude

We collected the 1-minute values of *D* and *H* at 41 geomagnetic observatories in Mainland China and calculated their 3-hourly Vr indices and their daily sums. Figures 4(a) and (b) show the latitudinal distribution of the daily sums on 8 July, 2008. From the two figures, we see that the Vr values of *D* and *H* increased with the increase in latitude.



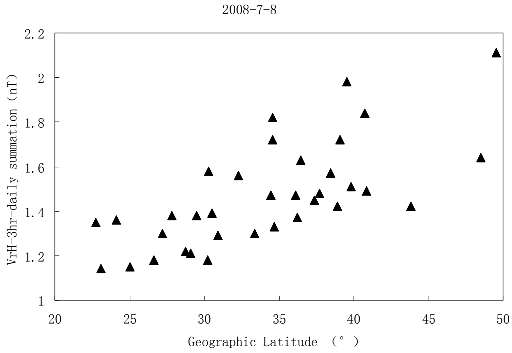


Figure 4(a). The latitudinal distribution of Vr*D*

Figure 4(b). The latitudinal distribution of Vr*H*

Figure 5 shows the latitudinal variation of the standard deviation of the first order difference in the *X*-component at about 85 geomagnetic observatories in the world (Jeffrey, 2010). With an increase in latitude, the standard deviation of the first order difference in the *X*-component first gradually increased and then increased rapidly at latitudes greater than 50° in both hemispheres, which suggests that the rate of change became bigger with the increase in latitude. Our results coincide well with this and provide more details for the region with latitudes from 20° to 50°.

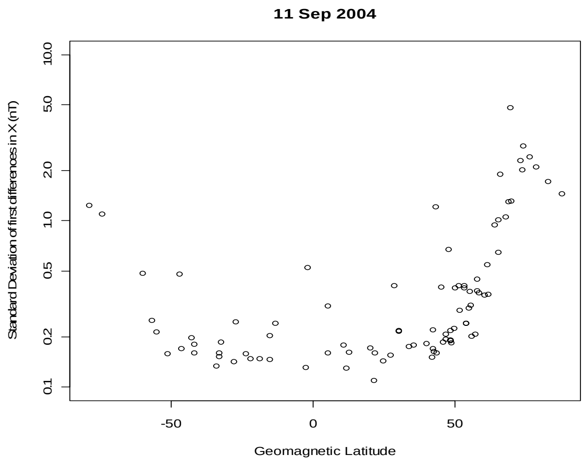


Figure 5. Latitudinal distribution of the standard deviation of the first order difference in the *X*-component

4.2 Variation Characteristics of the Vr Index with Longitude

From Section 3, we understood that the variation of the Vr index with longitude depended on the local time. In 2008, geomagnetic horizontal components (*H*) and declinations (*D*) at five geomagnetic observatories, namely SJG, MMB, CLF, HON, and WMQ (as shown in Table 1), which share similar latitudes but even-sampling longitudes around the world, were collected for the research. First of all, hourly Vr indices were calculated, and the local time correction was employed. Then the yearly sum of Vr indices for each hour at each observatory in 2008 was utilized for the peak normalization method.

Finally, the averaged Vr index around the world was estimated by the average of values at the five observatories after normalization. Results after the above-mentioned processing were carried out for an analysis of the local time effect of the Vr index.

Table1. Geographic coordinates and geomagnetic coordinates of the observatories

IAGA code	Geographic latitude	Geographic longitude	Geomagnetic latitude	Geomagnetic longitude	Local time differences referred to UTC
CLF	48.017°N	2.267°E	49.56°N	85.73°E	+0h
WMQ	43.800°N	87.700°E	34.15°N	162.52°E	+6h
MMB	43.910°N	144.189°E	35.44°N	148.23°W	+10h
HON	21.320°N	158.000°W	21.59°N	89.70°W	-11h
SJG	18.117°N	66.150°W	27.93°N	6.53°E	-4h

The variation characteristics of hourly VrH with local time are illustrated in Figure 6(a). The values at dawn, from 0^h to 11^h, were less than those at dusk, from 12^h to 23^h. In other words, there is a distinct dusk-dawn asymmetry. From midnight, the Vr index decreased gradually and reached its minimum at 5^h in the morning. Then it began to increase from 6^h and reached its maxima at 13^h. From then on, it fell slowly to the night values. Wu et al. (2008) proposed an asymmetric distribution of geomagnetic activity, which depends on local time. The dusk-dawn asymmetry was quite distinct with a larger disturbance at dusk compared to that at dawn. The asymmetry was ascribed to a partial ring current. One reason for the local time asymmetry of geomagnetic activity is that the ring current whose maximum appears at the dusk-dawn plane was smaller during the day than in the night. In every case, the ring current demonstrated a dusk-dawn asymmetry, and the strong ring current shifted from dawn to dusk (Le, Russell, & Takahashi, 2004; Akasofu & Chapman, 1964). The variation characteristics of the Vr index of *H* with local time were similar to the distribution characteristics of the ring current. Therefore, a preliminary conclusion was proposed stating that the variation characteristics of the Vr index were related to the ring current.

The variation characteristics of the hourly VrD are demonstrated in Figure 6(b). This reveals a distinct dusk-dawn asymmetry, with larger peak values at dawn and smaller peak values at dusk. The Vr index reached its two peaks at 7^h and 19^h respectively and decreased gradually along both sides of these peaks. One valid explanation for two peaks at dawn and dusk is that the field-aligned currents emerge at dawn and dusk. Gao Yufen proved the presence of dawn and dusk field-aligned current while conducting research on the relationship between the seasonal variation of Sq and field-aligned current. The magnetic field intensity excited by current on the ground was about several nTs. At dusk, a reverse current was possible as well but having smaller intensity (Gao, 1992). The maximum value of the field-aligned current appeared at dawn and dusk (Le, Russell, Takahashi, 2004) and the minimum at midnight and midday. Therefore, the field-aligned current is responsible for the local time effect of the hourly Vr.

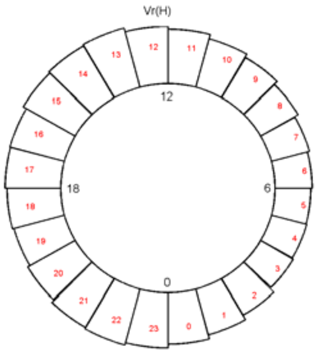


Figure 6(a). The variation of Vr*H* with LT

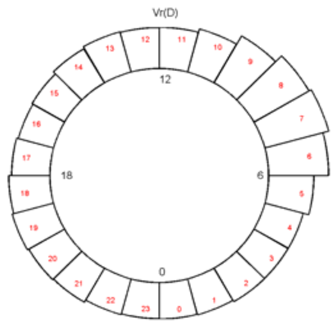


Figure 6(b). The variation of Vr*D* with LT

5 CONCLUSIONS

After studying the temporal-spatial distribution of the Vr index, we concluded that

(1) The Vr index showed 27-day solar cycle recurrences due to solar rotation.

(2)From 2008 to 2010, the variation of the VrD was similar every year. It changed more drastically in summer than in winter and equinox. While the variation of VrH was different every year, it was responsive to the solar wind bulk speed.

(3) Both VrH and VrD increased with latitude in the middle latitude region.

(4) The Vr index also showed local time dependences and showed obvious dawn-dusk asymmetry. These might be related to the partial ring current and the field-aligned current.

6 ACKNOWLEDGEMENTS

This work was supported by project DQJB09B01. We thank the Chinese magnetic observatories and the INTERMAGNET for providing observation data. Thanks to Dr. Liu Xiaocan for her suggestions while this work was in progress. The authors greatly thank the anonymous reviewer for his/her constructive comments.

7 REFERENCES

Akasofu, S. & Chapman, S. (1964) On the asymmetric development of magnetic storm fields in low and middle latitudes. *Planet Space Sci.* 12, 607-626.

Gao, Y. F. (1992) Seasonal variation of Sq(Y) and field-aligned current. *Chin. J. Space Sci* (in Chinese) 12(2), 118-122.

Le, G., Russell, C., & Takahashi, K. (2004) Morphology of the ring current derived from magnetic field observations. *Annales Geophysicae* 22, 1267-1295.

Love, J. Personal communication

Wu, Y.Y., Xu, W.Y., Chen, G.X., et al. (2008) Ground magnetic characteristics of the storm-time ring current Asymmetry. *Science in China(Series D-Earth Science)* (in Chinese) 38(4), 424-431.

Xu, W.Y. (2003) Geomagnetism(in Chinese). Beijing: Seismological Press.

Xu, W.Y. (2009) Yesterday, today and tomorrow of geomagnetic indices. *Progress in Geophys.* (in Chinese) 24(3), 830-841.

Yang, D.M., He, Y. F., Chen, C.H., et al. (2010) Vr: A new index to represent the variation rate of geomagnetic activity. *Earth Sci*, 23(4), 343-348.