V_r : A new index to represent the variation rate of geomagnetic activity*

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Abstract By calculating the hourly standard deviation of the first-order differences of the horizontal geomagnetic component minute data, a new index V_r to represent the variation rate of the geomagnetic field was introduced. V_r -indices show similar trends in the temporal change at different observatories and have simultaneous peak values at the observatories covering a large span geographically, which reveals that the source of geomagnetic disturbances represented by V_r is in the magnetosphere. Based on the comparison among V_r , K_p and a_p , it is found that generally V_r changes linearly with K_p and a_p , which means that the rapid changes of magnetic field usually exist together with magnetic disturbances. But there are exceptions. As V_r can be easily produced by individual observatory in quasi real time and is more sensitive to the variation rate of geomagnetic field rather than the field itself, it can be expected to serve for monitoring or predicting the geomagnetic-induced event in a quick and intuitive way.

Key words: V_r index; first-order difference; standard deviation; variation rate of geomagnetic field; geomagnetic-induced event

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1 Introduction

K_p and its related index a_p are widely used for measuring worldwide geomagnetic activity in ionospheric and magnetospheric studies. The planetary three-hour-range index K_p is derived from the standardized K index (K_s) of 13 magnetic observatories (Bartels, 1949). The K indices are determined by measuring the range (difference between the highest and lowest values) during three-hourly time intervals for the most disturbed horizontal magnetic field component with the quiet-day variation pattern (QDVP) being removed from the magnetogram (Bartels et al, 1939). The range is then converted into a local K index taking the values 0 to 9 according to a quasi-logarithmic scale which is station specific. Then conversion tables are applied to obtain standardized indices K_s for each of the 13 selected observatories. The conversion tables are obtained by using

statistical methods to eliminate the annual cycles of daily variations due to the geographic and geomagnetic coordinates of the observatories. The standardized index K_s for each of the 13 selected observatories provides a basis for the global geomagnetic index K_p which is the average of a number of “ K_p stations”. The three-hour index a_p is directly related to the K_p index but is expressed in a linear scale in the unit of 2 nT.

However, K_p is not suitable for describing the high frequency magnetic disturbances. As shown in Figure 1, the first-order difference of horizontal component (H) in January of 2010 at Manzhouli observatory exhibited so much high frequency disturbances even when K_p indices are less than 2.

In this paper, a new index so called V_r that is the standard deviation of the first-order differences of magnetic field was introduced to represent magnetic disturbances. Its spatio-temporal distribution characteristics and its relationship with K_p and a_p were analyzed. The results show that this new index can be used in those issues associated with the variation rate of geomagnetic field.

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Figure 1 First-order differences of horizontal magnetic component at Manzhouli observatory in January of 2010 together with the three-hourly K_p index labeled at the bottom of each three-hourly segments.

2 Data and analysis

2.1 Calculation of V_r

The index V_r , i.e., standard deviation of the first-order difference of horizontal geomagnetic component, was calculated according to the following procedure: firstly, the first-order differences of the minute values of the horizontal geomagnetic component (H) were calculated; secondly, the hourly standard deviations of the first-order differences were calculated; thirdly, background noises were subtracted from the hourly standard deviations to get the V_r indices. In practice, the background noises were chosen to be 0.1 nT because the resolution of fluxgate magnetometers used for recording variation of geomagnetic field at the observatories were

0.1 nT. In the case that the hourly standard deviation was less than 0.1 nT, V_r value was set to be 0.

2.2 V_r indices at different observatories

Following the above procedure, V_r indices were calculated for 41 Chinese geomagnetic observatories from January of 2008 to April of 2010. At first glance the V_r values at different observatories showed the synchronously temporal variations in a relative high-frequency mode, with a little bit differences in amplitude. As an example, Figure 2 gave the variation of index V_r at four observatories, i.e., Manzhouli (MZL, 117.4°E, 49.6°N), Longyao (LYH, 114.7°E, 37.7°N), Wuhan (WHN, 114.6°E, 30.5°N) and Quanzhou (QZH, 118.6°E, 24.9°N). These four observatories cover over the Chinese territory of about 3 000 km from Manzhouli in

Figure 2 V_r indices at four observatories (Manzhouli, Longyao, Wuhan and Quanzhou from top to bottom) of Chinese mainland in January of 2010.

North China to Quanzhou in South China.

The strongly synchronous pattern of V_r index at the four observatories (Figure 2) implies that the source for the disturbances represented by V_r index should be originated at least thousands kilometers away from the Earth's surface. The features of short-period disturbances also indicate that the source is an external origin instead of an internal one due to the skin effect in the Earth's interior. A possible origin for the disturbances

might be the magnetosphere whose bottom is located about 1 000 km above the ground.

Figure 3 shows the spatial distribution of V_r -amplitude in the 16th one-hour interval on January 20, 2010 (UTC). The corresponding K_p is 4 (see Figure 1). It seems to the authors from Figure 3 that, generally speaking, V_r values in North China are a little bit larger than those in South China although the differences are insignificant.

Figure 3 Spatial distribution of V_r values in the 16th one-hour interval on January 20, 2010 (UTC).

2.3 Relationships between indices V_r , K_p and a_p

Physically, V_r index describes the variation rate of magnetic field in one-hour segment, while K_p and a_p define the magnetic field deviation with respect to QDVP in 3-hour intervals. In order to statistically analyze the relationship between indices V_r and K_p (a_p), it is necessary to construct V_r index in 3-hour intervals and the daily sum of V_r ($\sum V_r$). Figure 4 gives the statistical analysis result between $\sum V_r$ and daily sum of K_p ($\sum K_p$) and daily sum of a_p ($\sum a_p$) respectively for the year of 2008.

The linear relation between $\sum V_r$ and $\sum K_p$ ($\sum a_p$) indicates that the more intense the magnetic variation is, the higher the variation rate of the magnetic field is. In other words, the field variation coincides with its variation rate, which might be taken as one of the features of V_r index.

But there are some exceptions that large $\sum K_p$ and large $\sum a_p$ correspond with insignificant $\sum V_r$, and vice versa. For example, $\sum K_p$, $\sum a_p$ and $\sum V_r$ at the observatory Manzhouli are 34.4, 285 and 6.56 nT/min respectively on March 27, 2008, and they are 25.9, 169 and 9.24 nT/min respectively on August 9, 2008. The magnetic disturbance on March 27 was stronger than that on August 9. But the changes in the magnetic field on March 27 were less than those on August 9. This implies that at least in these cases the source causing the distortion of diurnal variation might not be the same as that causing rapid change of the geomagnetic field.

3 Discussion and conclusions

The indices K_p and a_p define the magnetic field deviation with respect to QDVP in 3-hour intervals, whereas the index V_r denotes the variation rate of

Figure 4 Statistical relationship between ΣK_p , Σa_p and ΣV_r .

magnetic field in unit of nT/min.

From our study, the index V_r increases with latitude. Li et al (2009) found that the averaged amplitude of variations in the main phase of H component increases linearly during storms with $D_{st} > -300$ nT as the latitude of the observatory decreases after analyzing the data recorded in the chain of magnetic observatories in eastern China. This is consistent with the common knowledge that storm-time magnetic field variation is caused by equatorial ring current, especially during the main phase of storms. Increasing of V_r with latitude (Figure 2) seems to reveal that the magnetic changes which V_r index represents would come from the sources different from the equatorial ring current.

As far as we know up to now, there are four major current systems in the magnetosphere which greatly affect the space environment and geomagnetic observation

on the Earth's surface. They are Chapman-Ferraro current in the dayside magnetopause, ring current (symmetric and partial ring currents), field-aligned currents (region 1 and region 2 currents) and magnetic tail current respectively. Except for the symmetric ring current, all other currents are distributed in special local time section. At present we could not make sure which current would be associated with V_r index, because what we have is only that V_r indices showed the same temporal change at different observatories with slight difference in the amplitude depending on the latitudes of the observatories; while as for the changes of V_r indices with longitudes we have known little, which need to be further studied using data of the global magnetic network. That might be helpful to understand the physical source for the V_r indices.

After reviewing 50 magnetic indices currently used, Xu (2009) suggested that it is necessary to produce new indices for geomagnetic-induced field in close to real time. V_r index seems to be a possible solution due to its nature of first-order difference of horizontal component of magnetic field. Furthermore, as V_r index is easy to be calculated, we can try to get V_r index in different time intervals such as three-hour, one-hour and even several tens of minutes according to the intended use of the index.

Based on the theory of geomagnetic induction, it is deduced that the geomagnetic disturbances of H component have induced effects on the variations in E-W component of geoelectric field, and the geomagnetic disturbances of declination have induced effects on the variations of N-S component of geoelectric field (Zhang and Yang, 2010). In this sense, V_r should be calculated not only based on H component but also on declination in the future.

In recent years, with rapid development of space weather observation, the requirement for understanding the effect of magnetic storms on ground-based infrastructures such as long-distance pipelines and electric power grids (Liu, 2008; Liu et al, 2008, 2009) has become urgent as one of important issues in national economy. Based on the statistic analysis on the relationship among the intensities of geomagnetic-induced current (GIC), the horizontal geomagnetic component and K_p index, Liu et al (2008) found that the intensity of GIC depends on the variation rate of horizontal geomagnetic component rather than the horizontal component itself. Although the possibility for producing significant GICs will increase with K_p indices, the intensities of GICs change widely for the same K_p , whereas for the same intensity of GIC, the K_p indices might change from 3 to 9. Furthermore, Liu et al (2009) pointed out that the researches on these effects should be jointed together with the variation rate of magnetic field and with the regional conductivity structure of underground media. V_r index might serve as one of the means. For

example, we might build up a model to tell what level of V_r index will be significant to protect ground-based infrastructures if the data has been greatly accumulated.

Quantitative relationship between V_r and K_p (and a_p) needs to be studied with longer time series in the future.

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