Proc. Symp. Solar Planetary Phys. Jan. 20-24, 1976
Ahmedabad, India, Vol.4, pp. 25-36.

ELE.JET.

ANOMALIES IN THE VERTICAL COMPONENT OF GEOMAGNETIC FIELD VARIATIONS AT ANNAMALAINAGAR, KODAIKANAL AND TRIVANDRUM

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Abstract

The variations in the geomagnetic field components ΔH and ΔZ during short period events like SSC's or bays have the same phase at all three magnetic observatories, Annamalainagar (ANR), Kodaikanal (KOD) and Trivandrum (TRV) which lie under the equatorial electrojet. However, the phase relationship for Sq variations is different. ΔH is maximum at three stations around 1100 hrs (IST) whereas ΔZ decreases reaching its minimum value around 1300 hrs at ANR and around 1200 hrs at KOD. At TRV ΔZ increases and becomes maximum at around 1000 hrs. The amplitudes of ΔZ at ANR and TRV are much larger than their normal values expected at these latitudes.

It is found that Parkinson's relation $Z = A \Delta H + B \Delta D$ is obeyed at all three stations for SSC's and bays. Fisher's Z-test shows the correlation to be highly significant. This suggests that Schmucker's concept of separating the total field into a normal and anomalous part is applicable here and most of the ΔZ is of anomalous origin induced by ΔH and ΔD. The constant A was found much larger than B. To test this FET amplitudes of ΔH, ΔD and ΔZ recorded during night time of a storm were analysed. For all three observatories ΔZ was found to follow ΔH. Parkinson's relation did not hold good for Sq variations. We used the IGY data for which

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the normal part of the variations were computed for each harmonic using the coefficients calculated by Matsushita and Maeda. This normal part was then subtracted from the observed value by taking phases into account to obtain the anomalous part. Most of the ΔZ is of anomalous origin and it does not correlate with the normal part of either ΔH or ΔD or ΔZ. The anomaly at Sq periods in ΔZ is thus due to channelling of internal currents through the deep ocean adjacent to the southern tip of the peninsula.

Introduction

It has been established by many workers that a part of transient vertical component variations is due to currents induced in the earth. The spatial differences in Z-variations are very marked in the Indian Peninsula. These have always been the principal features for detecting induced variations due to lateral conductivity contrasts. In estimating the effect of induced variations, Parkinson's relation (1959) is used. In a modified form the relation is written as:

$$\Delta Z = A.\Delta H + B\Delta D + \xi \qquad .. \quad (1)$$

Here ΔZ, ΔH and ΔD signify changes in the vertical (Z), horizontal (H) and declination (D), the three elements of the earth's magnetic field. The above relation is used to fit a set of observed variations and estimate A and B through the method of least squares. In Eqn (1) ξ is the part of ΔZ that does not correlate with the horizontal component of the field. The constants A and B are called transfer functions and are characteristic of a certain station and frequency. In the case of continuous data such as storms, A and B are complex too. The vector sum of A and B gives us the induction vector S, which is a measure of the induced part of ΔZ and the direction of this vector gives the azimuth of the horizontal field most correlated with ΔZ. Its direction is perpendicular to the flow of induced currents or equivalently to the strike of the conductivity contrast.

The interpretation of the induction vector is based on a very crucial assumption that the external inducing field is uniform over a large spatial extent. If this condition is violated, the non-uniform external field itself will give rise to Z amplitudes that could be mistakenly interpreted as being due to induction. In the case of quiet day variations at electrojet stations, the field is not uniform and is rapidly varying over a small spatial extent. As such Parkinson's relation cannot be applied, and a quantitative estimate of induction is difficult to make. Therefore, in this paper, the results of fitting a model to Sq variations is tried and the deviations in ΔZ at Annamalainagar (ANR), Kodaikanal (KOD) and Trivandrum (TRV) from the model are discussed.

Analysis and Results

(a) Bays and SSCs:

Forty events each of bays and SSCs occurring at night were selected, all the events being of significant amplitude and recorded at all the three stations (ANR, KOD and TRV). The amplitudes of ΔH, ΔD and ΔZ were scaled directly from the magnetograms and fitted in Eqn (1) to compute A and B by the method of least squares. For both types of events a good fit was obtained.

Fisher's Z-test showed the correlation to be significant. The values are given in the following table.

Table

Event / Station	SSCs				Bays			
	ΔH and ΔD observed at the station.		ΔH and ΔD taken as average of ALB and HYD		ΔH and ΔD observed at the station		ΔH and ΔD taken as the average of ALB and HYD	
	A	B	A	B	A	B	A	B
ANR	0.48	-0.11	0.56	-0.37	0.54	0.25	0.55	0.09
KOD	0.50	-0.05	0.50	0.05	0.42	-0.57	0.52	-0.52
TRV	1.33	-0.28	1.27	-0.19	1.01	0.76	1.09	0.02

In an alternate computation the averages of ΔH and ΔD at Alibag (ALB) and Hyderabad (HYD) were substituted for ΔH and ΔD observed at the station, in Eqn (1). The reason for this substitution is that in an earlier study by the same authors it was seen that ΔH and ΔD at ANR and TRV have some anomalous component. Since the D variometer at KOD has a very low sensitivity, the averages of ALB and HYD had to be used. It is seen that A is larger than B for ANR and TRV and this indicates that ΔZ is induced by ΔH mainly. This is also evident from the traces of a bay on 9 July, 1970 (Fig.1) shown for all three stations. Traces at ALB and HYD are also included in the figure to illustrate that ΔH for bays does not vary much over a wide range of latitude (10°) in low latitudes.

In Fig. 2 the result of fast Fourier transform of a storm, digitized at 3 min intervals at all three stations, is shown. At all three stations the spectra of ΔZ follows ΔH spectra confirming that ΔZ originates from the currents induced by the horizontal field variations (ΔH). This is in conformity with the large value of A in Eqn (1) for all these stations and this in turn indicates that the induced currents flow on the south side of the tip of the Indian peninsula.

(b) Solar quiet day variations (Sq) :

We used the IGY data from January through December 1958 in this analysis. The year was divided into three seasons, D months, E months and J months. Spherical harmonic analysis of hourly values for this period has been performed by Matsushita and Maeda (1965) and the coefficients calculated by them were used to estimate the expected Sq variations in the three components. Since these coefficients calculate X, Y and Z components, we will compare in this section ΔX, ΔY and ΔZ with the observed values. In their calculations the Sq variations are expressed as:

$$\Delta X = \sum_{m=1}^{4} \sum_{n=m}^{m+1} \left(\tilde{a}_n^m \cos m\lambda + \tilde{b}_n^m \sin m\lambda \right) X_n^m(\theta).$$

$$\Delta Y = \sum_{m=1}^{4} \sum_{n=m}^{m+9} \left(-\tilde{b}_n^m \cos m\lambda + \tilde{a}_n^m \sin m\lambda \right) Y_n^m(\theta) \quad \ldots (2)$$

$$\Delta Z = \sum_{m=1}^{4} \sum_{n=m}^{m+1} \left(a_n^m \cos m\lambda + b_n^m \sin m\lambda \right) P_n^m(\theta).$$

where, $X_n^m(\theta) = \frac{1}{n} \frac{\partial P_n^m(\theta)}{\partial \theta}$, $Y_n^m(\theta) = \frac{m}{n} \frac{P_n^m(\theta)}{\sin \theta}$

and $P_n^m(\theta)$ is Schmidt's function. θ stands for dip latitude of the station and λ is the local angular time measured from midnight. The constants a_n^m, b_n^m, $\tilde{a}_n^m$ and $\tilde{b}_n^m$ were estimated by Matsushita and Maeda through the usual method of spherical harmonic analysis.

The hourly values calculated using Eqn (2) are shown in Fig.3. In the same figure we have also plotted the observed variations reduced to exact hours of the local time of each observatory. For this reduction we followed Price and Stone (1964). A comparison of the computed and observed variations shows that Z-component is highly anomalous at all three stations. To test the validity of Parkinson's relation, we took the calculated amplitudes and phases of each harmonic as the normal part of the variation field and subtracted the same from the observed values by taking phases into account to obtain its anomalous part. Major part of ΔZ is found anomalous and it does not show any systematic correlation with normal part of either ΔX or ΔY or ΔZ. The results lead us to conclude that the anomaly does not conform to Parkinson's relation.

Discussion

The nature of ΔZ at ANR, KOD and TRV for SSCs and bays exhibits the usual coastal effect. For night time variations the inducing fields are uniform over a region much larger than the skin depth of the eddy currents and under normal conditions ΔZ should be very small at low latitude stations. The external and internal components will cancel each other over a region which does not have any lateral gradient in conductivity. However, the conductivity contrast of the land-sea boundary and possibly the contrast in the conductivity of the upper mantle, produces perturbations in the current system near the boundary to produce large values for Δ Z. That the observed Δ Z at ANR, KOD and TRV are due to such perturbations follows from their correlation with the horizontal component of the variation field (Fig.2).

However, as we have observed earlier the mechanism causing the anomalously large Δ Z at Sq periods is rather complex. Δ Z is negative at ANR and KOD, when the Sq current system reaches its peak value and it is positive at TRV. (Both for SSCs and bays all three have identical Δ Z variations). The values are much larger than what could be expected from the current system calculated by Matsushita and Maeda (1965). The large Δ Z are undoubtedly a local feature of the peninsula.

Bennett and Lilley (1973) also observed large ΔZ in south-east Australia. This region incidentally has a topology similar to the south tip of the Indian peninsula. But in their study the anomalous part of Δ Z correlated with the horizontal field normal to the coast. A similar calculation here fails to show the same effect. It may however be pointed out that over regions under the equatorial electrojet the scale length of the inducing field for Sq variations and their skin depth are both of comparable magnitude. In this way the present situation is entirely different from the situation over the Australian region where the inducing field is more uniform. Non-uniformity of the source field is known to inhibit the strength of induced currents, and even the existence of currents induced by jet part of the Sq field is still an open question. One aspect, that the normal part of the Sq current system near the dip equator does induce currents, is settled. We also know that the temperature of the upper mantle under oceans is higher than that of the continents.

The direction of induction vectors for bays suggests that the induced current flows preferentially around the tip of the Indian peninsula. The situation for Sq differs from the bay field in the sense that at ANR and KOD the gradient in the jet current system gives a large variation in the vertical component, which on the other hand is practically zero for bay fields. Hence, for Sq variations ΔZ at ANR and KOD will have a large external part, and TRV being closest to the channelled currents will receive a major contribution from the induced currents.

A calculation of ΔZ using the uniform band model of Onwumechilli (1967) gives for ΔZ from external part of the jet field a value of -42 gamma and -32 gamma respectively for ANR and KOD. We have taken the height of the electrojet as 100 km., its half-width as 250 km and strength as 130 amp/km. These values have been estimated by Yacob (1966) for our region for E-months of 1958. The computed ΔZ are quite close to the recorded variations for these months at ANR and KOD. For TRV, the computed value is only 9 gamma, which is much smaller compared with the recorded ΔZ. It lends support to our interpretation that ΔZ at ANR and KOD are mostly of external origin and TRV being close to the channelled currents gets from these a substantial addition to its Z variations.

In conclusion, it may be noted that the induced currents, both for bay and Sq fields, flow preferentially below the tip of the peninsula in the deep ocean. These currents should produce similar Z variations at all three stations. This is true for bays, but for Sq field the larger external part of Z arising from the jet currents causes at ANR and KOD a different behaviour.

Acknowledgement

We would like to thank Prof.B.N.Bhargava for bringing to our notice these unique features of magnetic records of ANR, KOD and TRV. Many discussions with Mr.A.Yacob are gratefully acknowledged. Prof.S.Matsushita is thanked for supplying us the coefficients we used to calculate the Sq field.

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Figure Captions

Fig. 1 The bay of 9th July, 1970. D and Z traces are similar for Alibag whereas for Annamalainagar, Kodaikanal and Trivandrum the Z trace is similar to H. Time is shown in IST.

Fig. 2 Fourier amplitude spectra at various periods for three stations from a magnetic storm on September 13, 1972.

Fig. 3 Solar quiet day variations of the three geomagnetic components X, Y and Z at ANR, KOD and TRV. The variations are shown for D months, E months and J months. Both recorded variations (——) and variations computed (----) in the model of Matsushita and Maeda (1965) are shown in the diagram.