IMF- GEOMAGNETIC FIELD COUPLING AND EARTHQUAKES

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Abstract: The interplanetary magnetic field (IMF) contains temporal variations. Solar wind-magnetosphere coupling mediates these disturbances to the geomagnetic field. The vertical variance (VV) index is an effective tool in analyzing this coupling. Analysis shows that the extent of effective coupling is characteristic of each station and varies with time. Since solar wind-magnetosphere coupling is a global phenomenon, this variation is strongly correlated between stations. However, this correlation is disturbed by local events whose signatures are present in the geomagnetic field. This paper examines the role of earthquakes in the loss of solar wind-magnetosphere coupling correlation between selected geomagnetic observatories, viz., Alibag, Huancayo, Phu Thuy, Qsaybeh. The inter-station geomagnetic field-IMF vertical variance index ratio (GM-IMF VVIR) correlations of the selected station pairs are analyzed. Anomalies in the form of dips are observed in the inter-station correlations prior to the occurrence of earthquakes. The findings made here have been substantiated by the fact that the anomaly is absent during earthquake (EQ) free intervals. Analysis for the months of April 2004 is presented in this paper. Even as EQs may not be the single source of local effects on the inter-station correlations, observations presented here suggest that EQs have a part in the IMF-geomagnetic field coupling anomaly.

***Index Terms* - Earthquakes, Anomaly, Precursors.**

I. INTRODUCTION

The geomagnetic field varies at different time scales. In broad terms, the long term variations are due to the changes in the dynamo region within the Earth while the short duration fluctuations are due to the current systems in the atmosphere and the magnetosphere (Courtillot and Mouel, 1988).

This work relates to the short term changes in the geomagnetic field. Newton (1943) brought out the clear association between changes in the space environment of the Earth and the geomagnetic field. Dungey (1961) elicited a detailed understanding of the mechanism of solar wind-magnetosphere coupling. The magnetic field which accompanies the solar wind is known as the interplanetary magnetic field (IMF). The dominant role played by the IMF in the solar wind-magnetosphere interactions and the resultant geomagnetic transients were pointed out by Crooker (1975). IMF (z), the north-south component of IMF interacts predominantly with the Earth's intrinsic field which results in the rapid variations in the geomagnetic field.

The effectiveness of different coupling functions in relating between the solar wind and 10 different magnetospheric indices has been objectively studied by Newell et al. (2007). This paper attempts to report the localized distortions observed in the IMF-geomagnetic field coupling in association with earthquakes (EQs). Scientists have been on the lookout for precursors and signatures of EQs.

II. METHODOLOGY OF ANALYSIS

The vertical variance (VV) index is a mathematical tool introduced by Abraham et al. (2010) to examine the IMF-geomagnetic field coupling. The index gauges the amount of disturbance in any transient data. If in a given data series, a quantity y varies with x, (x_i, y_i) and (x_{i+1}, y_{i+1}) being adjacent points in the data set, the VV index of the data set may be obtained as

$$VV \quad index = \sqrt{\frac{\sum_{i=0}^{n-1} \frac{(y_{i+1}(x) - y_i(x))^2}{(y_{i+1}(x) - y_i(x))^2 + (x_{i+1} - x_i)^2}}{n}}, \qquad (1)$$

Where, $n = \frac{(X_2 - X_1)}{(x_{i+1} - x_i)}$, X_2 and X_1 being the limits of the interval for which the index is being determined.

Figure 1 illustrates the application of VV index to four different test data sets. All the four data sets represent a variation in time from 0 to 4 units along the X axis. The limits of the variation along the Y axis are also the same for all the four cases, ranging from 0 to 5. However, the variations of the data within these limits are different for the four panels. The top right panel data is visibly the most disturbed of the four sets. The other panels show relatively less disturbance. The VV index quantifies the disturbance in these data sets. The highest VV index value is obtained for the top right panel (0.980) while a lower value is obtained for the top left panel (0.928). The two lower panels have an even lower value even as they have different shapes (0.848), indicating an equal content of variations. The index thus assigns a numerical value to the amount of disturbance in data. The VV index is normalized values in the range of 0 to 1.

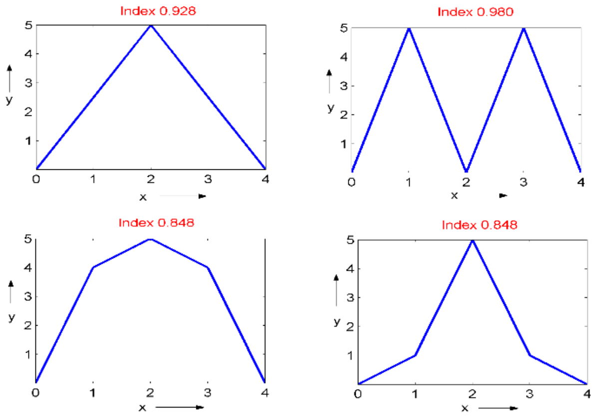

Figure 1: The figure shows the Vertical Variance (VV) index values of four different illustrative data sets highlighting the general behavior of the index.

The disturbance in geomagnetic or interplanetary magnetic field data sets is estimated using the VV index. While determining the daily indices and using adjacent minute magnetic field data values, $t_{i+1} - t_i = 1$ min and $n = 1440$. A linear relationship has been established between the IMF and geomagnetic data in terms of the daily VV index values for the stations (Abraham et al. 2010). It conclusively proves a transfer of disturbance from the IMF to the geomagnetic field through solar wind-magnetosphere coupling.

The daily geomagnetic VV indices and IMF VV indices are determined. The ratio between the daily geomagnetic field VV index value and the IMF VV index value (GM-IMF VVIR) for various geomagnetic stations is the key parameter employed in analysis, the ratio being an indicator of the effectiveness with which the IMF couples to the geomagnetic field.

The correlation coefficient between the GM-IMF VVIR of various station pairs is determined. Prominent dips are found in various inter-station GM-IMF VVIR correlations. These dips are treated as an anomaly in the correlation. This anomaly must owe its origin to locally induced perturbations in the GM-IMF coupling. Different inter-station correlation schemes were attempted and the six day advance correlation was found most suited to bring out the inter-station correlation anomaly in relation to EQs. Thus, the GM-IMF VVIR inter-station correlation for a particular day is determined on the basis of the GM-IMF VVIR of that day and the preceding five days. The results of the correlation are used for further analysis.

This paper attempts a month wise analysis to isolate the possible EQ anomaly. The analysis for the months of April (Table 1) is performed using the geomagnetic data for the stations of Alibag (18.64 ºN, 72.87 ºE and GM latitude 10.37 ºN), Huancayo (12.04 ºS, 75.32 ºW and GM latitude 2.07 ºS), Phu Thuy (21.03 ºN, 105.96 ºE and GM latitude 11.05 ºN) and Qsaybeh (33.87 ºN, 35.64 ºE and GM latitude 30.31 ºN) for the year 2004. IMF (z) data for the same period is also employed. The correlation between the data sets of different station pairs is observed to analyze the solar wind-magnetosphere coupling on a global scale and the deviations thereof owing to local events.

III. Data Selection and Preparation

The EQ data has been obtained from Advanced National Seismic System (ANSS). The distances of the geomagnetic observatories from epicenters of the EQs are determined from this data. There were 1683 quakes globally with magnitudes 5.0 and above in the year 2004, mostly Mw (moment magnitude) scale. The details of the EQs are provided in the order of occurrence in Supplementary Table 1. The first two digits of the number assigned to EQs in column 1 of the table refer to the year (04 for 2004). The remaining digits of the column give the chronological position of the event. The EQ numbers given in column 1 is used as the reference number of the events for further discussions.

The ACE satellite data is used to calculate the daily IMF VV indices. Geomagnetic data obtained from WDC, Kyoto is used to calculate the geomagnetic VV indices. The VV index ratios between the daily value of the geomagnetic field and IMF (GM-IMF VVIR) are given in the same table (column 7 to column 10). Further, the inter-station correlations determined between various station pairs (Alibag-Phu Thuy, Alibag-Qsaybeh and Huancayo-Phu Thuy) are given in the table (column 11 to column 13). The plot of correlation for months of April 2004 (Figure 2 and Table 1) is analyzed and discussed in detail here.

IV. Results

The analysis of the anomaly that appears in the GM-IMF VVIR correlation in relation to EQs is readied here on a detailed month wise basis. The analysis is presented in the paper for April 2004.

The key parameter of the stations that factors in this analysis is the distance from the station to the epicenter of the EQ. EQs with magnitudes between 5.0 and 6.5 are included for analysis, only if they occur within 2000 km of any one of the geomagnetic stations considered. However, all EQs with magnitude 6.5 and greater are included for analysis even when their distances to all the stations considered are greater than 2000 km. Here, it is assumed that these strong EQs influence the correlation even beyond this distance. Of the 1683 significant EQs in the year 2004 with magnitudes 5.0 and above, 313 meet these criteria.

While referring to the EQs in this table, the following terminology is employed for the convenience of discussion. When an EQ epicenter is within 1000 km of a station, it is referred to be "very close" and an event within 2000 km of the station is referred to as "close". When an EQ is beyond 2000 km but within 10000 km, it is referred to be either "not far" or "not close" in the appropriate context. When an event is beyond 10000 km from the geomagnetic station, it is said to be "far". A dip in the inter-station GM-IMF VVIR correlation below a value of 0.5 is treated as significant.

The characteristics of EQs during various months of the year 2004 are given in column 1 to column 7 of Table 1. Columns from 8 to 10 of this table provide observations of the correlation between the Alibag-Phu Thuy station pair. Of these, column 8 gives the date on which the said correlation begins to fall, provided that the correlation continues to fall to values below the minima criterion value of 0.5. Column 9 indicates the date on which minimum value is observed in a particular instance of the correlation loss. Column 10 gives the minimum value observed in that particular instance of the correlation loss. Column 11 to column 13 provides similar details of the Alibag-Qsaybeh station pair. Finally, column 14 to column 16 provides similar details for the Huancayo-Phu Thuy station pair.

4.1 April 2004

Table 1 summarizes events from EQ 04 402 on April 5, 2004 to EQ 04 491 on April 27, 2004 and refers to the Figure 2. EQ 04 402 which occurred close to Alibag (1994 km) with a magnitude of 6.6 Mw seems to influence the Alibag-Phu Thuy correlation with a down turn on April 1, 2004 and the minima on April 2, 2004.

Even though EQ 04 405 occurred close to Qsaybeh (1544 km), it had a relatively low magnitude of 5 (Mw) and was not close to Alibag (5504 km). This combination of EQ magnitude and distance from the relevant stations does not seem to affect the correlations. Similarly, EQ 04 413 is not close to any of the stations and does not seem to influence the correlations.

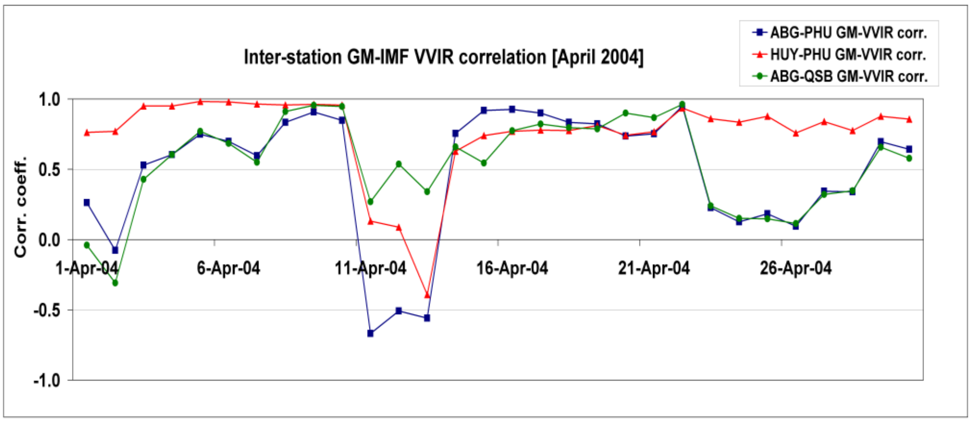

Figure 2: The figure shows the six day inter-station GM-IMF VVIR correlations for the station pairs of Alibag-Phu Thuy, Alibag-Qsaybeh and Huancayo-Phu Thuy for the month of April 2004.

A series of five EQ events occurred between April 10 and April 16, 2004 (EQ 04 418 to EQ 04 442). A minimum in all the three considered correlations starting from April 10, 2004 and exhibiting minimal values from April 11, 2004 is observed in association with these series of events. It is noted that Alibag-Phu Thuy correlation has the deepest minima (-0.66) while Alibag-Qsaybeh correlation does not drop as much. It can be noted in this context that four of these events (EQ 04 418, 04 438, 04 441, 04 442) were close to Phu Thuy and not far from Alibag. At the same time, Qsaybeh is relatively far. The dip in Huancayo-Phu Thuy correlation can be viewed in the light of the proximity of the above four events to Phu Thuy. Even though these events occur far from Huancayo, the multiplicity of events seems to influence this correlation. Besides, EQ 04 434 occurred close to Huancayo (1246 km).The correlations recover by April 14, 2004.

EQ 04 468 which occurred on April 22, 2004 was close to Huancayo (1484 km). However, it had a low magnitude (5 Mw) and was 19475 km away from Phu Thuy and does not visibly affect the Huancayo-Phu Thuy correlation. The event was far from other stations as well and has no observed effect on any correlation.

EQ 04 483 which occurred on April 24, 2004 was close to Phu Thuy (1642 km) and was not far from Alibag (5098 km). It is noted that both Alibag-Phu Thuy and Alibag-Qsaybeh correlations begin to dip around April 23 and reach a minima around April 26, 2004. However, it was very far from Huancayo (17715 km) and occurred as an isolated event of low magnitude (5.3 Mw) not affecting the Huancayo-Phu Thuy correlation.

EQ 04 491 which occurred on April 27, 2004 was also close to Huancayo (1486 km). However, it had a low magnitude (5 Mw) and was 19432 km away from Phu Thuy and has no apparent effect on the Huancayo-Phu Thuy correlation. The event was far from other stations as well and goes without affecting any correlation.

Table 1: The table gives details of the EQs and observations regarding the analyzed inter-station correlations for the month of April 2004.

Correlation Analysis Table (April 2004)

Earthquake							Correlation Minima								
							ABG-PHU			ABG-QSB			HUY-PHU		
EQ. No.	EQ Date	Magnitude	Distance of epicentre from HUY(Km)	Distance of epicentre from ABG(Km)	Distance of epicentre from PHU(Km)	Distance of epicentre from QSB(Km)	Date of Down Turn	Date of Minima	Minimal Value	Date of Down Turn	Date of Minima	Minimal Value	Date of Down Turn	Date of Minima	Minimal Value
04 402	05-Apr-04	6.6	15763	1994	3784	3210	01-Apr-04	02-Apr-04	-0.08	16-Mar-04	27-Mar-04	-0.31	26-Mar-04	29-Mar-04	0.48
04 405	07-Apr-04	5	11432	5504	8141	1544	No Minima			No Minima			No Minima		
04 413	09-Apr-04	6.5	12484	10949	7689	14622									
04 418	10-Apr-04	5.1	18864	2294	1613	6219	10-Apr-04	11-Apr-04	-0.66	10-Apr-04	11-Apr-04	0.27	10-Apr-04	13-Apr-04	-0.39
04 434	15-Apr-04	5	1246	16281	17744	12267									
04 438	15-Apr-04	5.3	18890	2556	1862	6549									
04 441	15-Apr-04	5	18881	2550	1870	6543									
04 442	16-Apr-04	5.6	18894	2556	1857	6548									
04 468	22-Apr-04	5	1484	16082	19475	12831	No Minima			No Minima			No Minima		
04 483	24-Apr-04	5.3	17715	5098	1642	8205	23-Apr-04	26-Apr-04	0.1	23-Apr-04	26-Apr-04	0.12	No Minima		
04 491	27-Apr-04	5	1486	16007	19432	12744	No Minima			No Minima			No Minima		

The correlations observed in the month of April 2004 deserve special mention. The value of all the three correlations remains near unity from April 14 to April 22, 2004. It is noted that there were no EQs to influence the correlations between EQ 04 442 on April 16, 2004 and EQ 04 483 on April 24, 2004. This observation is important in asserting a positive relationship between EQs and the GM-IMF VVIR correlation loss.

IV. CONCLUSION

The punctuation of GM-IMF correlation in accordance with seismic events is the primary observation of this work. Fraser-Smith (1978) has described the requirement of the elaborate experimental setup for observing the ULF geomagnetic pulsations occurring prior to EQs. The method used in this paper is so simple that 1-minute resolution geomagnetic data and IMF satellite data are the only requirements of the analysis. This is currently available. Correlation can be determined instantaneously even on a moderate performance computer and a critical fall in the correlation can be examined in relation to imminent EQs. The work can be replicated on data from various stations. Observing correlations from a suitably selected set of geomagnetic stations, EQ possibility across the globe could be assessed. The technique has to be adopted on a real time basis. It is not intended to suggest EQs as the only source of local effects on the inter-station correlations. However, in the instances observed in this paper, EQs seem to introduce considerable local aberrations on the same.

The loss of correlation may be related to factors like depth of the epicenter beneath the surface, crustal properties of the earth, etc. Owing to the probable involvement of such factors, it is not possible to pinpoint the exact epicenter-station distance and magnitude of an EQ which produces a particular extent of correlation loss.

Since six day advance correlation is employed to calculate the correlation value of a particular day, the vertical variance index of the previous five days is sufficient to calculate the correlation value of a particular day. Hence, the analytic technique adopted here enables the detection of the anomaly prior to occurrence of the associated EQs.

It has to be noted that it is not an aberration in the IMF which is being manifested in the anomaly. Any distortion in the IMF will affect all stations equally and the inter-station GM-IMF VVIR correlation will remain unaffected. Therefore, it must be the local disturbance content in the geomagnetic field which is reflected in the VV index of specific stations close to the EQ eventually leading to the fall in GM-IMF VVIR correlation.

The anomaly noted in this paper is a promising EQ precursor. It is imperative we explore all possibilities of this technique and make improvements in order to minimise the devastation caused by earthquakes.

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