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A COMPARISON STUDY BETWEEN THE GEOMAGNETIC ELEMENTS VALUES AS RECORDED AT MIDDLE AND HIGH LATITUDES GEOMAGNETIC OBSERVATORIES DUE TO NOVEMBER 7-12, 2004 GEOMAGNETIC STORM

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دراسة مقارنة بين قيم عناصر المغناطيسية الأرضية كما هو مسجل فى خطوط العرض المتوسطة والعالية لمراصد المغناطيسية الأرضية بسبب حدوث العاصفة المغناطيسية الأرضية ٧-١٢ نوفمبر ٢٠٠٤

الخلاصــة: العواصف هى فترات من الوقت مع شدة المجال الكهربائى تؤدى للحمل الحرارى بين الكواكب من خلال حقن كبيرة من الطاقة فى نظام المغنتوسفير - الأيونوسفير لحلقة التيار المكثفة طويلة وقوية بما فيه الكفاية لتتجاوز بعض العتبة الرئيسية من العاصفة وتحديدها بشكل كمى، ولقد أنتج التوهج الشمسى الفعال من ٦٩٦ منطقة من الشمس ثلاثة CME التى تسببت فى التفاعل مع الغلاف المغناطيسى للأرض. اثنان من ثلاث CME من القوة المغناطيسية أنتجا نشاط العواصف الأرضية والتى أسفرت عن التيارات المستحثة (GIC).

الهدف الرئيسى من هذا العمل هو دراسة سلوك ومخاطر آثار العاصفة المغناطيسية فى نوفمبر ٢٠٠٤ على المجال المغناطيسى للأرض، وتوليد تيارات مستحثة (GIC) فى مناطق خطوط العرض العليا والمتوسطة باستخدام البيانات المغناطيسية المستمدة من أكثر من ستة مراصد للمغناطيسية فى التحليلات. وتعتبر أيضا أرقام البقع الشمسية، A-DST مؤشراً ومؤثراً. وتشير النتائج إلى أن قمم DST بلغت حوالى –٣٨٣نانو تسلا، ومؤشر لحوالى ١٥٣ نانو تسلا ، ومتوسط عدد البقع الشمسية يصل إلى حوالى ٣٤,٣ . ويشير التحليل إلى أن متوسط الفروق فى العناصر المغناطيسية (Z, D, H) بين مناطق خطوط العرض العليا (٦٠° إلى ٩٠° شمال) وخطوط العرض الوسطى (٢٠° إلى ٦٠° شمال) تصل إلى نحو ١١٠٠، ٧٠٠ و ١١٠٠ نانو تسلا على التوالى. وهذا يؤدى إلى توليدمجال كهربى مستحث فى مناطق خطوط العرض العليا حوالى ثلاث مرات من حجمها فى مناطق منتصف خطوط العرض.

ABSTRACT: *The storms are intervals of time with a sufficiently intense and long-lasting interplanetary convection electric field leads, through a substantial injection of energy into the magnetosphere-ionosphere system, to an intensified ring current, strong enough to exceed some key threshold of the quantifying storm time Dst index. An active solar flare from region 696 of the Sun has produced three CME's that caused interaction with the Earth's magnetosphere. Two of the three CME passages encountered strongly the Earth's magnetosphere produced storm activity that resulted in Geomagnetic Induced Currents (GIC) observations.*

The main target of this work is to study the behavior and hazard effects of November, 2004 magnetic storm on the Earth's magnetic field, and in generating (GIC) at high and middle latitudes areas. In this respect, we use magnetic data derived from more than six Geomagnetic Observatories in the analyses. Also, the sunspot numbers, A-index and Dst-index are considered. The results indicate that the peaks of the Dst reached about -383 nT, the A-index about 153 nT, and the average sunspot number reaches about 34.3 (2). The analysis indicates that the average differences of the magnetic components (H, D and Z) between high latitude regions (60º to 90º North) and mid-latitudes (20º to 60º North) reach about 1100, 700 and 1100 nT respectively towards high latitude regions. This leads to generate GIC at high Latitude areas about three times of its magnitude at the mid-Latitude areas.

INTRODUCTION

Two major solar flares, rated as R2 (*moderate /a ~X2*) and R3 (*strong / a ~X3*) on the NOAA Space Weather Scales, were erupted on November 9 and 10, 2004 and recorded by *the SOHO-Solar & Heliospheric Observatory-spacecraft*. During that period three separate *CME* passages occurred, generated by flare activity. The first two *CME* passages generated long duration geomagnetic storms at major to extreme levels, category G2 (*moderate*) to G5 (*extreme*), while the last one was minor with little geomagnetic storm activity.

Disturbances on the sun produce electric field that is arisen due to the magnetosphere-ionosphere interaction. These disturbance electric fields may lead to redistribution of ionosphere plasma, *(Fejer and Scherliess, 1995; and Kelly et al., 2003)*.During the period of the magnetic storm, the electric field, the charged particles and expand equator-ward effects are felt at sub-auroral latitudes. Intense convection electric fields appear in the expanded auroral oval *(Yeh et al., 1991)* while transient fields penetrate equator-ward of the shielding region near the inner edge of the ring current at mid latitudes *(Gonzales et al., 1983)*. The values of *K-index* are useful for describing the storm severity for GIC threats. It reaches about 9 that is correlated with the values that exceeds 500 nT during the storm time *(Figure 1-a)*.

In the recent years, a number of workers have used GPS based systems to assess the impact of geomagnetic storm on the total electron content of ionosphere *(Jakowaski et al., 1999; and Kutiev et al., 2005)*. They deduced that the magnetic storm has strong effect on the readings of GPS network system and the propagation of radio waves. The hazards due to magnetic storms and the related convection of the electric current as well as the charged particles on both high and mid latitudes regions caused by 7-12 November magnetic storm can be interpreted as follows:-

3. Description of 7-12 November Geomagnetic Storms

3.1. High latitude phenomena (± 60°- 90°):

During the early stages of the most magnetic storms the total electron content at sub-aurora latitudes, integrated vertically through the ionosphere F region, increases the storm positive phase *(Mendillo et al.,1970; Evans, 1970)*related this increasing to an uplifting of the F layer to altitudes where recombination proceeds more slowly. During disturbed conditions, rapid sunward convection from the post-noon mid-latitude ionosphere carries high-density solar-produced F region plasma through the dayside cleft and into the polar cap *(Joseph et al., 2006)*. This plasma is observed to spread out along convection trajectories within the polar cap where it constitutes a source for the observed polar cap F region density enhancements and their effects. The plasma tongue carried through the cleft from lower latitudes serves as a tracer of polar cap convection away from the cusp and cleft. The *Dst* is a geomagnetic index which monitors the world wide magnetic storm level. It is constructed by averaging the horizontal component of the geomagnetic field from mid-latitude and equatorial magneto-grams. The negative *Dst* values reaches about -383 *nT* during the 7-12 November geomagnetic storm *(Figure 1-b)*, which indicates the intense of the magnetic storm *(Table 1)*. The threshold for geo-effectiveness is chosen to be Dst < -80 *nT* for two hours or longer.

Table (1): Data for all numbered solar regions according to the Solar Region Summary, provided by NOAA/SEC.

Month	Average solar flux at Earth	International sunspot number
2004-11	129.6 (1)	34.3 (2)

3.2. Mid-Latitude Phenimena (± 20°- 60°):

The characteristics of the mid-latitude ionosphere are generally determined by the diurnal, seasonal, and solar cycle variations and by the coupling to the neutral atmosphere. When the level of geomagnetic disturbance increases, the electric fields and particle populations which characterize the aurora region expand equator-ward and their effects are previously felt at sub-aurora latitudes. A number of important magnetosphere boundaries are found near the aurora/sub-aurora transition (*nominally near 60° magnetic*) and these result in the ionosphere structure and dynamics characterized the mid latitudes areas. The equator-ward extent of the plasma sheet particle population lies on field lines near the plasma-pause. The precipitation from the plasma sheet alters the ionosphere conductance, currents and fields. During disturbed conditions, an intense (>100 *mV/m*) polarization electric field can be set up when freshly-injected plasma sheet ions lie equator-ward of the electros *(Galperin, 1974)* and this drives the latitudinal-narrow polarization jet or Sub-Aurora Ion Drifts *(SAID)(Spiro et al., 1979)*which directly or indirectly are responsible for a variety of ionosphere phenomena in the pre-midnight sector. The electric field shielding in the equatorial magnetosphere arises when the inward transport of injected plasma during the time of varying magnetic and convection electric field combined with the coronation electric field, result in electron and ion separation and the formation of plasma pressure gradients. In the theoretical treatment of *South wood and Wolf (1978) and Laura et al., (2008)* a northward electric field and rapid sunward convection at sub-aurora latitudes are created when a disturbance results in the penetration partial ring current ions to a lower L shell than the plasma sheet electrons. The strength of this electric field is inversely related to the latitudinal separation of the particle boundaries.

These effects couple to the ionosphere by particle precipitation, ionosphere conductivity, and field-aligned currents to control the convection structure and to prevent the convection electric field from further inward penetration.

4. Data Analysis and Interpretations:

The data has been collected from more than different six mid-latitudes and high-latitudes International Geomagnetic Observatories (*Table 2*) from 7 to 14 November 2004 for *H*, *D* and *Z* components. To evaluate the hazards due to this magnetic storm, different magnetic components data are interpreted in two trends as follows:-

4.1. The Effects of the magnetic storm to the main Earth's magnetic components:-

Correlations have been performed for three different zones between each two geomagnetic observatories located at mid-latitudes and high-latitudes with ±5° longitudes.

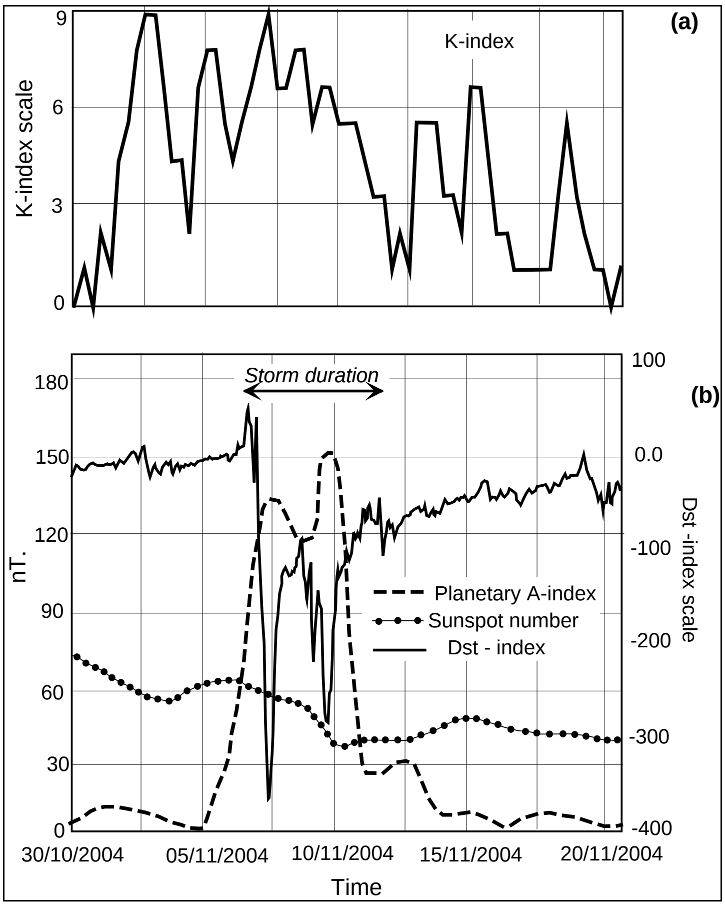

Figure (1): Effect of the Sun flares and solar activities on elements during 7-12 November, 2004 Geomagnetic storms,
a) K-index, b) A & D-indices, and sunspot number.

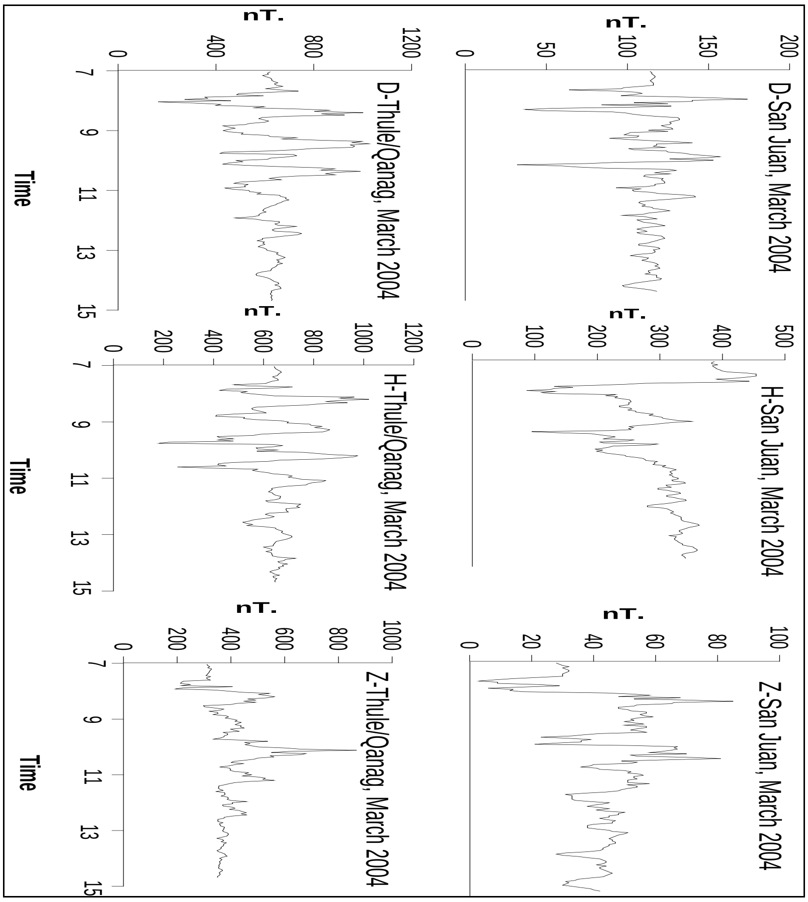

Figure (2): Correlation between D, H and Z for the first area (Thule/ Qomag observatory represents the high latitudes and Sao Juan observatory represents the mid latitude).

The first zone *(Thule/Qanag observatory represents the high latitudes and San Juan observatory represents the mid latitude)* the difference in magnetic field reaches about 450, 650 and 615 *nT* for *H*, *D* and *Z* components respectively *(Figure 2)*. The second area *(Sodankyla observatory represents the high latitudes and Misallat observatory represents the mid latitude)*; it shows that the magnetic values are increased at high latitudes by 1250, 320 and 1100 *nT*for *H*, *D* and *Z* components respectively*(Figure 3)*. Also at *Borok observatory* that is representing the high latitudes and *Qsaybeh observatory* representing the mid latitude, the different in the magnetic field reach about 540, 290 and 780 *nT* for *D*, *H* and *Z* respectively *(Figure 4)*.

The results listed in *(Table 2)* indicate that the effect of the magnetic storm at the high latitudes areas is about three times with respect to its effect on the mid latitudes areas.

4.2. Constructing a contour map for Earth's magnetic components*:*

The mean values of each magnetic components *(H, D and Z)* during the period of the storm are plotted according to its coordinates to obtain a contour map illustrating there effects at different latitudes. These maps illustrate that the most affected zone by the magnetic storm is restricted between the Latitudes 60° to 90° N which indicate that this area is occupied by high condense of the charged magnetic particles that extended southward the equatorial region. This region is considered the highest part subjected to the magnetic storm hazards.

Two profiles are selected along the West and East sides of longitudes 0° to show intensity distributions of the magnetic components from high latitudes to mid latitude areas.

It is very clear that the H and Z magnetic components are the most affected by the magnetic storm and D-magnetic component is the least effected. The difference in the magnetic values between the high latitudes and the low latitudes for the *D-magnetic component* reaches about 500 *nT*, and about 1000 *nT* for the *Z-component* whereas 900for the *H-magnetic component(Figures 5 & 6 and 7)*. This is because of the geometry of the magnetic field, and the position of the magnetic poles.

4.3. Relation between the intensity of the magnetic storm and Geomagnetically Induced Current (*GIC*) at different Latitudes*:*

The hazards of solar wind to generate a ground *GIC* flow in power grids and core of transformers are high at the high latitude regions rather than the mid latitudes regions *(Fig. 8)*. Its intensity is depending on the duration and intensity of the magnetic storm. When the *GIC*is over-excitation, it causes an internal heating damage for the power transformers *(e.g. October 2003 storms, 15 large power transformers were reported as permanently damaged and taken out-of-service at a large African utility company)*. Also, it can cause errors in *GPS* readings, geomagnetic readings during the magnetic survey and corruption of the buried pipes. Furthermore it can cause melting and burn-through of large amperage copper windings and leads in these transformers. The hazard effects of the magnetic storm due to generating *(GIC)*have been studied for two regions located at high and middle Latitudes in *USA*. A close correlation for these two locations, it can be noticed that the intensity peak of 7-12, magnetic storm reached 40 *nT/min* and its long duration would result in long intervals of *GIC* caused over-excitation *(Fig. 8)*. The correlation also indicates that the magnitude of *GIC* at high latitudes is about three times regarding its magnitude at the mid-latitudes areas.

Table (2): The differences between the mean values of the magnetic storm for the magnetic components at high and mid latitudes geomagnetic observatories.

Magnetic component	First zone		Second zone		Third zone	
	Thule/Qanag	San Juan	Sodankyla	Misallat	Borok	Qsaybeh
	77º:48 N - 69º:17W	18º:11 N - 66º:15W	67º:37 N - 26º:63E	29º:15 N - 30º: 89 E	58º:07 N - 38º:23E	33º:87 N - 35º: 64 E
H (nT)	820	370	1600	350	900	360
D (nT)	800	150	500	180	450	160
Z (nT)	700	85	1200	100	850	70

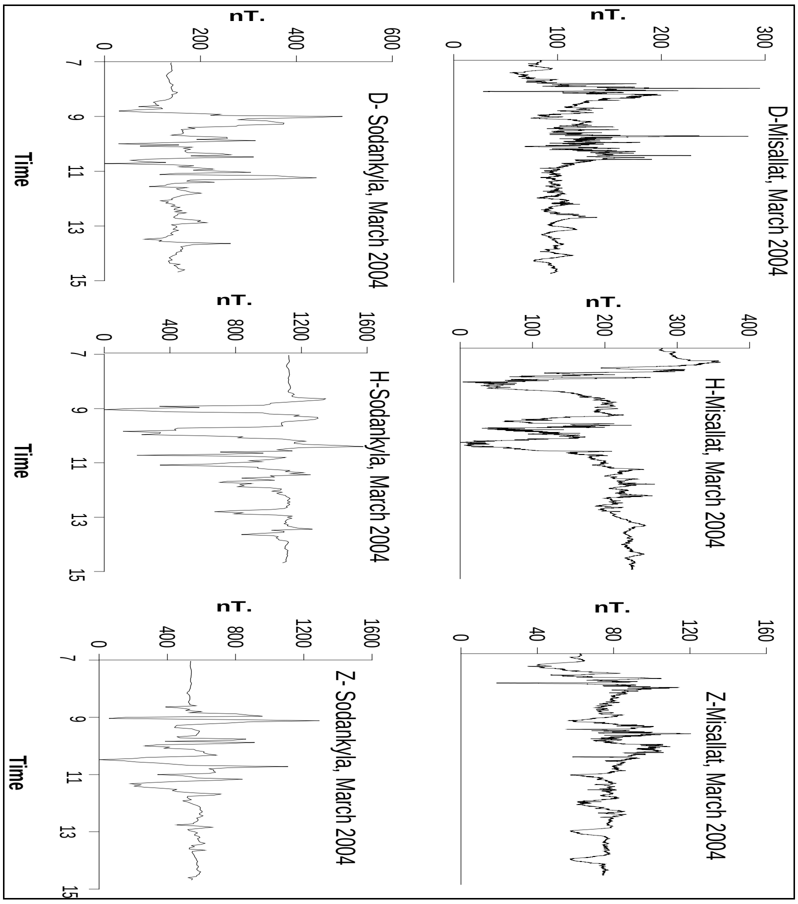

Figure (3): Correlation between D, H and Z for the third area (Sodankyla observatory represents the high latitudes and Misallat observatory represents the mid latitude).

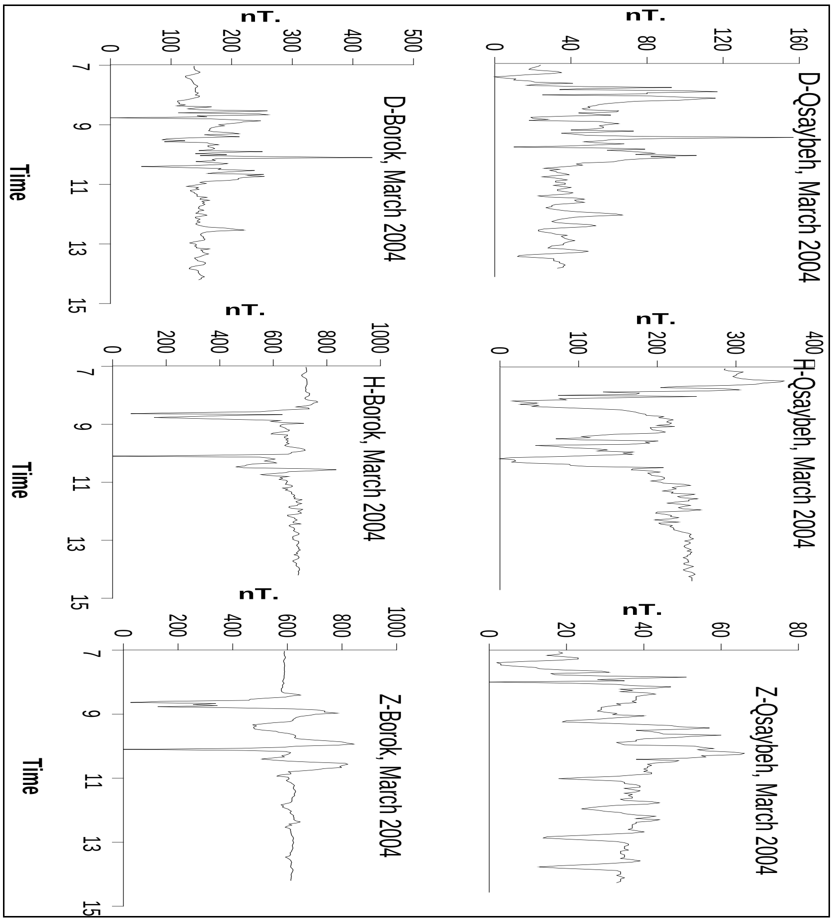

Figure (4): Correlation between D, H and Z for the third area (Borok observatory represents the high latitudes and Qsaybeh observatory represents the mid latitude).

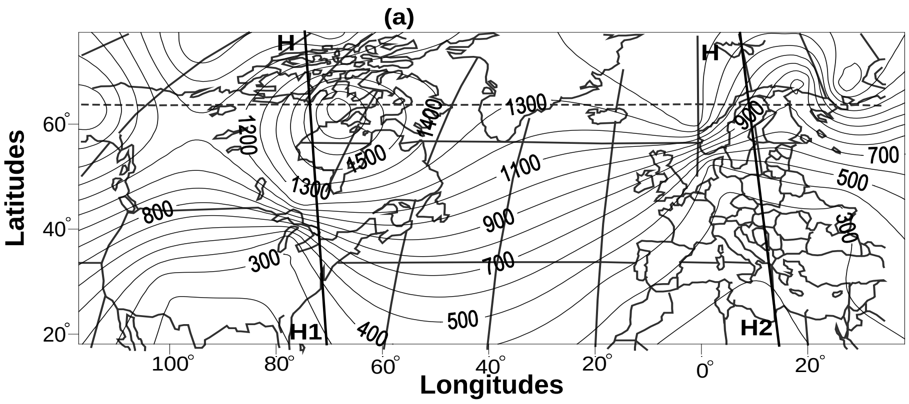

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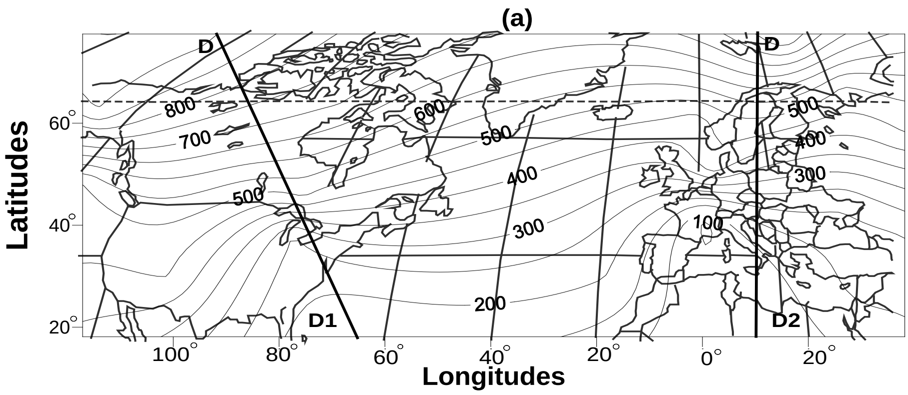
Figure (5): Distribution of the D-component of the magnetic field during the storm time; a) contour map for the D-component for high and mid latitudes regions, b) cross-profile along high and mid latitudes regions.



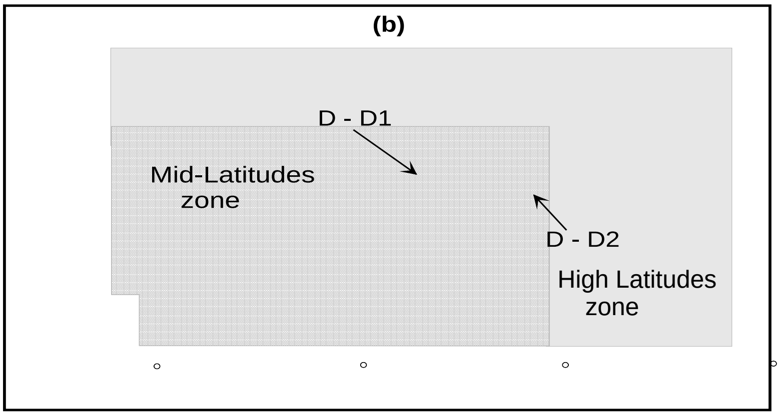


Figure (6): Distribution of the H-component of the magnetic field during the storm time; a) contour map for the H-component for high and mid latitudes regions, b) cross-profile along high and mid latitudes regions.

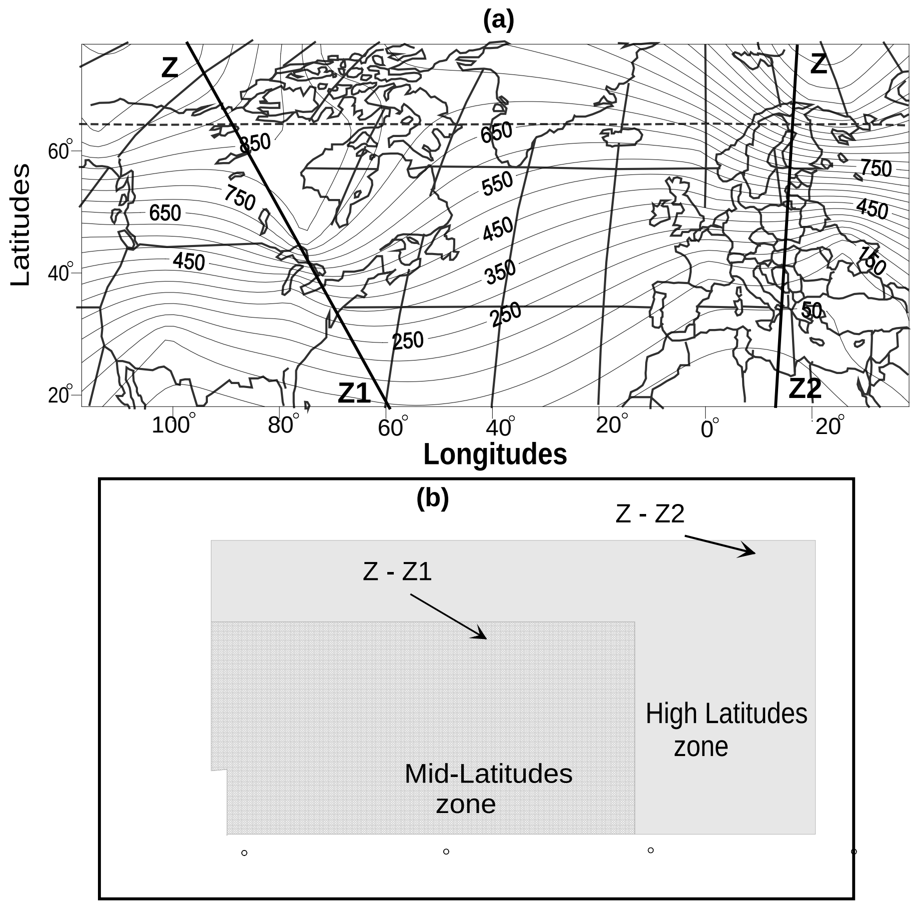


Figure (7): Distribution of the Z-component of the magnetic field during the storm time; a) contour map for the Z-component for high and mid latitudes regions. b) cross-profile along high and mid latitudes regions.

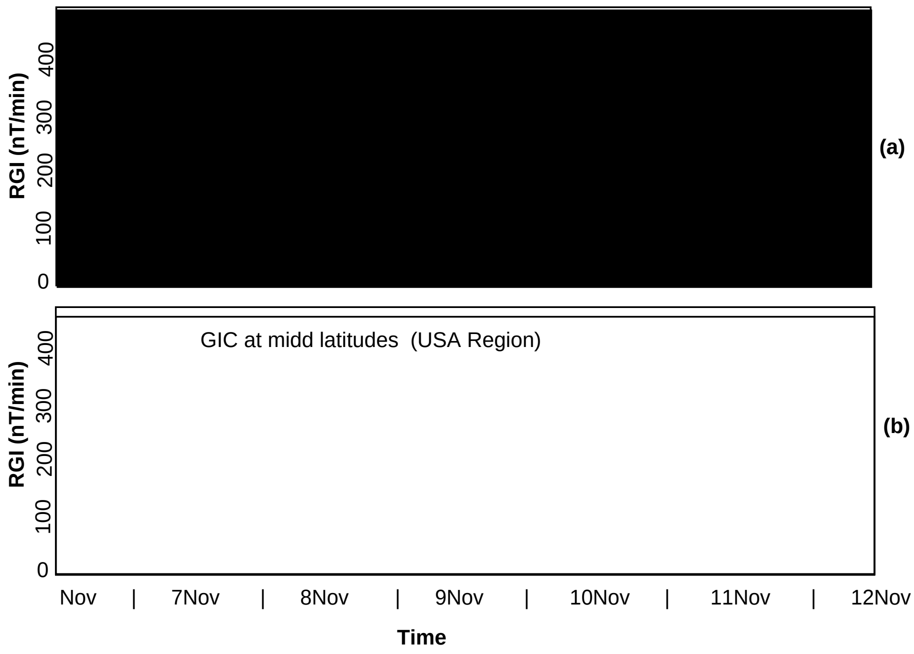


Figure (8): Strength of GIC during the storm time for:

a) High latitude area,
b) for mid-latitude region.

5. DISCUSSION AND CONCLUSIONS:

The 7 to 14 November 2004 geomagnetic storm is caused by three CME's that interacted with the Earth's magnetosphere. The disturbances were not limited to the high-latitude Polar Regions but it extended to mid-latitudes and equatorial regions by the interplanetary magnetic field (IMF). The measured magnitude of the geomagnetic storms, given by the Dst index is about -383 nT during the storm time. At mid-latitudes the dominant geomagnetic effects show strong variations in the ring current location and composition. During magnetic storms, that lasted 5 days, transient magnetopause compressions moved the circular current closer to the Earth and subsequent ion injections from the magneto-tail increasing its density started at the polar region and extended southward to mid latitudes and equatorial areas. A close examination of the magnetic data indicate that all the geomagnetic conservator's records are participating in the same starting time of the first phase of the magnetic storms (SSC). The second part of the magnetic storm (*main phase*) is different according to the latitudinal variations. Where the duration of this part increases at the middle latitudinal areas, it reaches its maximum duration at the high latitudinal parts. The duration of the recovery phase increased to reach its maximum at the high latitudinal areas. Two regions located at high and middle Latitudes in *USA* are used to study the hazards of the storm due to GIC. The correlations show that the intensity peak of the magnetic storm reached 40nT/min. The long duration of this storm generated GIC which caused over-excitation and corruption for the electric transformers. The correlations also indicate that the magnitude of GIC at high latitudes is about three times regarding with its magnitude at the mid-latitudes areas.

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