# Variations of time derivatives of the horizontal geomagnetic field and horizontal geomagnetic field along 96-degree magnetic meridian

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***Abstract***: The Energetic particles are released from the Sun by solar flares or eruptive ejections interaction with geomagnetic field producing geomagnetic storms and more ionization in the ionosphere. The geomagnetic substorms are classified as one of major factor that influence geomagnetically induced currents (GIC) that affect the operation of technological system through the geomagnetic field variations. The direct representation of GIC is the time derivative of the horizontal geomagnetic field. 138 substorms onset events were obtained from IMAGE magnetometer data from Northern Europe, using Dst (Disturbance storm time) to determine the substorm events of varying strengths, for five stations (Addis Ababa, Abisko, Bangui Hermanus and Nurmijarvi). The data used in this study covers the periods from 1999 to 2001. Positive high correlation exhibited between the maximum value of time derivatives of the horizontal geomagnetic field ($dH/dt_{max}$) and maximum value of horizontal geomagnetic field (max H). Also, Monthly variations of the maximum value of time derivatives of the horizontal geomagnetic field ($dH/dt_{max}$) and maximum value of the horizontal geomagnetic field (max H) were also investigated.

***Keywords***: Substorms, Geomagnetically induced current, Disturbance storm time, Time derivatives of the horizontal geomagnetic field and Horizontal geomagnetic field.

## 1.0 Introduction

Sun releases energetic particles that interact with the magnetic field of the Earth. This interaction produces geomagnetic storms and increase ionization in the ionosphere [1] (Stauning, 2013). Literatures revealed the geomagnetic disturbance posed by a coronal mass ejection (CME) generated geomagnetically induced currents (GICs) on the operation of technological systems such as power grids, communication cables, oil pipelines and human health [2-4] (Tom, 2002; Watari et al., 2009 and Pulkkinen et al., 2010). All these are manifestations of the ground effect of space weather at high geomagnetic latitude, which are known to cause problems. The GICs flowing along electric power-transmission systems are produced by a naturally induced geo-electric field during geomagnetic disturbances. Whenever a current flowing through neutral point, the operating point of transformer shift from the optimum point, resulting in transformer loss in form of the over heating or harmonic being produced that may affect the protective relay leading to malfunctioning of the transformer.

The auroral electrojet, ionospheric and magnetospheric current systems, are considered to be the major causes of geomagnetic disturbances which manifest to GIC. During the geomagnetic disturbances of the Earth's magnetic field, varying electrical currents in the ionosphere and magnetosphere induced electric fields in the Earth's surface. GIC can be obtained if the spatiotemporal behaviour of ionospheric currents is known and the Earth's conductivity is available. Then the horizontal geoelectric field which drives GICs can be computed. The GIC are considered as factors of time derivative of the geomagnetic field, the electric resistivity of the Earth and resistances of the power grid. [5-8] established that GIC also occurs at mid and low latitudes even at Africa and South Africa.

Based on the fundamental of Faraday's law, linking temporal changes of the magnetic flux to the electromotive force, the geoelectric field is associated varying geomagnetic field, indicating that the time derivatives of the geomagnetic field provide direct representation for GIC activity, especially with the horizontal component (dH/dt) [9-10]. The geoelectric field could be obtained from the measured geomagnetic field as statistical estimation of the GIC occurrence in a particular location. The major driver for GIC is the horizontal electric field induced at the Earth's surface as a result of time-varying ionospheric current systems. In the creation of GIC, substorms play significant role [11-14].

Several studies of geomagnetic field variations focused on higher latitude regions investigating on time derivative of the horizontal geomagnetic field (dH/dt). High values of dH/dt appear during the main phase expansion of geomagnetic storm using the International Monitor for Auroral Geomagnetic Effects (IMAGE) network. Increase in max dH/dt with increasing latitude equatorward of the auroral oval and decrease at the poleward were observed [15]. [16] compared the storm time substorms and non storm time substorms, the size of max dH/dt can be doubled by storm time substorms at all latitudes. The electrojet has great influence on the horizontal geomagnetic field (H), dH/dt is more liable to be influenced by smaller scale of ionospheric features [17].

In this paper, the hourly and monthly variations of the time derivatives of the horizontal geomagnetic field (dH/dt) and horizontal geomagnetic field (H) were analyzed. Also the relationship between the dH/dt and H during geomagnetic activity from 1999-2001 were also investigated. In this work, d*H*/d*t* is a direct representation of geomagnetically induced current (GIC).

## 2.0 **Material and Methods**.

The data used in this research includes Dst values (Disturbance storm time) and horizontal geomagnetic field component *H* for three years from 1999-2001. The substorm onsets are divided into those that occur during storm time conditions (Dst<−40 nT) were considered and this activity level defines substorm events. The *Dst* index data were provided by the World Data Center for Geomagnetism at Kyoto University (WDC). 138 substorms events were obtained from IMAGE magnetometer data from Northern Europe, using Dst to determine the substorm events of varying strengths for five stations (Addis Ababa, Abisko, Bangui Hermanus and Nurmijarvi). The time derivatives of the horizontal geomagnetic field were calculated to obtain a good measure of the GIC. The idea of local time (LT) was engaged throughout in the study using the concept of [18-19]. Coordinates of the stations engaged in this work are shown in Table 1.

**Table 1: Geographic and geomagnetic coordinates of magnetic observatories**

| Stations | Codes | Geographic Latitudes | Geographic Longitudes | Geomagnetic Latitudes | Geomagnetic Longitudes |
|---|---|---|---|---|---|
| Addis Ababa | AA | 9.030 | 38.770 | 0.16 | 110.47 |
| Abisko | AB | 68.356 | 18.824 | 65.11 | 102.31 |
| Bangui | BAN | 4.333 | 18.566 | -5.27 | 90.13 |
| Hermanus | HER | -34.425 | 19.225 | -42.35 | 82.15 |
| Nurmijarvi | NUR | 60.580 | 24.655 | 56.82 | 102.50 |

## 2.1 Correlation between the dH/dt and H

In section 2.1 we obtained regression analysis of both hourly time derivatives of the horizontal geomagnetic field (dH/dt) and horizontal geomagnetic field (H) components. Tables 2 presents the regression analysis performed to test the relationship between max time derivatives of the horizontal geomagnetic field ($dH/dt_{max}$) and max horizontal geomagnetic field (max H) at different latitudes, recorded at five stations in the period of 1999-2001 for substorm storm-time. The correlation coefficient between $dH/dt_{max}$ and max H are quite high for the three years. The difference in correlation clearly reflects the geographical orientation of the stations. This indicates that the (substorm) mechanism behind the relation between max H and $dH/dt_{max}$ may be independent of storm conditions as suggested by [20]. The GIC has a good relationship with the geomagnetic field variations due to the underground conductivity.The geoelectric field is always associated with varying geomagnetic field [21].

**Table2: Shows regression analysis of max H and max dH/dt for 1999, 2000 and 2001**

| Stations | r (1999) | r (2000) | r (2001) |
|---|---|---|---|
| Addis Ababa | 0.7068 | - | 0.6812 |
| Abisko | 0.8238 | 0.6875 | 0.6956 |
| Bangui | 0.7234 | 0.9331 | 0.6722 |
| Hermanus | 0.6456 | 0.6462 | 0.7765 |
| Nurmijarvi | 0.7079 | 0.8365 | 0.8108 |

Despite the differences, the hourly value of $dH/dt_{max}$ is always a good indicator for the hourly amplitude of GIC. The results involving the time derivatives also have good correlation coefficients in all stations.

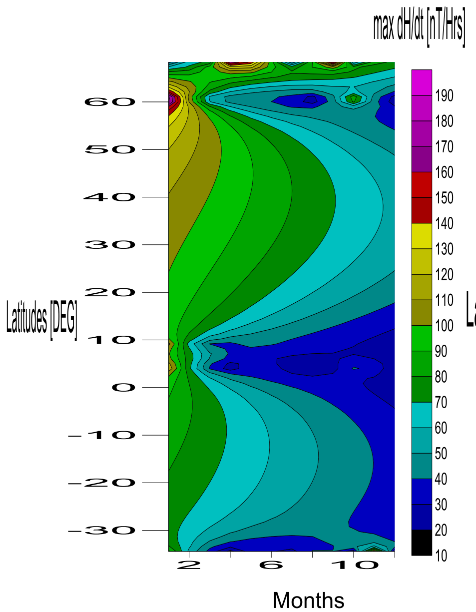
## 2.2 Monthly variation of max time derivatives of horizontal geomagnetic field ($dH/dt_{max}$) & max horizontal component of geomagnetic field (max H).

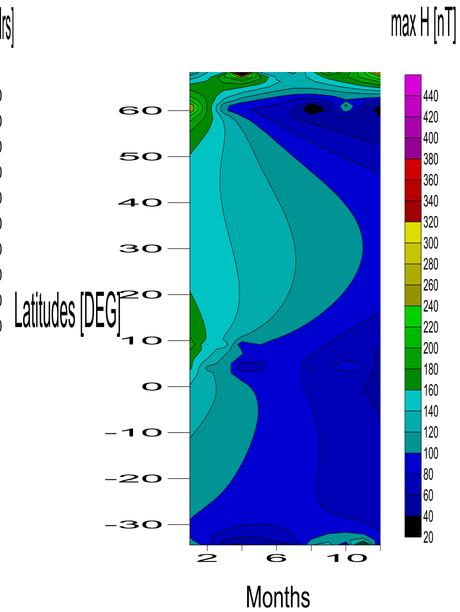
Monthly occurrence of $dH/dt_{max}$ and max H are illustrated in Figures 1(a and b) to 3(a and b). Figures 1 (a and b) indicate that there is high activity of $dH/dt_{max}$ and max H during the months of March in Abisko. In Bangui and Nurmijarvi both max H and $dH/dt_{max}$ were noticed in September, also in Hermanus both $dH/dt_{max}$ and max H were observed in the month of October and November. While high activity is also noticed in January at Addis Ababa. During these substorms, $dH/dt_{max}$ was larger in the auroral region and the sub auroral region than lower region. The substorm onset for 1999 is in agreement with the general increase in geomagnetic activity observed near the equinoxes.

It is quite clear from Figures 2a and 2b substorms onset for 2000 that auroral regions (Nurmijarvi and Abisko) have the highest value of $dH/dt_{max}$ noticed in the month of February, April, August, September, October and November. In Hermanus, $dH/dt_{max}$ was observed in the month of August with another peak in February, October, November and December. At low latitude (Bangui), $dH/dt_{max}$ is high in the month of April and July. While max H also follow the same trend at auroral regions and lower latitude.

Figures 3a and 3b substorms onset for 2001 shows the distribution pattern of $dH/dt_{max}$ and max H varies strongly in the auroral region. The $dH/dt_{max}$ and max H occurs in the month of March, April, October and November at Abisko, Nurmijarvi, Bangui, Hermanus and Addis Ababa.

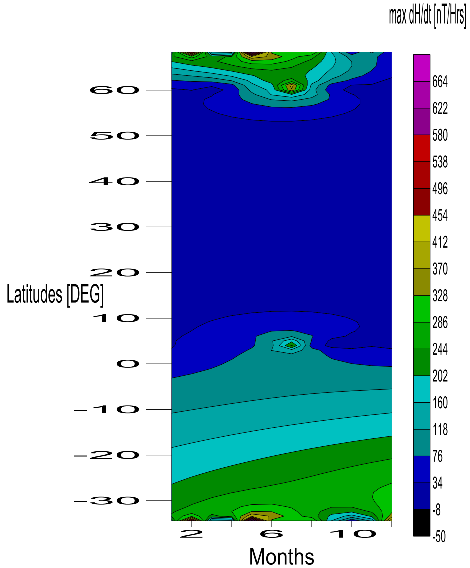
**1a** **b.**

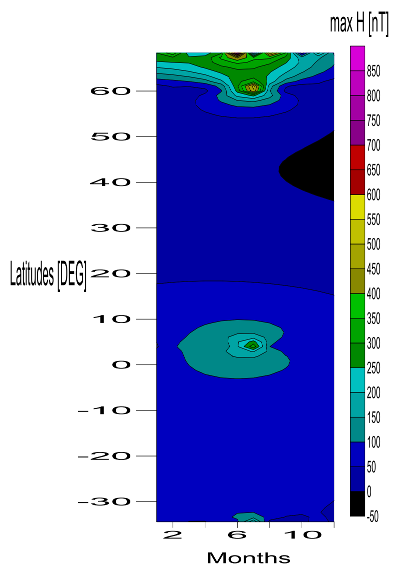



**Figures 1 (a and b): Monthly variation of $dH/dt_{max}$ and max H for 1999.**

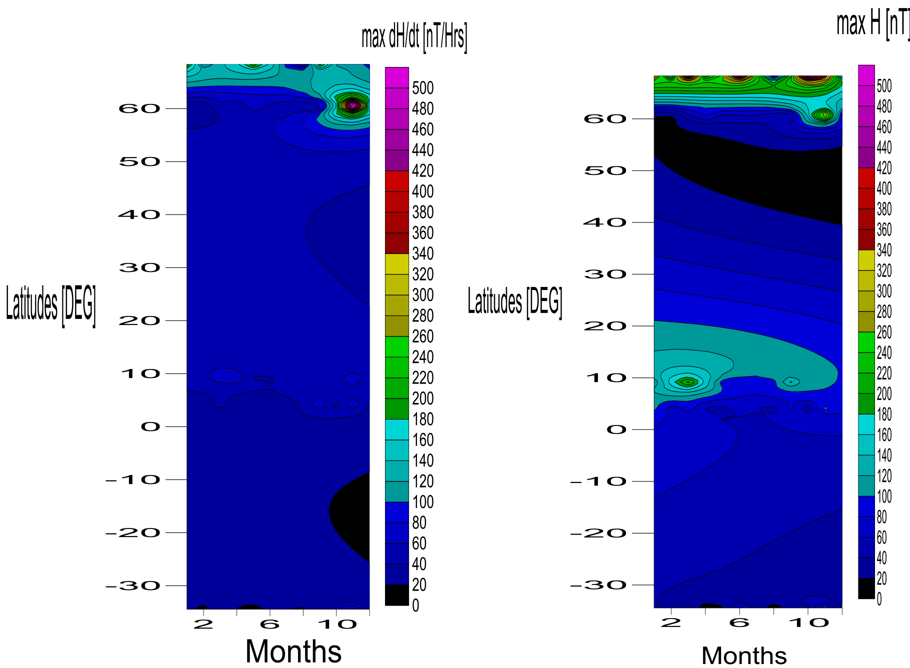
**2a.** **b.**




**Figures 2 (a and b): Monthly variation of $dH/dt_{max}$ and max H for 2000**

**3a.** **b.**



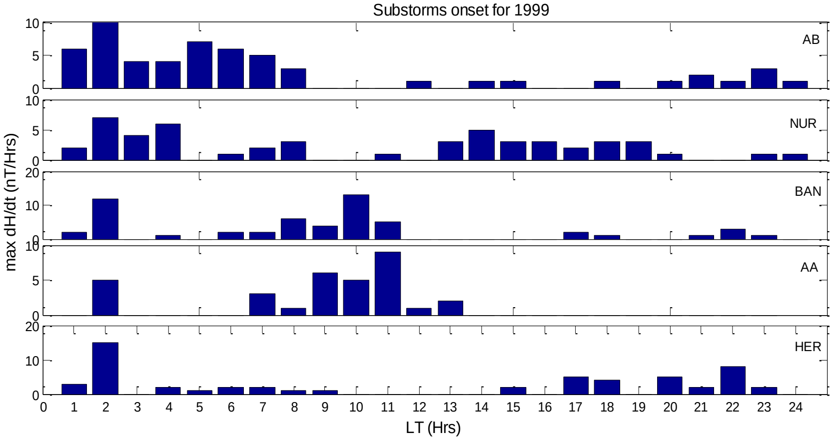

**Figures 3 (a and b): Monthly variation of $dH/dt_{max}$ and max H for 2001.**

The monthly distribution of $dH/dt_{max}$ and max H may be as a result of sudden pulse noticed during the commencement of the magnetic storm and variation of the geomagnetic field during storm [22]. It was also confirmed that large GIC events occur most frequently at high latitudes in the vicinity of auroral electrojets and other dynamic ionospheric current systems [23-24].

### 2.3. Time occurrence of $dH/dt_{max}$ and max H for substorms onset

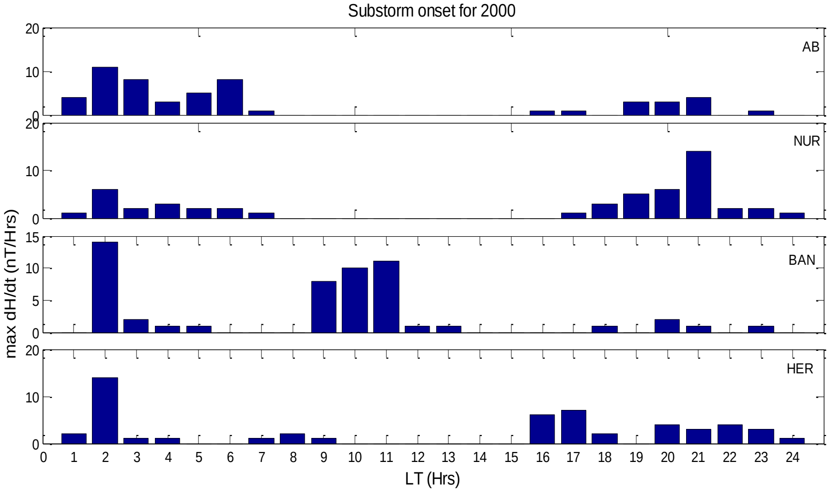
Figure 4 (a-c) illustrates the hourly occurrence of $dH/dt_{max}$ from 1999 to 2001. Figure 4a shows $dH/dt_{max}$ around the early morning hours, and nearly vanishes during noon time at Abisko in 1999. The occurrence of large $dH/dt_{max}$ has two daily maxima, one around the afternoon and another in the morning at Nurmijarvi. In Bangui, the maximum values of occurrence were noticed in the morning time. In Addis Ababa, during the daytime $dH/dt_{max}$ shows a large enhancement over the equatorial zone while during the nighttime the amplitude has decreased monotonously. It collaborates with the electrojet strength. In Hermanus, $dH/dt_{max}$ was noticed during morning time and nighttime. In 2000 (Figure 4b), it can be seen that the variation patterns are quite the same in early morning time for all the stations. The amplitude of the $dH/dt_{max}$ variation at the stations in the morning is generally much higher than the afternoon time. But AA has no data for 2000. In 2001, $dH/dt_{max}$ shows nearly the same variation forms with a slight difference in the morning and afternoon due to a diurnal pattern in AB and NUR. Addis Ababa (AA) and Bangui (BAN), $dH/dt_{max}$ on the magnetic equator shows the maximum value around the local noon period. In HER, the $dH/dt_{max}$ varies in the morning and nighttime (Figure 4c).

**4a**.



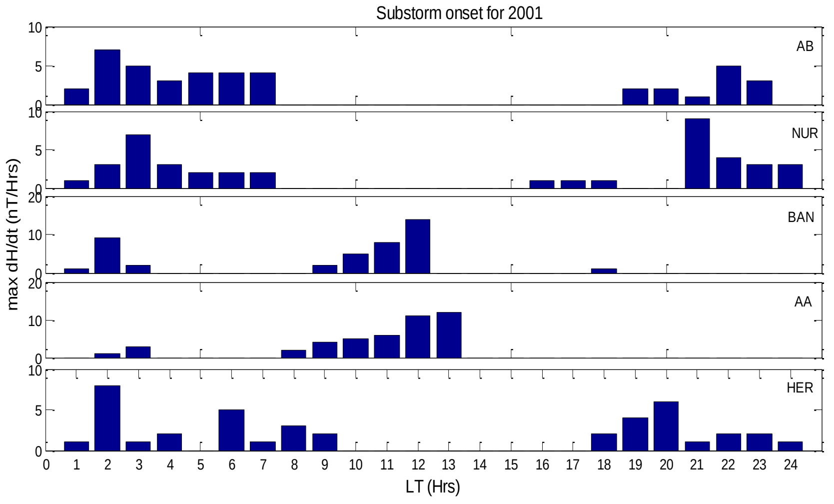

**Figures 4a: Shows the hourly occurrence of $dH/dt_{max}$ for 1999**

**b**




**Figures 4b: Shows the hourly occurrence of $dH/dt_{max}$ for 2000**

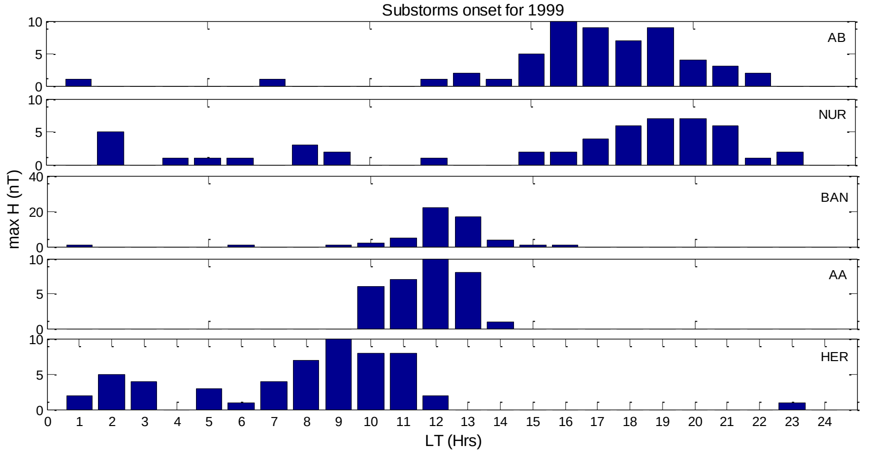
**c.**




**Figures 4c: Shows the hourly occurrence of $dH/dt_{max}$ for 2001.**

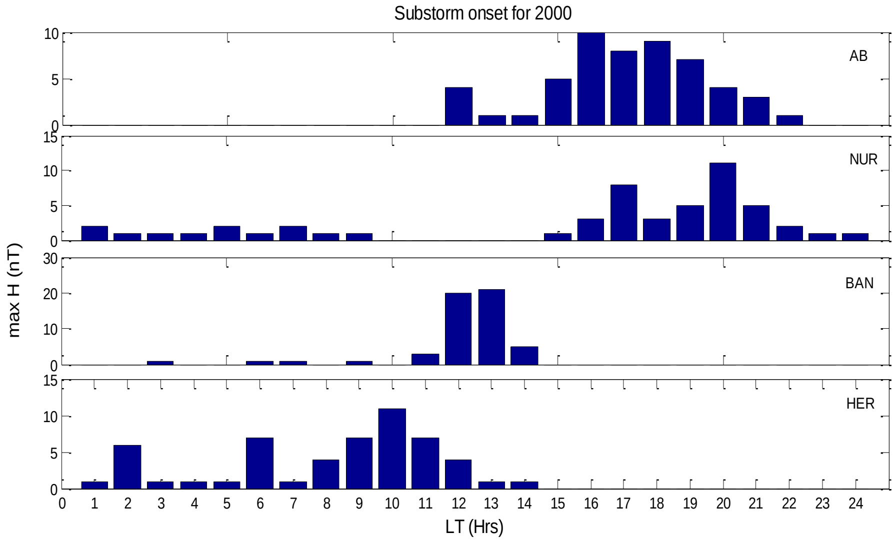
Figures 5 (a-c) illustrates the hourly occurrence of max H, for the period of 1999, 2000 and 2001 the night time max H are generally greater than the day time magnitudes for AB, NUR and BAN for hourly variation. The variation of max H appeared to be showing a maximum around 12:00 noon at AA in 1999 and 2000 due to the electrojet current. In HER, max H was noticed from morning time attaining peak magnitude in the early morning at 2:00 LT and gradually decrease to night time value after sunset.

**5a.**



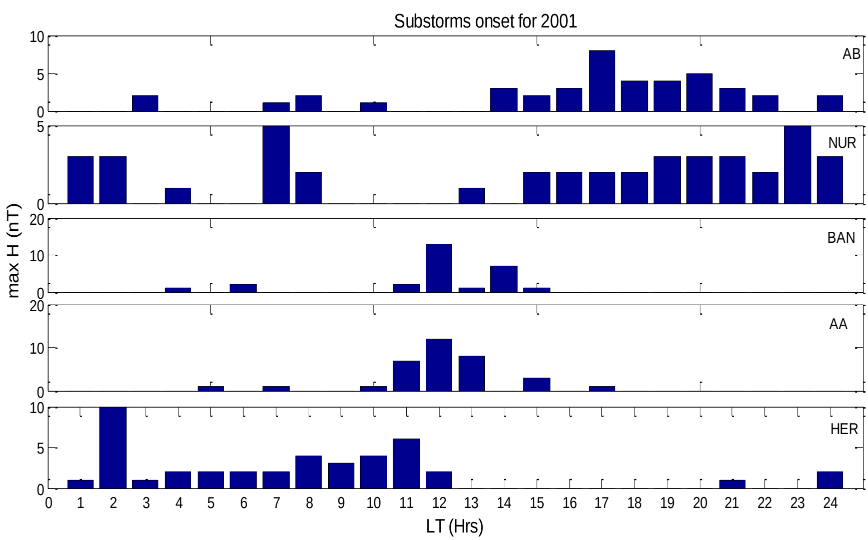

**Figures 5a: shows the hourly occurrence of max H for 1999.**

**b.**




**Figures 5b: shows the hourly occurrence of max H for 2000.**

c.




**Figures 5c: shows the hourly occurrence of max H for 2001.**

## 3.0 Results and discussion

The solar wind and the Earth magnetic field interactions affect the physical process in the magnetosphere and ionosphere, the result of this interaction is observed as variation of geomagnetic and geoelectric fields. Table 2 contains summaries of events used in this study, the correlations between the $dH/dt_{max}$ and max H are given by the correlation coefficients which varies from one station to another station from 1999 to 2001.

Generally, correlation coefficients are high for all the stations. This indicates a strong relationship between the $dH/dt_{max}$ and max H. For relations tested values 0.8238-0.6456, 0.9331– 0.6462 and 0.8108-0.6722 are high for all the stations in Table 2. These numbers shows that the variation may be associated with high latitude disturbance driven by electrojet intensifications which produce large differences in geoelectric field response for these disturbance years. The variation in ground observation of dH/dt changes with respect to intensity, location, and orientation of the aurora electrojet [25].

The contour plot in Figures 1 (a and b), 2 (a and b) and 3 (a and b) shows the $dH/dt_{max}$ and max H increases with latitude for substorms onsets. The value of $dH/dt_{max}$ increases with increasing latitude at the auroral and decreases at toward the equator. The $dH/dt_{max}$ and max H events occur most frequently at high latitudes in the vicinity of auroral electrojets. It was also observed from Figures 1(a and b) to 3(a and b) that Autumn and Spring have the highest values of $dH/dt_{max}$ and max H. This implies that more storms occur during Autumn and Spring, as a result of increase in the energy input by solar wind magnetosphere coupling. Max H is noticed at Addis Ababa (AA) as a result of equatorial electrojet activity stronger in AA as it is closer to the magnetic dip equator.

Figures 4 (a-c) illustrates the time occurrence of $dH/dt_{max}$ effect. In Figure 4a it is obvious that maximum time derivatives of the horizontal geomagnetic field ($dH/dt_{max}$) effect exist in early morning with negligible occurrence during the day time and slight occurrence at the night time in AB. The $dH/dt_{max}$ is more noticeable in the early morning time and turns weak during the nighttime at NUR. The $dH/dt_{max}$ was seen around the noon time. It means that equatorial enhancement is much higher during the daytime than the night time at AA and BAN. At mid latitude (HER), the variability occurrence of $dH/dt_{max}$ was dawn to dusk phenomena and observed in the daytime and turns very strong during the nighttime. Figures 4b and 4c have similar pattern with Figure 4a. It have long been established that ionospheric current flows at the dip equator with high current intensities during the daytime. The field aligned current generated in the boundary regions between the Earth magnetosphere and the solar wind have influence on the ionospheric current at the morning time and evening time of high latitudes. At nighttime the intense ionospheric current at high latitudes are driven by field aligned current from substorm processes in the unstable magnetospheric tail region. The

$dH/dt_{max}$ occurs during night-time events may be governed by westward ionospheric currents.

The max H is illustrated in Figures 5(a-c), the day to day variability peaks were noticed during the daytime after the local noon time and the nighttime at AB and NUR respectively from 1999 to 2001. Various reasons were suggested to be responsible for these nighttime variations amongst include asymmetric ring currents in the magnetospheric currents, magnetospheric effects like the westward ring current even during fairly quiet periods, also variations due to disturbances suggesting possible non-ionospheric origin. The occurrence of max H was noticeable during daytime at local noon of AA and BAN for the years. AA and BAN stations are located in the equatorial regions. Also, AA (0.18 dip latitude) is station within equatorial electrojet zone with high amplitude in 1999 and 2001. This is eastward band of electric currents in the ionosphere called Equatorial Electrojet current suggested by [26]. The variation of max H at HER shows a maximum variation morning time before noon and decrease towards the nighttime. The day time variability noticed may be attributed to ionospheric electric field mainly controlled by the E-region dynamo process and the tidal forces from the lower atmosphere [27].

## 4.0 Conclusions

The monthly and hourly variations of maximum value of time derivatives of the horizontal geomagnetic field ($dH/dt_{max}$) and maximum value of the horizontal geomagnetic field (max H) were investigated between 1999 and 2001. From our results the following conclusions are drawn.

During the monthly variation, $dH/dt_{max}$ activity increases with increasing latitudes at the auroral region and decreases toward the equator. $dH/dt_{max}$ and Max H is high during the Spring and Autumn. This implies more storms occur during these two seasons. $dH/dt_{max}$ activity is high around the early morning hour and night time hour, vanishes around noon time at high attitudes (Abisko and Nurmijarvi). While max H occurrence for substorm onset occur during the nighttime at Abisko and Nurmijarvi. $dH/dt_{max}$ and Max H activity is high around the noon time at Addis Ababa and Bangui due to an eastward electric current in the ionosphere which is known as Equatorial Electrojet.

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