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Variability of the Horizontal Geomagnetic Field at High-Latitude during Sunspot Maximum

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Abstract: *In this paper we study the horizontal component of the Earth's magnetic field and the effect of solar features on geospheric conditions is carried out and carried out at the Indian Antarctic Station "MAITRI"(geom. Lat. 62°S, Long. 52.8°E), during sunspot maximum activity (2003-2004). The results of the analysis carried out revealed that the amplitude of H has diurnal variation which peaks during the evening and night time while minimum is seen during daytime. Variability is higher during equinox (2003) and summer (2004).The equinoctial maximum is due to enhanced subauroral zone electron density at equinox. From a correlative study of variability in H with possible causative factor such as sunspot activity, magnetic activity and solar activity, it is seen that the magnetic activity has appreciable association with the variability of H. We have also compared the variability during quiet, disturbed days and daily disturbances. No distinct association between disturbed days and daily disturbances is observed. It is observed that maximum number of GMSs have occurred during the maximum solar activity years 2003 than 2004 of 23rd solar cycles.*

Keywords: *Magnetospheric interactions; Geomagnetic storm; horizontal component; solar flux; magnetic activity; sunspot numbers; solar flare; coronal mass ejection*
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1. Introduction:

In this study we observed that Sunspots are the most obvious features of disturbed surface of the photosphere in the solar atmosphere and play a key role in causing major geomagnetic disturbances. When these disturbances encounters the Earth they interact with the magnetosphere causing geomagnetic storms (GMSs) and are associated with ionospheric effects. The occurrence of prominence and flare is also associated with varying phases of sunspot cycle and leads to changing conditions in the occurrence pattern of geomagnetic storms geomagnetic disturbances causing GMSs. Over the past half-century, it is thought that solar flares are responsible for major interplanetary particle events (IPEs) and GMSs [1].On the other hand; it is found that GMSs are more associated with coronal holes than the solar flares [2]. Recently, it is observed that CMEs are the key causal link to solar activity that produces GMSs [3]. Winds in the lower ionosphere lead to the dynamo action to produce electric currents responsible for the diurnal pattern of geomagnetic variations. In an article concerning ionospheric current systems caused by non-periodic winds [4] has investigated the possible contribution of large-scale prevailing winds to the daily geomagnetic variation. In view of this it appears that the meteorology of the lower atmosphere may be of help to space research. One source of variable solar particle radiation in the vicinity of the earth and incident on the upper atmosphere is the continuous magnetic records made at the surface of the earth. Commonly employed in research is the geomagnetic activity index Kp and (and Ap based on it) which is derived from the magnetic records. If there are effects in the magnetograms, in addition to the normal daily variation, arising form the behavior of the terrestrial atmosphere, it is important that these be identified as such and not taken to be of direct solar origin. The magnetic activity at high latitudes is influenced by a number of different current systems. The auroral oval region are dynamic in nature and they can shift polewards or equators, depending on the degree of electromagnetic disturbance in geospace. With change in geospace disturbance, the sub-auroral locations are ideal to sense the rapid changes in space weather. Maitri occupy such an important location and shift in and out of auroral oval with increasing magnetic disturbance. These are driven primarily by field-aligned currents (FACs) caused by plasma convection or pressure gradients in the outer magnetosphere. At time when the magnetosphere is very quiet the FACs calm down. During those times it may be possible to observe the response of the auroral ionosphere to electric fields produced internally by thermospheric wind dynamo actions [5]. The degree of ionospheric activity is primarily controlled by the solar wind-magnentospheric interaction. The other factor influencing the current intensity is the ionospheric conductivity. Primarily, the source for the generation of charged particles in the ionospheric E-region is the solar extreme ultra-violet (EUV) radiation. Subsequently, we study the relation of the various magnetic indices to the quiet conditions at high latitude. We may special attention to the accompanying H conditions. Finally, we present an attempt to predict time of high magnetic activity at subauroral latitudes. Geomagnetic quiet day (Sq) variations have been widely analyzed by many scientists. There is an obvious annual increase in amplitude during the summer months and a seasonal shift of the maximum early in summer and late in winter for solar quiet day (Sq) variations at middle-and low-latitude stations [1]. The quiet time variations at low and mid-latitudes are generally described by the Sq [solar quiet] current system and the magnetic activity conditions are well described by the planetary activity index Kp. The Kp index [6] is obtained from a number of magnetomerter stations at mid-latitudes. When the stations are not greatly influenced by the auroral electrojet equatorward, however, these stations can record the effects of the auroral electrojet current system and of the magnetospheric ring current and field aligned currents that can connect it to the ionosphere. This occurs during so-called magnetically disturbed periods. The mid –latitude stations are rarely directed under an intense horizontal current system and thus magnetic perturbations can be dominant in either the H or D component. The Kp index cetilizes both these perturbations by taking the logarithm of the largest excurtion in H or D over a 3-h period and placing it on a scale from 0 to 9.The ap index is obtained by converting the values of Kp to nanotesla using a conversion table. The daily average of ap gives the Ap index that ranges from 0 to 400nT and is given in units of 2nT. A comprehensive review of K-derived indices is given by [7]. At high latitude, a separate term S^p_q system has been introduced as polar part of the global Sq system [8], although there is a close relationship between S^p_q and Sq. The S^p_q system can be observed only when the solar wind input to the magnetosphere is minimal. It is believed that the thermo-tidal dynamo is operating independent of magnetic activity and its effect is modulated primarily by the conductivity of the ionospheric E region. As a consequence, clear seasonal dependence of the current intensity is expected. The regular tidal movement of the upper atmosphere across the vertical component of the earth's magnetic field generates a global system of electric field in the ionosphere. The electric field acting on the ionization in the E-region of the ionosphere generates a global system of ionospheric currents causing a regular diurnal variation in the Earth's magnetic field. The aim of this study is to investigate the characteristics of magnetic variations at auroral latitudes during quring quiet periods. While the studies of daily Sq variation at mid and low-latitudes have been pursued for almost a century [9], systematic examination of the quiet-time variation at high-latitudes is sparse [10-11]. This is mostly due to the lack of high-quality observations at these remote places. A worldwide disturbance of the earth's magnetic field, distinct from regular diurnal variations. In the present communication, we have studied day-to-day variability of H component, its seasonal dependence and the changing influance of solar-geophysical parameters on H at auroral latitude stations during sunspot maximum (2003-2004). Analysis of GMSs at Maitri is also to understand the association of GMSs with different solar and heliospheric sources: on associated with transient solar activity that peaks with the sunspot number and the other associated with recurrent CIRs, CMSs and high speed streams from coronal holes during the declining phase. In terms of space weather, CMEs are the most important kind of transient activity because they kink the activity at the Sun and its propagation through the heliosphere to the Earth.

2. Data Selection and Methodology:

In this study we have used data of Horizontal magnetic field variation, collected by the digital fluxgate magnetometer (DFM) installed at MAITRI, Indian Antartic Station. Data is minute resolution. Maitri is located in sub-auroral zone (geomagnetic coordinates are lat. 62°S, long. 52.8°E).By observing geomagnetic variations at different latitudes on the Earth's surface we can map the above discussed different physical phenomena in the magnetosphere, caused by different current systems in the ionosphere/magnetosphere. Accordingly, several sets of geomagnetic indices have been implemented in order to represent these different irregular activities from different perspectives. The study is carried out on the data of year 2003 and 2004 of the MAITRI, various global geomagnetic parameters are taken from the NCAR data server.Here we have calculated Hmean by averaging H of whole month corresponding to time. ($Hmean_{hh:mm}$= $H_{hh:mm\ 1}$ + $H_{hh:mm\ 2}$+ $H_{hh:mm\ 3}$……. $H_{hh:mm\ n}$/j ; n= Day of the month, j =1 to 31 number of days in a month), similarly yearly mean is calculated. To know the H mean of quite and disturbed days we have taken the mean of five international quite and disturb day data and computed the result.

3. Result:

3.1 H mean variation:

The yearly mean of H component obserbed at MAITRI during the year 2003 and 2004 arer shown in the figure 1. It is seen that during both the years,

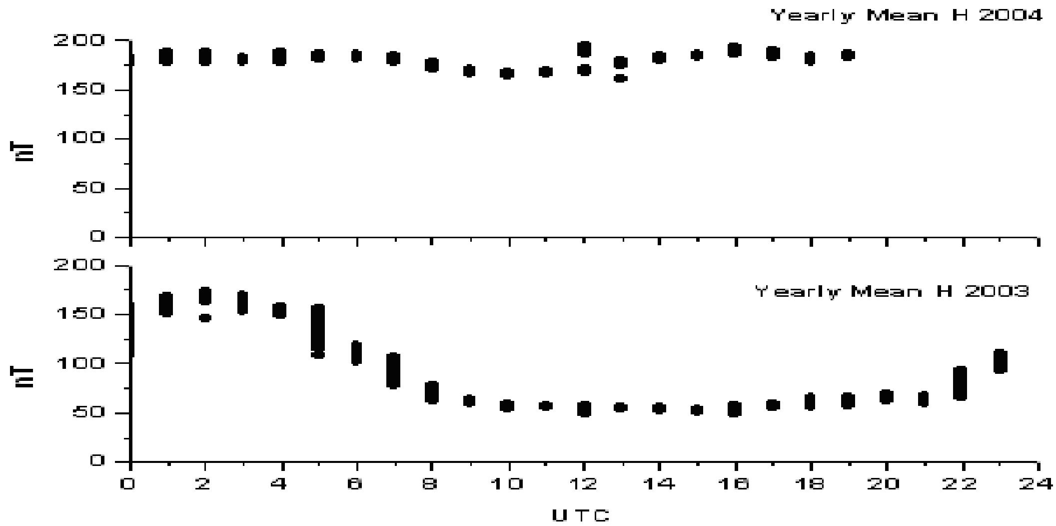
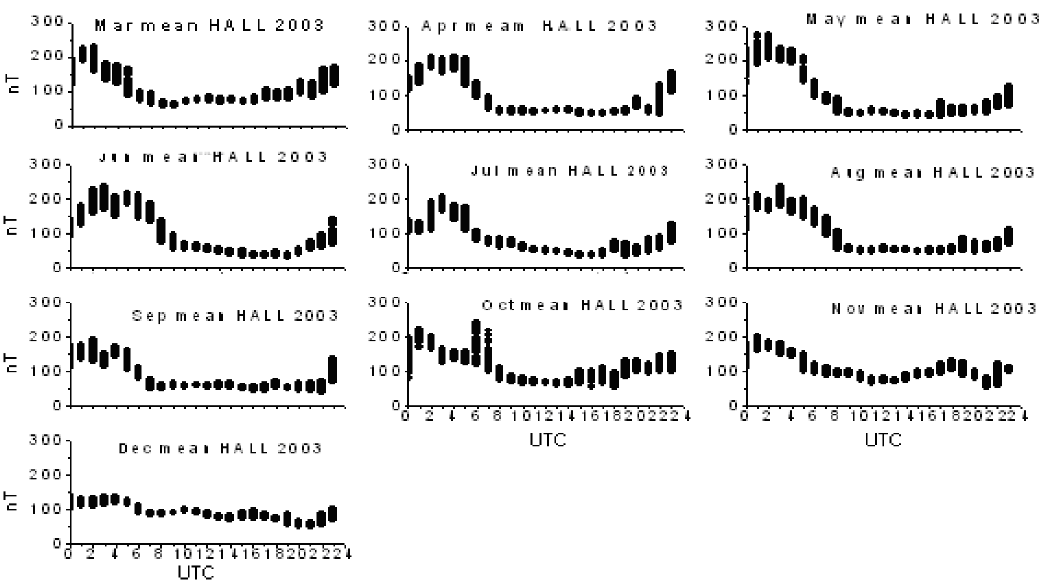


Figure 1: Annual mean variability of H component on y-axis as a function of universal time on x-axis.

The variation of the variability parameter is almost same, although it is slightly higher during 2004.

Figure 2 shows the monthly variability of H component during 2003 and 2004, the as con from the midnight to the early morning sector, whereas we can see fluctuates only in the month of July 2004 and 2004 November rest of the month shows uniform nature in H component.

a



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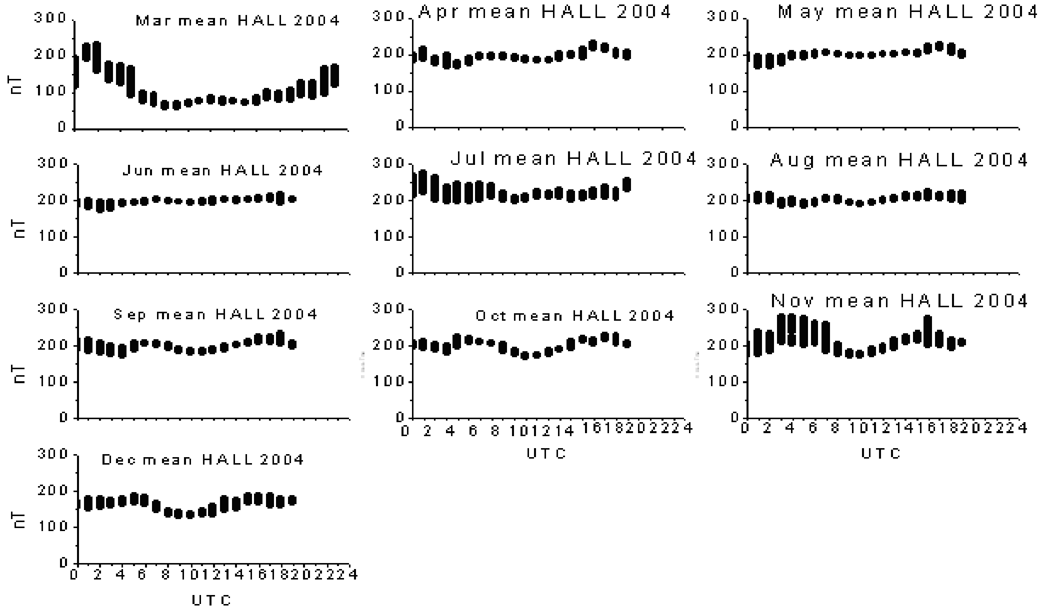
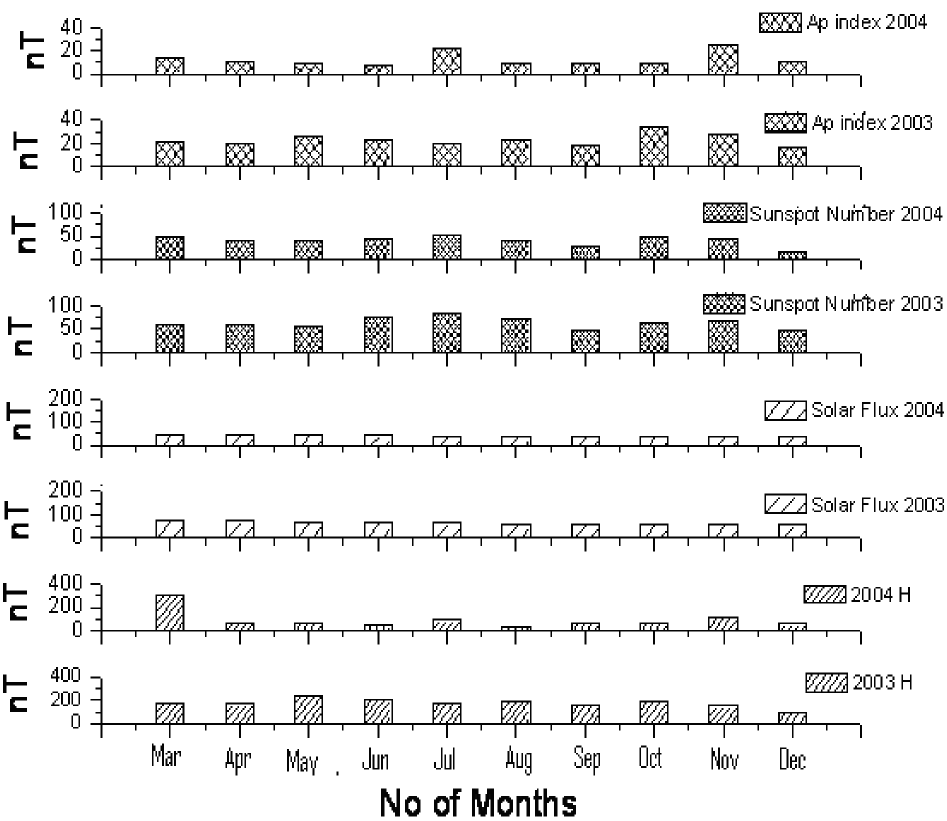


Figure 2. Variability of H on y-axis as a function of UT on x-axis during day time hours and night time hours (a) 2003, (b) 2004 for Maitri.

The month to month and annual variation of global indices of the 2003 and 2004 are shown in figure 3 , which show that the Ap index is higher for the year 2003, same for the sunspot number lower and also uniform with them we have shown the variation of the solar flux comparison for the year 2003 and 2004.



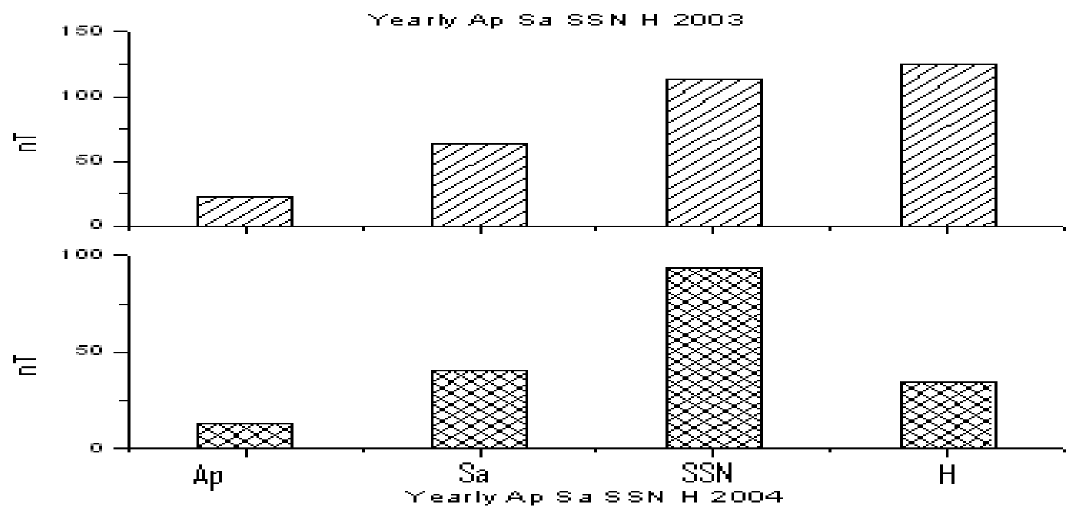


Figure 3. Month to month variation of variability bottom to top for (A,B) H component (C,D) Solar flux (E,F) Sunspot number (G,H) Ap-index on x-axis and their magnitude variability on y-axis. With corresponding different block for 2003 and 2004. At the bottom annual variability for all above parameters for years 2003-2004 on x-axis and their magnitude on y-axis.

Figure 4 Now coming on the seasonal variation in these two years Winter, Summer and Equinox. During the winter value is higher in 2004 as compared to 2003, but the variation level in mid-night sector is higher in 2003. Similarly in the summer duration year 2004 show no significant variation from the mean but the summer of 2003 shows variation also in the case of the equinox same behavior is observed. During 2003 variability in H and solar flux, sunspot number is well correlated at Maitri. During the other period, which is considered in the present study, did not find any influence of the solar geophysical parameters on the variability of H , i.e. seasonal variation is in correspondence with the global parameter.

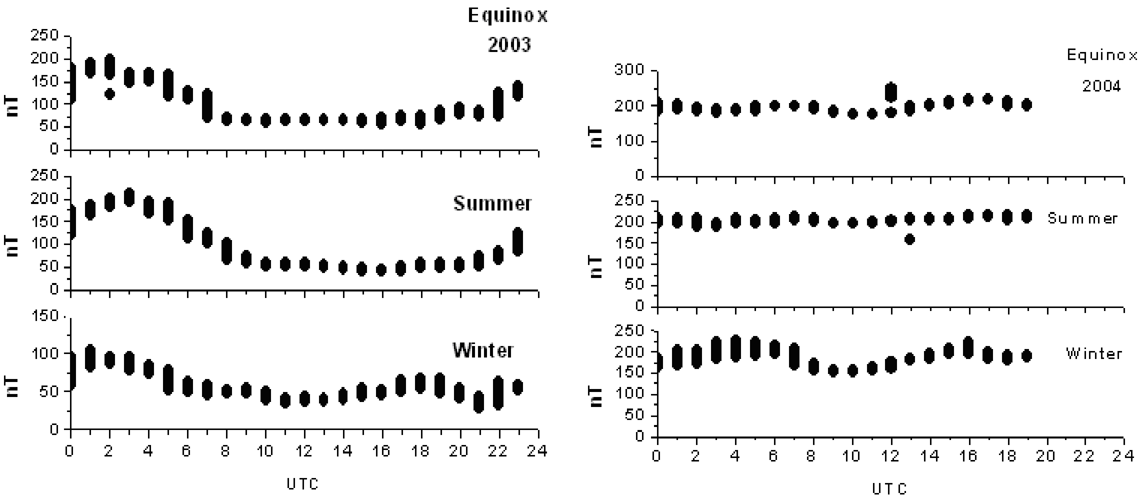


Figure 4. Seasonal variation of the variability parameter on y-axis as a function of UT on x-axis for Maitri 2003 and 2004 from lift to right.

During 2003 it is higher for summer month while lower for winter months and during 2004 it is higher for equinox months while lower for winter months.

3.2 <u>Effect of activity levels</u>:

Annual mean and month to month, seasonal variation of variability parameter)

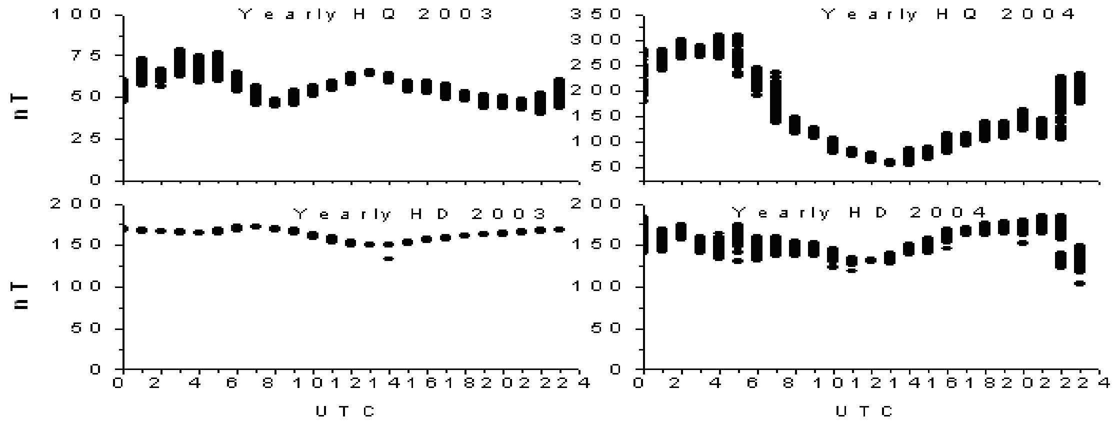
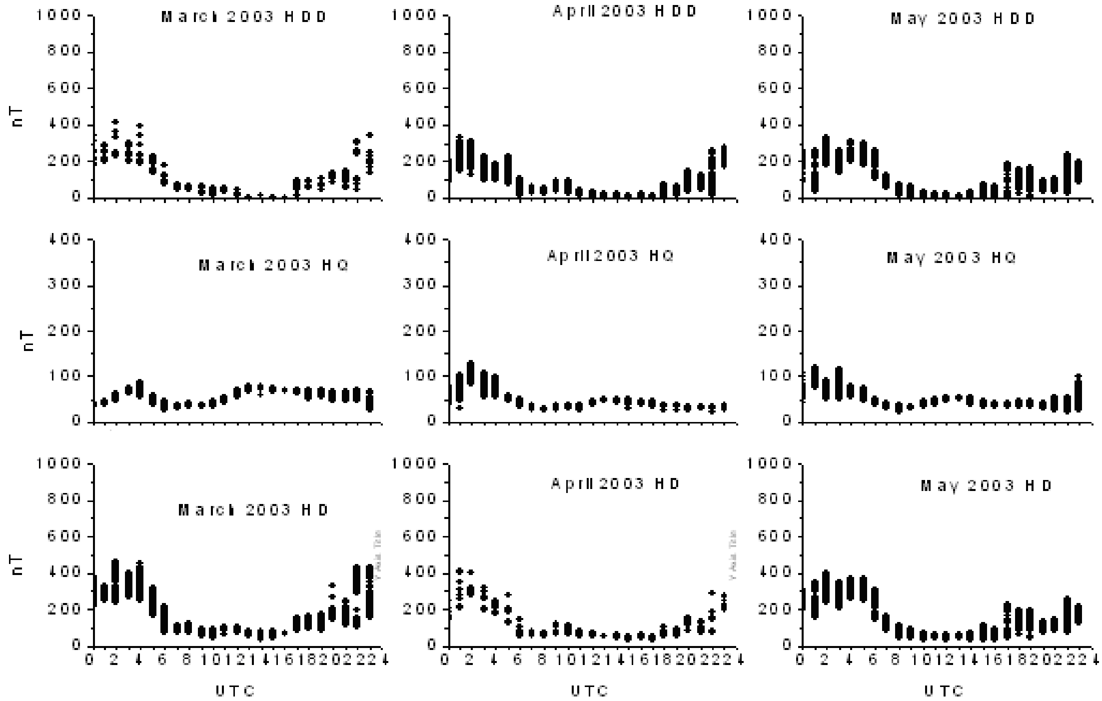


Figure 5. Variation of the annual mean variability parameter on y-axis for Maitri 2003-2004 during quiet and disturbed days as a function of UT on x-axis.

separately for almost all quit days (Q-days) and almost all disturbed days (D-days during 2003-2004 have shown in Figure 5 and 6, 7, 8, 9. It is seen that almost for all the time on Maitri station show that the variability on D-days is higher than that for Q-days, but the yearly mean value of H_Q mean for the 2004 is higher than that of the 2003 which between 200 and 150 around 180 nT. Now looking at the disturbed days lot we can see that for yeay 2003 H_D mean shows variation from below 100 to above

300 nT and in the year it remain between 100 to 200 nT.

L



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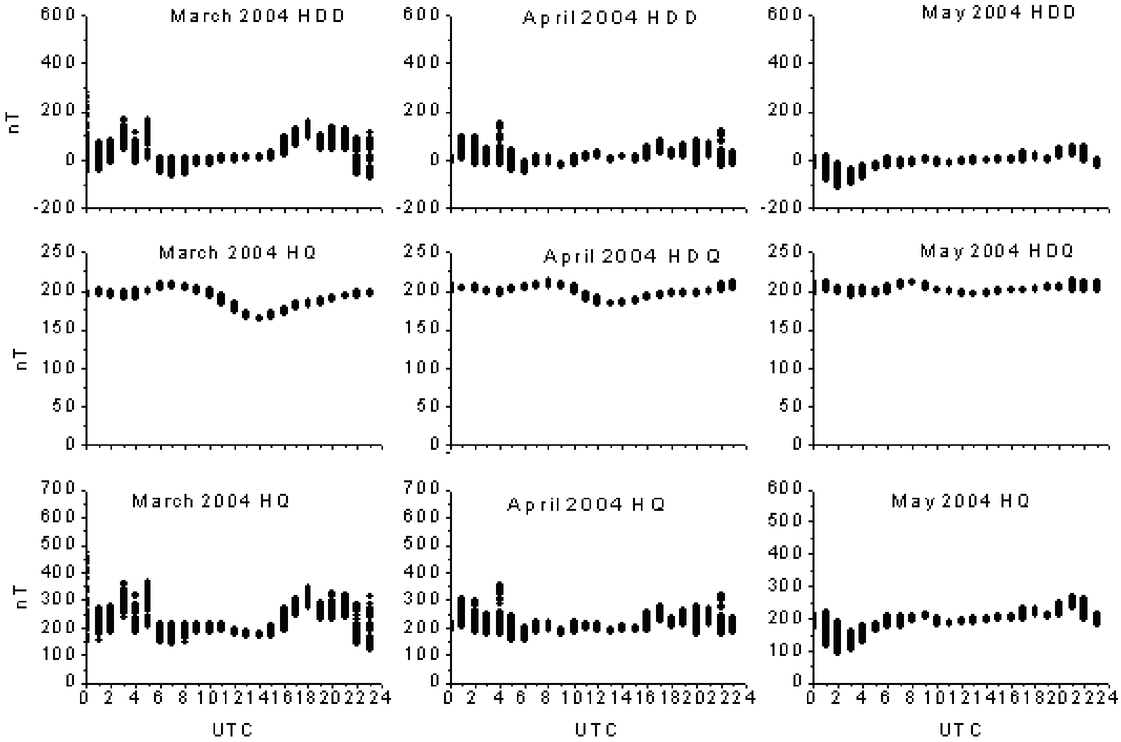

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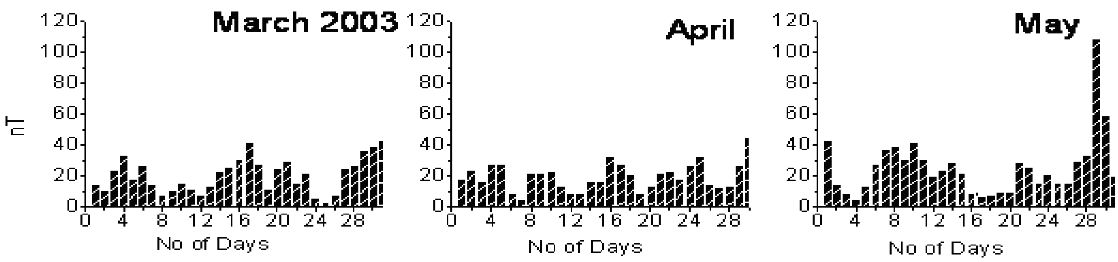

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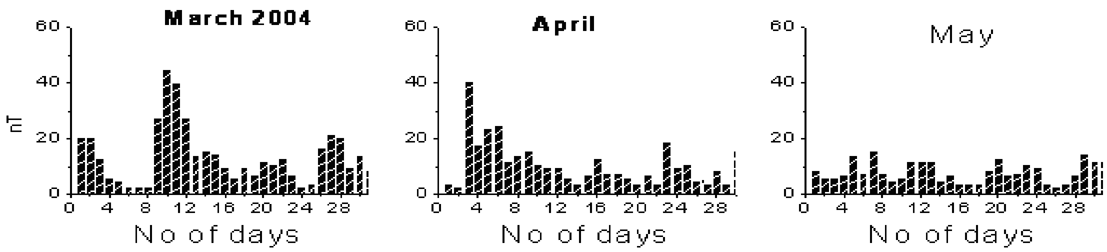
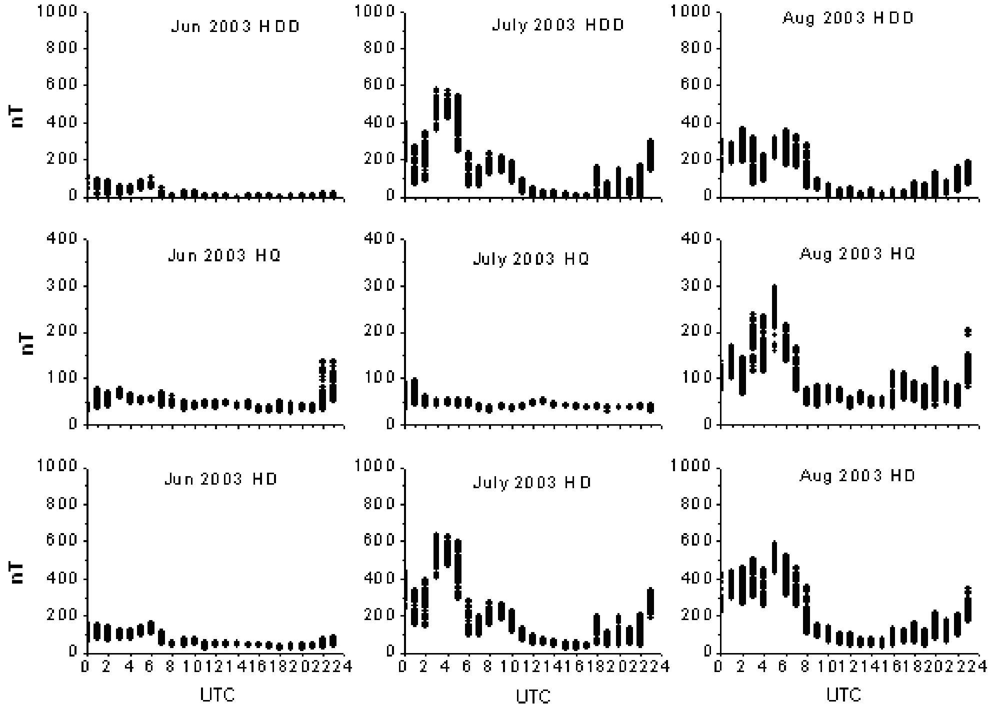


Figure 6. From bottom to top **v**ariations of the H field at Maitri averaged over five international quiet and disturb days and the daily disturbance variations with monthly Ap sum index of March, April and May 2003(J,L)-2004(I,K).

P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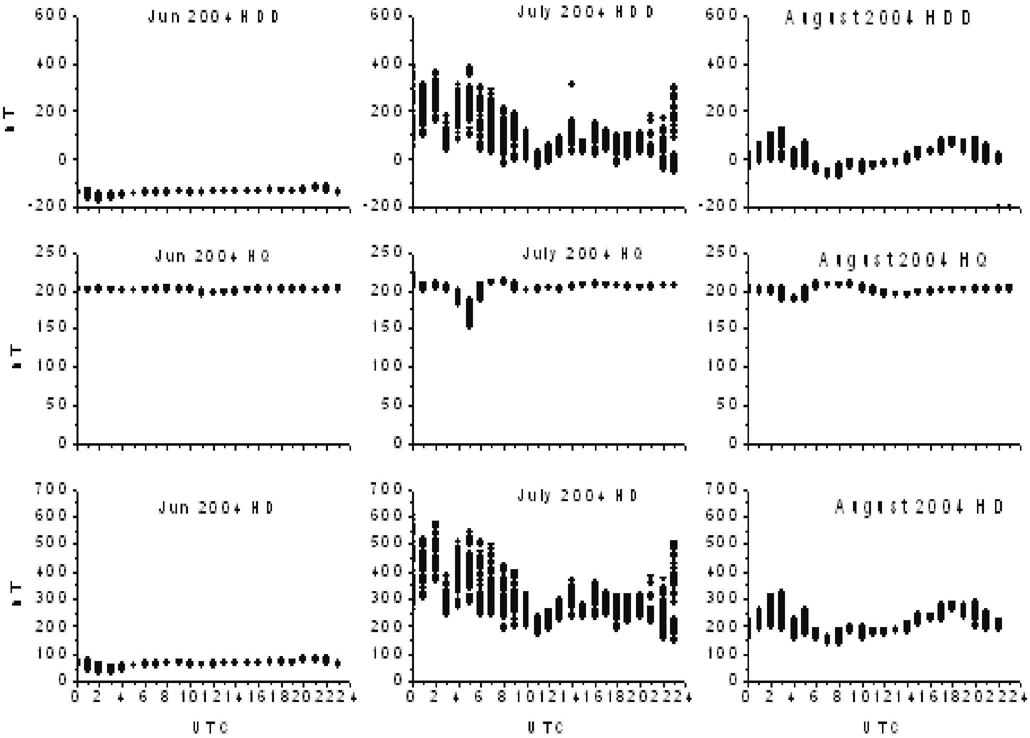
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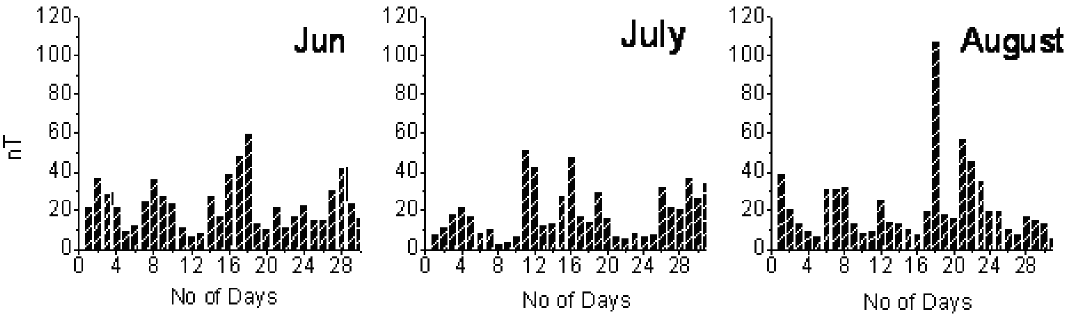

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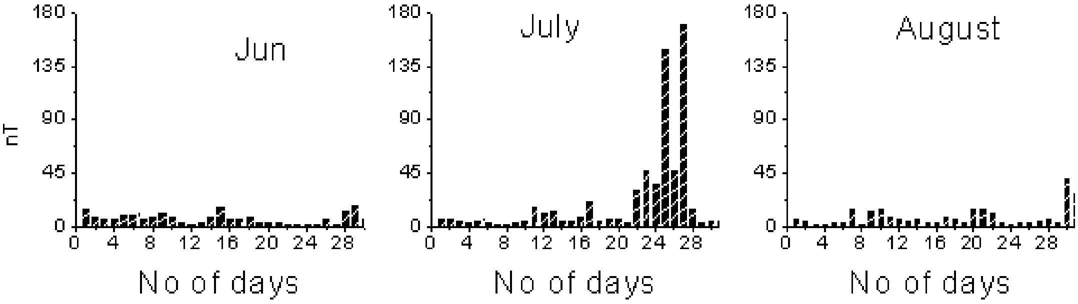
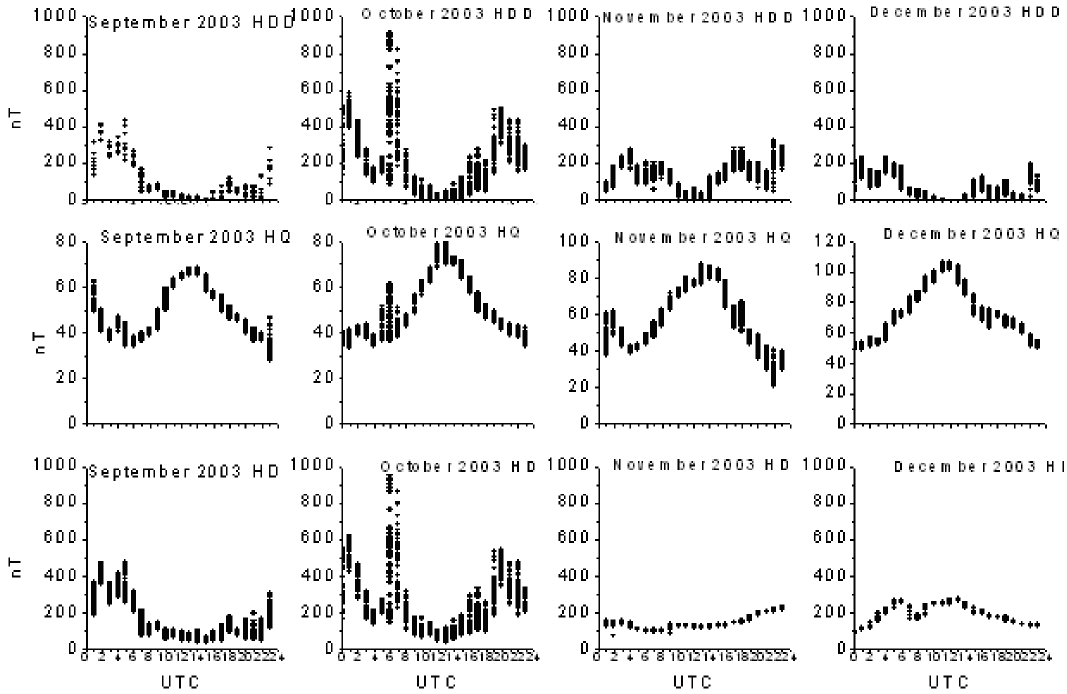


Figure 7. The mean monthly daily variations of horizontal field (H) for international quiet and disturbed days of the year 2003(O,P)-2004(M,N) and the daily disturbance variations corresponding Ap sum during June, July and August at Maitri.



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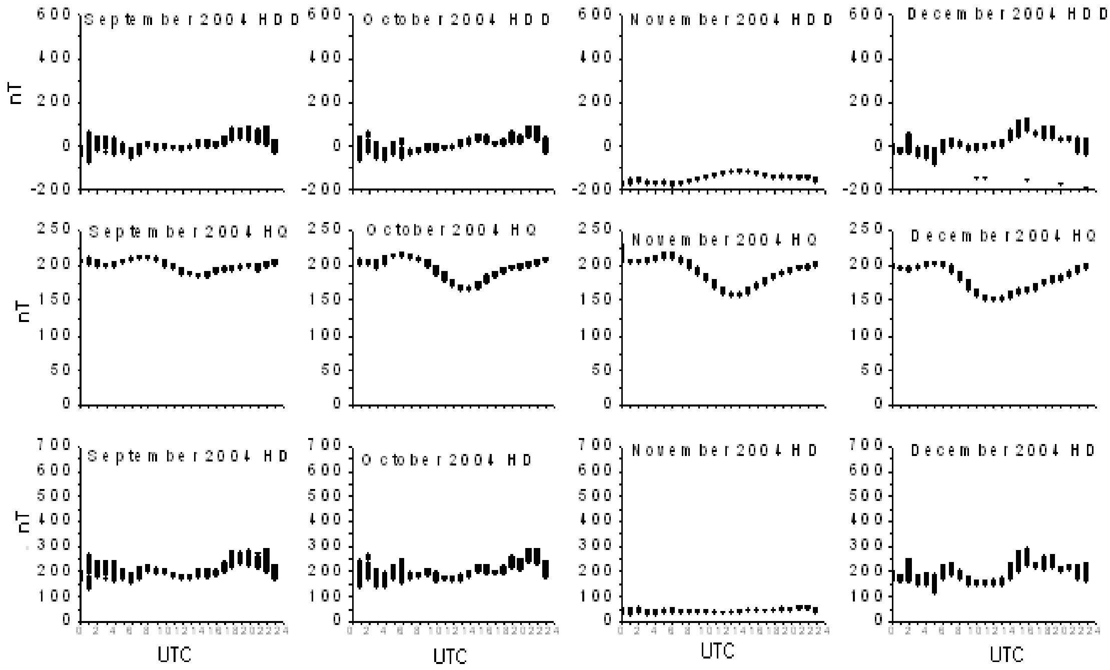

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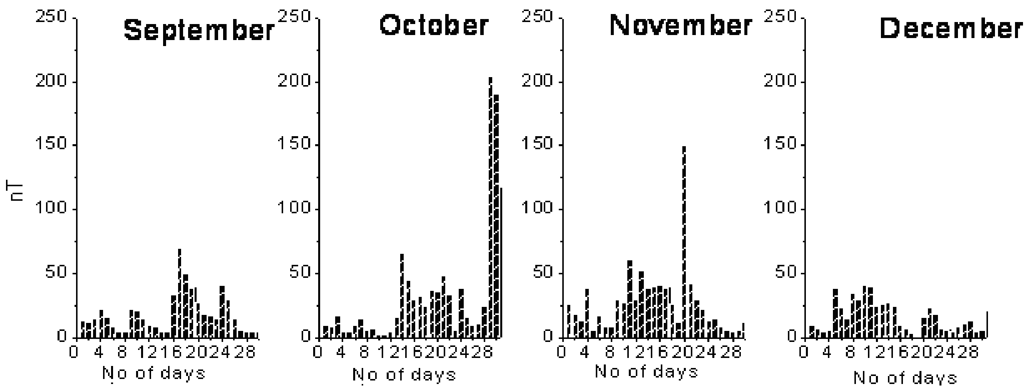

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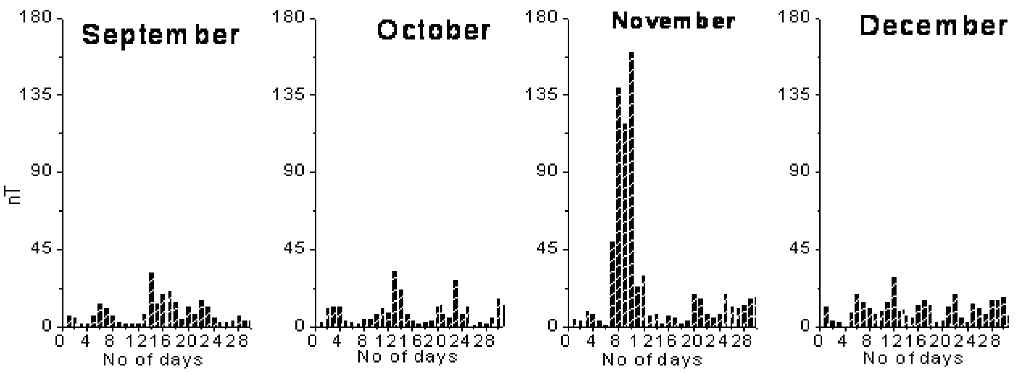
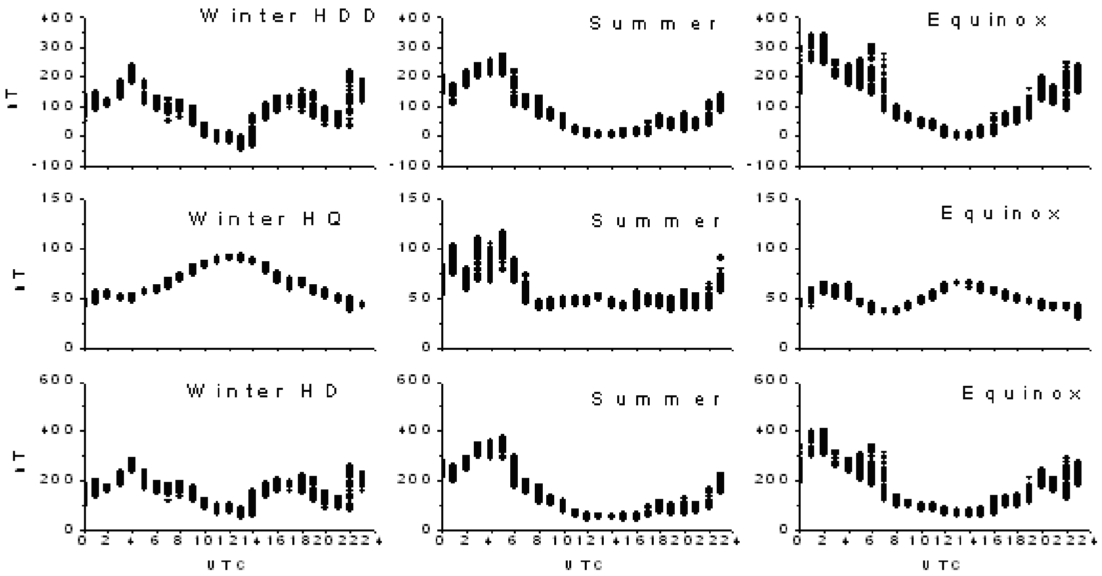


Figure 8. From bottom to top variations of the H field at Maitri averaged over five international quiet and disturb days and the daily disturbance variations with monthly Ap sum index of September, October, November and December 2003(R,T)-2004(Q,S).

Figure 8 shows the seasonal variations of the average variability parameter for 60International quiet and disturbed days. During 2003 it is higher for summer month lower for winter months and 2004 it is higher for Equinox months while lower for winter months.

Figure 9 shows the seasonal variations of the average variability parameter for 60 International quite and disturbed days. During 2003 it is higher for summer month



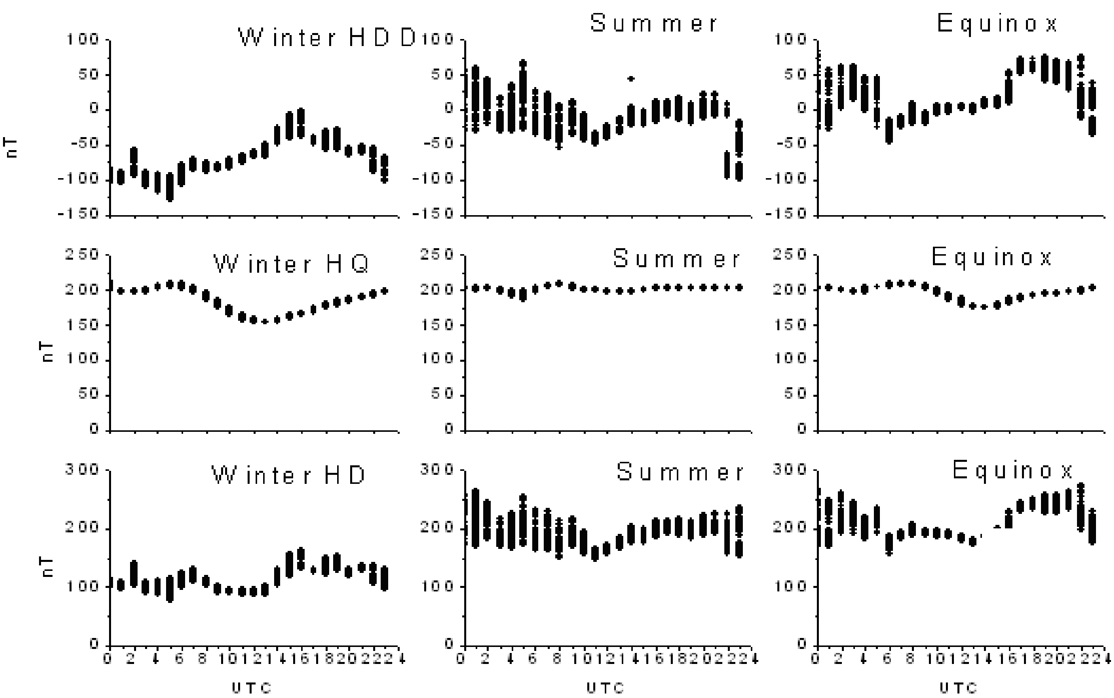


Figure 9. Variations of the average variability parameter for 60 International quiet days and 60 International disturbed days 2003-2004 from top to bottom.

Lower for winter months and 2004 it is higher for Equinox months while lower for winter months.

4. Summary and Discussion:

Our present study of the solar wind interaction with the magnetosphere and some of the properties of the solar wind and the Sun, we can provide plausible mechanisms to explain the various cycles of geomagnetic activity. It is evident that an explanation for the diurnal variation is not as simply derived, in view of the success of the study in explaining the semiannual, annual and 22-yr cycles. This is probably due to the fact that the diurnal variation is associated with ionospheric effects rather than due to some deficiency in our understanding of the magnetosphere. Also, the Pedersen currents contribute little to the magnetic field magnitude [12] as long as the conductivity gradients are small, which can be expected during quiet periods. [13] have suggested a current configuration for this S_q^p . We observe that the variation of the strength of electrojet current at auroral zone station at quiet and disturb days. The results negate the theory that the ionospheric conductivity over the auroral zone is inversely proportional to the mean magnetic H component field. Transient, radiative and corpuscular emission from the Sun associated with solar features produced outstanding disturbances in the environment of the Earth [14] which causes GMSs at various locations of the Earth such as, polar, mid-latitude and equatorial regions. These GMSs are observed and represented by equatorial index Dst and different planetary indices Kp and Ap.Yearly and monthly occurrence of GMSs and their association with sunspot numbers, solar flux have been in figure 3 during the period 2003-2004. When the solar activity periods are maximum and min imum, statistically the GMSs are observed higher and lower respectively. This is true for 23rd solar cycles. Thus, it is evident that maximum number of GMSs have occurred during maximum activity years 2003 of 23rd solar cycles. A result has been obserbed during the years 2003-2004 when sunspot numbers decreases rapidly while GMSs increase significantly and the Sun is more active for producing large number of GMSs during these years respectively. Monthly and seasonal occurrence of quiet and disturbed days with $Ap \geq 20$ has been plotted in figure 4, 6, 7,8 and it is found that the number of disturbed days have occurred large than quiet days during the year 2003-2004.When SSNs decrease rapidly whereas number of disturbed days increase drastically which shows that the Sun is more active during these years. It is evident that maximum number of disturbed days are found in the months of summer and equinox seasons which shos that the number of disturbed days are likely to vary with seasons. A number of workers [15-16] have shown the association of different types of GMSs with sloar flares and suggested that the solar flares of high importance can produce large (intense) GMSs. We have performed a statistical analysis of the quit-time variations at sourthen auroral latitudes. The considered time period lasts from March to December 2003-2004 and coincides thus with the solar maximum. Our observations conform a clear dependence of the Sq amplitude on the season. As expected, largest deflections are recorded in Summer, indicating the importance of the solar EUV radiation for the ionospheric conductivity on quiet days. The signature of the magnetic field varitions reflected over large parts of the fluxgate magnetometer the response to the Sq current system. Afternoon hours often experience small positive variations in H component field. Early morning hours often experience large positive variations in H component field in the two year interval. Mid-night hours are most disturbed in H component in the two year interval from 2003-2004. Winter season is the magnetically quietest time in the month of Nov-Dec (2003-2004). Summer is less quiet or than winter but better than the months around equinox May-Aug (2003-2004). Equinox times are statistically most disturbed month of March-April & Sep-Oct (2003-2004). Most of the months in the 2004 are quiet but only three months are magnetically disturbed. Even in the quiet days the H component shows variation in the year 2003 and whole months of the year are magnetically most disturbed. Also find monthly mean sunspot numbers, solar flux is higher in 2003 as compare to 2004. More and less GMSs are obserbed during maximum and minimum activity years of the 23rd solar cycle respectively, result has been observed during the years 2003-2004 at Maitri when SSNs decrease very rapidly while the number of GMSs increase. Somehow, larger number of disturbed days have occurred during these years. Number of disturbed and quiet days varies with seasons. More GMSs are associated with solar flares/CMEs. The results of the analysis carried out revealed that the amplitude of H has diurnal variation which peaks during the evening and night time while minimum is seen during daytime. Variability is higher during equinox (2003) and summer (2004).The equinoctial maximum is due to enhanced subauroral zone electron density at equinox. From a correlative study of variability in H with possible causative factor such as sunspot activity, magnetic activity and solar activity, it is seen that the magnetic activity has appreciable association with the variability of H. We also find that compared the variability during quiet is less as compared to disturbed days, in the declining phase of the solar cycle 23 the geomagnetic activity is high due to high solar active cycle in the year of 2003 as compared to 2004. So we concluded that 2003 is the more disturb year than 2004. More research work, if carried out in these new regions will be useful in more new contributions to the field of the dynamics of the sub auroral zone electrojet region.

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Caption of figures:

Figure 1: Annual mean variability of H component on y-axis as a function of universal time on x-axis.

Figure 2. Variability of H on y-axis as a function of UT on x-axis during day time hours and night time hours (a) 2003, (b) 2004 for Maitri.

Figure 3. Month to month variation of variability bottom to top for (A,B) H component (C,D) Solar flux (E,F) Sunspot number (G,H) Ap-index on x-axis and their magnitude variability on y-axis. With corresponding different block for 2003 and 2004. At the bottom annual variability for all above parameters for years 2003-2004 on x-axis and their magnitude on y-axis.

Figure 4. Seasonal variation of the variability parameter on y-axis as a function of UT on x-axis for Maitri 2003 and 2004 from lift to right.

Figure 5. Variation of the annual mean variability parameter on y-axis for Maitri 2003-2004 during quiet and disturbed days as a function of UT on x-axis.

Figure 6. From bottom to top variations of the H field at Maitri averaged over five international quiet and disturb days and the daily disturbance variations with monthly Ap sum index of March, April and May 2003(K,I)-2004(J,H).

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Figure 9: Variations of the average variability parameter for 60 International quiet days and 60 International disturbed days 2003-2004 from top to bottom.

Name of the month	**Mont-hly mean Sun Spot No (SSN) 2003**	**Month-y mean Sun Spot No (SSN) 2004**	**Max H mean values of quiet and disturb days during 2003-2004**								**Max Ap monthly values & category of Storm**					
			Hq 2003	**UTC**	**Hd 2003**	**UTC**	**Hq 2004**	**UTC**	**Hd 2004**	**UTC**	**Ap Max 2003**	**Day's**	**Category of Storm**	**Ap Max 2004**	**Day's**	**Category of Storm**
Jan	79.7	37.3	-----	------	-----	-------	117	00	**390**	02:00	28	25	minor	64	22	**major**
Feb	**46.0**	**45.8**	-----	------	-----	-------	105	14:00	75	02:00	**52**	02	**major**	30	12	minor
Mar	**61.1**	49.1	**82**	04:00	**442**	02:00	201	01:00	**459**	00:00	42	17	minor	45	10	minor
Apl	**60.0**	39.3	**121**	02:00	**402**	01:00	**205**	01:00	**341**	04:00	45	30	minor	41	03	minor
May	**54.6**	41.3	**114**	01:00	**398**	02:00	**209**	01:00	210	01:00	**109**	29	**sever**	16	07	minor
Jun	**77.4**	43.2	72	01:00	121	01:00	200	01:00	65	01:00	**60**	18	**sever**	19	29	minor
Jul	**83.3**	**51.1**	**84**	01:00	**615**	003:00	206	00:00	**595**	00:00	**52**	11	**sever**	**171**	27	**sever**
Aug	**72.7**	40.9	**289**	05:00	**577**	005:00	202	01:00	**306**	03:00	**108**	18	**sever**	42	30	minor
Sep	**48.7**	27.7	66	13:00	**453**	02:00	204	01:00	**254**	01:00	70	17	**sever**	33	13	minor
Oct	**65.5**	**48.0**	**78**	13:00	**926**	06:00	204	02:00	**260**	02:00	**204**	29	**sever**	14	32	minor
Nov	**67.3**	43.3	**82**	13:00	**299**	04:00	204	01:00	35	01:00	**150**	20	**sever**	**161**	10	**sever**
Dec	46.5	17.9	**105**	12:00	**250**	01:00	194	02:00	**232**	02:00	41	10	minor	29	12	minor