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# Formation and identification of counter electrojet (CEJ)

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**This study investigates the possible occurrence of counter equatorial electrojet (CEJ) and a quicker method for identification of CEJ. Data from a chain of magnetic observatories of World Data Center for Geomagnetism in Tokyo, Japan, was employed. It is strikingly interesting to observe that most CEJ occurred from morning through new dusk, with almost the same pattern of dHin depression. In Ascension Island (ASC), Huancayo (HUA) and Pondicherry (PND), most ∆H were found to be less than zero, which reveals an indication of full CEJ. Partial CEJ occurrences were observed during some hours at these stations where ∆Hin >0. It is suggested that IMF turning north indicates CEJ, hence storm effects could also be attributed to CEJ existence. Some of our new findings are at variance with results of some previous workers; hence further work is suggested for further clarification. A quick method of easy identification of CEJ is suggested.**

**Key words:** Electrojet, geomagnetic element, counter electrojet, geomagnetism, interplanetary magnetic field (IMF).

## INTRODUCTION

For a long time now, there has been varying opinions about the nature and formation of counter electrojet phenomena. A lot of inconsistencies exist from the results of several workers. There is therefore need to actually attempt to specify cause(s) and formation for counter equatorial electrojet (CEJ) and throw some more light to its origin and formation.

Onwumechili (1997) modified the definition of Mayaud (1977) and defined CEJ as a westward electric current flowing on a very quiet day within a narrow band, centered on the dip equator. It could also be termed reversed equatorial electrojet (EEJ). It is important to note that westward currents and depression of H outside the EEJ zone and those within EEJ zone on magnetically disturbed periods are excluded. When the westward current flows outside the narrow band where the normal EEJ flows eastwards, then it is not definite whether it is CEJ or not. Since it has been observed that negative depressions of Sq(H) in the equatorial zone frequently come from the ring current, magnetosphere – ionosphere coupling, and polar-equatorial coupling, it becomes vital that emphasis must be laid on very quiet periods. This implies that the negative depressions of Sq(H) could be as a result of CEJ as small as -10nT or by disturbance with Ap = 5 (Onwumechili, 1997). He recommended that the study of CEJ should be limited to quiet days with Ap ≤ 6.

Gouin (1962) observed a conspicuous depression of the H component of geomagnetic element at local noon, at Addis Ababa. He noted that the H values were well

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**Table 1.** Coordinates of EEJ stations.

| Country | Observatory | Code | Geog Lat | Geog. Long. | Geomag. Lat |
|---|---|---|---|---|---|
| Ascension Island | Ascension | ASC | 7.95S | 14.38W | 2.36S |
| Peru | Huancayo | HUA | 12.04S | 75.32W | 1.80S |
| India | Pondicherry | PND | 11.92N | 79.92E | 2.85N |
| India | Alibag | ABG | 18.68°N | 72.87°E | 19.50N |

below the night level on a very quiet day of January 3rd 1962 with Kp 3+ and Ap of 2. Several workers have examined the cases of various counter electrojet events at different longitudes and observed that the depression of H-field at these longitudes are changing in nature, for example, Rastogi (1974); Mayaud (1977); Marriot et al. (1979); Kane (1976) and Onwumechili (1997). Okeke and Hamano (2000) attributed the pre-noon and after noon maximum in dH to CEJ in some of the abnormal quiet days.

Alex and Mukherjee (2001), found that most frequent and simultaneous occurrence of CEJ at the equatorial stations almost correspond and are found on days of EEJ. Rastogi (1975), ascertained that the solar flare effect on the horizontal component of the geomagnetic field (H) during the period of counter equatorial electrojet current is characterized by a negative crochet (decrease of H-field) at an equatorial electrojet station and a positive crochet (increase of H field) at a low latitude station outside electrojet belt. Gurubaran (2002) suggested that a possible relationship exists between the CEJ field and the noontime D variation observed at low latitudes. Mayaud (1977), Marriot et al. (1979) and Stening (1992) concluded that CEJ are mostly observed in a few hours after dawn and a few hours before dusk and are rarely observed around local noon. In other words, CEJ is never a night phenomenon. Crochet et al. (1979) noted that a very strong day time counter electrojet was observed on Janury 1977 near the magnetic equator in Africa. Also, Rastogi (1999) observed abnormally large westward currents almost the whole of the day time hours on a series of days.

The work of Manoj et al. (2008) concluded that the penetration of electric fields into the equatorial ionosphere is not dependent on the polarity of IMF Bz. This present work examines the formation of CEJ and classifies for the first time nature of type of CEJ that exist.

#### METHOD OF ANALYSIS

This study employs the steps described by Onwumechili (1997), in identifying CEJ. The first stipulates that a depression of Sq(H) below its night-time level, within a very quiet period, indicates preliminary sign that the current above the observatory has reversed direction. The problem with the above is that it does not indicate which of the two current layers has reversed, since the ionospheric current above the EEJ zone flows in two layers. Hence, there is need for another condition. Again, he introduced a perturbation $\Delta H_{in}$ at a station inside EEJ zone and another $\Delta H_{out}$ at a station in the same longitude but just outside the influence of the EEJ.

Hence, $\Delta H_{in} - \Delta H_{out}\ \Re 0$............. (1)

If the above equation holds, then it implies existence of CEJ. Further, the perturbation by upper current layer which is associated with the worldwide part of Sq gives perturbation of $\Delta H_u$ and that of the lower current associated with EEJ gives perturbation $\Delta H_L$. Onwumechili (1997) equally ascertained that WSq is very wide and its current density profile is almost flat, then he summarized as follows:

$\Delta H_{out} \sim \Delta H_U$ and $\Delta H_{in} = \Delta H_L + \Delta H_U$..... (2)

It is clear from Equations (1) and (2) that when $\Delta H_L\ \Re 0$, Equation (1) is satisfied; the implication is that CEJ occurs only when the lower current layer associated with EEJ has reversed westward in part or in whole, that is, $\Delta H_L\ \Re 0$.

In summary, if $\Delta H_{in}\ \Re 0$, it means full CEJ. On the other hand, if $\Delta H_{in}\ \Re 0$, it is partial CEJ. In line with the method described above, the perturbations $\Delta H_{in}$, $\Delta H_{out}$, $\Delta H_U$, and $\Delta H_L$ were calculated, and the steps required were taken for the analyses.

#### Source of data

The data used in the study was obtained from World Data Center for Geomagnetism in Kyoto, Japan. The data consists of hourly values of both H and Z components of geomagnetic intensities recorded for three internationally most quiet days as shown in Table 2 of the year 2000. The work focuses on three equatorial electrojet stations namely Ascension, Huancayo and Pondicherry, and one station located considerably outside the region of the EEJ namely Alibag (Table 1).

## RESULTS

## ANALYSES OF DATA

Figures 1(a-d) depict diurnal variation of H and Z geomagnetic components at one of the stations, Alibag (ABG) under study, for the quiet days of the year 2000. H-field and Z-field variations in ABG on the quiet days indicated follow the normal enhancement of the H around noon and the Z depression, which is the expected trend.

In Ascension Island (ASC) (Figure 2a-b) a very thin band of current flows between 0:00 h and 5:00 h throughout the month of the year except for July. Subsequently, there is enhancement of ΔH with a peak at about 15:00 h, maximizing at approximately 50nT in all the months of the year except in September, where there

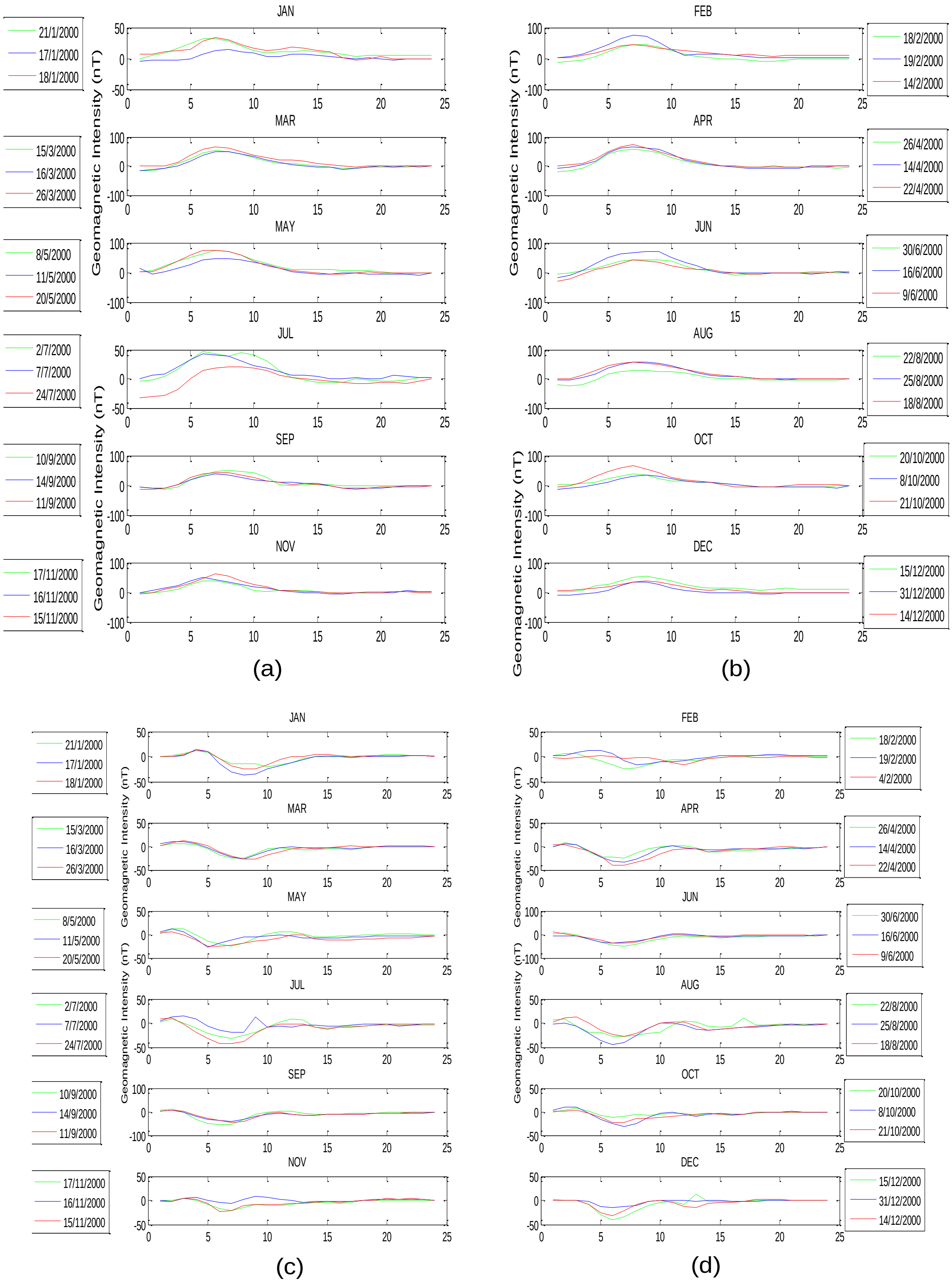


**Figure 1.** (a, b) Diurnal variation of delta ΔH component at ABG in year 2000, (c, d) Diurnal variation of delta Z-component at ABG in year 2000.

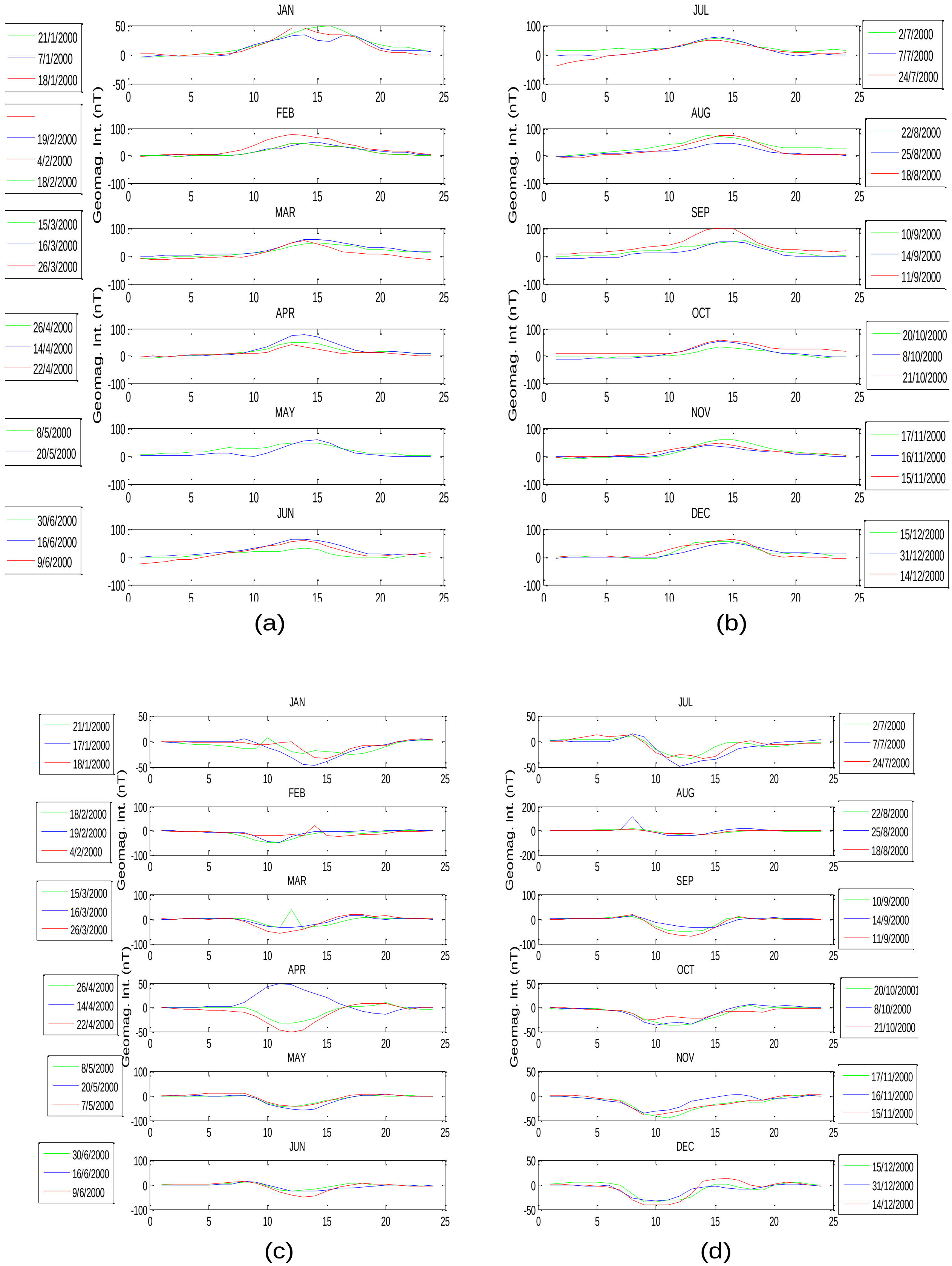


**Figure 2.** (a, b) Diurnal variation of delta ΔH component at ASC in year 2000, (c, d) Diurnal variation of delta Z-component at ASC in year 2000.

**Table 2.** International Quiet Days for 2000.

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 18 | 15 | 26 | 08 | 30 | 02 | 22 | 10 | 20 | 17 | 15 |
| 17 | 19 | 16 | 14 | 11 | 16 | 07 | 25 | 14 | 08 | 16 | 31 |
| 18 | 04 | 26 | 22 | 20 | 09 | 24 | 18 | 11 | 21 | 15 | 14 |
| 09 | 17 | 27 | 18 | 07 | 25 | 06 | 19 | 09 | 09 | 03 | 20 |
| 08 | 20 | 04 | 25 | 21 | 17 | 25 | 26 | 22 | 06 | 02 | 30 |

**Table 3.** Monthly averages of ΔH-field component of all the stations.

| Month | ABG [$\Delta H_{out}$] | ASC [$\Delta H_{in}$] | ASC$\Delta H_{in}$ - $\Delta H_{out}$ | HUA [$\Delta H_{in}$] | HUA$\Delta H_{in}$ - $\Delta H_{out}$ | PND [$\Delta H_{in}$ | PND$\Delta H_{in}$ - $\Delta H_{out}$ |
|---|---|---|---|---|---|---|---|
| Jan | 13.50 | 13.86 | 0.36 | 22.50 | 9.00 | 12.12 | -1.38 |
| Feb | 15.12 | 19.45 | 4.33 | 36.37 | 21.25 | 21.3 | 6.18 |
| Mar | 20.83 | 14.51 | -6.32 | 36.21 | 15.38 | 22.2 | 1.37 |
| Apr | 24.07 | 15.80 | -8.27 | 28.01 | 3.94 | 23.4 | -0.67 |
| May | 17.26 | 14.10 | -3.16 | 32.06 | 14.80 | 22.43 | 5.17 |
| Jun | 21.77 | 14.64 | -7.13 | 24.78 | 3.01 | 20.95 | -0.82 |
| Jul | 16.90 | 15.75 | -1.15 | 33.78 | 16.88 | 17.56 | 0.66 |
| Aug | 17.07 | 22.14 | 5.07 | 30.32 | 13.25 | 20.6 | 3.53 |
| Sep | 17.67 | 21.50 | 3.83 | 36.21 | 18.54 | 16.83 | -0.84 |
| Oct | 17.53 | 12.32 | -5.21 | 38.83 | 21.30 | 17.53 | 0.00 |
| Nov | 14.77 | 13.07 | -1.70 | 27.04 | 12.27 | 15.23 | 0.53 |
| Dec | 9.94 | 14.06 | 4.12 | 27.69 | 17.75 | 17.00 | 7.06 |

is an enhancement up to 100nT. A depression, which is more conspicuous on January 21 followed by that on January 7 and then that on $18^{th}$ January with a peak of 5nT, was observed. Nonetheless, a narrow band of current flowed at night-time between 20th and 24th hours, conspicuously in January, February, December and September on 14th.

Interesting is the features on the $15^{th}$ of March in Figure 2a, where the Sq(H) variation depicts a peculiar pattern. There was no pronounced enhancement, rather, almost a horizontal trend was observed. It could rather be termed a slight depression which cause or route could be attributed to the ring current, magnetosphere-ionosphere coupling or polar-equatorial coupling if not on quiet period as has been chosen in this study. Basically, the Z-component variation in Figure 2c on same day shows enhancement rather than depression so it has given room to further investigate if CEJ has occurred. This is because it has given us information from ΔH that EEJ truly reversed westwards. From Table 3, it is clearly seenthat $\Delta H_{in}$ for ASC minus $\Delta H_{out}$ is less than zero ($\Delta H_{in}$ – $\Delta H_{out}$ $\Re$0), which indicates the existence of counter electrojet. This occurrence of CEJ at ASC during the noon could be attributed to late morning reversal of $E_z$, meaning that the reversal could have taken place around noon. Since $\Delta H_{in}$ in this station is greater than zero, it is then partial counter electrojet that occurred. More interesting is the fact that, it occurred around the local noon. This is in variance with findings of Mayaud (1977), Marriot et al. (1979) and Stening (1992). Our findings are with agreement with work of Ezema et al. (1996), who found latitudinal profiles of CEJ at all hours from 07 to 17 h local time.

Incidentally, from Figure 2c and d ΔZ-field shows no reversal on all the days above, except on March 15. Therefore, since it is only the H profile that has reversed in this EEJ station, then it is only the EEJ that has reversed westwards. However, a marked reversal in ΔZ-field was observed on April 14 and slightly on March 15.

Figure 3a-b show a continuous series of enhanced ΔH-component in Huancayo (HUA) occurring between 12:00 h and 20:00 h throughout the year. This trend is preceded by a flat feature in the early hours of all the quiet days under study. A distinct scenario of ΔH depression is noted in the month of December on $31^{st}$, $15^{th}$ and $14^{th}$ respectively, in order of higher magnitudes of depression. Though there is a westward flow of current from about 1600 to 2400 h, this is associated with a reversal of the ΔZ-component (Figure 3c-d) of same periods in the month of December. While ΔZ-component enhancements are manifested from noon to 18:00 h in the months of January, February and March, the ΔH-components continue to be enhanced at the same time. Figure 4a-d depict geomagnetic intensity at Pondicherry (PND) during the three geomagnetic quietest day under consideration for the year 2000. Results show gradual enhancement of

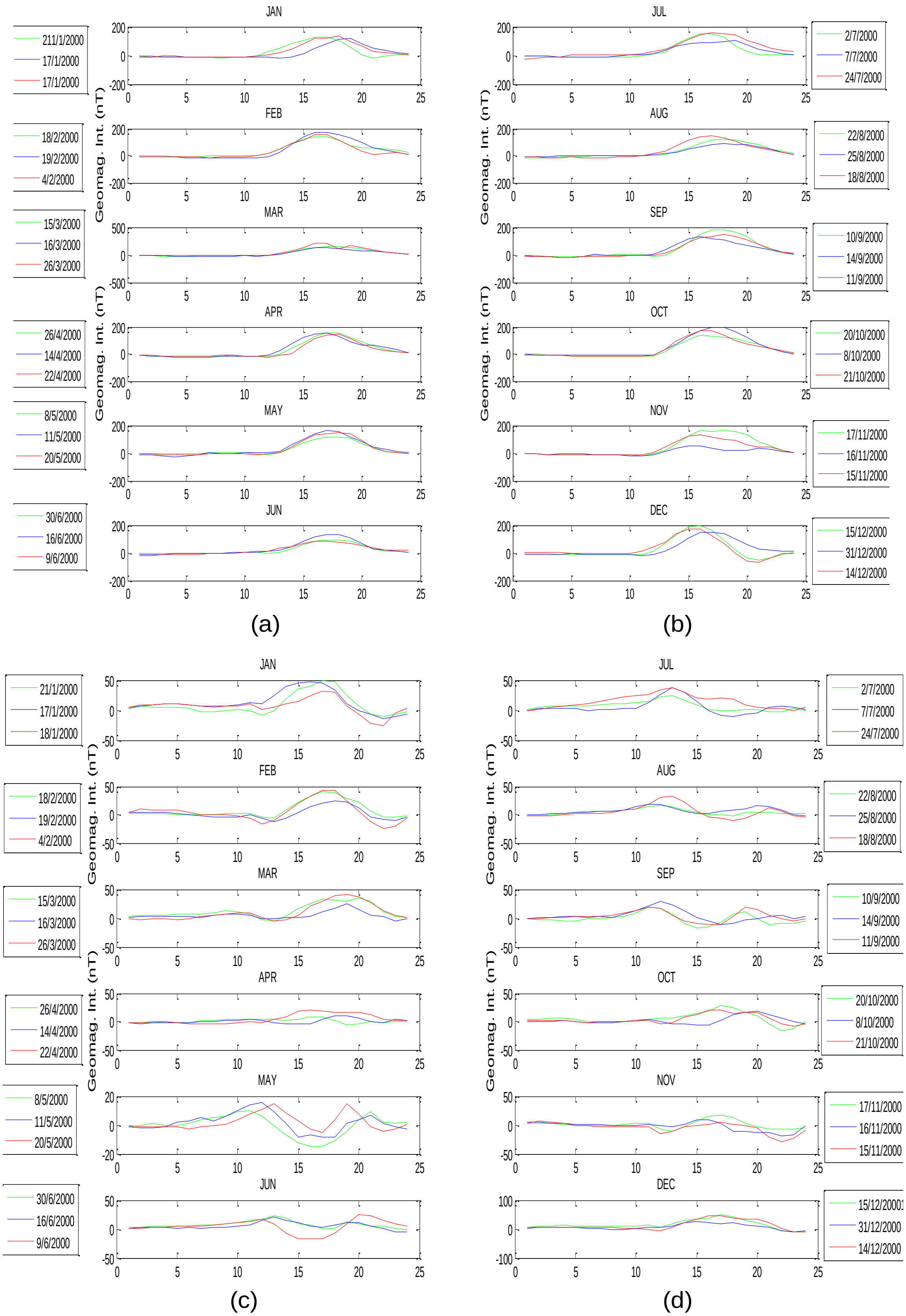


**Figure 3.** (a, b) Diurnal variation of delta ΔH component at HUA in year 2000, (c, d) Diurnal variation of delta Z-component at HUA in year 2000.

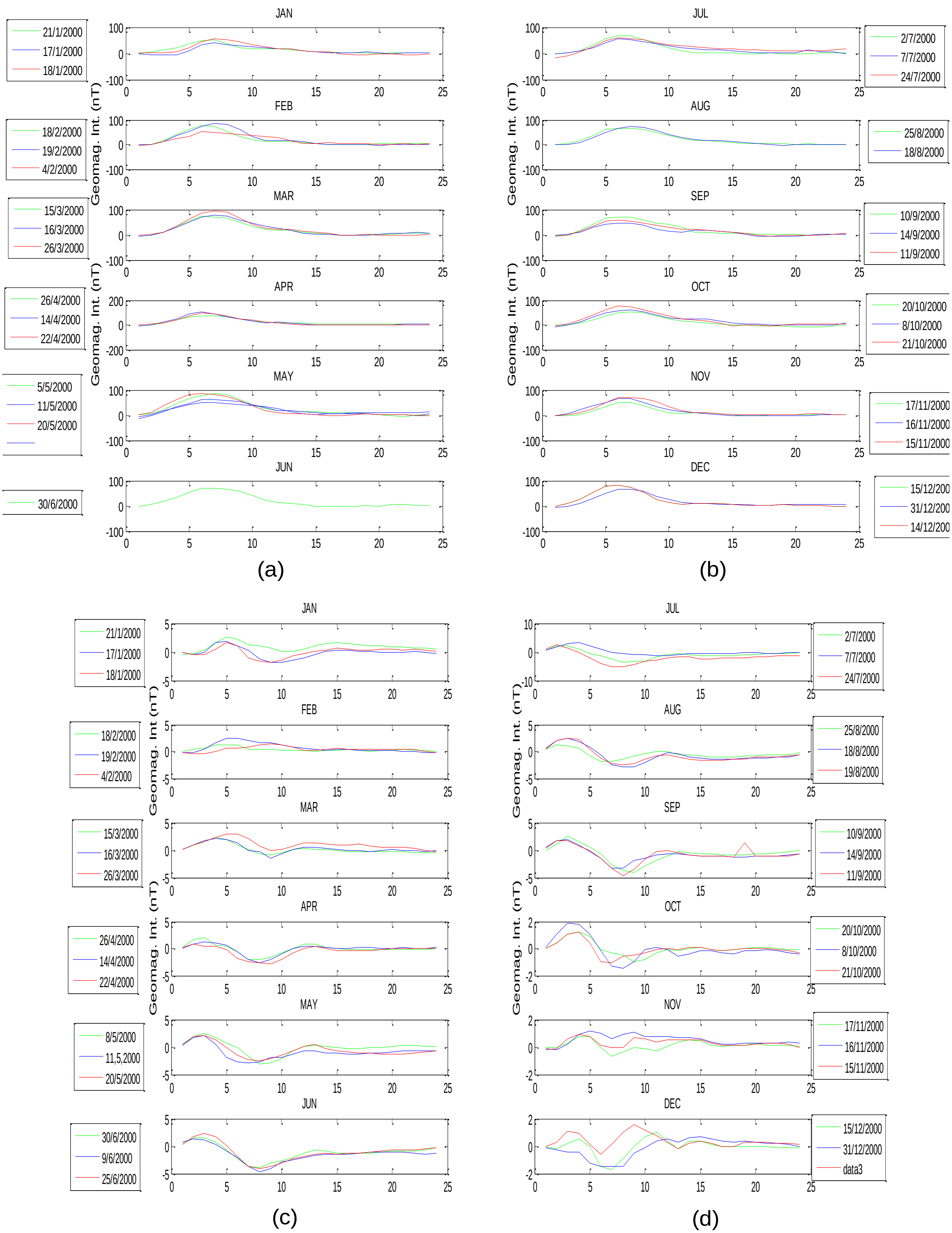


**Figure 4.** (a, b) Diurnal variation of delta ∆H component at HUA in year 2000, (c, d) Diurnal variation of delta Z-component at HUA in year 2000.

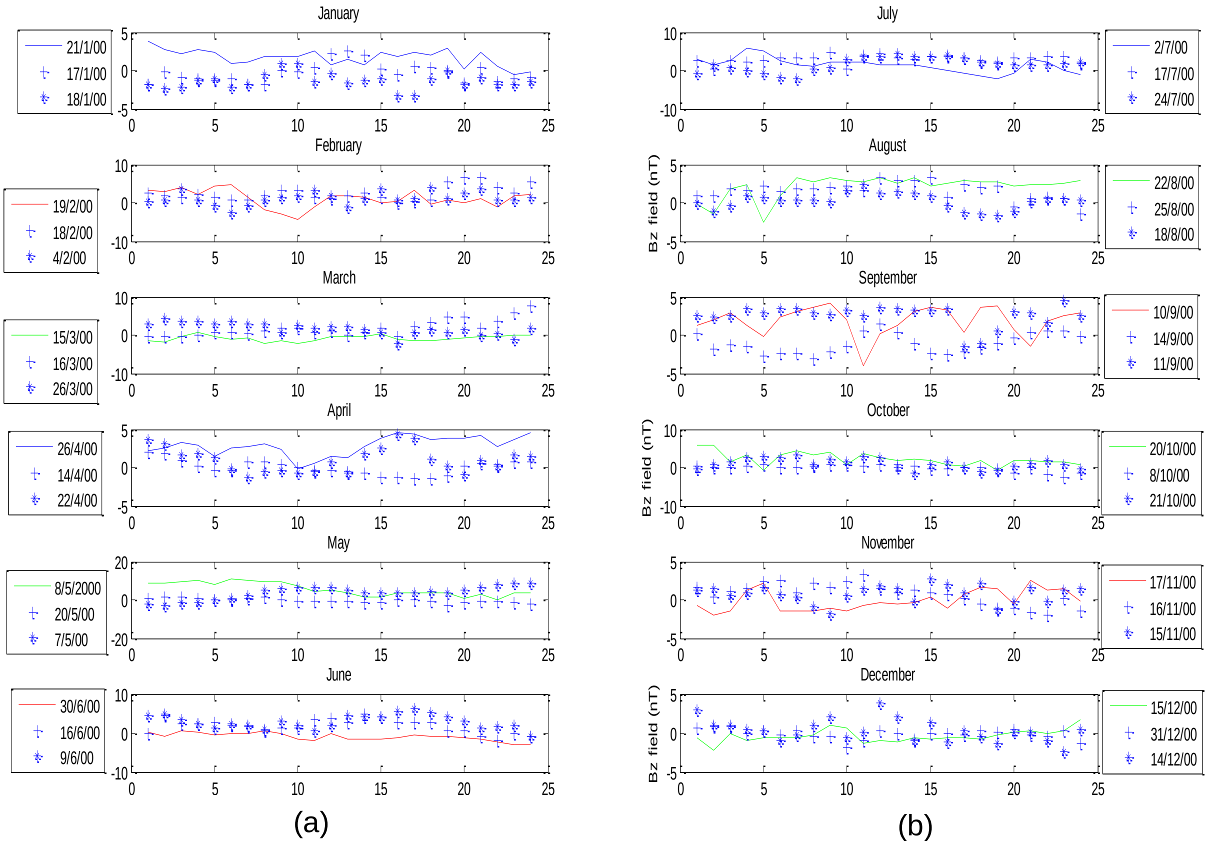


**Figure 5.** (a) IMF Bz orientation for three quietest days of January - June 2000, (b) IMF Bz orientation for three quietest days of July - December 2000.

ΔH-component from 3:00 h, with a peak at about 8:00 h on all the three most quiet days of the year. This trend is accompanied by depression of ΔZ-component at the same period of time.

From Table 3, it is apparent that the CEJ flow in each of the observatories is not continuous across all the months of the year. For instance, in ASC $\Delta H_{in} - \Delta H_{out} \Re 0$ holds for the months of March, April, May, June, July, October, November and December. And in PND, Equations (1) and (2) are true for January, April, June and September. The significance being that the lower current layer, which is associated with the EEJ reversed westwards in the months indicated. This also confirms findings from previous workers (Marriot et al., 1979; Hutton and Oyinloye, 1970; Rastogi, 1974), who concluded from their works that afternoon CEJ is most frequent in local summer solstice. Since inconsistency exists both with the concept of definition of CEJ time of occurrence and causes, hence, this study further investigated the relationship between interplanetary magnetic field (IMF) and the CEJ. It was discovered from IMF movement, that as soon as $B_z$ component of IMF turns from South direction to North, then CEJ occurs. Figure 5a and Table 4 support this finding, where northward turning of IMF $B_z$ is observed in the early hours of the three quietest days of the months of January through May. Also, northward movement of IMF $B_z$ is a post-noon phenomenon as is apparent on February 18 and 19; March 16, April 26 and May 8 of the year 2000. Very remarkable feature of the northward turning was very obvious on April 26, which was the quietest day of that month, where the IMF $B_z$ remained northward throughout the day with greater pronouncements in both pre-noon and post-noon hours.

In Figure 5b, on September 10, the quietest day of the month, the IMF $B_z$ suddenly changed from south to north at 11:00 h and retained its northward orientation for a considerable number of hours. This signature was repeated throughout the day and on September 11, which confirms a CEJ occurrence observed on same dates and time in ASC (Figure 2a-d), in HUA (Figure 3a-d) and in PND (Figure 4a-d). This is a new finding and should be further investigated fully in our next paper.

## Conclusion

Common occurrence of ΔH depression with the same obvious pattern could be attributed to the same route cause. The quick method to identify the existence of CEJ

**Table 4.** IMF Bz magnitudes and orientations for the three quietest days in the year 2000.

| Month | 1$^{ST}$ QD | Bz Mag. (nT) | Bz Dir | 2$^{ND}$ QD | Bz Mag. (nT) | Bz Dir | 3$^{RD}$ QD | Bz Mag. (nT) | Bz Dir |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 21 | 1.2 | N | 17 | 0.2 | N | 18 | -0.6 | S |
| Feb | 18 | 1.2 | N | 19 | -0.9 | S | 04 | 0.5 | S |
| Mar | 15 | -0.3 | S | 16 | 1.3 | N | 26 | 1.1 | N |
| Apr | 26 | 1.5 | N | 14 | -0.8 | S | 22 | -0.4 | S |
| May | 08 | 5.4 | N | 11 | 0.0 | N | 20 | -1.0 | S |
| Jun | 30 | -1.2 | S | 16 | 1.7 | N | 09 | 2.8 | N |
| Jul | 02 | 1.2 | N | 07 | 0.6 | N | 24 | -0.1 | S |
| Aug | 22 | 1.1 | N | 25 | -0.3 | S | 18 | -0.2 | S |
| Sep | 10 | 1.1 | N | 14 | -0.2 | S | 11 | 3.4 | N |
| Oct | 20 | 0.1 | N | 08 | -1.2 | S | 21 | 1.1 | N |
| Nov | 17 | 0.5 | N | 16 | 0.3 | N | 15 | 0.6 | N |
| Dec | 15 | 0.2 | N | 31 | -0.2 | S | 14 | -0.0 | S |

is to study IMF movement. As soon as $B_z$ component of IMF turns from South direction to North, the CEJ occurs, which is in variance with prediction of Manoj et al. (2008), who claimed that penetration of electric fields into the equatorial ionosphere is not dependent on the polarity of IMF $B_z$. It is then easier to examine other contributing factors like the values of $\Delta H_{in}$ and the reversal of EEJ and the $\Delta H$ values. This study of occurrence of CEJ and causes has constituted an active area of research work as long as the world in which we are is dynamic and not static. The causes of CEJ are yet to be fully explained. Hence, more future work is recommended for more robust results. One of our findings from this work, which revealed that CEJ could equally occur during night-time, is at variance with findings of earlier workers, who on the contrary ascertained that CEJ phenomenon is a morning event. They concluded that CEJ could only occur in the morning hours (Mayaud, 1977; Marriot et al., 1979; Stening, 1992). Hence, further investigation is required in order to confirm this existing controversy.

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