Defining different type of CEJ currents based on ground-based geomagnetic data record at Langkawi station, Malaysia

N I M Rosli¹, N S A Hamid¹, M Abdullah²,³, and A Yoshikawa⁴

¹Department of Applied Physics, Faculty of Science and Technology,
²Space Science Centre (ANGKASA), Institute of Climate Change,
³Department of Electrical, Electronics and Systems Engineering, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia.
⁴International Center for Space Weather Science and Education, Kyushu University, Fukuoka, 812-8581, Japan

Abstract. A negative decrement in geomagnetic data in equatorial region is not necessarily cause by the well-known counter electrojet, CEJ but it is also can be affected by solar activity such as a solar flare. Relying on this matter, we did a comparison between CEJ and unusual solar flare effect called as SFE* on geomagnetic data before introducing several types of CEJ that can be extracted from EUEL index. This study used ground data from MAGDAS network located in Langkawi (LKW) with 1-minutes resolution during solar cycle 24 and applied EUEL index. From the results, it is crucial to ensure the minimum duration of EUEL depletion is within an hour because less than an hour depletion could be possibly cause by solar activity. Four interval of time that has been introduced in our study composed of several types of CEJ which are morning CEJ, afternoon CEJ and evening CEJ, with additional the controversial CEJ occurrence which is night CEJ. We also successfully demonstrated a rare CEJ occurrence that associated with solar flare effect using EUEL index.

1. Introduction
The eastward flow of equatorial electrojet current, EEJ at dip-equator once in a while tends to oppose its actual direction, causing the flow to change westward. This reversal occurrence is known as equatorial counter electrojet current, CEJ and usually happen due to the tidal modes [1,2], wind [3] and any other factors. CEJ was early reported by [4] based on the negative depression of horizontal component of geomagnetic field observed at the equatorial region of African sector. In some studies, the CEJ is divided into different Local Time intervals. For instance, study by [5] suggested four intervals to represent four types of CEJ which are morning CEJ (MCEJ, 0600-0800 LT), noon CEJ (NCEJ, 1100-1200 LT), afternoon CEJ (ACEJ, 1300-1400 LT), and evening CEJ (ECEJ, 1500-1800 LT). These diurnal intervals for the occurrence of CEJ are commonly introduced, since theoretically the EEJ current strength is strong during daytime hours, while weaken and returns at dawn. Despite that, the intervals are inconsistent and depending on how the times of the day is defined. Hence, this study is going to discuss several types of CEJ that can be extracted from EUEL index. The controversial CEJ occurrence which is during night time hours that in contrast to the earlier basis (CEJ as daytime event) will be included as well as additional to the current study.
2. Method and analysis

We utilized ground-based magnetometer data from MAGDAS network located in Southeast Asia region for categorizing CEJ into several types. This data comprised of geomagnetic field H component data on the quiet days (Kp≤3) during solar cycle 24 with 1-minute resolution. Before extracting CEJ, a series of calculation proposed by [6] is applied to obtain EUEL index. EUEL is an index that combines two components, EU (electrojet upper) to monitor EEJ and EL (electrojet lower) to identify CEJ signature.

Initially, the original value of H component is subtracted to its median value to obtain ER of magnetometer station, ER\text{station}. The ER\text{station} is then subtracted to EDst value (mean collected from night-time stations, LT=1800-0600 along the magnetic equatorial region) to ensure the final result is equatorial disturbance free. CEJ is identified from EUEL index based on two conditions. The value of the index should be below 0 nT and must be last long at least 1-hour. This duration is calculated from the starting point of negative EUEL until the end point where it reached 0 nT. In addition to this time duration criteria, we also neglected data gap to avoid any incomplete CEJ.

Apart of that, we suggested four intervals of time over a day, including night time period as in Table 1. These intervals are used to characterized different CEJ types based on the time of its peak value. The peak particularly refers to the lowest negative value of EUEL index. The occurrence of CEJ associated with solar activity such as solar flare is also demonstrated as both events could happen simultaneously. The existence of solar flare is monitored from X-ray flux data provided by GOES 15 satellite.

| Types of CEJ | The interval (LT) |
|--------------|------------------|
| Morning      | 0500-1100        |
| Afternoon    | 1300-1600        |
| Evening      | 1700-2300        |
| Night        | 0100-0400        |

3. Results and Discussion

A proper way of extracting CEJ from EUEL index is essential as negative decrement of EUEL sometimes not necessarily cause by CEJ, instead it also might due to the solar activity. An example of common solar activity that affect EUEL is the solar flare. Solar flare is known as a sudden flash from the surface of the Sun that caused short term disturbance (~within few minutes) in geomagnetic data. We presented this effect in our study as to highlight the importance of implementing time duration in EUEL decrement for CEJ extraction.

Most of the time, solar flare occurrence normally caused a sudden short term increment effect on geomagnetic data called SFE, due to the sudden increase of ionization process in ionospheric layer. Nevertheless, previous study by [7] reported unusual effect, SFE* that contradict to this normal behaviour, which caused the depletion of geomagnetic data. Hence, we presented in this study the difference between SFE* and CEJ plot as in Figure 1(a) and (b). This figure illustrated the trends of EUEL decrement in between 1500 LT and 1800 LT on two different days, which are August, 15th of 2012 and August, 9th of 2011. The result obviously shows that long term decrement in Figure 1(a) can be consider as CEJ since the duration is exceeding 1-hour period. On the other hand, it is unlikely to consider short term decrement in Figure 1(b) as CEJ since the duration is too short and it is proved by X-ray flux data by GOES 15 satellite (not shown here) the presence of solar flare X6.9 during this time.
Based on the proposed intervals as in Table 1, we have collected a few quiet days in the year of 2012 from Langkawi (LKW) station as representation to types of CEJ. The Dst index is attached together as indicator to quiet geomagnetic condition. In Figure 2(a), morning CEJ is extracted in January, 28\textsuperscript{th} and the occurrence happen within 0445 LT to 0845 LT with peak at 0744 LT. Afternoon CEJ for (b) is extracted in August, 15\textsuperscript{th} with occurrence within 1523 LT to 2107 LT and peak at 1625 LT. Evening CEJ for (c) is in January, 5\textsuperscript{th} within 1751 LT to 2038 LT and peak at 1912 LT, whilst night CEJ for (d) is in August 22\textsuperscript{nd} within 0252 LT to 0458 LT and peak at 0425 LT. These values are summarized as in Table 2.

**Table 2. Types of CEJ according to the time interval of the CEJ occurrence**

| Types of CEJ     | Initial | Peak  | Final  |
|------------------|---------|-------|--------|
|                  | Time (LT) | Index value | Time (LT) | Index value | Time (LT) | Index value |
| Morning CEJ      | 0445    | -0.20 | 0744   | -20.82     | 0845      | -0.43       |
| Afternoon CEJ    | 1523    | -0.19 | 1625   | -18.85     | 2107      | -0.28       |
| Evening CEJ      | 1751    | -0.15 | 1912   | -14.25     | 2038      | -0.07       |
| Night CEJ        | 0252    | -0.05 | 0425   | -3.70      | 0458      | -0.27       |
Figure 2. Types of CEJ (a) morning occurrence on January 28th (b) afternoon occurrence on August 15th (c) evening occurrence on January 5th and (d) night occurrence on August 22nd.

Despite the difference between effect of CEJ and SFE*, CEJ can be associated with solar flare too. Previously, this finding was found by [7] in South Africa region, where magnetometer observation from Addis Ababa (AAB) station showed the existence of the unusual effect of solar flare in morning CEJ occurrence. We analysed EUEL on the same date as the reported event, which is on August, 4th of 2011. In Figure 3, we verified that the CEJ observation from EUEL index is also affected by solar flare as the occurrence is in conjunction to the sudden drop at 0635 LT with the minimum value of -31.36 nT.
Figure 3. CEJ occurrence associated with solar flare effect observed using EUEL index

4. Conclusion
Extracting CEJ from EUEL index needs to be precise as negative depletion of EUEL is also influenced by other factor such as solar activity. The duration of EUEL depleted below threshold must be at least more than one hour to ensure non-CEJ event is excluded. Considering that CEJ happen at any time per day, thus it be can be classified it to several types, depending on the time when CEJ value is minimum. For a rare event that is not usually happen, we can observe effect of solar flare and the existence of CEJ at the same period.

Reference lists
[1] R. J. Stening, Magnetic variations at other latitudes during reverse equatorial electrojet, J. Atmos. Terr. Phys., 1977.
[2] R. T. Marriott, A. D. Richmond, & S. V. Venkateswaran, The quiet time equatorial electrojet and counter electrojet, J. Geomag. Geoelectr., 1979.
[3] R. Raghavarao and B. G. Anandarao, Equatorial electrojet and counter-electrojet, Indian J. Radio and Space Phys., 1987.
[4] P. Gouin, Reversal of the magnetic daily variation at Addis Ababa, Nature, 1962.
[5] S. Alex and S. Mukherjee, Local time dependence of the equatorial counter electrojet effect in a narrow longitudinal belt, Earth, Planets and Space, 2001.
[6] T. Uozumi, K. Yamoto, K. Kitamura, S. Abe, Y. Kakinami, M. Shinohara, A. Yoshikawa, H. Kawano, T. Ueno, T. Tokunaga, D. McNamara, J. K. Ishituka, S. L. G. Dutra, B. Damtie, V. Doumbia, O. Obrou, A. B. Rabiu, I. A. Adimula, M. Othman, M. Fairos, R. E. S. Otadoy, & MAGDAS Group, A new index to monitor temporal and long-term variations of the Equatorial Electrojet by MAGDAS/CPMN real-time data: EE-Index. Earth Planets and Space, 2008.
[7] N. M. N. Annadurai, N. S. A. Hamid, Y. Yamazaki, & A. Yoshikawa, Investigation of unusual solar flare effect on the global ionospheric current system, Journal of Geophysical Research: Space Physics, 2018.

Acknowledgement
We extend gratitude to all members of MAGDAS project for their data contribution to this study. Financial support is acquired by the grant GUP-2019-053 of Universiti Kebangsaan Malaysia.