



Quiet Period Variation of Horizontal Component of Geomagnetic Field along 210° Magnetic Meridian during the Low Solar Activity Year of 2010

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Abstract

This study presents a quantitative analysis of the quiet-time variation of the horizontal (H) component of the geomagnetic field along the 210° magnetic meridian (210° MM) during the solar minimum year of 2010. Diurnal Sq(H) variations at DAV and YAP exhibit the characteristic daytime maximum, nocturnal minimum, and peak value at local noon. The maximum Sq(H) amplitude was recorded during the March equinox, with DAV reaching 94.81nT at 11:00 LT and YAP recording 85.54nT at 12:00 LT. During the September equinox, DAV peaked at 92.78nT at 10:00 LT, while YAP magnitude was 76.42nT at 11:00 LT. Solstitial analysis showed that the December solstice Sq(H) at YAP peaked at 84.73nT, exceeding the June solstice peak of 52.19nT. DAV recorded Sq(H) magnitudes of 89.56nT and 66.01nT during the December and June solstices, respectively, reflecting enhanced solar zenith proximity and seasonal conductivity during Southern Hemisphere summer. The latitudinal comparison revealed that DAV exhibited consistently higher Sq(H) amplitudes than YAP, despite YAP being closer to the magnetic equator. This is attributed to longitudinal variation in EEJ strength and regional differences in ionospheric conductivity. EEJ strength showed clear daytime enhancement. The maximum EEJ strength was observed at DAV with a magnitude of 62.30 nT at 10:00 LT with a corresponding early morning counter electrojet (MCEJ) of -6.91nT at 06:00 LT during the September equinox. The maximum EEJ and CEJ values of 61.69nT at 12:00 LT and -14.52nT at 08:00 LT were observed at YAP during the December and June solstices, respectively. The observed Sq(H) and EEJ profiles confirm established equatorial electrodynamics like enhanced Sq(H) during equinoxes, reduced amplitude during solstices, and peak EEJ near local noon. The results reinforce the role of solar zenith position, ionospheric conductivity, and geomagnetic latitude in modulating low-latitude current systems during solar minimum conditions.

Keywords: Geomagnetic field intensity, Solar quiet (Sq), Equatorial Electrojet (EEJ) current, 210° magnetic meridian, Diurnal and Seasonal variations.

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Introduction

Earth's geomagnetic field is a complex and extremely dynamic phenomenon that is largely maintained by convective motions in the planet's outer core via a process called the geodynamo (Campbell, 2003; Olson and Christensen, 2006). In addition to being essential for orientation and navigation, this

field acts as a shield against dangerous cosmic and solar radiation. The horizontal (H) component, a crucial component of the geomagnetic field, is very sensitive to magnetospheric and ionospheric current systems, especially when the geomagnetic field is quiet (Campbell, 1997). Although the solar quiet (Sq) current and other regular

ionospheric current systems cause variations in the H-component even during quiet times, global-scale interactions between solar radiation, ionospheric conductivity, and neutral winds are the source of these currents in the dynamo area of the Earth's upper atmosphere (Matsushita and Campbell, 1967). The H-component daily quiet-time variation caused by solar-driven ionospheric currents in the E-region is represented by the Sq(H). Another important characteristic is the Equatorial Electrojet (EEJ), an intense eastward current that exists in the equatorial ionosphere (Adimula *et al.*, 2011; Bolaji *et al.*, 2013). This enhances the H-component obviously during noon at the equator (Forbes, 1981). The 210° Magnetic Meridian (210° MM) is a longitudinally aligned system of geomagnetic observatories that spans latitudes from the equator to the auroral zone in the Asia-Oceania region. This meridian, which was created by a Japanese project, provides a unique framework for studying the dependence of geomagnetic changes on latitude (Yumoto *et al.*, 1996). In both calm and disturbed geomagnetic settings, it is an effective instrument for examining the dynamics and structure of existing systems. However, calm times offer the best opportunity to study ionospheric current systems in their most stable, unaltered state. Dependent on latitude, season, and local time, the Solar quiet (Sq) changes are still poorly described across the 210° Magnetic Meridian, especially during extended solar minima, such as that in 2010 (Mayaud, 1980). The year 2010, one of the low activity years between Solar Cycles 23 and 24, with long stretches of little disturbance, weak solar wind conditions, and consistently low sunspot counts, was the hallmark of this protracted quiet phase. This rare state of solar inactivity provides a great chance to study natural latitudinal variations in the H-component of the geomagnetic field.

This quiet period variation in H-component geomagnetic field along the 210° MM during the year of low solar activity in 2010 gives an insight into the temporal (diurnal and seasonal) and spatial (latitudinal) trends in H-component behaviour using data from three observatories: Yap Island (YAP), Davao (DAV), and Muntinlupa (MUT). Additionally, the analysis identifies possible sources of H-component variations during periods of low solar activity and assesses consistency or departures by comparing observed variations with previous research. In this way, the study advances our knowledge of ionospheric electrodynamics in low-activity solar conditions.

Materials and Method

Data and Method of Analysis

The geomagnetic field data used in this research were the horizontal (H-component) of the geomagnetic field obtained from the ground-based magnetometers network. The data were 1 minute's record of the H-component converted to an hourly value to show their temporal diurnal variations. Specifically, the data were obtained across the three stations: Yap Island (YAP), Davao (DAV), and Muntinlupa (MUT). The station MUT was selected as the off-EEJ station, whose $Sq(H)_{\text{non-EEJ}}$ was utilized in the estimation of the EEJ strength for this study. The ten International Quiet Days (IQDs) per month in 2010 were used for the analysis. The coordinates and location on the world map of the stations whose data were utilized for this study are given in Table 1 and Figure 1, respectively. The ten (10) international quiet days (IQDs) and concept of the local time (LT) were used for the analysis. The baseline (BL) is defined as the mean of the four (4) hours flanking the local midnight H_{23} , H_{24} , H_{01} , and H_{02} , respectively, and represented by equation 1.

Table 1: The geographical and geomagnetic coordinates of MUT, DAV, and YAP.

Station name	Station ID	Country	Geographical		Geomagnetic	
			Lat(°)	Lon(°)	Lat(°)	Lon(°)
Muntinlupa	MUT	PHILIPPINES	14.37	121.02	4.95	193.26
Davao	DAV	PHILIPPINES	7.00	125.40	-2.22	197.90
Yap	YAP	YAP ISLAND	9.50	138.08	1.14	20.25

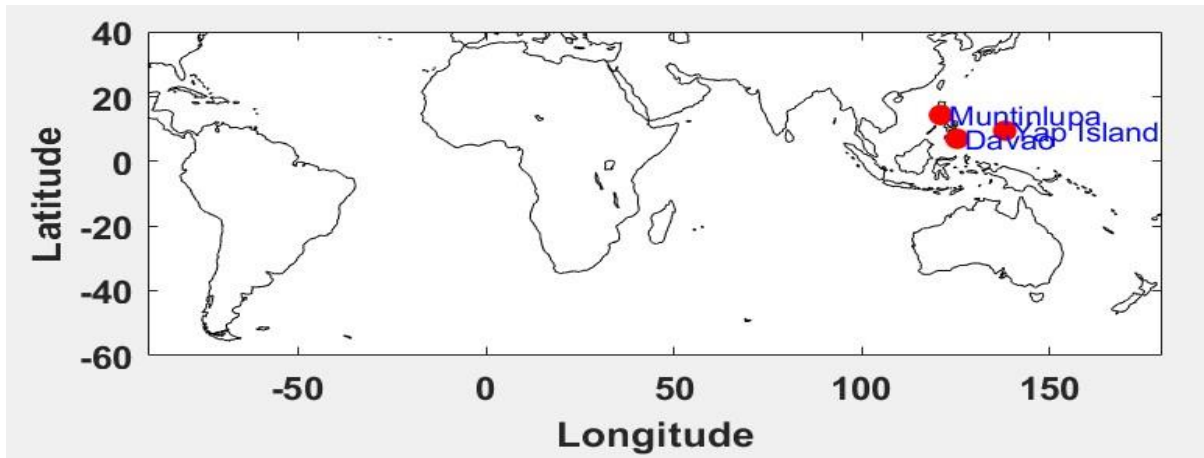


Figure 1: World map showing the location of the stations.

$$BL = \frac{H_{23} + H_{24} + H_{01} + H_{02}}{4} \quad (1)$$

where H_{23} , H_{24} , H_{01} , and H_{02} are the hourly values of the H-component at 23, 24, 01, and 02 hours LT, respectively. The $Sq(H)$, which is the hourly departure that gives the H-component hourly amplitude geomagnetic field, is estimated by subtracting the value of the baseline (BL) of a given day from each hourly value of that same day, expressed by equation 2.

$$Sq(H) = \Delta H = H_t - BL \quad (2)$$

where $t = 01$ to 24 hours.

The Llyod's season classification and the pair-station approach were used to obtain the seasonal variations, and the equatorial electrojet (EEJ) intensity was calculated using the relation:

$$EEJ = Sq(H)_{EEJ} - Sq(H)_{non-EEJ} \quad (3)$$

where $Sq(H)_{EEJ}$ and $Sq(H)_{non-EEJ}$ are the hourly departures for a station on the EEJ strip and for a station not on the EEJ strip, respectively, provided they are on the same longitude.

Results and Discussion

The diurnal $Sq(H)$ every month for Davao (DAV) and Yap Island (YAP) for the low solar year of 2010 is presented in Figure 2. The graphs have almost the same shapes, and the peak amplitudes occur between 0900 and 1200 LT; however, the precise values differ per station and month. At about 1100 LT in October, the peak $Sq(H)$ magnitude for DAV was 103nT. On the other hand, YAP recorded a maximum $Sq(H)$ of 91nT at 1200 LT in March of the same year. Additionally, it was noted that the DAV peak magnitudes in

January, February, March, October, November, and December occurred approximately 1100 LT. In the morning and evening, there were slight depressions in $Sq(H)$, which corresponded to the lower H-component field component linked to the counter electrojet (CEJ). The observed peak amplitudes of $Sq(H)$ about local noon are due to high ionization rate during the day when the sun is vertically overhead compared to the nighttime (Abbas *et al.*, 2012; Rabiun *et al.*, 2007). The eastward ionospheric current system impacts the H-component of the geomagnetic field are due to the solar heating and atmospheric winds (Campbell, 1997; Matsushita and Campbell, 1967).

Figure 3 depicts the seasonal variation of $Sq(H)$ at DAV and YAP. The two stations' seasonal peaks were 94nT at 1100 LT for DAV and 85nT at 1200 LT for YAP during the March equinox. DAV's maximum $Sq(H)$ strength was recorded between 1000 and 1200 LT, while YAP's minimum $Sq(H)$ peak (42nT) was recorded around 1000 LT during the June solstice in 2010. Except for the December solstice, an equinoctial maximum and a solstitial minimum were typically noted; during this time, YAP recorded a peak of 84nT during the December solstice, which was more than the equinoctial and June solstice values for the same station. This result was attributed to the favourable solar zenith positioning, enhanced E-region conductivity, and wind asymmetry in the 210° MM region (Yumoto, 1996; Forbes *et al.*, 2008). The semi-annual pattern of this seasonal fluctuation is followed

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by a seasonal ionization pattern that is caused by the EEJ (Rastogi *et al.*, 1994). According to Chandra *et al.*, (2000), Feng *et al.*, (2008), and Onwumechili (1997), the enhancement of

Sq(H) at equatorial stations is more favourably influenced during the equinoctial months than during the solstitial months.

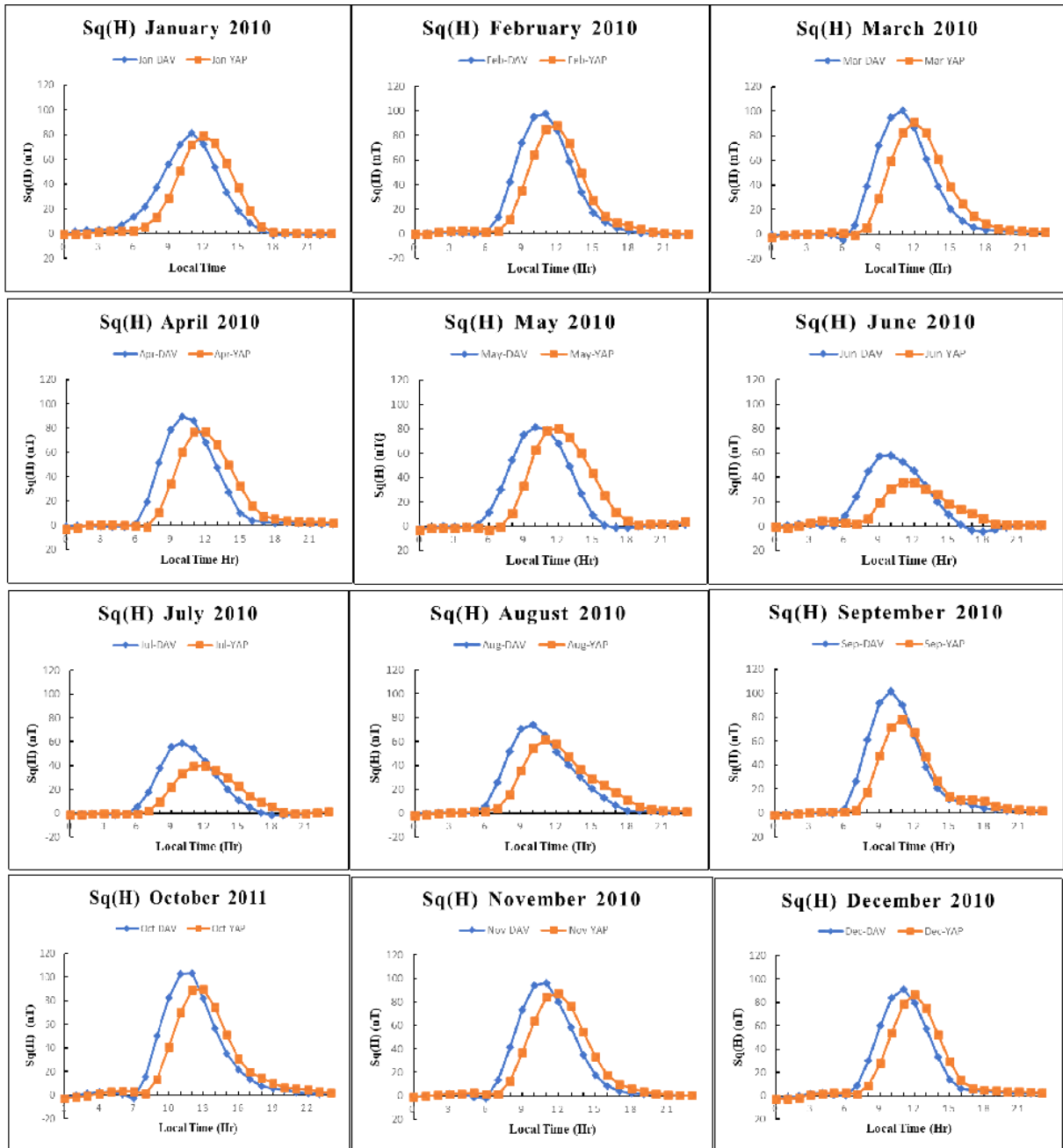


Figure 2: Diurnal Variations of Sq(H) for Davau (DAV) and Yap-island (YAP) (2010)

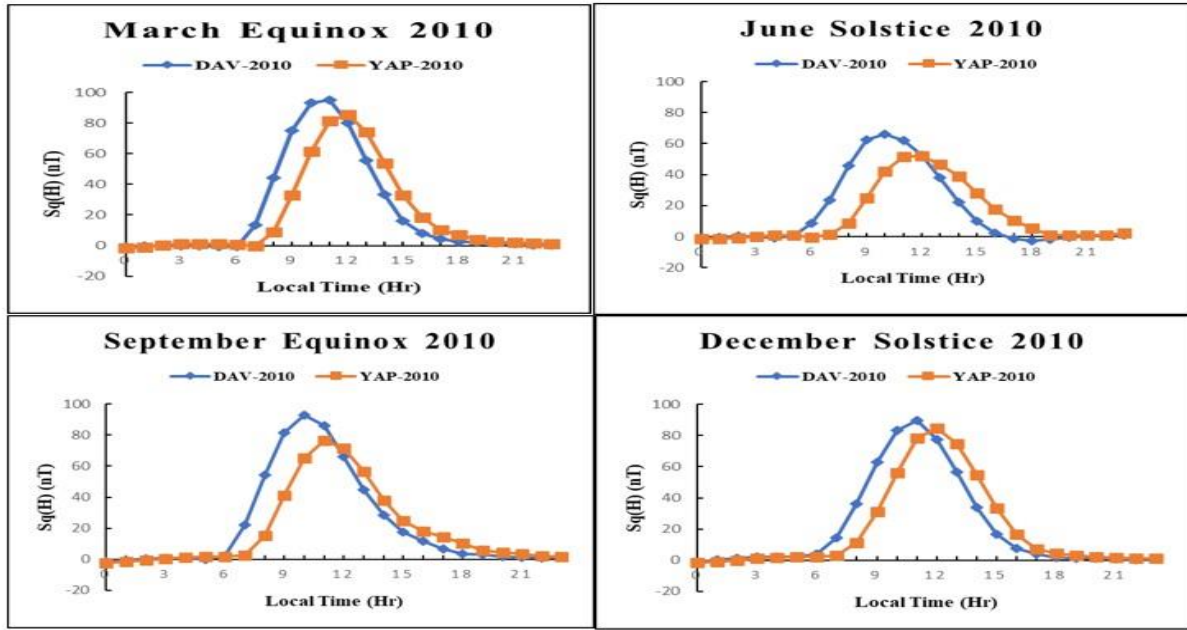


Figure 3: Seasonal Variations of Sq(H) for Davau (DAV) and Yap-island (YAP) (2010)

Equation (3) was used to calculate the EEJ strengths of the two stations, as seen in Figure 4. The DAV-EEJ and YAP-EEJ station pairs' profiles show a normal increase beginning at sunrise, peaking at midday (0900–1100 LT), and then dropping toward sunset. In October, DAV observed peak levels of 62nT at about 1000 LT in October, whereas YAP recorded peak values of 61nT at noon in January. The lowest observed peaks were 13nT in July at 1500 LT for YAP and 19 nT in July at 0900 LT for DAV, indicating the superiority of EEJ strength at DAV. Furthermore, the Counter Electrojet (CEJ), a reversed EEJ, was detected at YAP (−15nT at 0800 LT in June) and DAV (−6.91nT at 0600 LT in October).

Additionally, Vineeth *et al.* (2012) linked substorm activity, local interactions between altitude-dependent winds and global wind systems, nighttime current reversal delays, and gravity waves associated with vertical winds to CEJ activity. According to Lühr *et al.*, 2004 and Doumouya *et al.*, 2003, the higher EEJ strength recorded at DAV compared to YAP was ascribed to the fact that DAV lies in a region of stronger EEJ activity longitudinally than YAP. Moreover, neutral wind speeds and crustal conductivity may be factors enhancing EEJ at DAV. The DAV's higher EEJ values are consistent with the past 210° MM studies (Yumoto *et al.*, 2007).

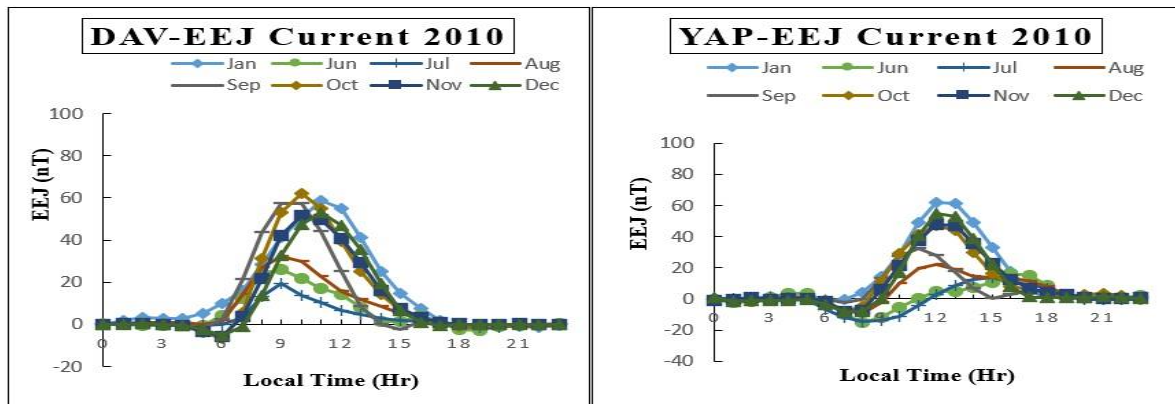


Figure 4: Monthly variation of equatorial electrojet (EEJ) strength for DAV and YAP (2010)

Figure 5 gives the comparison of the Sq(H) values for DAV and YAP. These two equatorial stations are typically impacted by the same ionospheric current systems, namely the EEJ, as seen by the high positive correlation in Sq(H) magnitude ($r = 0.877$). The regression equation's slope of 0.7522 indicates that in 2010, the magnetic response at DAV was typically larger in magnitude than at YAP. The plot's scatter pattern is associated with localized ionospheric anomalies in the E-region dynamo, which are more noticeable when the magnetic intensity is higher. Furthermore, little offsets in the local conductivity of the two equatorial sites could be the cause of the positive intercept of 2.897.

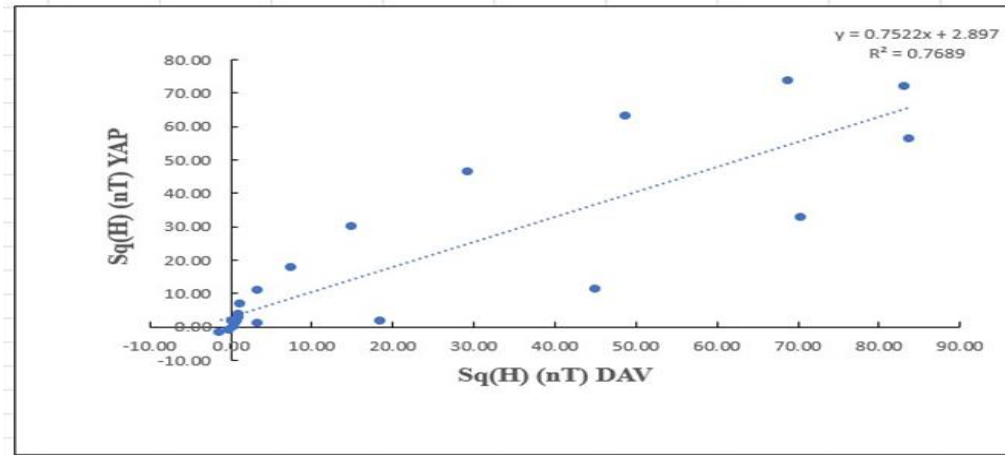


Figure 5: Correlation between the mean Sq(H) of DAV and YAP (2010)

The investigation of geomagnetic variations across stations along the 210° MM during the 2010 low solar activity period led to the following results. A steady morning rise, a distinct midday peak (usually between 1000 and 1200 LT, and an afternoon decrease are the hallmarks of a continuous diurnal pattern in Sq(H), as shown by the research. Eastward ionospheric currents brought on by solar heating and atmospheric tides are responsible for these patterns, which are most noticeable during equinoctial seasons. DAV recorded a maximum of 94nT at 1100 LT, and YAP reached 85nT at 1200 LT at the March equinox, while YAP recorded a maximum of 76nT at 1100 LT and DAV recorded a maximum of 92nT at 1000 LT during the September equinox. According to Forbes et al. (2008), seasonal asymmetries in neutral wind dynamics, ionospheric conductivity, and thermospheric conditions are responsible for the enhancement during the March equinox. Additionally, the study discovered that the December solstice had higher Sq(H) values than the June solstice and September equinox. This was most noticeable at YAP, which recorded 84nT at 1200 LT as opposed to 52nT

and 76nT for the June solstice and September equinox, respectively. More favourable solar zenith angles and E-region conductivity in the Asia-Pacific sector during the Southern Hemisphere summer account for this seasonal variation (Yumoto, 2007). DAV consistently showed greater Sq(H) amplitudes than YAP, even though both were located within the EEJ zone (± 3 geomagnetic latitude). Because the EEJ is known to be more intense over Southeast Asia than in the central-western Pacific, this is explained by longitudinal variation in EEJ strength (Keiling *et al.*, 2018). Furthermore, the observed variance in the Sq(H) magnitudes at DAV and YAP is the E-region dynamo system, which is also the primary driver for the EEJ. The movement of the neutral tidal winds across the geomagnetic field lines results in an electric field in the conducting E-layer (Zhao *et al.*, 2022).

Conclusion

The regional differences in ionospheric conductivity, especially the Pederson and Hall conductivities, control these currents responsible for the disparity in measured Sq(H) noticed in the two stations (DAV and YAP), even though the two (2) stations are

situated in the equatorial electrojet region. The EEJ strength peaked close to local noon, following the predicted diurnal trend. During the September equinox and December solstice, the maximum EEJ strength was 62nT at 1000 LT at DAV and 61nT at 1200 LT at YAP, respectively. Additionally, EEJ intensity showed a semi-annual change, supporting the impact of seasonal conductivity and solar zenith position on current systems. With magnitudes of -15nT at 0800 LT in June at YAP and -6nT at 0600 LT in October at DAV, there was a minor early morning counter electrojet (CEJ). The satisfactory correlations between the stations support the findings that there is a small daily variation in EEJ strength along the dip equator. The conclusions offer a reliable profile of EEJ dynamics and Sq(H) during a solar minimum. By highlighting the contributions of latitude, season, local time, and regional ionospheric dynamics, these results support the theoretical understanding of quiet-time geomagnetic field behaviour.

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