Variations of Zonal Wind Velocity in the Thermosphere Observed at Southeast Asian Sector During Quiet and Active Geomagnetic Days

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Abstract. The present work aims to investigate the variation of zonal wind velocity in the thermosphere on quiet and active geomagnetic days over Southeast Asia across the period of 2011 (medium solar activity (MSA)) and 2012 – 2013 (high solar activity (HSA)). This work is important to understand the neutral dynamic of the ionosphere as well as its very useful from the scientific modeling point of view. The zonal wind data were recorded using a Fabry-Perot interferometer located at stations of Kototabang, Indonesia (KTB) and Chiang Mai, Thailand (CMU) through the 630-nm airglow. In general, changes of the zonal wind variation can be observed during an event of disturbance such as geomagnetic storm, happened at the ionospheric layer. Several previous studies have reported such variation over different longitude sectors. However, general and preliminary study of geomagnetic storms' effect on the zonal wind velocity variations over Southeast Asia is the first time to be reported. Our analysis reported that the range of zonal wind velocity was reduced with geomagnetic activity during the HSA period in which variation at KTB is higher than CMU. On the other hand, it is found that zonal winds during MSA are higher during geomagnetically active days compared to quiet days. The range of zonal wind velocity during MSA was significantly higher than HSA, while variation during both solar activity levels is comparable for quiet days.

Keywords: Zonal wind velocity; Fabry-Perot interferometer; Geomagnetic storm.

I. INTRODUCTION

Thermospheric neutral winds consist of zonal and meridional winds which are components of eastward winds and northward winds. Path dominance for both of these wind components varies according to the latitudes. At low latitudes, zonal winds tend to show significant observation

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during magnetic activity disturbances. Next, at middle latitudes i.e., around ± 30 – 60˚, observations of change wind variations can be seen by both components. Finally, in the polar area, significant observations can only be witnessed by meridional winds compared to zonal winds [1]. Thermospheric winds have fundamental effects on the composition and electrodynamics of both the ionized and neutral components of a coupled ionosphere-thermosphere (I-T) system. Zonal winds play an important role in the generation of low-latitude ionospheric electric fields and current systems [2]. The I-T system responds to the energy and momentum inputs from interplanetary sources and the magnetosphere, through interactions of electrodynamical and chemical processes on different spatial and temporal scales [3, 4].

During geomagnetic storms, the I-T system is disturbed with an enhanced magnetospheric energy input [5, 3] that results in large changes to its plasma and neutral density, temperature, composition, and electrodynamics [6, 7]. Increased solar activity and geomagnetic disturbances can lead to a large variability in the upper thermospheric neutral winds, density, and temperature. During HSA, the F region dynamo is henceforth fully activated, while a period of low solar activity makes it not fully activated since the plasma density is lower. When the level of solar activity is very strong, it will have an impact on every matter that is in space and without exception on planet Earth. Disruption that occurs is a geomagnetic storm which is a phenomenon in which particles charged from the solar wind successfully penetrate the Earth's magnetosphere. Earth's magnetosphere serves to protect the Earth from any disturbance. Active days represent the definition of the presence of geomagnetic storms on Earth and vice versa for quiet days. The geomagnetic storm phenomenon has three phases namely initial, main and recovery phases. Geomagnetic activity, together with other factors simultaneously influence neutral winds. Such variations were investigated considerably through ground-based optical measurements [8, 9, 10]. However, most of these studies were confined to the nighttime and did not effectively separate the effect of geomagnetic activity from that of solar flux levels during different seasons mainly due to data deficiency. During the occurrence of geomagnetic storms, charged particles interact with air molecules through an ionization process then increase the rate of ion density. This results in changes in ion velocity values and interferes with radio signals. For example, the occurrence of a geomagnetic storm in 1859 has caused damage to telegraph wires and fires at several telegraph stations.

The thermospheric wind has been observed in the past using DE-2, UARS, and CHAMP satellites [11, 12, 13, 14]. A past study by [11] particularly used the DE-2 data to examine the longitudinal variations in the thermospheric winds at equatorial region and reported larger zonal wind variations than meridional. The longitudinal variations were clearer under geomagnetic quiet conditions. A difficulty with satellite observations is the limited local time coverage, and the analysis needs to be based on long data sets. Thus, the recent past studies on zonal wind velocity variations and its dependence towards season, solar activity and time have been reported in various sector by using ground-based instrument which called Fabry-Perot interferometer (FPIs) [15, 18]. One of the previous studies using an FPI data was that of [18], which was based on 2-days data collected in North Africa. They reported that the zonal wind velocity variations decrease during a geomagnetic storm. Effect of geomagnetic storms on the zonal velocity of EPB also recorded a similar observation where the zonal velocity of EPB decreased at geomagnetic active days [15].

In this work, the zonal wind velocity measured using FPI is used to investigate the variation of zonal wind velocity, *w* [18] during both quiet and active geomagnetic days at Kototabang (KTB), Indonesia and Chiang Mai (CMU), Thailand. The analysis was conducted for 96 days (KTB and CMU stations) on the *w* in general during quiet and active geomagnetic days. Also, the analysis was extended to investigate the *w* variation based on the season and universal time (UT) which considered 80 days of data (CMU station) at two different solar activity levels. Further investigation specifically included the *w* data of December solstice high solar activity (HSA) level in order to investigate the dependence of *w* on solar activity.

II. DATA OBSERVATION

Zonal Wind Velocity Observation

In this study, the *w* data were obtained from FPI instruments located at KTB (100.3°E, 0.2°S, dip 10.0°S) and CMU (98.9°E, 18.8°N, dip 8.9°N) which operating are under the Optical Mesosphere Thermosphere Imagers (OMTIs) [20] regulated by the Institute for Space-Earth Environmental Research (ISEE), Nagoya University. Each station is represented by its own code name and reading data; CMU station, Thailand (FP02) and KTB station, Indonesia (FP03). The conjugate position of these two near equator stations [21] allows the study of *w* variations in parts of the Southeast Asian sector. Table 1 details the geographical position of the stations.

TABLE 1. Coordinates of the observation stations.

Station		**Geographic**		**Geomagnetic**	
Location	**Code**	**Lat (°)**	**Long (°)**	**Lat (°)**	**Long (°)**
Chiang Mai, CMU	FP02	18.79	98.92	8.92	171.51
Kototabang, KTB	FP03	-0.20	100.32	-10.63	171.93

The selected *w* data are based on good sky conditions i.e., bright skies and visible stars, slightly cloudy and many stars as well as cloudy and few stars. This is in order to avoid errors in wind composition readings. Meanwhile, data recorded at stations FP02 and FP03 were found to range from around 1200 UT (2000 LT) to 0000 UT (0700 LT). Next, to find out the availability of *w* data on the selected date, data record access was identified from the OMTI Data Viewer portal. After obtaining the data for the selected day, the application of Kp (Planetary-K index) index and F10.7 index (solar radio flux) were used to determine the state of geomagnetic activity and the level of solar activity. A review of both index values was made on the OMNIweb Plus website, NASA. Index Kp is a global measure of changes in geomagnetic components from stations around the world [22]. The geomagnetic activity represented by this Kp index is between the scale of 0 to 9. The scale value stated refers to the strength of the geomagnetic storm and the value of the Kp index can also be represented by the G-scale value. The F10.7 index is a measurement of the noise level of solar activity at a wavelength of 10.7 cm and is given in solar flux units (s.f.u). This index is related to the change in the position of the sunspots during the complete rotation of the Sun. In addition, the change in the direction of the solar magnetic field also occurs and it takes 11 years to return to its original state. Throughout the exchange, the levels of solar activity were at low, medium and high levels. As such, solar activity levels are capable of recording values between 50 – 300 s.f.u. as stated on the NOAA website, Space Weather Prediction Center. A study by [23] in turn reported that the mean values of the F10.7 index for low (2008), medium (2009 – 2011) and high (2012 – 2013) levels of solar activity were 69 s.f.u, 89 s.f.u and 122 s.f.u, respectively. The next step is to determine the geomagnetically quiet and active days. The World Data Center for

Geomagnetism, Kyoto has listed 10 quiet days and 5 active days of a month by taking into account the minimum and maximum strength of geomagnetic activity. Determination of geomagnetic day types have been identified through website *The International 5 and 10 Quietest and 5 Most Disturbed Days* where this study considered the three years data of 2011 to 2013. Based on those records, it was found that the quiet day recorded an index value of Kp ≤1 and the value of the index range of F10.7 was ~80 – 170 s.f.u while the geomagnetic active day recorded Kp index values of 1 to 5 and the value of the F10.7 index range is ~100 – 140 s.f.u.

Availability of Zonal Wind Velocity Data

Analysis of the state of sky condition and geomagnetic activity showed that the availability of *w* data from KTB station was low compared to CMU station during 2011 to 2013 as listed in Table 2 and the details by year in Table 3. Data from both stations based on the table were used in the analysis in order to investigate the dependence of *w* on geomagnetic activity. However, since the data from KTB station are limited, the analysis of *w* against universal time, season and solar activity level will be continued by analyzing the data from CMU station only. Table 4 shows the distribution of CMU data based on the state of geomagnetic activity according to the equinox, Jun solstice and December solstice.

TABLE 2. Coordinates of the observation stations.

FPI Station	**Number of Zonal Wind, *w* Data**	
	Quiet day	**Active day**
KTB	11	5
CMU	57	23

TABLE 3. Number of days for zonal wind velocity data by year.

FPI Station (Year)	**Number of Zonal Wind, *w* Data**	
	Quiet day	**Active day**
KTB		
2011	1	2
2012	2	0
2013	8	3
CMU		
2011	20	4
2012	22	16
2013	15	3

TABLE 4. Number of days for zonal wind velocity data at CMU station by season.

Season (Year)	**Number of Zonal Wind, *w* Data**	
	Quiet day	**Active day**
Equinox		
2011	-	2
2012	8	1
2013	8	1
June Solstice		
2011	2	-
2012	-	2
2013	1	-
December Solstice		
2011	18	2
2012	14	13
2013	6	2

III. RESULTS AND DISCUSSION

Dependency of Zonal Wind Velocity on Geomagnetic Activity

Kp index readings are used to identify quiet and active days. Data analysis is shown in Table 3 is based on the Kp index readings of 0-1 (quiet day) and 1-5 (active day). Figure 1 shows the variation of *w* on a quiet (top panel) and active day (bottom panel) at KTB station. The results of the analysis found that the variation of *w* during quiet days is higher in the evening (~70 – 150 m/s) than at midnight (~50 – 100 m/s) and postmidnight (~50 – 80 m/s) in 2013. Meanwhile, during the active days, *w* was found to decrease from midnight (~30 – 60 m/s) to postmidnight (~20 – 60 m/s) in 2013. Additionally, it can be observed that *w* data in 2011 and 2012 for both quiet and active days is incomparable due to insufficient data. A comparison of *w* variations for quiet and active days illustrates that in 2013, both *w* showed a decrease after 2130 UT from ~80 m/s to ~50 m/s (quiet days) and ~40 m/s to ~0 m/s (active days). At midnight, variations in *w* during quiet days (50 – 100 m/s) and active days (30 – 60 m/s) were found to be different. Variation of *w* for 2011 and 2012 were not compared because *w* readings were at different times and the number of data was limited. This causes the findings at the KTB station to differ from the results of previous studies. Therefore, this study continued by examining the *w* data at the CMU station.

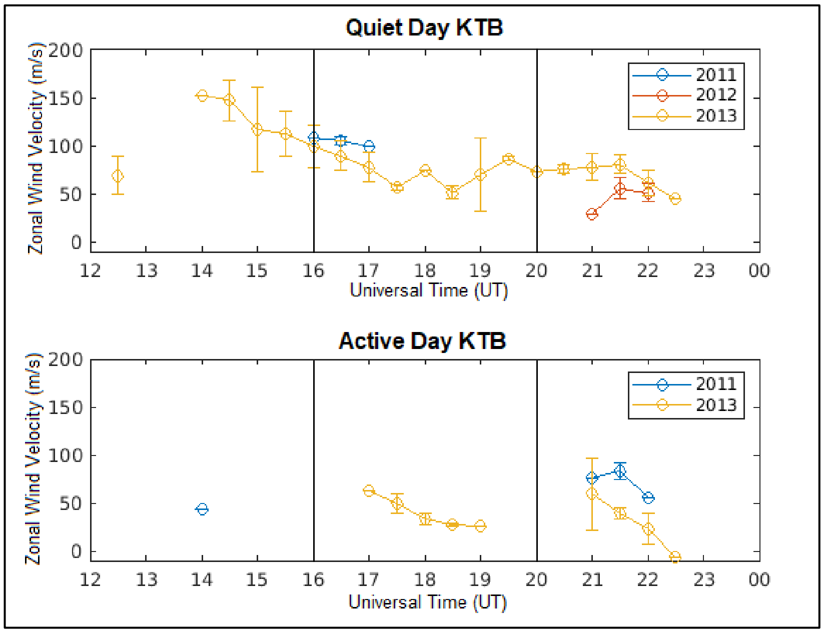

FIGURE 1. Zonal wind velocity variations on quiet and geomagnetically active days at KTB station.

Figure 2 shows the variation of *w* on a quiet (top panel) and active day (bottom panel) at CMU station. Variations of *w* during quiet days at CMU station showed insignificant differences from 2011 to 2013. The *w* ranges were 40 – 100 m/s (2011) and 50 – 100 m/s (2012 and 2013). However, it can be observed around 1200 – 1300 UT the *w* in 2011 and 2012 were found to be almost similar i.e., ~80 – 90 m/s while in 2013, *w* variation was found to increase from ~50 m/s (1200 UT) to ~80 m/s (1300 UT). At 1330 UT, the *w* variation for 2011 – 2013 shows a similarity in which the velocity increases up to 1600 UT. Furthermore, *w* variations during midnight were higher in 2011 (~90 – 100 m/s) than in 2012 and 2013 (~70 – 90 m/s). Similarly at 1930 UT, *w* in 2011 (~90 m/s) were higher than in 2012 and 2013 (~70 m/s). In addition, the variation of *w* for these three years was found to decrease from midnight to postmidnight.

Analysis of *w* variations during geomagnetic active days showed significant differences from 2011 to 2013. The *w* range was high in 2011 (~30 – 130 m/s), followed by 2012 (~50 – 90 m/s) and 2013 (~0 – 70 m/s). Based on the analysis in 2011, it was found that the *w* varies from evening to postmidnight. At the same time, *w* variations were found to decrease sharply after 1800 UT and subsequently increase again after 1930 UT. The variation of *w* in 2012 was found not to change significantly where the readings were in the range between ~50 – 90 m/s. A significant decrease from midnight to postmidnight were observed from the variations in *w* in 2013. However, the analysis was limited to that particular time only because there were data gaps in the previous time period.

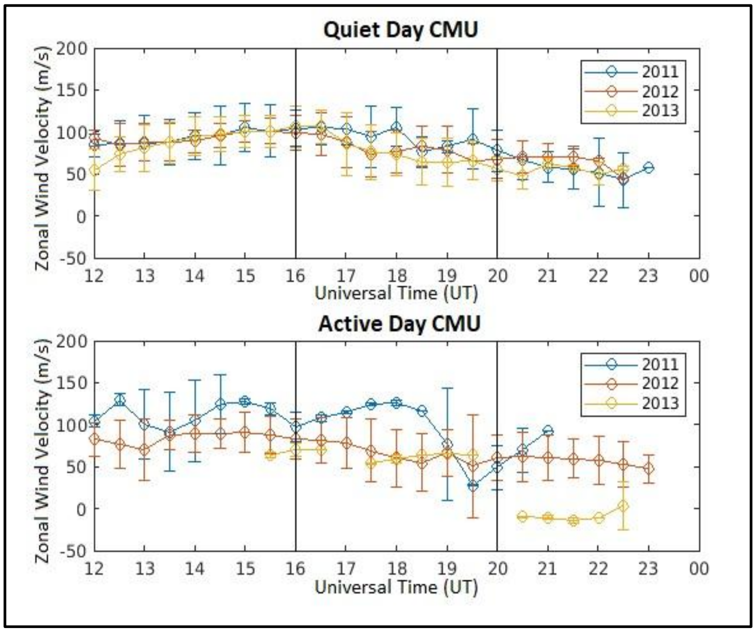

FIGURE 2. Zonal wind velocity variations on quiet and geomagnetically active days at CMU station.

A comparison of *w* ranges in 2011 showed that *w* during quiet days (~40 – 100 m/s) were lower than *w* during active days (~30 – 130 m/s). The results of the analysis were found to differ from the findings in 2012 where the range of *w* during a quiet day was higher (~50 – 100 m/s) than on an active day (~50 – 90 m/s). Moreover, a comparison of *w* ranges in 2013 also showed that the *w* during quiet days (~50 – 100 m/s) was higher than the *w* during active days (~0 – 70 m/s). Thus, the results of the analysis found that *w* in 2012 and 2013 decreased with the presence of geomagnetic storms. In short, the results of the analysis at the CMU station are said to be similar to the results of the study by [18] who stated that *w* decreases with the presence of geomagnetic storms. Furthermore, the results of previous studies also explain that zonal velocity EPB decreases with the presence of geomagnetic storms [15].

Dependency of Zonal Wind Velocity on Local Time, Seasonal, and Solar Activity

Dependency studies against local time and season are investigated using data for the year 2012 and 2013. Table 4 explains that the number of data is divided according to the seasons i.e., the equinox (March-April and September-October), June solstice (May-August) and December solstice (November-February). The division explains that the data findings on the December solstice season are higher compared to equinox and June solstice. This is contrary to the study by [16] who found that *w* data coverage during the December solstice was less favorable than the equinox and June solstice. A possible explanation for the difference in the range of zonal wind velocities between the December solstice season versus the equinox and June solstice is zonal winds are closely related to ionization process. During the equinox and June solstice, the ionization is greater due to the closer position of the Sun and Earth than during the December solstice. Therefore, it affects the zonal wind velocity range during December solstice and the other two seasons. However, the study is based on analysis in the Southwest sector and uses data years 2011 – 2012, then the difference in data coverage is likely due to the longitude factor or the number of data collected itself.

The dependency of *w* variations on local time and season was studied based on three time periods namely evening, midnight and postmidnight. Figure 3 shows that the *w* variation during the equinox season in 2012 (quiet day) found that *w* was higher in the evening (~80 – 110 m/s) than midnight (~60 – 90 m/s) and postmidnight (~50 – 90 m/s). Similar findings were also observed for 2013 where *w* in the evening (~100 – 110 m/s) were higher than midnight (~50 – 110 m/s) and postmidnight (~50 – 60 m/s). Furthermore, the variation of *w* for 2012 during the December solstice season (quiet day), again showed that the *w* during the evening (~80 – 100 m/s) was higher than midnight (~50 – 100 m/ s) and postmidnight (~50 – 70 m/s).

The results of the analysis show similarities with the results of the study by [24] who stated that *w* in the evening is higher than midnight and postmidnight. Meanwhile, it can also be observed that the variation of *w* for 2013 during the December solstice was found to increase from ~50 m/s (1200 UT) to ~100 m/s (1500 UT). Next, *w* variations were found to vary between ~80 – 120 m/s around 1500 – 1900 UT and as it passes midnight, the *w* is found to decrease with time from ~90 m/s (1930 UT) to ~30 m/s (2030 UT). Finally, the results of the analysis during the June solstice season (quiet day) in 2013 showed a decrease in *w* variation at the end of midnight which was ~50 m/s (1900 UT) to ~20 m/s (2030 UT).

The study continued by examining the dependency of *w* variations against the level of solar activity. Table 4 shows that the data from the season of the December solstice is suitable for use in studying the variation dependencies of *w* versus solar activity level. Solar activity level in the study is divided into two namely medium solar activity, MSA (2011) and high solar activity, HSA (2012 – 2013). Figure 4 revealed the insignificant variations from 2011 to 2013 where the respective wind velocity ranges were ~40 – 100 m/s (2011), ~50 – 100 m/s (2012) and ~30 – 120 m/s (2013). However, the variation of *w* during MSA (2011) was found to be almost the same (80 – 100 m/s) from 1200 UT to 1700 UT and began to decrease with time at midnight (~80 m/s to ~40 m/s). Next, the analysis of *w* variation in 2012 showed a variable velocity pattern where at 1400 – 1630 UT, the *w* was found to increase from ~90 m/s to ~110 m/s, subsequently the *w* decreased until 2000 UT. As it entered midnight, the *w* increased again from ~50 m/s (2000 UT) to ~70 m/s (2200 UT). Meanwhile, the variation in *w* in 2013 also showed an increase around the evening of ~60 m/s (1200 UT) to ~120 m/s (1630 UT). Finally, *w* variation was found to vary between 30 – 120 m/s (1630 – 2030 UT).

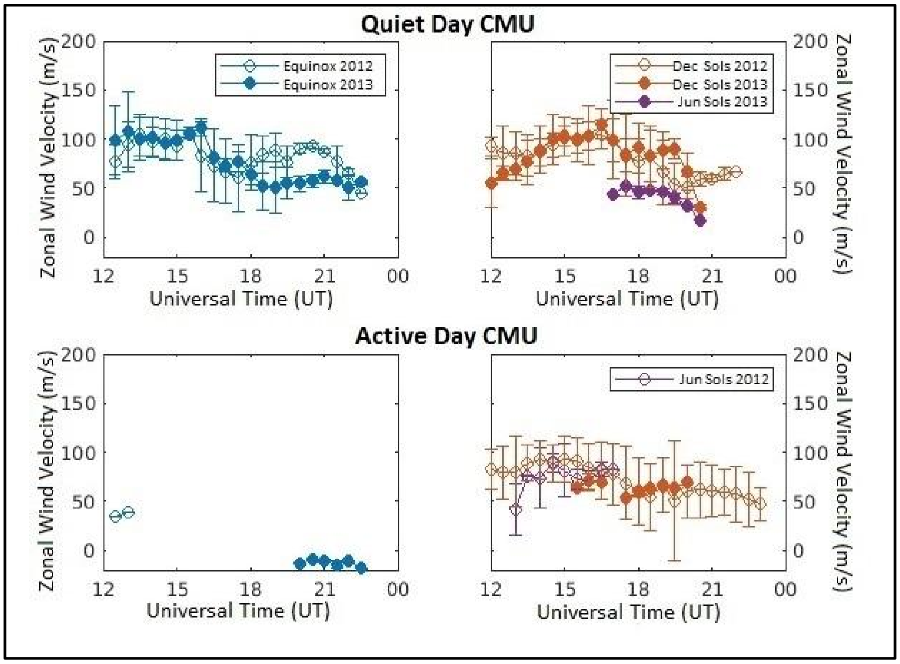

FIGURE 3. Variation of zonal wind velocities in 2012 – 2013 according to season.

The results of the analysis of *w* variations during geomagnetic active days showed significant variations between the three years. Variation of *w* in 2011 was found to increase from 1200 UT (~100 m/s) to 1430 UT (~140 m/s). Similar observations were also observed where *w* was found to increase at night (~100 m/s to ~130 m/s) and midnight (~80 m/s to ~90 m/s). Furthermore, the variation of *w* in 2012 showed a similar reading over the time period of ~50 – 90 m/s while in 2013, the variation of *w* was found to increase in the late evening (~ 60 m/s to ~ 70 m /s) and late midnight (~50 m/s to ~70 m/s).

A comparison of the zonal wind velocity range between the two levels of solar activity during quiet day illustrates that the variation of *w* at MSA (2011) is lower than that of HSA (2012 – 2013) which is ~10 m/s. Moreover, the variation of *w* at 1630 UT (quiet day) showed that *w* at the HSA (~120 m/s) was higher than the MSA (~100 m/s). Similar observations can be seen at 2100 – 2200 UT (quiet day) where *w* at HSA (~60 – 70 m/s) are higher than at MSA (50 – 60 m/s). These results were found to agree with previous studies stating that *w* increase during HSA [17], but the recorded velocity differences were insignificant. Therefore, the results of these findings are said to be less in agreement with the results of previous studies.

A comparison of the *w* range between MSA and HSA during active day shows that the variation of *w* in 2011 (~80 – 140 m/s) was higher than in 2012 – 2013 (~50 – 90 m/s). These observations is found to be different when the EPB appearance is considered as recently reported [19] using data in the same sector. The F -region dynamo is fully active during HSA compared to MSA depending on plasma density. Consequently, during HSA, the pressure gradient produced by solar heating is larger, and the *w* becomes stronger. Following that, the *w* is expected to be larger during periods of HSA compared to MSA. Additionally, the I-T system is disturbed with an enhanced magnetospheric energy input that results in large changes to its plasma and neutral density, temperature, composition, and electrodynamics. Besides, the variation in *w* between the two levels of solar activity (quiet day) was found to decrease with time in which it agrees with previous studies where EPB zonal velocity and *w* decrease with time [25]. However, this present study analyzes limited data set that only cover three years period with some constraints in data availability. Therefore, a future in-depth study utilizing a long-term and comprehensive data is proposed to support the current findings.

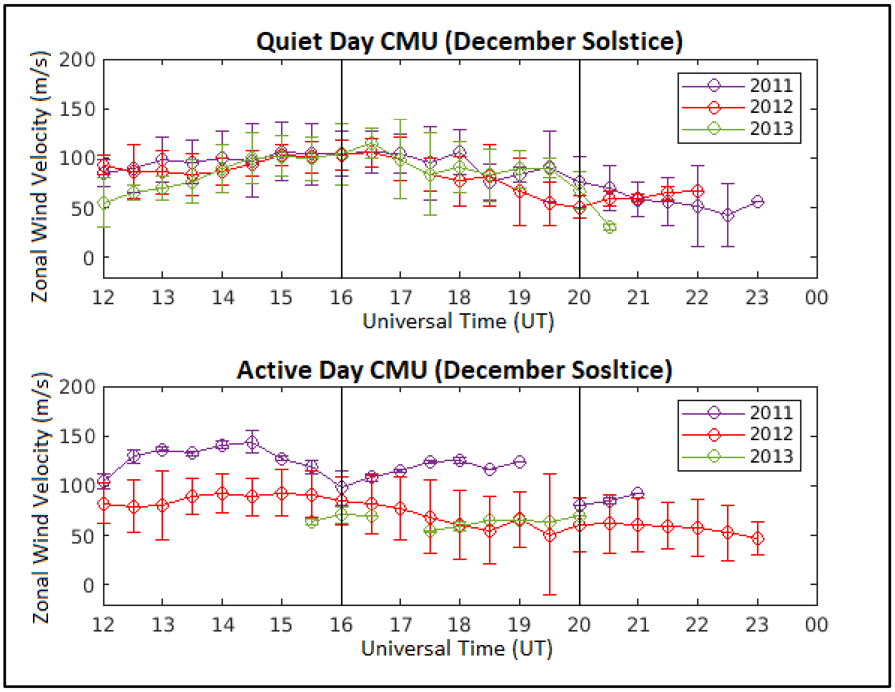

FIGURE 4. Variation of zonal wind velocity during the December solstice season according to the level of solar activity.

IV. CONCLUSIONS

The present study investigated the variation of zonal wind velocity during quiet and active geomagnetic days over Southeast Asian sector. The results of the study at KTB station showed that variation zonal wind velocity during geomagnetic active days is lower than variation during quiet days in 2013. However, limited data coverage factors make these findings unreliable. Thus, the study of zonal wind velocity variations on geomagnetic activity was continued at CMU station. The results of the study at the CMU station found that variation wind velocity during active days is lower than quiet days in 2012 and 2013. Moreover, this study found that in 2012 (quiet day), zonal wind velocity was high in the evening compared to midnight and postmidnight for instance during the equinox and December solstice. The zonal wind velocity range on quiet days is high during the December solstice season compared to equinox and June solstice. The results of the analysis in 2013 (quiet days) illustrate that wind velocity is the maximum during the December solstice. Results of dependency studies on the level of solar activity (active days) in turn explains that the range of wind velocity at MSA are higher compared to HSA.

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