# Effect of Rossby and Kelvin Waves on Intensification and Lifetime of Tropical Cyclones in the Western Pacific

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**Abstract**: The Equatorial Planetary Wave (EPW) can affect weather variability in the tropics. One of the effects is the modulation of the tropical cyclone (TC) intensity. TC is a meteorological phenomenon that occurs on the synoptic scale to the mesoscale in tropical waters.. Weather variability in the tropics can be affected by the Equatorial Planetary Wave (EPW). Identification of the active phase of the EPW wave is undertaken by using a filter on the daily Outgoing Long Radiation (OLR) anomaly data in the period of TC occurrence for five years which aims to determine the EPW wave in modulating the intensity and lifetime of the TC. This study focused on two main EPWs: Rossby and Kelvin waves. The results showed that the EPW wave modulated the TC frequency by 92% of all cases for five years in the Western Pacific Ocean which tended to be modulated by the Rossby wave by 45%. While Convectively Coupled Equatorial Wave (CCEWs) modulate TC by 36%, and Kelvin waves modulate TC by 11%. According to the study, 70% of tropical cyclones have lifetimes that are equal to or greater than the average. This suggests that EPW waves have an impact on the duration of TCs. The study also found that during the occurrence of TCs within the past five years, there was a cyclonic pattern and wind speeds exceeding 40 knots at the 850 hPa layer in the study area. This supports the formation of TCs in this region.

Keywords: Rossby Wave, Kelvin Wave, Tropical Cyclone, Modulation.

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## I. INTRODUCTION

Equatorial Planetary Waves (EPW) are waves from adiabatic heating processes that can affect atmospheric conditions in the tropics. This is due to the organized large-scale convective heating in the tropics around the equator, which is around 20°N and 20°S [1]. Equatorial planetary waves or also known as tropical waves, are generally separated into five types, namely, MJO (Madden-Julian Oscillation), TD (Tropical Depression), Kelvin waves, mixed Rossby-gravity (MRG) waves, and Equatorial Rossby (ER) [2, 3].

Tropical Cyclone (TC) or tropical cyclone is a meteorological phenomenon whose energy is obtained from warm tropical ocean conditions with a Sea Surface Temperature (SST) ranging from 26.5°C or more which affects weather conditions in the tropics and can cause extreme weather in the area that is passed [23]. While the impact of tropical cyclones can reach 20-40 from the center [16]. The initial process of the formation of a tropical cyclone is as a low pressure area or a center of low pressure that has a maximum wind speed around it of more than 34 knots which grows in waters with warm surface temperatures and its lifetime reaches 3-18 days [18]. The growth and development of TC is influenced by environmental conditions on a large scale found in most tropical waters, especially in the summer periode on Western North Pacific Ocean (WNP) or more precisely when the sun is in the Northern Hemisphere which can increase the potential for the formation of TC genesis [4–12].

EPW waves in the equatorial region can modulate TC genesis and can also affect tropical weather conditions by causing significant fluctuations in pressure, humidity, temperature, wind and convection [13–16]. The active phase of two planetary waves affects the dynamics of the atmosphere in an area so that it can modulate the cyclogenesis of tropical cyclones. The formation of two planetary waves creates environmental conditions that support the occurrence of tropical cyclones by looking at the cyclone vorticity parameter in the lower layers, which increases and the formation of shear lines triggers a vertical convergence zone [17]. In identifying the active phase of the equatorial wave at the time of TC, an analysis was carried out based on OLR data and the average TC genesis formed in the Western Pacific Ocean could be associated with the increase in convection caused by tropical waves [18].

The active phase of tropical waves can modulate tropical cyclones. Research [19, 20], found that waves in the sinoptik scale and intra-seasonal waves significantly affected the TC genesis formed in Western North Pacific (WNP), which was 79% which was indicated by TC formed together with the active phase of one or more of these types of waves. The dominant tropical cyclone is modulated by Rossby and Madden Julian Oscillation (MJO) waves and also investigated by Quasi Biweekly Oscillation (QBWO) waves, however, these waves do not modulate tropical cyclones. As many as 84.1% of tropical cyclone cases that are formed are in the active phase of CCEW (Convectively Coupled Equatorial Wave) of which 71.3% have an active phase of one or two waves that coex-

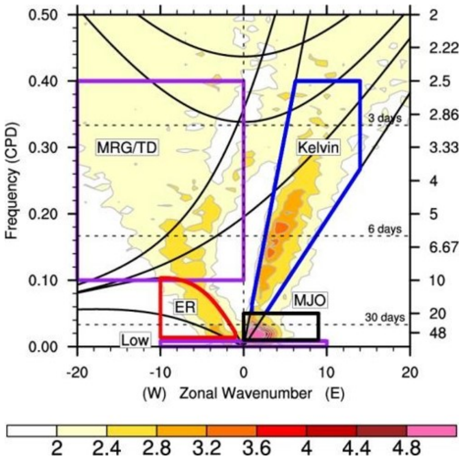



FIG. 1: Filter Frequency and Wavenumber NCICS [23]

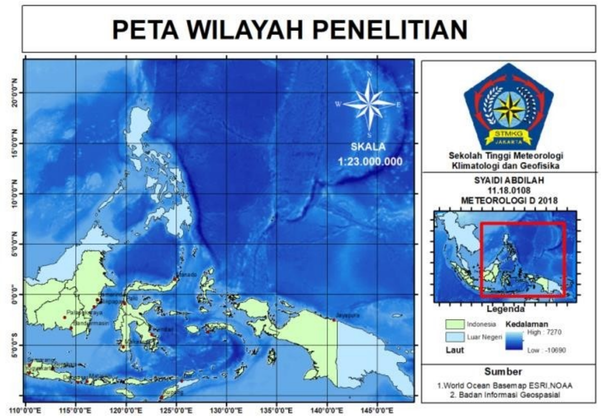



FIG. 2: Map of The Research Area

ist. This is due to a meeting between Tropical Depression and Mixed Rossby Gravity (MRG) which interact with each other on a synoptic scale and increase the potential for TC formation in WNP. Based on the research conducted by [21] it was found that most of the TC genesis events are related to tropical wave activity and they are formed in direct relationship with the combination of active convection induced by equatorial waves and low-level vortices. Several factors of environmental conditions that affect the growth of cyclogenesis, one of which is the maximum vorticity value in the lower troposphere layer and the presence of convection induction in the atmosphere which can be influenced by Equatorial waves [22]. Therefore, in this sub-chapter, an analysis of the relationship between the Equatorial waves which modulate the TC lifetime in the Western Pacific Ocean is carried out. Therefore, it is necessary to study the Rossby and Kelvin waves that affect the intensity and lifetime of tropical cyclones with a longer time span so that they can be used as input in making more accurate tropical cyclone predictions, especially in the Western Pacific Ocean region.

## II. METHODOLOGY

In order to determine the effect of EPW waves on TC, identification of the active phase of Rossby and Kelvin waves at the same period CCEWS which affects the intensity and lifetime of TC was carried out by utilizing the daily OLR anomaly filter adopted from the study [17]. The Rossby wave filter has a wave number of -10 to -1 with a time period of 10-40 days, while the Kelvin wave it has a wave number of 1 to 12 and a time period of 3 - 20 days which can then be seen in Fig. 1 and Table I.

To examine how the CCEWS wave impacted the strength and duration of tropical cyclones in the western Pacific Ocean from 2016 to 2020, researchers conducted a comprehensive study of wind circulation during the cyclone season and active CCEWS wave phase. The research area is located at 20°N-0°S and 120°E-150°E which can be clearly seen in Fig. 2.

The data used in this study were daily OLR raw data obtained through the website of the National Centers for Environmental Information-National Oceanic and Atmospheric Administration (NCEI-NOAA) in the NetCDF format and 2.5° x 2.5° of grid spatial resolution. It aimed to analyze the existence of the active phase of the EPW wave. Then we processed using the NCL (NCAR Commands Languages) application. The daily OLR data were downloaded from NOAA: https://www.ncei.noaa.gov/data/outgoing-longwaveradiation-daily/access/

Meanwhile, the second data was the intensity and lifetime of tropical cyclones for 2016-2020, updated every 6 hours from the International Best Track Archive for Climate Stewardship (IBTrACS) website with the .csv data file extension. It displayed the intensity and lifetime of tropical cyclones. The link to access the data is https://www.ncei.noaa.gov/data/international-best-track-archivefor-climate-stewardship-ibtracs/v04r00/access/csv/. The intensity and lifetime data of tropical cyclones were then filtered at maximum wind speed parameter >34 knots using the Microsoft Excel application to ensure that they had entered the tropical cyclone cyclogenesis phase. Besides, we also used the reanalysis zonal component (u), and meridional component (v) winds layer 200 hPa and 850 hPa during tropical cyclones and the active phase of CCEWS waves from 2016-2020. Then, the data were averaged using the CDO (Climate Data Operator) application and visualized using the GrADS application to obtain general atmospheric circulation patterns. Here is a link to access data from the Copernicus Climate Data Store web:https://cds.climate.copernicus.eu/cdsapp!/dataset/reanalysis-era5-pressure-levels? tab=forms.

## III. RESULT AND DISCUSSION

### A. Tropical Cyclone Potential

Between coordinate 20°N and the equator, 80%-90% of tropical cyclones occurred. They were due to several groups

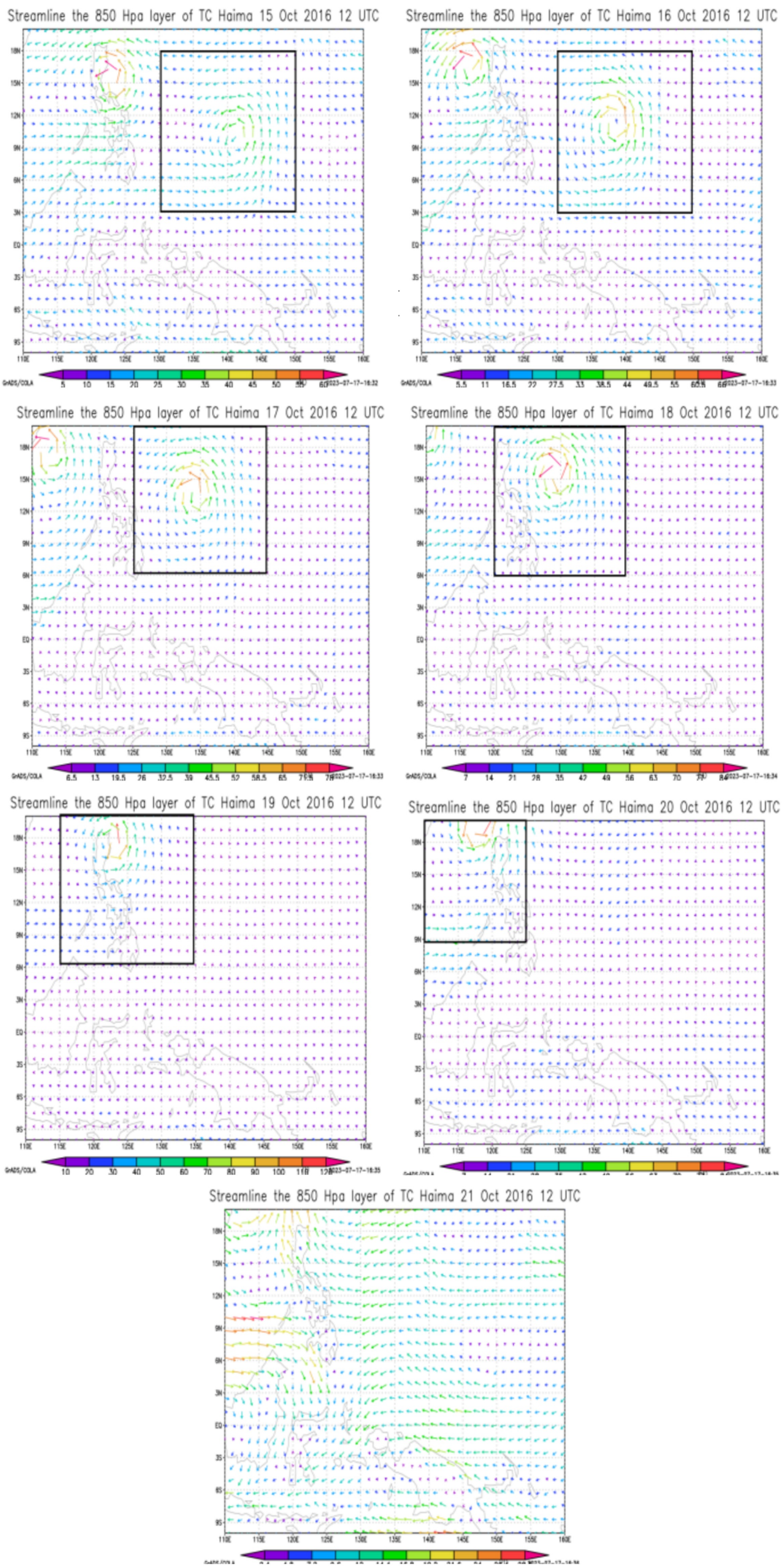



FIG. 3: Streamline 850 Hpa Layers at 12 UTC of TC Haima 15 - 21 October 2016

TABLE I: Percentage of Tropical Cyclone Occurrence from 2016-2020 in the Study Area

| Years | 2016 | 2017 | 2018 | 2019 | 2020 | Total | Percentage |
|---|---|---|---|---|---|---|---|
| Total occurence of TC | 26 | 28 | 29 | 29 | 23 | 135 | 100% |
| TC occurred insideresearch area | 16 | 14 | 18 | 18 | 8 | 74 | 55% |
| TC occured outside in research area | 10 | 14 | 11 | 11 | 15 | 61 | 45% |

TABLE II: Total Distribution Equatorial Wave Modulating Tropical Cyclones

| Table of Rossby and Kelvin Waves Affecting Tropical Cyclones | | | | | | |
|---|---|---|---|---|---|---|
| Category | Years | | | | | Total |
| | 2016 | 2017 | 2018 | 2019 | 2020 | |
| Total occurence of Tc | 16 | 14 | 18 | 18 | 8 | 74 |
| Rossby Wave | 5 | 6 | 11 | 7 | 4 | 33 |
| Kelvin Wave | 1 | 3 | 1 | 3 | 0 | 8 |
| Rossby and Kelvin | 9 | 5 | 5 | 6 | 2 | 27 |
| Absence of Rossby and Kelvin Wave | 1 | 0 | 1 | 2 | 2 | 6 |

of the equatorial waves that modulate cyclogenesis at the equator [7]. Filtering the maximum wind speed parameter > 35 knots shows that the percentage of TC occurrences in 2018 and 2019 tended to increase and decrease in 2020. The percentage of TC in the Western Pacific was used to see the distribution of the occurrence of TC in research locations in the Northern Indonesian area. It shows that 74 cases of TC occurred at the study site out of 135 cases of TC in the western Pacific for five years, with a percentage value of 55%. Meanwhile, 45% or 61 cases were outside the research area. The details of cases of TC occurrence for five years can be seen in Table II.

One of the TC cases that occurred in the study area was Haima TC which had a life span of 6 days after passing through the tropical depression phase. In Fig. 3 and 4, a streamline map is presented at 12 UTC on layers 850 and 200 Hpa when TC Haima occurred on 15-21 October 2016. The black box is shown for the location where TC Haima is located. The wind speed of TC Haima in the 850 Hpa layer starts from 60-120 Knots reaching its peak on 19 October 2016 and on October 21 TC Haima has experienced a decay phase with a maximum wind speed of 29 Knots. Whereas in the 200 Hpa layer the maximum wind speed of TC Haima reaches 78 Knots which occurred on 19 October 2016.

On the streamlined average map when tropical cyclone Haima occurs, the tropical cyclone pattern can also be seen, but the average maximum wind speed TC Haima in layers is 850 and 200 Hpa to 60 Knots which can be seen in Fig. 5.

TABLE III: Total number of TC cases based on lifespan

| TC Lifetime Classification | Years | | | | | Total | Percentage |
|---|---|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2019 | 2020 | | |
| Above Average | 6 | 5 | 12 | 7 | 4 | 34 | 46% |
| Average | 5 | 3 | 2 | 6 | 2 | 18 | 24% |
| Below Average | 5 | 6 | 4 | 5 | 2 | 22 | 30% |
| Total | 16 | 14 | 18 | 18 | 8 | 74 | 100% |

### B. Distribution of Equatorial Waves in Modulating Tropical Cyclone Frequency

Identification of the equatorial waves that modulate the TC frequency is carried out by analyzing the map generated from the OLR filter for each wave (Table II) in one TC event. Fig. 6 shows the processed OLR map that has been filtered to identify Rossby waves at the Haima TC incident that occurred on 15-21 October 2016, while Fig. 7 shows the map output from the Kelvin wave OLR filter. The active phase of the Rossby wave is identified as having a negative OLR (Purple Color) and is characterized by the presence of two active vortices at TC Haima which occurred on 15-18 October 2016 which can be seen clearly in Fig. 3. While the positive OLR (Red Color) is used for identify Kelvin waves. Seen in Fig. 4 the active phase of the Kelvin wave in modulating TC Haima starts on October 17-21 2016. Meanwhile the active phase of the Rossby wave occurs on July 15-18 2016. Section H in Fig. 6 and 7 is a map of the average Rossby wave and Kelvin during Haima's TC period. It can be seen on the map that there is an active phase of the Rossby and Kelvin waves (CCEWS) on 15-21 October 2016 which modulates TC Haima.

In the monthly distribution image of the equatorial waves affecting tropical cyclones, three data are presented, which contain the Kelvin wave marked in green, the Rossby wave marked in red, and the number of TC events marked in blue. The monthly frequency distribution of tropical cyclones and equatorial waves in the study area for five years appeared from July-November. The highest cases of seven cases occurred in August 2018, while the lowest cases occurred in February, March, and April, each consisting of one case of TC that occurred that month. In 2018 showed an increasing variation in the distribution of the formation of TC every month. TC began to form in February, March, June-November, but the variation in the distribution of TC in 2020 in each month modulated. In general, Fig. 8 shows an active phase of Rossby or Kelvin waves during the occurrence of TC. It is in line with the research [11] results, which showed that 84.1% of cases of TC genesis occurred in the active phase of CCEWS. CCEWS leads to unstable atmospheric conditions to produce more TC genesis.

The total occurrence of TC in the study area was 74 cases. In 2016, 9 cases of TC were more dominantly modulated by Rossby and Kelvin waves, followed by 5 cases of TC modulation with Rossby waves, 1 case of TC modulation with Kelvin waves, and the absence of TC modulation by Rossby waves and Kelvin as much as 1 case. Subsequently, in 2017 an active phase of one or two Rossby and Kelvin waves modulated

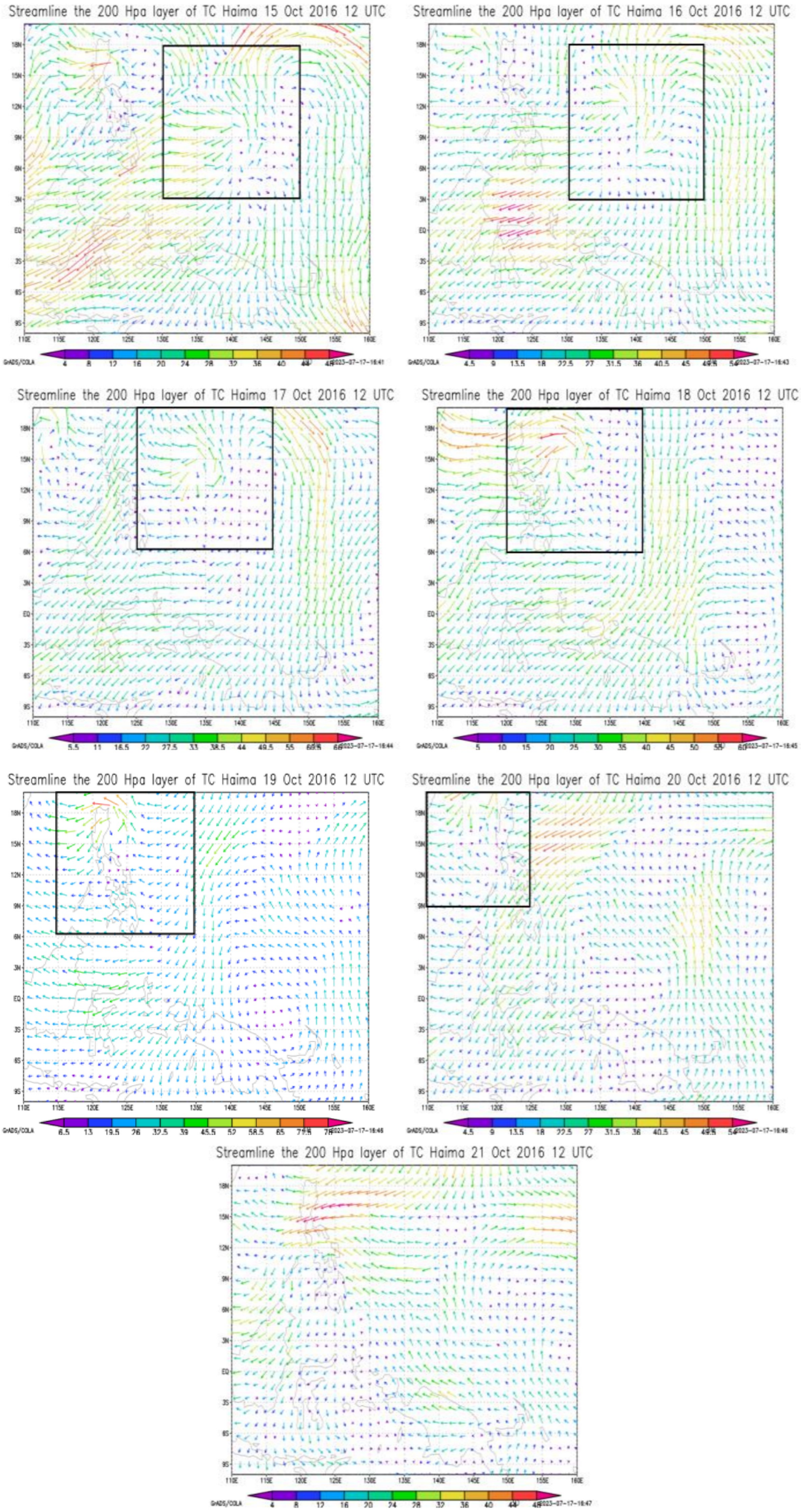



FIG. 4: Daily Streamline 200 Hpa Layers at 12 UTC of TC Haima 15 - 21 October 2016

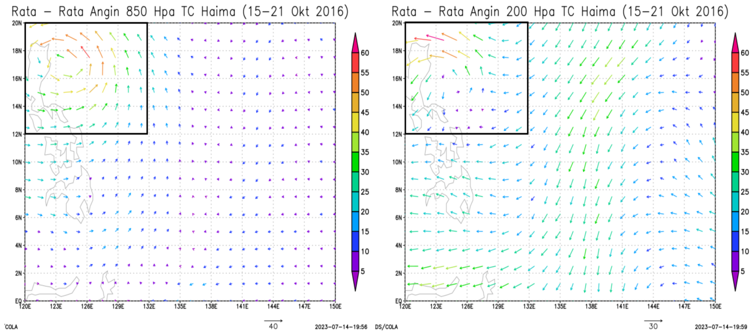
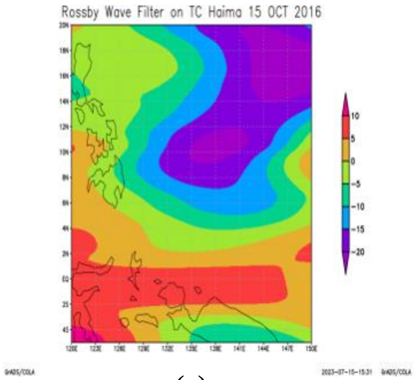



FIG. 5: Streamline the 850 dan 200 Hpa layer of TC Haima 15-21 October 2016

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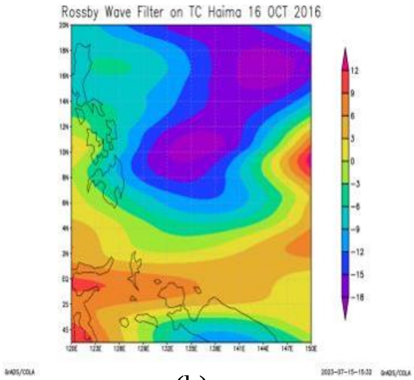


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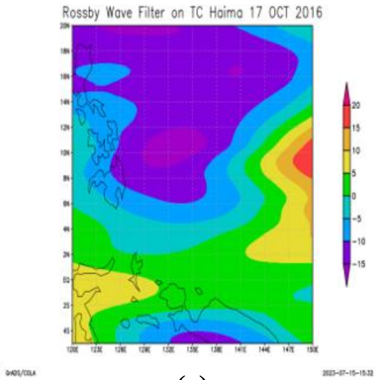


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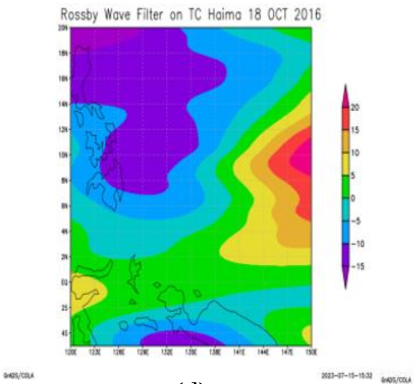


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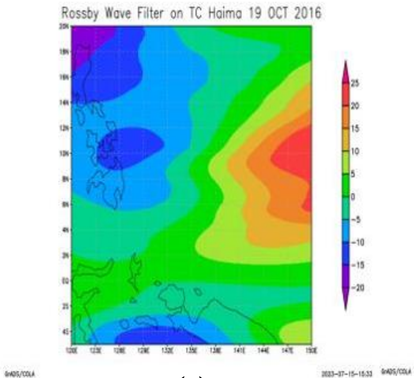


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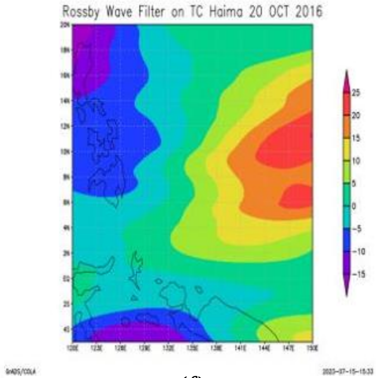


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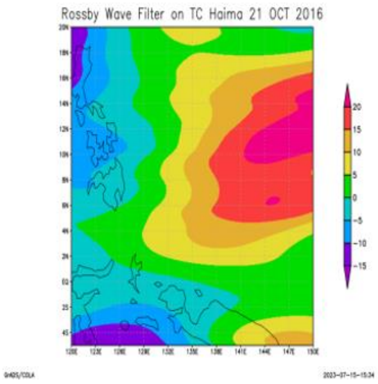
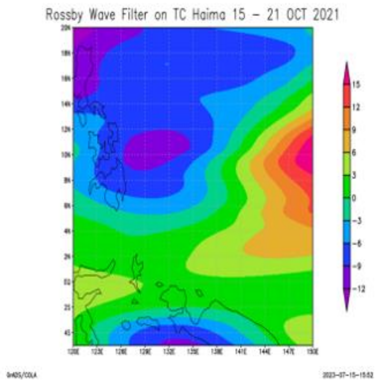



(g)




(h)

FIG. 6: Rossby Wave OLR Anomaly Filter in the Case of TC Haima

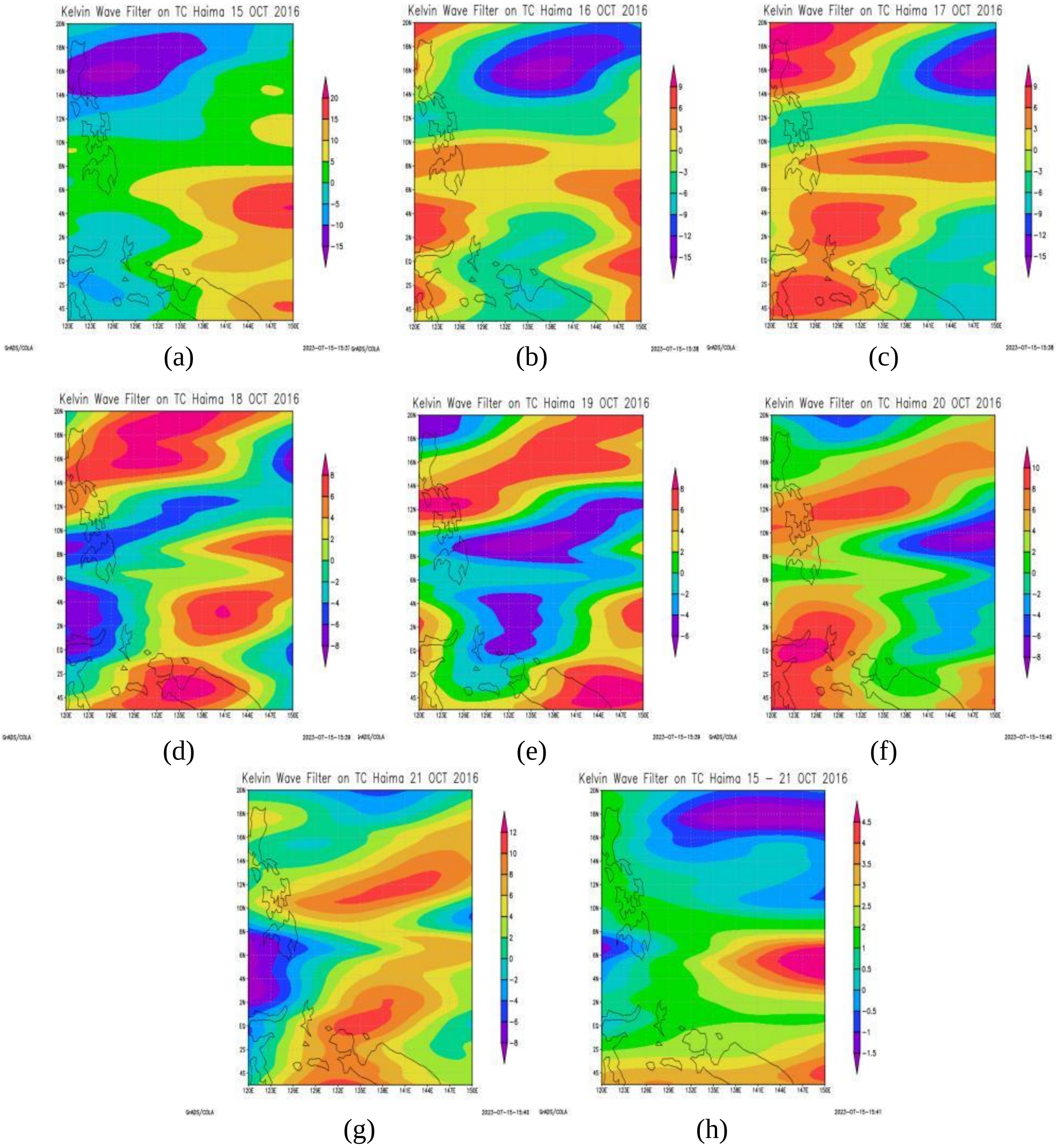



FIG. 7: Kelvin Wave OLR Anomaly Filter in the Case of TC Haima

all existing TC cases. Most cases of TC were modulated by Rossby waves in as many as 6 cases, then modulated by the active phase of two Rossby and Kelvin waves in asmany as 5 cases, then TC modulation with Kelvin waves in as many as 3 cases. In 2018 there were 1 in 18 cases not modulated by Rossby and Kelvin waves.

The remaining 17 cases of TC were modulated by Rossby and Kelvin waves, with the dominant influence originating from 11 cases of Rossby wave modulation, 5 cases of the active phase of two Rossby and Kelvin waves modulating TC, and 1 TC case of Kelvin wave modulation.Furthermore, in 2019 the total cases were the same as in 2018, which was 18 cases, but there were 2 cases of TC that did not modulate Rossby and Kelvin waves. In 2018 cases of TC were more dominantly modulated by Rossby waves in 7 cases, and active phase modulation of two Rossby and Kelvin waves were 6 cases, and the active phase of Kelvin waves which modulated TC was 3 cases. Meanwhile, 2020 was the year with the least number of TC cases, with 8 cases. In addition, from all the TC cases, there was no active phase modulation of

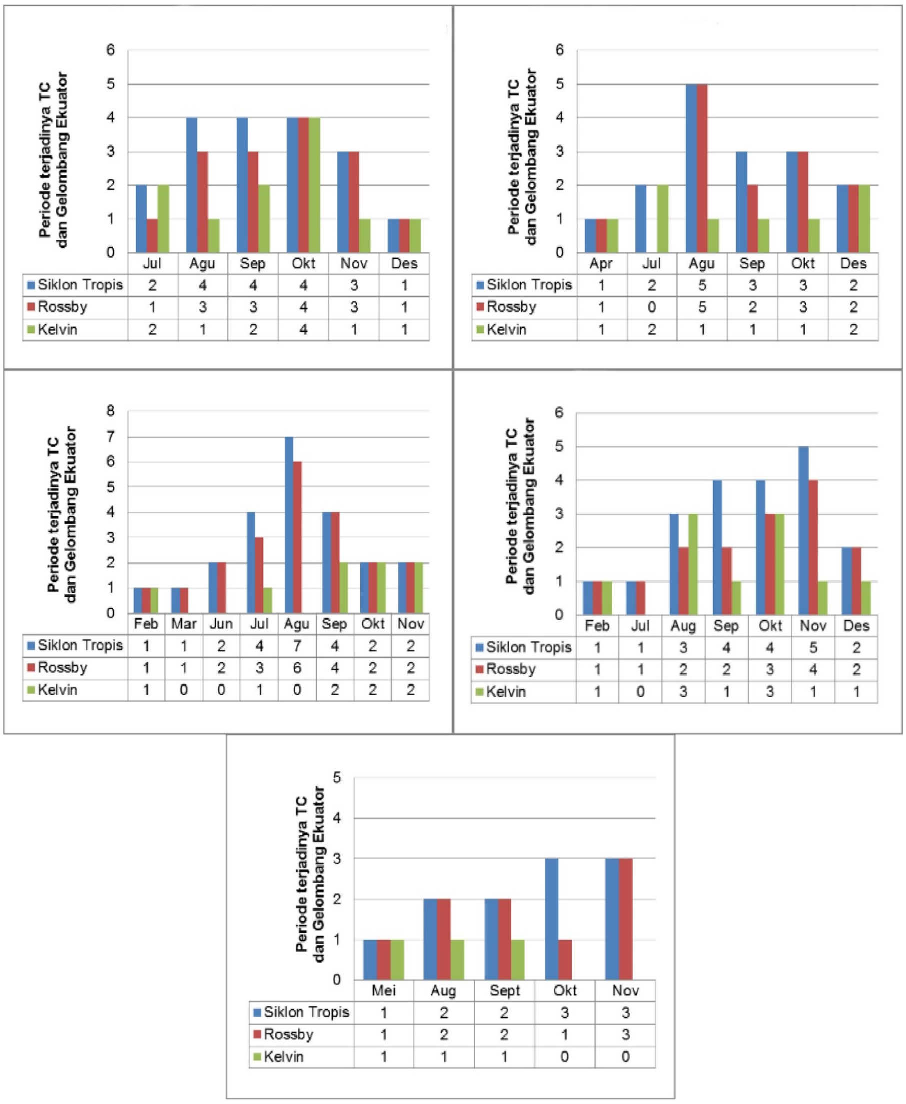



FIG. 8: Tropical Cyclone and Equatorial Wave Monthly Frequency (2016-2020)

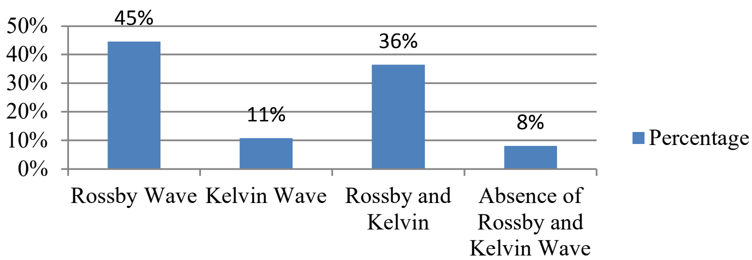



FIG. 9: Percentage of Rossby and Kelvin waves that modulate tropical cyclones

one Kelvin wave in modulating TC. 2020 showed that the TC cases were more modulated by the active phase of one Rossby wave in as many as 4 cases, and the active phase of 2 Rossby and Kelvin waves, which modulated TC by 2 cases, and there were 2 cases of TC which were not modulated by Rossby and Kelvin waves. The details can be seen clearly in Table III.

Fig. 9 shows the percentage of Rossby and Kelvin waves that modulate TC for 5 years. Of the 74 cases of TC that occurred in the Western Pacific Ocean, it tends to be modulated by Rossby waves by 45% or as many as 33 cases. Furthermore, TC cases were also modulated by the active phase of two Rossby and Kelvin waves in 27 cases or 36%. While the

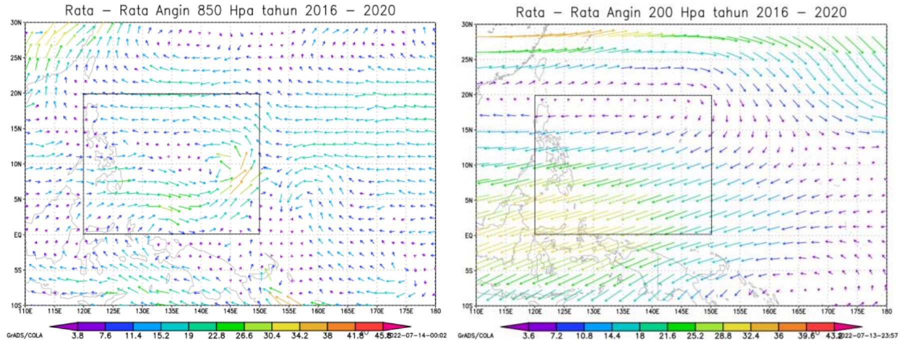



FIG. 10: Percentage of Rossby and Kelvin waves that modulate tropical cyclones

active phase of one Kelvin wave modulates TC by 11% or as many as 8 cases, and the case of TC which is not modulated by the active phase of one or two Rossby and Kelvin waves by 6 cases or by 8%. So it can be seen that the overall TC formed in the Western Pacific Ocean for 5 years was modulated by the active phase of one or two Rossby and Kelvin waves with a total of 92% of the 74 TC cases that occurred. TC is more often formed in the active phase of one or more tropical waves, because these waves can affect atmospheric conditions on a synoptic scale and create favorable environmental conditions for the formation of TC genesis [1, 4, 7, 11, 17, 23, 25].

### C. Distribution of Equatorial Waves Modulating the Lifetime of Tropical Cyclones

In the 5-year period of TC occurrence in the research area, there is a maximum lifetime of TC for 11 days with an intensity of 115 knots formed in the period October-November 2018, while for a minimum lifetime of TC for 1 day with an intensity of 35 knots formed in the period November 2016, and the average lifetime of TC is 5 years (2016-2020) which is 5 days which is used as the averagel threshold for the lifetime of TC. TC lifetime analysis is done by classifying TC into 3 types. Category 1 TC cases that have an above-average lifetime, category 2 TC cases that have an average lifetime, and category 3 TC cases that have a below average lifetime.

Table IV presents the total distribution of the equatorial waves modulating the TC lifetime for five years. It showed that 46% of total TC cases had an above-average lifetime, with 34 cases. Meanwhile, the total TC cases with the same lifetime were 18 or 24%. The total TC cases with a lifetime below the average were 22 or as much as 30%. So overall, we can conclude that the effect of the active phase of one or two Rossby and Kelvin waves on TC lifetime was that 70% of TC cases for five years have a lifetime more than or the same as the average, while as many as 30% of cases TC has a less than average lifetime.

### D. Global Circulation Patterns

Zones propagating waves in the tropical atmosphere play an important role in causing cyclogenesis because they improve local conditions in favorable areas [15]. These waves can increase convection and vertical upward motion, which tends to increase the relative humidity in the deep layers, as well as increase low-level vortices, change vertical shear patterns locally, can also trigger convection processes in zonal winds in the convergent region and usually the wave energy also exists in the area

In the 850 hPa layer there is a cyclonal pattern in the study area with the maximum velocity at the center of the cyclonal pattern reaching $>$ 40 knots. This speed is one of the conditions for the formation of a TC genesis with a speed threshold of $>$ 35 knots. However, this is still not able to form TC, but in the research area it is clear that there is a low pressure area so that it creates a strong updraft force which is indicated by the cyclonal pattern. The updraft force can support the formation of TC if it can increase the relative humidity of the moist layer at 700 hPa. This is in line with research [8] on environmental conditions that support the formation of cyclogenesis. Meanwhile, at the average wind circulation of 200 hPa in the TC period and the Equatorial waves for 5 years, there is no pattern that might affect the TC genesis.

## IV. CONCLUSION

A conclusion was obtained based on the results of the analysis and discussion, namely: the active phase of one or two tropical waves in modulating TC in the Western Pacific Ocean for 5 years showed very significant results, namely 92% which was dominantly modulated by Rossby waves as much as 45%. However, there are 8% of TC cases that are not modulated by equatorial waves either only Rosby waves or only Kelvin waves or when both are active.. This indicates that the active phase of tropical waves can affect the frequency of TC formation. The average life span of a 5 year tropical cyclone is 5 days. It has been observed that the active phase of one or two tropical waves can have an impact on the duration of TCs. Research has indicated that up to 70% of TC cases experience a longer- than-average lifespan during the active phase of the Rossby or Kelvin waves, while up to 30% have a shorter-than-average lifespan during this phase. In the case of the tropical cyclone Haima it is known that there is an increase in the intensity of tropical cyclones with a maximum speed of up to 120 Knots, and a longer cyclone life span is included in the category of above average life span reaching 6 days due to the active phase of the Rossby and Kelvin waves during the cyclone Tropical Haima. 850 hPa in the TC period modulated by Rossby and Kelvin waves for 5 years showed a cyclonal pattern and wind intensity of more than 40 knots that supported the formation of TC genesis, but in the 200 hPa layer there was no pattern that affected TC.

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