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PRELIMINARY STUDY OF HORIZONTAL AND VERTICAL WIND PROFILE OF QUASI-LINEAR CONVECTIVE UTILIZING WEATHER RADAR OVER WESTERN JAVA REGION, INDONESIA

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Abstract. One of the weather phenomena that potentially cause extreme weather conditions is the linear-shaped mesoscale convective systems, including squall lines. The phenomenon that can be categorized as a *squall line* is a convective cloud pair with the linear pattern of more than 100 km length and 6 hours lifetime. The new theory explained that the cloud system with the same morphology as squall line without longevity threshold. Such a cloud system is so-called *Quasi-Linear Convective System* (QLCS), which strongly influenced by the ambient dynamic processes, include horizontal and vertical wind profiles. This research is intended as a preliminary study for horizontal and vertical wind profiles of QLCS developed over the Western Java region utilizing Doppler weather radar. The following parameters were analyzed in this research, include direction pattern and spatial-temporal significance of wind speed, divergence profile, vertical wind shear (VWS) direction, and intensity profiles, and vertical velocity profile. The subjective and objective analysis was applied to explain the characteristics and effects of those parameters to the orientation of propagation, relative direction, and speed of the cloud system's movement, and the lifetime of the system. Analysis results showed that the movement of the system was affected by wind direction and velocity patterns. The divergence profile combined with the vertical velocity profile represents the inflow which can supply water vapor for QLCS convective cloud cluster. Vertical wind shear that effect QLCS system is only its direction relative to the QLCS propagation, while the intensity didn't have a significant effect.

Keywords: *horizontal and vertical wind profile, QLCS, doppler weather radar, Western Java Region, Indonesia*

1 INTRODUCTION

The line-shaped convective system often associated with a significant weather event, both wind field and rainfall. Terms of squall line often used is referenced to Maddox (1980) definitions, linear type of convective system that persist more than 6 hours. Referring to that definition, the tropical convective system may not meet those lifetime criteria even has a line-shaped. A new terminology described by Lombardo and Colle (2010) concerning the line-shaped convective system by taking only on the size, and the length-width ratio of the convective cloud, as Quasi-Linear Convective System (QLCS). A convective cloud of QLCS defined by weather radar reflectivity as 30 dBZ or more and 50 dBZ embedded. Minimum length is 50 km with 5:1 ratio of length and width of a convective cloud. Since it's still a line-shaped convective system, physical behaviour that triggers its formation and a decaying process can be referred to the squall line (Lombardo 2012).

Since dynamical process (horizontal and vertical wind profile) play more

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prominent role in QLCS formation and evolution than its thermodynamic process (Lericos *et al.* 2007), it becomes important to do a research about horizontal and vertical wind profile occurring in QLCS, moreover, it often persists just in a short period of time. In the previous research of the convective line system, Houze (2004) explain that a divergence pattern captured in the stratiform cloud, and in an opposite, convergence patterns occur over the leading edge. Another aspect that plays important roles in QLCS evolution is vertical wind shear that lead to the new cell formation along the line due to cold pool behaviour (Thorpe *et al.* 1982; Rottuno *et al.* 1988; Parker and Johnson 2000; Weissman and Rotunno 2004; Cohen *et al.* 2007). Vertical wind shear profile at the level 0-3 km and 3-6 km gives significant effect to QLCS evolution (Lombardo and Colle 2012).

The difference between mid-latitude and tropical weather system make this investigation important. Horizontal field analysis will be done in the aspect of wind speed and direction relative to the linear system, and divergence profile. Vertical wind shear and vertical velocity are considered as important aspects to be analysed in the vertical direction. This research is expected to provide characteristic of horizontal and vertical wind profile on the occurrence of QLCS in Indonesia, so the forecaster in operational work can obtain more information about the formation and evolution of QLCS, and its characteristics can be taken into consideration in issuing early warning of damaging wind together with heavy rainfall due to QLCS.

2 MATERIALS AND METHODOLOGY

Doppler weather radar is used as the main tool to obtain the horizontal and vertical wind profile in analysing all QLCS occurrence. The total number of 34 QLCS events in the 2015-2016 period were analysed without considering the seasonal factor since Indonesia has only two seasons.

QLCS observed by the Lombardo criteria in MAX product, length-width ratio measured by the distance measurement tool in every edge of its linear convective. Every evolution stage and its duration are defined by the theory of convective system as revealed by Tjasyono (2008). Universal Wind Technique (UWT) algorithm is used to analyse the wind speed and direction overlaid into reflectivity pattern and continued by the analysis for the spatial and temporal change relative to the convective line. Divergence, vertical wind-shear, and vertical velocity profile obtained from Vertical Velocity Processing (VVP) algorithm.

Horizontal divergence profile is presented in the vertical direction and analysed for its dominance in the formation, mature, and dissipating stage. This way of analysis is also done in a vertical velocity profile. Both divergence and vertical velocity are intended to find out the role of updraft in the mature stage, and how downdraft will affect the dissipating process. Vertical wind shear profile is analysed in the interval of 1-3 km correlating its value with each QLCS lifetime, and its direction to the propagation direction. In accordance to the theory revealed by Chaudari (2010), the longer convective system lifetime, the more significant vertical wind shear value. Perpendicular vertical wind shear direction to the elongated system often encountered (COMET 2013).

3 RESULTS AND DISCUSSION

The radial velocity data at the lowest elevation (0.5^0) was processed using the UWT algorithm which was then combined with the radar dBZ data to determine the direction profile and wind speed in each QLCS segment. The lowest elevation is used to get a lower layer wind profile that has the most direct impacts on the environment. The wind speed and direction are analysed relative to the direction of propagation of QLCS subjectively and objectively. Relative wind speed and direction analysis will be focused on the growing stage, the mature stage (when QLCS forms a linear pattern), and the decaying stage. The result of the analysis is then used to analyse the effect on the movement of the system (stationary or fast-moving).

In the growing stage, 9 cases showed a parallel (Figure 3-1a) and 13 cases with perpendicular (Figure 3-1b) wind direction pattern toward the QLCS propagation across all segment, while 8 cases with combined parallel and perpendicular wind direction patterns in different segments (Figure 3-1c). Different segment here means perpendicular direction located along the centred segment, while parallel direction occurs in both flank segment. In the mature stages, 7 cases show a parallel, 11 cases of perpendicular, and 12 cases combined parallel and perpendicular wind pattern. A rather similar pattern develops while the convective line begins to decay, 8 cases in the pattern of parallel, 12 perpendicular, and 8 patterns combined parallel and perpendicular.

All those wind direction patterns are the patterns from the most significant wind speed that flows in each segment. A rest number that not included as parallel, perpendicular, and combined of parallel-perpendicular lies in a not significant wind flow (Figure 3-4). Based on those result, the wind speed with the perpendicular pattern is significant in the centred segment of QLCS and is relatively weaker in the flank segment either in the growing, mature, or decaying stage. It can be referred that wind direction pattern occurs at the growing stage has a significant influence on the next stage. Another result found that the wind speed and direction affect system movements. Systems with perpendicular significant wind pattern in all segments and combined parallel-perpendicular are relatively moved faster than the parallel wind patterns across the segments.

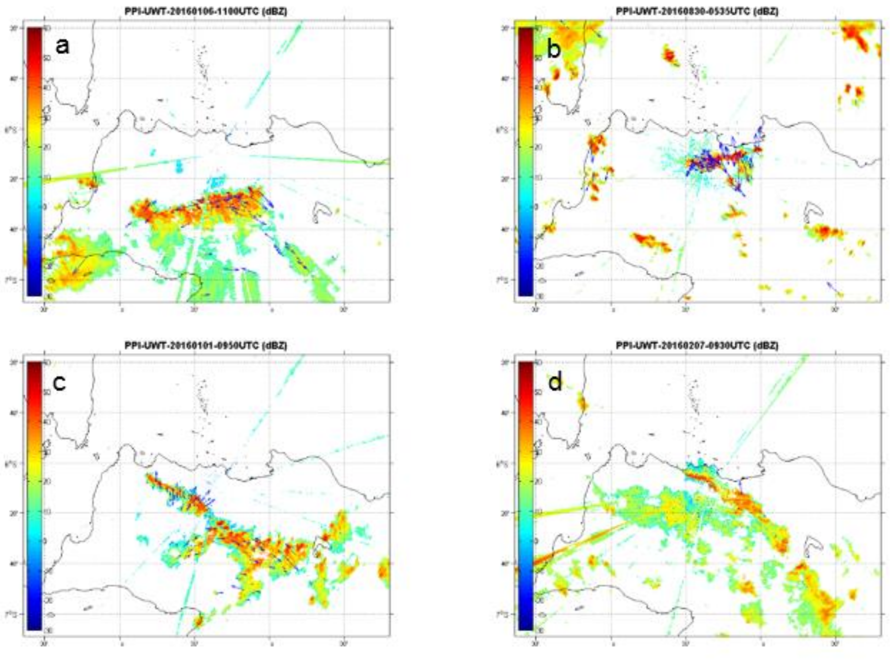

Figure 3-1: A sample of QLCS with parallel wind pattern (a), perpendicular pattern (b), combined parallel-perpendicular in centred and flank segment (c), and insignificant wind pattern along all segment (d)

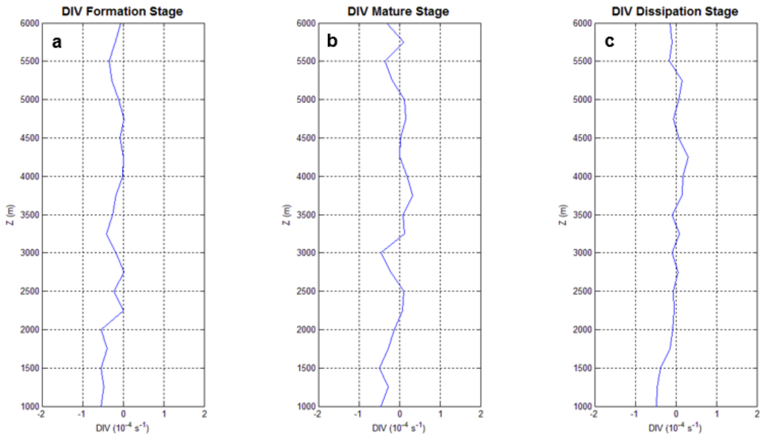

Figure 3-2: Horizontal divergence profile at 1.0-6.0 km altitude in average value for 34 cases of QLCS. (a) Growing stage, (a) Mature stage, and (c) Decaying stage (c)

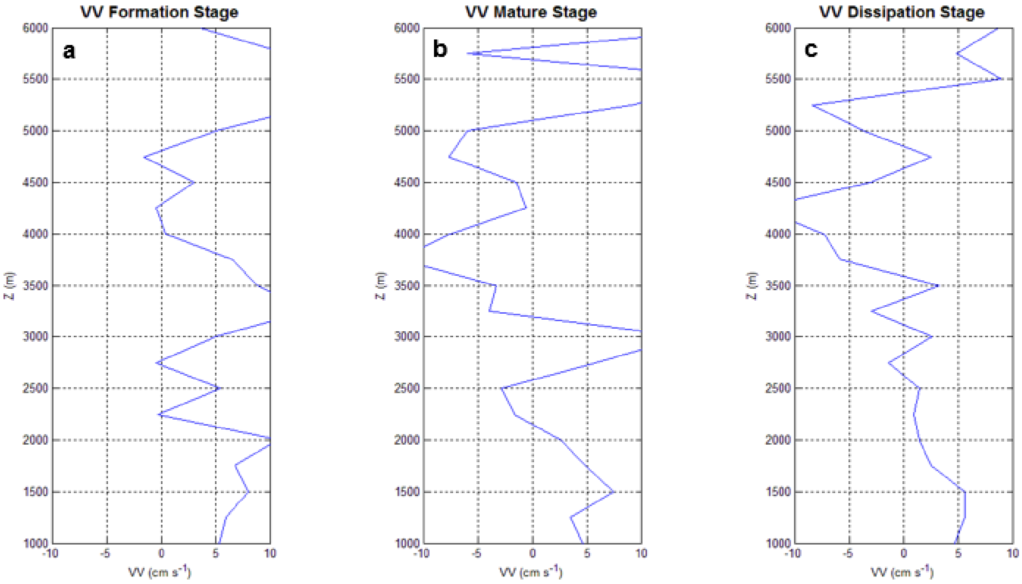

Figure 3-3: Vertical velocity profile at 1.0-6.0 km altitude in average value for 34 cases of QLCS. (a) Growing stage, (a) Mature stage, and (c) Decaying stage (c)

Based on the system movement categories by Barnes and Sieckman (1984), 5 cases were classified as fast-moving convective cloud line, 17 cases were intermediate-moving convective cloud line, and 10 cases were classified as slow-moving convective cloud line. In the case of the fast-moving convective cloud line, the wind pattern is dominated by a perpendicular pattern across segments as well as in the centred segment, whereas parallel wind patterns occur only in the flank segment and there are no cases with parallel wind patterns in all. The case of intermediate moving convective cloud line has the same wind behaviour pattern as the fast-moving convective cloud line, but there are 3 cases with parallel wind patterns across the segment. While in the case of slow-moving convective cloud line, the wind pattern is dominated by parallel patterns across the segments and wind patterns that are not significant. But there are also 4 cases with wind patterns perpendicular across segments.

The analysis of divergence is done together with vertical velocity analysis since it has a strong relevance. Both divergence and vertical velocity are also analysed at the growing, mature, and decaying stage in a mean value of 34 cases. Data chose to be analysed lies along the level between 1.0 - 6.0 km altitudes based on the availability of data from VVP products. The average profile of divergence in the growing stage (Figure 3-2a) shows the convergent flow occurs prominently in all level, which the most significant convergent flow occurs in the 1.0 - 2.0 km layer. This convergent flow is accompanied by positive vertical velocity (updraft motion) in a layer (Figure 3-3a). This result is like the results of Gamache and Houze (1985) research which mentions that the convergent flow at GATE Squall Line occurs in the surface layer up to 700 MB. The convergent flow in the lower layers is indispensable by QLCS in forming convective cloud cells to form linear patterns.

Convergent flow is still detected in the mature stage till a height of 2.2 km, but the intensity is lower when compared to the growing phase, and in other layers, divergent pattern begins to flow (Figure 3-2b). The convergent flow in the lower layers that causing the updraft (Figure 3-3b) is still needed in the formation of new cloud cells to maintain the linear pattern. In accordance with the theories exposed by Roger and Yau (1989) and Tjasyono (2008) concerning downdraft at the mature phase, positive divergence values are detected at 3.5 - 5.0 km altitude. This divergent flow will cause a downward current and rain begins to fall (Holton 2012).

In the average divergence profile of the decaying stage (Figure 3-2c), the condition is predominantly divergent flow from a height of 2.5 - 5.2 km, this is due to the extreme value in the data distribution of the decay phase divergence (Figure 3-4) is more dominant in the positive area. Convergent flow is still detected at the 1.0 - 2.0 km layer that leads an updraft motion (Figure 3-3c) but its intensity is lower than the growing phase and the mature phase. The whisker length in the divergence data distribution also shows a longer value in the positive area. This is consistent with convective cloud theory in the decay phase of the dominance of the decreased airflow which can be represented by positive divergent values (Roger and Yau 1989; Tjasyono 2008; Holton 2012).

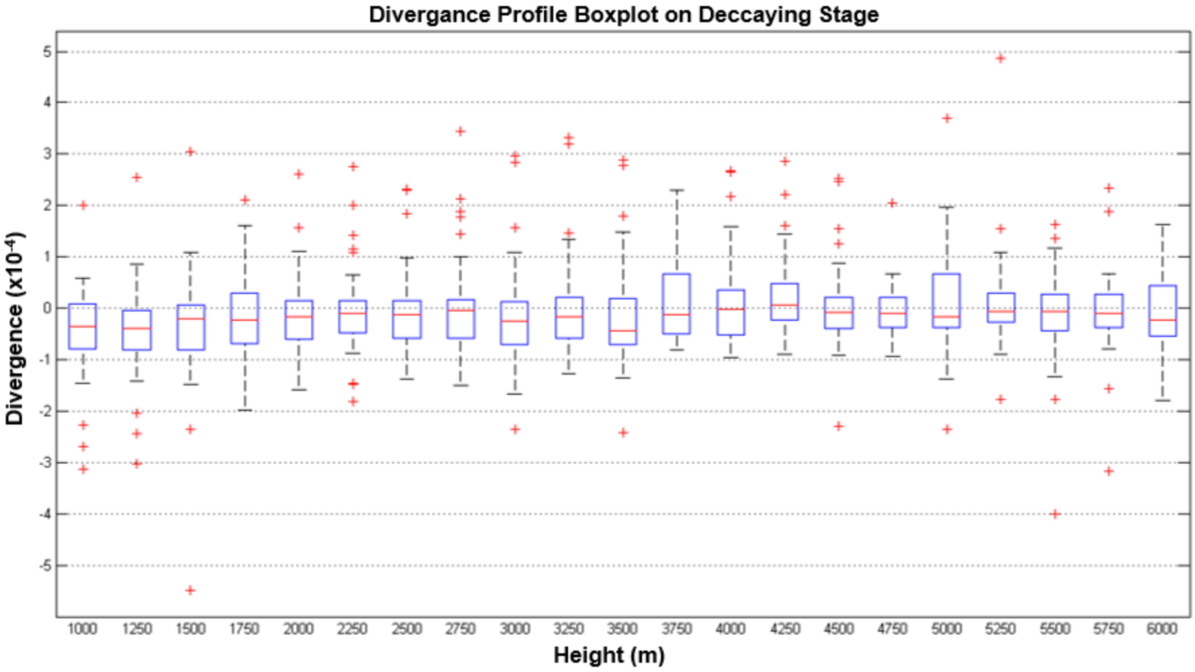

Figure 3-4: Boxplot of divergence value in each level showing data distribution. This boxplot showing a dominance value of divergent flow. An average profile showing convergent flow at 2.5-5.2 km due to some cases has really high negative value.

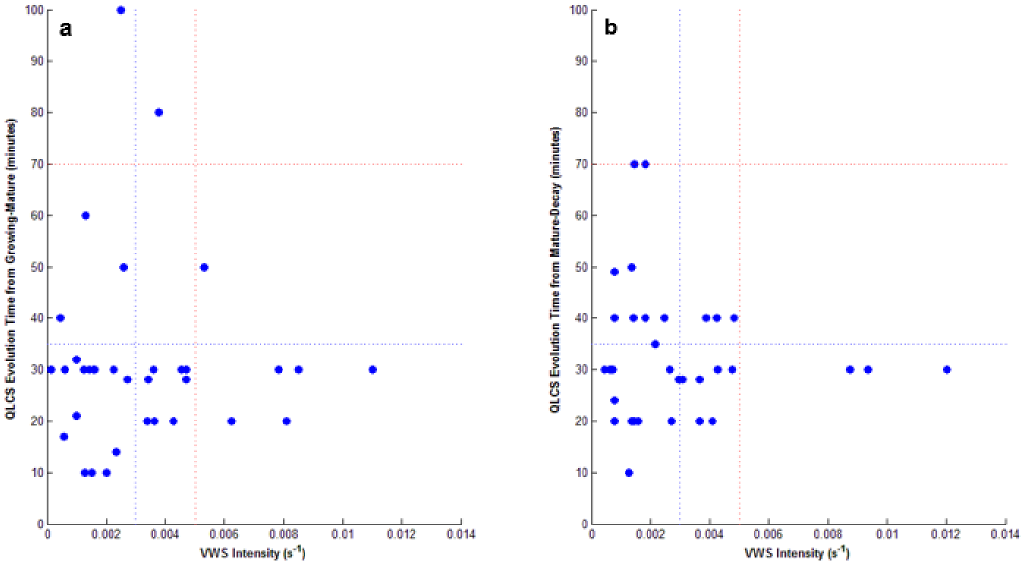

Figure 3-5: A scatter plot showing vertical wind shear value in each time interval for QLCS growing stage to mature stage (a), and QLCS mature stage to decaying stage (b).

The direction and intensity of vertical wind shear (VWS) are analysed through VVP products at an altitude of 1.0 - 3.0 km. The intensity of VWS is analysed to determine its effect on the life span of QLCS, while the direction is analysed relative to the propagation direction of QLCS to determine its tendency.

In the study of Coniglio *et al.* (2010), the intensity of VWS in the lower layers greatly affects the evolution of the system from the growing to the mature stage (when the system forms a linear pattern). Systems with strong VWS intensity will be RDMs (Rapid Developing MCSs) with the evolution of fewer than 5 hours. Conversely, systems with weak VWS intensity will become SDMs (Slowly Developing MCSs) with evolution over 7 hours. The results of that study can be analogous to the QLCS system occurring in West Java with the time of evolution is not using the threshold by Coniglio (2010) but relative to all observed events. Scatter plot to know the effect of VWS intensity on the time of evolution is shown in Figure 3-5. In the interval from growing to mature stage (Figure 3-5a), the evolution time frequency of all 34 QLCS cases that less than 35 minutes appears dominant with 82.35% percentage, but it spreads in the weak VWS intensity category (less than 0.003s-1), moderate (0.003 s^{-1}- 0.005 s^{-1}), and strong (more than 0.005 s^{-1}). The frequency number of 41.17% were distributed at weak intensity, 23.52% in moderate intensity, and 14.70% at the strong intensity. While the evolution of more than 35 minutes only has a percentage of 17.65% with a weak intensity distribution of 11.76%, medium intensity of 2.945%, and strong intensity of 2.945%. This suggests results that are inconsistent with Coniglio's research.

In the mature stage evolution to the decay stage (Figure 3-5b), VWS intensity distribution is still concentrated in the weak category. The percentage of QLCS events with weak VWS intensity and evolution time that less than 35 minutes is 41.17%, while evolution time more than 35 minutes equal to 23.53%. In moderate intensity, 17.64% had an evolution time of fewer than 35 minutes, and 11.76% had an evolution time of more than 35 minutes. Three QLCS events (8.8%) have strong VWS intensity with evolutionary time of fewer than 35 minutes. These results also indicate that the intensity of VWS in the mature to extinct phase also does not affect the duration of the linear pattern and is inconsistent with the results of the Lombardo and Colle research (2012) where QLCS with slowly decaying and sustaining decay patterns has a stronger VWS intensity in the lower layers.

Another aspect of VWS that can affect the QLCS system is the VWS direction. Squall lines of less than 100 km long will be propagated and move perpendicular to the average VWS direction of the lower layer (COMET 1999). In addition, in the fast-moving QLCS system, the VWS direction of the lower layer (0-3 km) is also perpendicular to the direction of propagation (Barnes and Sieckman 1984). In this study, the direction of VWS is observed in layers of 1-3 km through a VVP product. The base height of 1 km is chosen because the data reliability level below 1 km is low for VVP products. VWS direction analysis is done at the time of growth phase, maturity phase, and dissipation phase then analysed the dominant direction of VWS relative to QLCS propagation (parallel or perpendicular), its influence on the direction of movement of QLCS, and its effect on system speed.

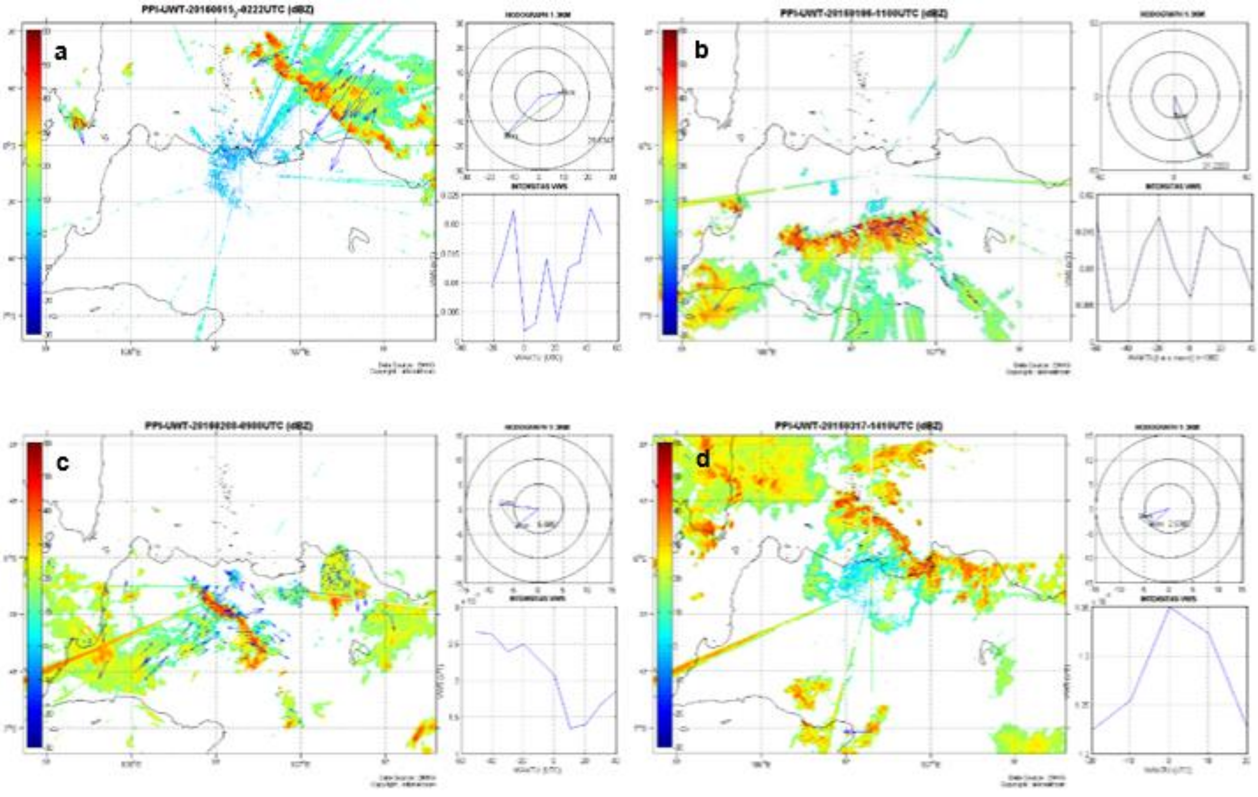

Figure 3-6: An analysis of vertical wind shear direction relative to the QLCS propagation and time series of vertical wind shear intensity. The direction of wind speed analysed by 1-3 km hodograph (upper right in each picture). The samples for the perpendicular direction of VWS relative to QLCS propagation are shown in (a) and (b), while parallel direction in (c) and (d).

Based on the comprehensive analysis, VWS direction perpendicular relative to the QLCS propagation direction (Figure 3-6a and 3-6b) occurred as many as 18 cases (52.94%) in the growing phase, 25 cases (73.52%) in the mature phase, and 21 cases (61.76%) in the decay phase. While the relative parallel direction (Figure 3-6c and 3-6d) occurred as many as 16 cases (47.06%) in the growing phase, 9 cases (26.48%) in the mature phase, and 13 cases (38.24%) in the decay phase. This shows the dominance of the VWS direction perpendicular to almost all phases.

This VWS change of direction causes precipitation in the cloud to drop in the same location as the inflow, so the system will gradually become extinct due to the absence of inrush. It is this factor that causes the VWS direction changes to be opposite to the direction of motion occurring in the mature to decaying phase.

Based on the results of the analysis of 34 QLCS events, the influence of VWS on the system movement (speed and direction) is divided into 4 categories. Category 1 is a parallel VWS direction that causes slow-moving system, while category 3 causes intermediate to fast moving. Category 2 is a parallel VWS direction that causes intermediate to fast moving system, while category 4 causes intermediate to fast moving. The percentage of each category of VWS influence on 34 QLCS events is shown in (Figure 3-7). The most dominant influence occurred in category 4 of 44%, but the variation of VWS influence in other categories is quite significant. This matter is possible because of the influence of thermodynamic factor. The movement of the squall line system (which has the same morphology as QLCS) can be affected by a combination of CAPE (Convective Available Potential Energy), CIN (Convective Inhibition), and VWS variables (COMET 1999).

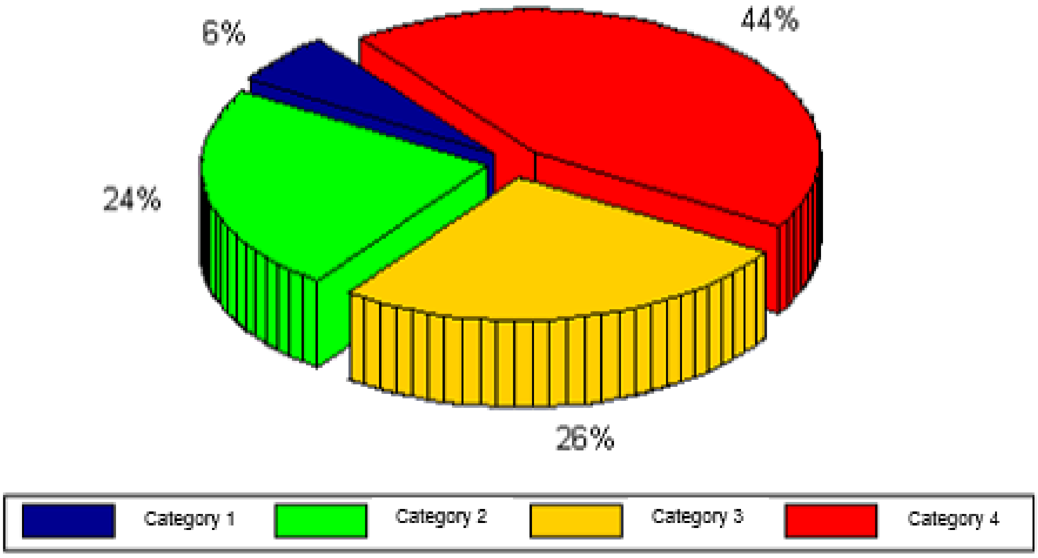

Figure 3-7: Pie chart showing the percentage of VWS direction influence to the QLCS movement divided into 4 categories. QLCS movement category based on Barnes and Sieckman (1984).

4 CONCLUSION

Preliminary studies conducted to provide information that the dynamic process in QLCS that occurred in West Java is heavily influenced by vertical and horizontal wind profile. The characteristics of the wind speed and direction pattern along the centred segment are dominated by a perpendicular pattern while the flank segment is dominated by a parallel pattern of cloud propagation direction, and its pattern quite influences the direction and movement of the system. The divergence profile combined with the vertical velocity profile can represent inflow in a convective QLCS cloud, where the growing stage is marked by updraft dominance, a mature stage characterized by downdraft and updraft, as well as a decaying stage that is dominated by downdraft flow. The intensity of VWS at an altitude of 1-3 km does not affect the length of life of QLCS, whereas the direction of VWS is dominated in a direction perpendicular to the orientation of QLCS and gives a significant influence on the direction and velocity of motion.

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