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Analysis of Quasi Linear Convective System (QLCS) Based on Doppler Weather Radar in The South Sulawesi Region

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Abstract

This research aims to analyze the characteristics of the Quasi Linear Convective System (QLCS) based on weather radar in the South Sulawesi region, which influences extreme weather. This research is a case study that focuses on the occurrence of QLCS, which grows around the waters of the Makassar Strait and moves east towards the mainland area of South Sulawesi. The study area is limited to a radius of 200 km from the weather radar center. The data processing technique uses the Rainbow application with weather radar data input from the Hasanuddin Makassar Meteorological Station. Next, the radar data output in the form of MAX products is filtered according to the criteria of Lombardo and Colle (2010) to obtain QLCS cases. The selected QLCS cases were then analyzed for their characteristics based on spatial and temporal distribution, type of formation, propagation, and Vertical Wind Shear. The data processing results found 24 cases of QLCS in South Sulawesi with varying characteristics, where the formation location was most often in the waters of the Makassar Strait with a lifetime of around 60-90 minutes. The most common type of QLCS formation is a broken line, and the most dominant QLCS propagation is towards the east, with fast-moving speed and a strong VWS category.

Introduction

Indonesia is a maritime country with around 17,508 islands and a coastline of 80,791 km, with a water area of 2/3 of its total area [1]. Indonesia also has mountainous and hilly landforms on land, while there are straits, capes, gulfs, and others in the waters. The interaction between the vast ocean and the atmosphere significantly influences weather formation in Indonesia, while its various forms or topography make the weather in Indonesia more and more complex [2]. Topography is needed to determine the weather conditions that occur. An area on the inland coast will have weather conditions different from mountainous regions. Usually, in areas close to the coast, rain will often occur in the morning or evening, while for areas close to the inland, rain frequently occurs in the afternoon or evening [3].

The South Sulawesi region has a varied topography, both on land and in the water. Based on the percentage of land slope, the topography of South Sulawesi consists of areas with flat and sloping land, respectively 43% and 6% of the area in the south and east, especially in Wajo, Bone, Barru, Sidrap, Soppeng, Pangkep, Bulukumba, Jeneponto, and Takalar Regencies. Meanwhile, undulating, hilly to mountainous areas with rather steep, steep, and very steep slopes, respectively 17%, 16%, and 19%, are found in the north, including Tana Toraja, Pinrang, and Luwu Utara Regencies [4]. Meanwhile, in the waters of South Sulawesi, there are Makassar Strait, Bone Gulf, Bira Cape, etc. The various topography causes the formation of weather in South Sulawesi to be quite complex.

The South Sulawesi region is also influenced by the activity of the Asian Monsoon, which flows towards South Sulawesi after passing through the vast waters of the Makassar Strait. Therefore, the existence of the Makassar Strait is an essential factor in weather formation in South Sulawesi, as research conducted by Kunarso et al. states that the water conditions of the Makassar Strait are influenced by Arlindo and the monsoon system, which then causes variability in sea surface temperature as an essential factor in weather formation [5]. The Asian Monsoon winds that pass through the Makassar Strait take a lot of water vapor, causing high rainfall in the South Sulawesi region. Extreme weather in the form of heavy rain and strong winds, which often occur every year when entering the Asian Monsoon period, causes various kinds of disasters such as floods, landslides, fallen trees, damage to houses and infrastructure, and even fatalities. In fact, in early 2023, during the research period between October 2022 and February 2023, the most severe flooding occurred in the last 40 years in South Sulawesi. The worst flood in South Sulawesi, specifically in the city of Makassar, was recorded in 1981 on a massive scale and submerged the zero-kilometer area of the town. Meanwhile, at the time of the research in January 2023, based on data from BPBD, flooding spread to residential areas in the south, southeast, east, west, and north of the city, with an estimate of up to 150.000 residents exposed to flooding, in 72 sub-districts and 13 districts. Not only in Makassar but flooding also affected around 1.3 million residents in Gowa, Takalar, Maros, and Pangkep, four districts within 3 to 50 km from the provincial capital [6].

Extreme weather events are associated with several weather phenomena, including the Mesoscale Convective System (MCS). MCS research on heavy rain has been carried out several times in South Sulawesi. Abisusmita et al. found that the long-lived and slow-moving MCS phenomenon is the leading cause of flood disasters in places such as the South Sulawesi region. At the time of the MCS incident on December 27 and 28, 2018, rainfall in several districts in the South Sulawesi region was above 50 mm in a day [7]. The other research related to MCS in the South Sulawesi region was conducted by Pandjaitan [8], who researched the impact of the MCC (a particular type of MCS). Based on research, it can be concluded that the region where MCC occurred can impact the increase in the amount and volume of precipitation. During the MCC, there was a low-level convergence, high humidity, the equivalent potential temperature, which is more than 348 K, the negative value of vertical velocity, high convective available potential energy (CAPE), the moderate value of vertical wind shear in the area around the MCS, and warm sea surface temperatures.

MCC is a weather system that has the potential to bring heavy rain and strong winds and cause damage to the surface. The linear type of mesoscale weather system is one of the weather systems that has the potential to cause extreme conditions. Mesoscale convective system research is also carried out by identifying convective structures based on weather radar images by looking at the temporal and spatial distribution of the linear convective system and dividing it into four regions, namely upslope, high terrain, slope/coastal plain, and coastal ocean [9]. In addition, linear convective systems are limited to a reflectivity value (Z) of ≥ 35 dBZ on radar images, a comparison of the length and width of the system, and the lifetime of the system to determine the convective clouds. Then, Lombardo and Colle [10] researched this linear convective system and called it the Quasi-Linear Convective System (QLCS), with the criteria of a minimum system length of 50 km, which has a maximum length and width ratio of 5:1 and a radar reflectivity of ≥ 35 dBZ with a cell core of ≥ 50 dBZ.

QLCS is one of the causes of extreme weather, such as tornadoes in high-latitude areas. Research has been conducted to estimate that QLCS is a causal factor in approximately 20% of tornadoes that occur yearly in the United States [11]. Research on QLCS, such as the intensity and time distribution of tornadoes formed by QLCS and compared with tornadoes formed from the other storm cells [12], is increasingly being carried out. This research found that the intensity of tornadoes caused by QLCS was weaker than those formed from other storm stem cells. Studies on QLCS in Indonesia have been conducted less than in high-latitude regions. More research is needed on the correlation between QLCS and extreme weather, such as tornadoes in Indonesia. Some studies have only found a correlation between QLCS, heavy rain, and strong winds, not tornadoes. This research was conducted by Siregar et al. [13]; they found that on March 10, 2019, there was rain accompanied by strong winds in Kupang, which caused damage to public facilities and residents' houses due to the QLCS event. In her research, Nuri also reported that most of the QLCS in the Lampung region caused impacts in the form of rain and strong winds [14]. Several people have also conducted research that only looks for QLCS characteristics. One of the studies carried out was to classify QLCS into two, namely flat land QLCS and sea coastal QLCS, and it was found that no QLCS system could last for more than 6 hours [15]. Further research was carried out by observing the West Java region's horizontal and vertical wind profiles [16]. Other research was conducted regarding the characteristics of QLCS in areas with different topography, including mountains, sea/islands, and lowlands [17].

QLCS research in southern Sulawesi, which often appears in the waters of the Makassar Strait, is an attractive research area. Moreover, it is known that the South Sulawesi region has high rainfall intensity and a very long rain duration that can reach a week or more continuously without a break. Throughout late 2022 to early 2023, several incidents of heavy rain and strong winds have caused floods and other disasters. Several incidents of heavy rain and strong winds in South Sulawesi are suspected to be correlated with the formation of QLCS, which grew over the waters of the Makassar Strait and then moved inland. Further research on this hypothesis can be carried out by comparing rainfall and wind data when QLCS appears.

The research related to QLCS is carried out more accurately using weather radar than other remote sensing methods because weather radar has better spatial and temporal resolution. Weather radar can quantitatively detect meteorological phenomena such as gust fronts, wind shear, and microbursts and is very useful in preparing early warnings against extreme conditions, such as floods, tornadoes, and storms [18]. Based on this, the author tries to identify and analyze the formation of QLCS using the Doppler weather radar at the Hasanuddin Makassar Meteorological Station. This research focuses on the South Sulawesi region, which is directly bound to the Makassar Strait and within the weather radar range.

Method

This study's research type is descriptive qualitative, which describes QLCS events based on weather radar image displays. The study area in this research is the South Sulawesi region, which directly borders the Makassar Strait.

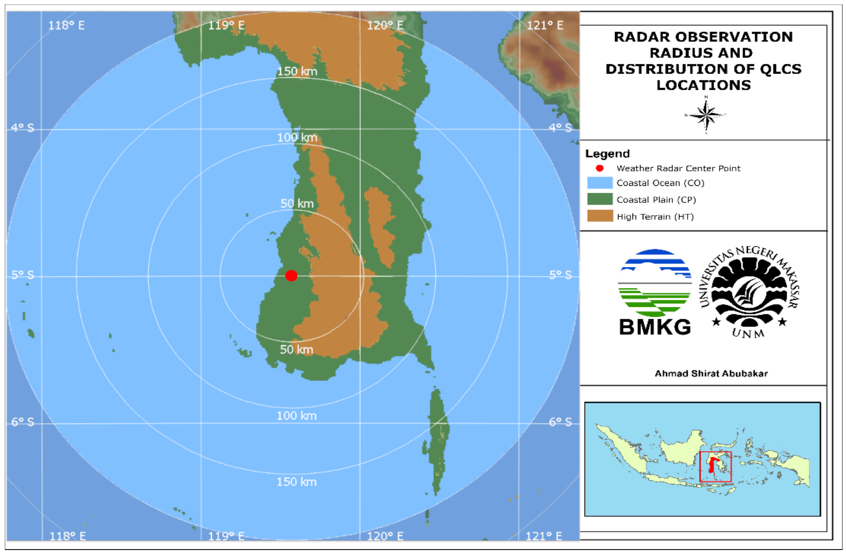

Figure 1. Radar Observation Radius and Distribution of QLCS Locations

The research design is a case study examining QLCS events' characteristics. The data used is Gematronic radar data at the Hasanuddin Meteorological Station from October 2022 to February 2023. This is the rainy season in South Sulawesi, and cloud growth occurs more often. The choice of this period was also based on weather radar monitoring within a year, and it was found that clouds rarely appeared outside this period, let alone the formation of QLCS. The radar data processing uses the Rainbow Display, Analysis, and Research Tool (DART) software version 5.49.13. After generating the raw data, it produces MAX products. MAX stands for Maximum Display, a radar product that uses a polar volume set converted to a cartesian coordinate volume, producing three sub-images (North-South, West-East, TOP) and a combination of the three to be displayed as an image [19]. MAX products will be filtered to look for QLCS events according to Lombardo and Colle's criteria [9,10], those having a length of >50 km, a maximum length and width ratio of 5:1 with a reflectivity of more than 35 dBZ (embedded 50 dBZ). After obtaining a QLCS case, its characteristics are identified by determining the phase (initiation, maturity, and dissipation) in each QLCS case spatially and temporally analyzed from the MAX product, for the temporal distribution of QLCS is divided into four-time classifications as reported by Mulya et al. [20], those are early morning or pre-dawn (PD) at 00.00-05.59 LT, early morning or morning (M) at 06.00-11.59 LT, midday or afternoon (A) at 12.00-17.59 LT and evening (E) 18.00-23.59 LT. The lifetime or the length of time QLCS survives is classified into four categories those are <60 minutes, 60-90 minutes, 91-120 minutes, and >120 minutes. Spatially, the distribution of locations where QLCS occurred in each phase is divided into the ocean or coastal ocean (CO), lowland or coastal plain (CP), and highland or high terrain (HT) with an observation radius of 200 km from the weather radar center point, such as in Figure 1.

The type of formation in each QLCS was analyzed from the weather radar MAX product following the classification of Bluestein and Jain [21], namely broken line (BL), back building (BB), broken area (BA), and embedded area (EA). Next, the direction and speed of QLCS propagation are obtained through the MAX product tracking feature or tool that has been generated. Propagation speed is divided into slow-moving (S) for speeds < 3 m/s, intermediate moving (I) for speeds 3 - 7 m/s, and fast-moving (F) for speeds > 7 m/s according to research by Barnes and Sieckman [22]. On the other hand, the direction of propagation is based on eight cardinal directions, namely North (N), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W), and Northwest (NW). The vertical shear velocity (VWS) value in QLCS is obtained from the VSHEAR radar product, which is grouped into 3 categories based on research by Chaudhari et al. [23] becomes weak (Wk) for VWS values < 3 m/s/km, moderate (Md) for VWS values of 3-5 m/s/km and strong (St) for VWS values > 5 m/s/km.

Result and Discussion

Based on weather radar monitoring for 5 months from October 2022 to February 2023, 24 cases of QLCS events were identified. The QLCS event was determined based on the criteria from Lombardo and Colle's research [9,10] with the requirements for a minimum system length of 50 km with a maximum length and width ratio of 5:1, and a radar reflectivity of ≥ 35 dBZ with a cell core having a reflectivity of ≥ 50 dBZ. The following are details of all QLCS cases, maximum reflectivity (Zmax), system length, and spatial-temporal distribution of each phase.

Based on Table 1, 24 QLCS cases were found in South Sulawesi and related to the intense convective activity that often occurred over the Makassar Strait. The observed QLCS cases occur every month during the transition season (October and November) and during the rainy season (December, January, and February). The highest number of QLCS cases occurred in December 2022 and the fewest in October 2022. This suggests that QLCS is correlated with the Asian monsoon, where when the monsoon activity weakens during the transition period, only a few cases of QLCS are found. Meanwhile, during the peak of the Asian monsoon season from December to February, many instances of QLCS were observed because the monsoon activity had strengthened at that time.

The maximum reflectivity value of QLCS varies from 50 dBZ to 53 dBZ (Table 1). The lowest maximum reflectivity value occurred in the first case (2022/10/01), 16th case (2022/12/30), and 23rd case (2023/02/14), while the highest maximum reflectivity value occurred in the 2nd case (2022/10/04), 5th case (2022/11/12), 12th case (2022/12/25), and 14th case (2022/12/27). The length of the QLCS system varies from the shortest system of 51.84 km in the 7th case (2022/11/30) to the longest, 141.63 km in the 19th case (2023/02/04).

Based on the table, it can also be seen that QLCS in the South Sulawesi region occurred in all regional locations, namely in the lowlands (CP), highlands (HT), and waters (CO). The location where QLCS occurred most frequently in the initiation phase was in the CO area (21 cases). In the mature phase, 12 cases were located both in CO and CP, while in the dissipation phase, the QLCS location varied, with the most cases being in CP with 12 cases. This may indicate that many QLCS events grow in water areas, then they can move to the land or even stay in water areas until the dissipation phase. The water locations where QLCS most often grows are in the

Makassar Strait, both in the northern and southern waters. This shows how vital the role of these waters is in weather formation, especially in the growth of QLCS in South Sulawesi.

Table 1. Details of QLCS cases

No	QLCS Date	Zmax (dBZ)	Length (km)	QLCS Location on Phase			QLCS Time on Phase			Lifetime (minutes)
				Ins	Mat	Dis	Ins	Mat	Dis	
1	01-10-2022	50	76,10	CO	CO	CO	E	E	E	70
2	04-10-2022	53	71,16	CO	CO	CO	E	E	PD	70
3	04-11-2022	52	55,50	CO	CO	CO	A	E	E	80
4	06-11-2022	52	94,83	CP	CO	CO	A	A	E	160
5	12-11-2022	53	53,94	CO	CO	CO	E	E	E	100
6	24-11-2022	51	132,30	CO	CO	CO	PD	PD	M	100
7	30-11-2022	51	51,84	CO	CP	CP	A	A	A	60
8	05-12-2022	51	59,54	CO	CO	CO	M	A	A	70
9	12-12-2022	51	52,64	HT	CP	CP	A	A	A	50
10	24-12-2022	51	91,37	CO	CP	HT	PD	M	M	70
11	25-12-2022 (1)	51	65,10	CO	CP	HT	E	E	E	70
12	25-12-2022 (2)	53	103,94	CO	CP	CP	M	M	M	100
13	26-12-2022	51	85,63	CO	CP	HT	E	E	E	70
14	27-12-2022 (1)	53	79,20	CO	CP	HT	M	M	A	90
15	27-12-2022 (2)	51	57,27	CO	CP	CP	A	E	E	70
16	30-12-2022	50	81,46	CO	CP	CP	A	A	A	60
17	06-01-2023	51	69,62	CO	CO	CP	M	M	M	80
18	10-01-2023	51	111,85	CO	CP	CP	M	M	M	120
19	04-02-2023	51	141,63	CO	CO	CP	PD	PD	PD	80
20	08-02-2023	51	90,51	CO	CO	CO	PD	PD	PD	90
21	11-02-2023	51	103,72	CO	CO	CP	A	A	A	70
22	12-02-2023	51	132,00	CO	CO	CP	M	M	A	100
23	14-02-2023	50	100,54	CO	CP	CP	PD	PD	PD	60
24	15-02-2023	51	106,98	CP	CP	CP	M	M	M	70

Abbreviations: CO, Coastal Ocean; CP, Coastal Plain; HT, High Terrain.
PD, Pre-Dawn; M, Morning; A, Afternoon; E, Evening.

Temporally, QLCS events in each phase almost evenly occur in the four-time classifications. The initiation phase of QLCS most often occurs in the morning (M) and afternoon (A); there are 7 cases each, while in the early morning/pre-dawn (PD) and evening (E), there are 5 cases each. The mature phase of QLCS occurred in 7 cases each in the morning (M) and evening (E), while in the afternoon (A), 6 cases were recorded, and only 4 cases were recorded in the pre-dawn (PD). The dissipation phase of QLCS occurred more frequently during the day (A) and at night (E), with a total of 7 cases. The remaining 6 cases occurred in the morning (M) and at least in the pre-dawn (PD), namely 4. From the life cycle starting from the initiation phase, maturity phase, to the dissipation phase, it appears that more than half of the total number of QLCS cases occurred in just 1 time, according to the time classification. If sorted into Initiation-Maturation-Dissipation, then they are E-E-E (4 cases), A-A-A (4 cases), M-M-M (4 cases), and PD-PD-PD (4 cases). This shows that the QLCS life cycle is relatively short because it occurs more often in one-time classification. The lifetime of the QLCS system can be seen based on the frequency graph below.

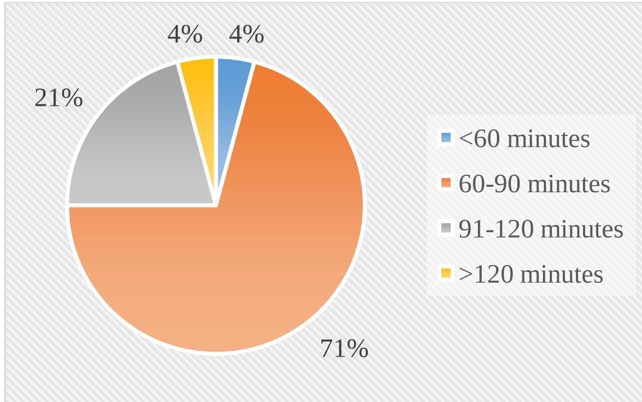

Figure 2. QLCS Lifetime Frequency

As many as 71% of QLCS cases, or most of the 24 cases observed, occurred within 60 to 90 minutes. 21% of QLCS cases had a lifetime of up to 2 hours (91-120 minutes). Then, 4% of QLCS cases or a case had the shortest lifetime (<60 minutes), and also a case had the most extended lifetime (>120 minutes). The QLCS case on November 6, 2022, had the most extended lifetime of around 160 minutes. The clouds that initiated QLCS began to appear at 08:45 UTC and reached the mature QLCS phase at 09:55 UTC. QLCS finally dissipated at 11.25, so the lifetime or period from maturity to dissipation reached 180 minutes. In other QLCS studies, such as those conducted by Mulya et al. [20] and Nuri et al. [14], the most extended QLCS lifetime was also relatively short. Mulya et al. studied the QLCS cases in the Pontianak area by dividing the QLCS lifetime into 3 classifications, namely 30-60 minutes, 60-90 minutes, and 90-120 minutes. All of the QLCS cases had a lifetime of 120 minutes. Nuri [14] analyzed QLCS in the Lampung region; the longest QLCS lifetime obtained was 150 minutes. This aligns with Ali et al. The result [15] found that no QLCS system could survive more than 6 hours. In contrast to the squall line, although it generally has the same physical characteristics as QLCS, its lifetime is very long. In Maddox et al. [24], squall lines have a lifetime of ≥ 6 hours, whereas in Lombardo and Colle [10], QLCS has no lifetime limit. So, in general, the QLCS cases found in the research cannot be called squall lines according to the criteria set by Maddox et al. This provides information that the linear convective system that often occurs in Indonesia is only QLCS because its lifetime is very short. Even though it survived briefly, QLCS in the research area has happened twice daily, such as the QLCS cases on December 25 and 27, 2022.

Based on Table 2, it is known that the type of broken line (BL) formation was the most frequently found in 10 cases, or 42%. The back building (BB) formation type was found in 3 cases (12%), the Broken Area (BA) formation type was found in 6 cases (25%), and the embedded area (EA) formation type was found in 5 cases (21%). The shape of the west coast of South Sulawesi, which extends from north to south, also influences the formation of the QLCS.

Table 2. Types of formation, propagation, and vertical wind shear QLCS

No	QLCS Date	Formation of QLCS		Propagation Direction		Propagation Speed		Vertical Wind Shear	
		Type	Location	Degree	points of the compass	m/s	Cat.	Value	Cat.
1	01-10-2022	BA	CO	260.5	W	5.07	I	-	-
2	04-10-2022	BB	CO	270	W	5.35	I	-	-
3	04-11-2022	BL	CO	270	W	4.01	I	-	-
4	06-11-2022	BB	CP	262.9	W	10.75	F	4.23	Md
5	12-11-2022	BL	CO	270	W	2.68	S	5.93	St
6	24-11-2022	BA	CO	153.4	SE	5.98	I	3.41	Md
7	30-11-2022	BB	CO	90	E	5.35	I	5.46	St
8	05-12-2022	BA	CO	108.4	E	4.20	I	-	-
9	12-12-2022	BL	HT	225	SW	1.88	S	-	-
10	24-12-2022	BL	CO	78.7	E	13.62	F	5.16	St
11	25-12-2022 (1)	EA	CO	95.7	E	13.38	F	5.14	St
12	25-12-2022 (2)	EA	CO	69.4	E	11.35	F	6.42	St
13	26-12-2022	EA	CO	101.3	E	13.57	F	6.67	St
14	27-12-2022 (1)	BL	CO	90	E	13.38	F	6.36	St
15	27-12-2022 (2)	EA	CO	113.2	E	10.14	F	5.97	St
16	30-12-2022	EA	CO	68.2	E	14.31	F	6.04	St
17	06-01-2023	BL	CO	90	E	5.33	I	5.91	St
18	10-01-2023	BL	CO	71.6	E	8.43	F	5.67	St
19	04-02-2023	BL	CO	59	NE	7.77	F	5.93	St
20	08-02-2023	BL	CO	129.8	SE	10.41	F	-	-
21	11-02-2023	BA	CO	105.9	E	9.71	F	6.51	St
22	12-02-2023	BL	CO	90	E	10.66	F	4.91	Md
23	14-02-2023	BA	CO	105.3	E	15.20	F	4.66	Md
24	15-02-2023	BA	CP	94.8	E	16.05	F	6.52	S

Abbreviations: BL, Broken Line; BB, Back Building; BA, Broken Area; EA, Embedded Area; CO, Coastal Ocean; CP, Coastal Plain; HT, Hight Terrain; W, West; E, East; SE, South-East; SW, South-West; NE, North-East; F, Fast; I, Intermediate; S, Slow; Md, Moderate; St, Strong.

Monsoon winds from the Asian region bring cold air masses and meet warmer air masses when they enter the plains of South Sulawesi, so this type of broken line often appears because it is a boundary plane/front that is perpendicular to the direction of movement of the monsoon wind which leads to the east. This is in line with the theory explained by Spiridonov and Curic [25] that air masses are separated from nearby air masses through boundary areas, which may be determined more accurately. When two air masses with different temperatures meet, a boundary is formed called a "front." Air masses cover thousands of square meters and extend vertically through the troposphere.

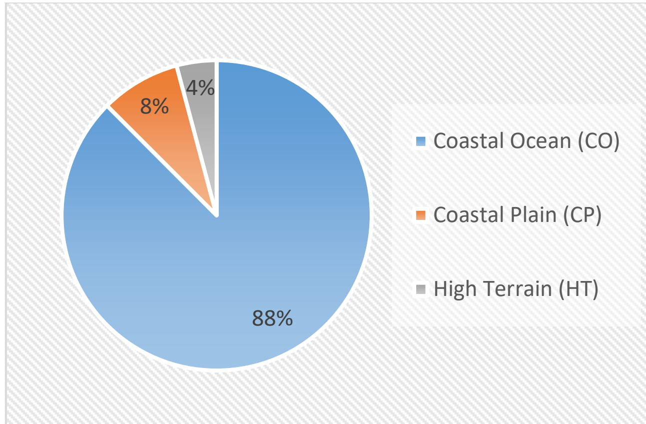

Figure 3. QLCS Formation Area

Meanwhile, in QLCS formation areas or at the initiation stage, almost all cases occurred in water areas, with various types of QLCS formation. The remaining 2 cases of QLCS formation occurred in lowland areas, and one case occurred in highland regions. This again shows that the QLCS in South Sulawesi is strongly influenced by the presence of the waters of the Makassar Strait, which was the initial location of its formation.

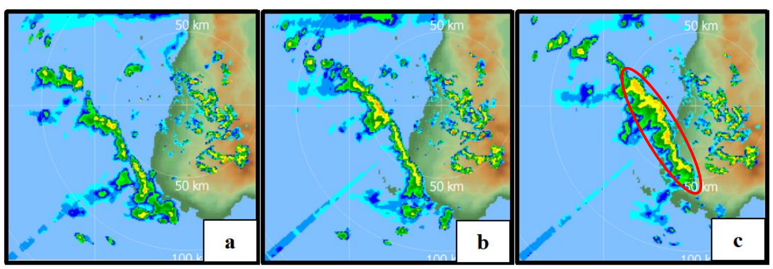

Figure 4. QLCS Broken Line Case on January 9-10, 2023, at (a) 23.45 UTC, (b) 00.15 UTC, and (c) 00.45 UTC

Figure 4 above shows a QLCS case with a broken line formation type from January 9 to January 10, 2023. At 23.45 UTC, cloud cells were observed as separate lines but close to each other over the waters of the Makassar Strait, near the coast (CO). These cloud cells showed that the initiation phase of the QLCS was being formed. Thirty minutes later, at 00.15 UTC on January 10, 2023, the QLCS began to develop, indicated by an increasingly clear line pattern, and moved into the CP area at the coast in Takalar Regency. Furthermore, at 00.45 UTC, the separated cloud cells had merged and formed a solid line, indicating the mature phase of the QLCS. In this mature phase, QLCS has moved further inland, but part of the system is still in the waters of the Makassar Strait.

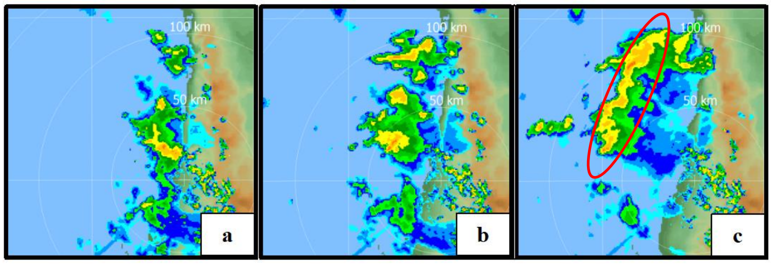

Figure 5. QLCS Back Building Case on November 6, 2022, at (a) 08.45 UTC, (b) 09.15 UTC, and (c) 09.55 UTC

An example of a QLCS case with the back-building formation type occurred on November 6, 2022, as shown in Figure 5 above. The QLCS began with an initiation phase at 08.45 UTC, which was indicated by a large cloud cell in the CP area or around the coastal region of Pangkep Regency. This large cloud cell was followed by the appearance of a small cloud cell to the north. Then, at 09.15 UTC, the large cloud cell continued to grow and move away from the land, while the small cloud cell in the north also grew and moved closer to the large cloud cell. At 09.55 UTC, large and small cloud cells were seen merging and forming a straight-line pattern, which means the QLCS has entered its mature phase. In this mature phase, QLCS has moved far away from the CP area and joined the CO area in the Makassar Strait.

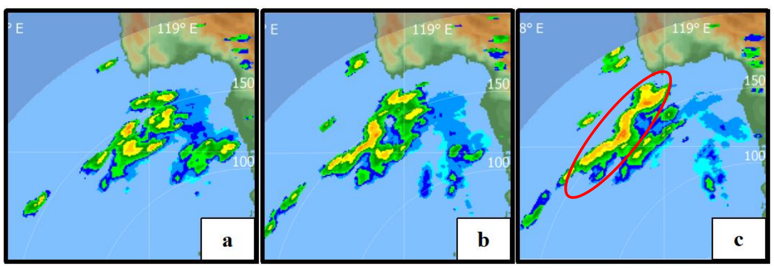

Figure 6. QLCS Broken Area Case on October 1, 2022, at (a) 13:55 UTC, (b) 14:15 UTC, and (c) 14:35 UTC

Figure 6 shows a QLCS case with a broken area formation type that occurred on October 1, 2022. In the initial phase at 13.55 UTC, several cloud cells with an unformed pattern were seen growing over the CO area to the west of the waters of Pare-Pare City. Then, at 14:15 UTC, these cloud cells merged into more giant cloud cells. The cloud cells continued to grow and formed a straight-line pattern at 14.35 UTC, indicating that the QLCS has reached the mature phase with its location still in the CO region.

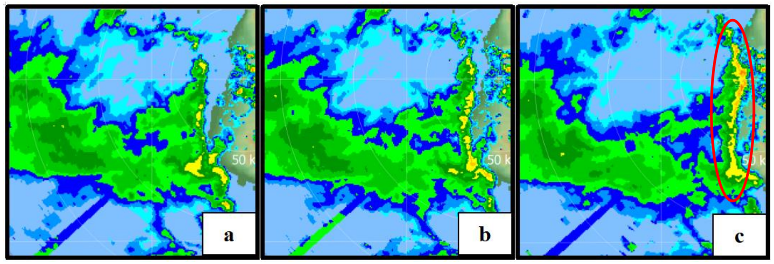

Figure 7. QLCS Embedded Area Case on December 26, 2022, at (a) 11.15 UTC, (b) 11.25 UTC, and (c) 11.35 UTC

The type of QLCS embedded area formation occurred on December 26, 2022, as shown in Figure 7 above. In the initiation phase at 11.15 UTC, a large stratiform precipitation with weak convective lines was observed, growing closer to the Makassar mainland area. The linear convective line became stronger 10 minutes later at 11.25 UTC and entered the mainland area of Makassar City and its surroundings. Then, at 11.35 UTC, the linear pattern became more substantial, along with the increase of reflectivity, indicating that the QLCS had entered the peak or mature phase. This convective line with a linear pattern extends from north to south parallel to the coastline.

In the early stages of broken line formation, as shown in Figure 4 (a), the cloud cells become more prominent and elongated. Besides that, several new cloud cells also appeared among the old ones. This broken line pattern is getting more solid and approaching land, bringing extreme weather. Like the fractured line formation pattern, the back-building formation also consists of several cloud cells in the initial stage. The difference is, in the formation of the back building, there is one large cloud cell, and then the tiny cloud cells around it merges with the large cloud cell. Meanwhile, for the broken areal pattern, the initial stage is marked by many cloud cells, but the shape is amorf or unclear. However, in the following stages, it is a straight line. Unlike the others, the pattern of embedded areal formation does not start from one cloud cell but from a stratiform area. This stratiform area is where the convective lines form the QLCS.

The distribution of QLCS propagation directions (Table 2) varies in almost all directions based on the eight cardinal directions, namely North (N), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W), and Northwest (NW). A total of 15 cases of QLCS or the most dominant propagation are E (towards the east). There are 5 cases of propagation W and 2 cases of propagation SE. Then, 1 case each with propagation NE and SW. Meanwhile, no cases of QLCS were found in propagation N, S, and NW. The highest QLCS propagation speed is in the fast category (F), divided into 15 cases with propagation E, NE, SE, and W. Furthermore, 7 cases are in the intermediate category (I) in the directions E, SE, and W, and 2 cases are in the slow category (S) in the directions SW and W.

The eastward direction of QLCS propagation mainly occurred in December, January, and February (DJF). This shows that the QLCS has a direction that aligns with the west monsoon wind activity during the DJF period, which also moves eastward. Meanwhile, the direction of QLCS propagation to the west mainly occurred in October and November during the transition period. This also shows that QLCS is influenced by the monsoon winds, which are still dominant towards the west. The propagation speed of QLCS is also influenced by monsoon winds, where the fast-moving category is more often found during the west monsoon period.

Based on Table 2, it can also be seen that in 6 QLCS cases, the VWS value was unknown because their location was more than 100 km from the radar center. The highest VWS value observed is 6.67 m/s/km in the 13th QLCS case on December 26, 2022. Meanwhile, the lowest VWS value (3.41 m/s/km) was observed in the 6th case on November 24, 2022. For the category VWS, as many as 14 cases, or the most frequent, were in the strong category, and only 4 cases were in the moderate category. Meanwhile, the weak category was not found at all. This varying VWS value is due to the different locations of QLCS growth. VWS influences the development of Cumulonimbus clouds due to increased convective activity. The greater the VWS value, the stronger the convective intensity of Cumulonimbus cloud growth [6].

Conclusion

The weather radar observations in South Sulawesi during the research period identified 24 cases of QLCS with varying characteristics. Based on spatial distribution, QLCS occurred in lowlands, highlands, and waters, with the formation areas most often in waters. Based on the temporal distribution, QLCS happened in the morning, afternoon, evening, and early morning, with the highest lifetime in the 60-90-minute range. The types of QLCS formation most frequently found in sequence are broken lines, broken areas, embedded area, and the most diminutive back building. The distribution of QLCS propagation directions varied with the dominant direction to the east, and the highest propagation speed was in the fast-moving category. The VWS value varied between 3.41-6.67 m/s/km; the highest VWS category is in the strong category. The characteristics of QLCS in the South Sulawesi region obtained in research have yet to show a correlation between QLCS and extreme weather that often occurs. Further research needs to be designed by adding extreme weather variables, such as heavy rain and strong winds, to be correlated with QLCS.

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