Effect of Nock-Ten Tropical Cyclone on Atmospheric Condition and Distribution of Rainfall in Gorontalo, Ternate, and Sorong Regions

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Abstract. Nock-Ten Tropical Cyclone is an atmospheric phenomenon that has claimed many lives in the Philippines. This super-typhoon cyclone grows in the Western Pacific Ocean, North of Papua. With the area directly contiguous to the trajectory of Nock-Ten Tropical Cyclone growth, it is necessary to study about the growth activity of this tropical cyclones in Indonesia, especially in 3 different areas, namely Gorontalo, Ternate, and Sorong. This study was able to determine the impact of Nock-Ten Tropical Cyclone on atmospheric dynamics and rainfall growth distribution based on the stages of tropical cyclone development. The data used in this study include Himawari-8 IR channel satellite data to see the development stage and movement track of Tropical Cyclone Nock-Ten, rainfall data from TRMM 3B42RT satellite product to know the rain distribution in Gorontalo, Ternate, and Sorong, and reanalysis data from ECMWF such as wind direction and speed, vertical velocity, and relative vorticity to determine atmospheric conditions at the time of development of the Nock-Ten Tropical Cyclone. The results of data analysis processed using GrADS application showed the development stage of Nock-Ten Tropical Cyclone has effect of changes in atmospheric dynamics condition and wind direction pattern. In addition, tropical cyclones also contribute to very light to moderate scale intensity during the cycle period of tropical cyclone development in all three regions.

Keywords: Tropical Cyclone, Rainfall, TRMM, Satellite Imagery

1. Introduction

On 22 December 2016, tropical cyclone has been tracking in the Western Pacific Ocean region north of Papua. Nock-Ten tropical cyclone moves with maximum wind velocity reaches 93 km/h and triggers rain events in some areas. Generally, the formation of this cyclones occurs in areas with latitude positions above 10^{o} or ranges over a distance of 500 km from the equator. Indonesia territory is not a sufficiently effective area for the growth of tropical cyclones. However, due to Indonesia's geographical position adjacent to tropical cyclone trajectory areas, the potential for weather disturbance caused by tropical cyclones is quite influential in Indonesia. For that purpose, study conducted to discuss the impact of Nock-Ten tropical cyclone which occurred in the Gorontalo, Ternate and Sorong areas.

Figure 1. Location of Gorontalo, Ternate, and Sorong Areas located in the northern part of Indonesia *(Taken from Google Map)*

The purpose of this study is to determine the atmospheric condition that occur based on the growth stages and analyse the effect of the cyclones on the conditions of distribution of rainfall in the three areas. Tropical cyclone is a low-pressure system with mesoscale power plant in a synoptic-scale area which has a maximum wind velocity condition of 34 knots or more, which dominates in its central region with a life span of at least 6 hours and grows over the oceans [4]. The growth stage of tropical cyclone consists of four stages, namely the formation stage characterized by the presence of tropical disturbances and the convective cloud areas of Cumulonimbus clouds, immature stages with convective areas that form a circular belt with maximum wind speed increased to reach the gale force wind, ranging from ≥ 34 knots or 63 km/h, the mature stage is characterized by a stable tropical cyclone condition as well as the tropical depression stages show warm cyclone center begin to disappear, with maximum wind speed extending and widening away from the center of the cyclone. Nock-Ten tropical cyclone impact analysis needs to be done in order to know the atmospheric dynamics occurring in Gorontalo, Ternate, and Sorong regions through four growth stages cyclones, i.e. forming stage, immature stage, mature stage and tropical depression stage.

2. Data and Method

This research uses data of Himawari-8 satellite channel of IR channel with wavelength 6.7 µm -7.3 µm. The data taken are daily data based on classification of tropical cyclone stage development. The Himawari-8 satellite image has a 10-minute temporal resolution and spatial resolution in the range 0.5 - 2 km. This study also uses TRMM satellite data which is NASA product to determine the intensity of rainfall at the time of the incident on 21 December to 27 December 2016. Since December 1997, TRMM has observed rain with multiple sensors [7]. TRMM is the first meteorological satellite specially used to gauge tropical and subtropical precipitation quantificationally [2]. TRMM data accumulated daily rainfall used is TRMM 3B42RT with a resolution of space 0.25° and resolution time of 3 hours [5]. The next data used is ERA-Interim reanalysis data which is the ECMWF (The European Center for Medium-Range Weather Forecasts) output. ECMWF data are used in weather forecasts, weather parameter analysis, climate analysis, providing data for reforecast needs and multimodel data. This research data has a resolution 0.75° x 0.75° with weather parameters such as wind patterns and vertical velocity layer 925 mb, 850 mb, 700 mb, 500 mb, and 200 mb.

The method used in this research is the data processing of Himawari-8 satellite image using one of the SATAID (Satellite Animation and Interactive Diagnosis) variation program developed by JMA (Japan Meteorological Agency) in the form of GMSLPC. SATAID serves to display binary satellite data into images. SATAID can display satellite images and combine NWP (Numerical Weather Prediction) numerical weather data. NWP data is separate from satellite imagery data, also obtained from JMA in one package with satellite image data. In general, the processing steps in SATAID start with program, register image data in memory, display image data and advanced operation. This research also use ERA-

Interim reanalysis data processing and TRMM satellite data using GrADS (Grid Analysis and Display System) application. GrADS is a software of WMO recommendation (World Meteorological Organization) to display spatial weather parameters and visualize data into object of map and graph [3]. GrADS can manipulate and visualize geo-science data to be displayed in both graphics and flow lines [6].

3. Result and Analysis

3.1. Satellite Analysis Himawari-8 IR Channel

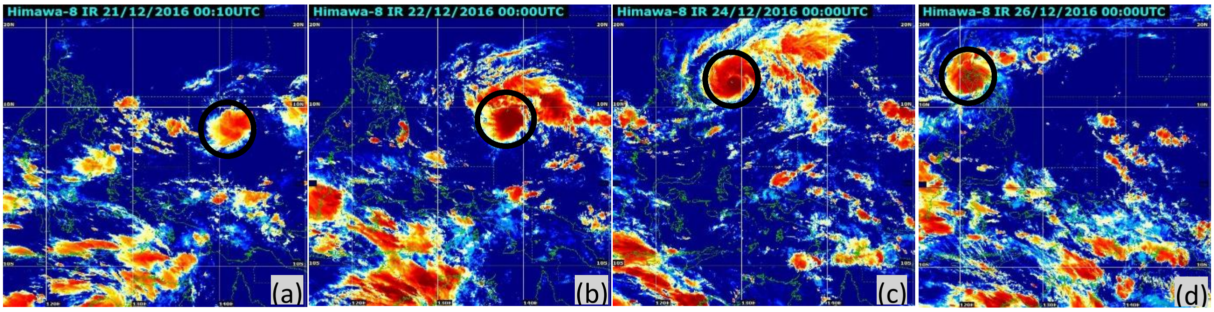

Figure 2. Satellite imageries shows the temporal change of Nock-Ten Tropical Cyclone movement track on **(a)** 21 December 2016, **(b)** 22 December 2016, **(c)** 24 December 2016, and **(d)** 26 December 2016 attached by black circle.

Himawari satellite IR channel imagery shows the temporal changes of Nock-Ten tropical cyclone movement track. Cloud conditions on 21 December 2016 show aggregate of convective clouds in the West Pacific Ocean region that marks the early stages of the cyclone. Then, the rotating cyclone moves and forms circulation also the presence of cloud circular belt indicates the start of cyclone eye formation on 22 December 2016 which shows the stage of cyclone intensification. On 24 December 2016, the cyclone reached a mature stage and moved towards Filipine. It is characterized by the thick convective wall of conventional around the center of the cyclone. On 26 December 2016, Nock-Ten tropical cyclone convective cloud area conditions gradually disappeared.

3.2. Satellite Analysis TRMM 3B42RT

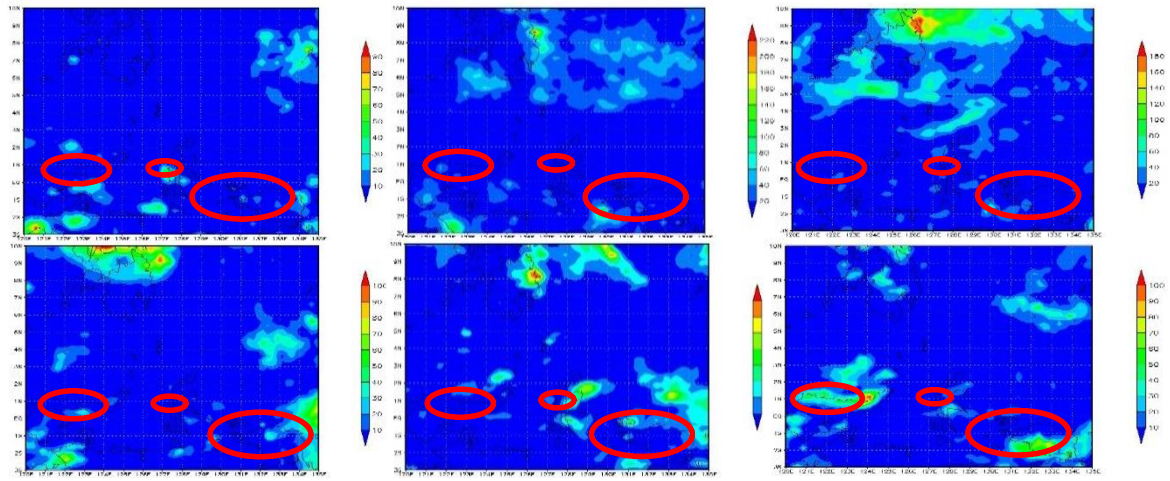

Figure 3. Accumulated rainfall conditions 1 Day through Satellite TRMM 3B42RT analysis ranging on 21 to 26 December 2016. Gorontalo, Ternate and Sorong areas marked by red circles.

From TRMM satellite image analysis results can be seen that on 21 December 2016, which is in the early stages of tropical cyclone formation, rainfall conditions in Gorontalo and Sorong areas generally only range ≤10 mm/day, except Ternate region has an intensity of 10-40 mm/day. On the next day, on 22 December 2016, tropical cyclones were immature and intensified moved towards the northeast of the Filiphina region. The rainfall potential of Gorontalo, Ternate and Sorong is generally only about ≤ 20 mm/day. The mature tropical cyclone stage begins on 24 December 2016. At this stage, the three regions generally have only a potential rainfall event of ≤10 mm/day. Furthermore, the depression occurred on 26 December 2016 with rainfall scale conditions in the three regions varying, ie 10-60 mm/day. From the TRMM analysis, it can be indicated at tropical depression, the three regions experienced an increased rainfall.

3.3. Surface Wind Analysis

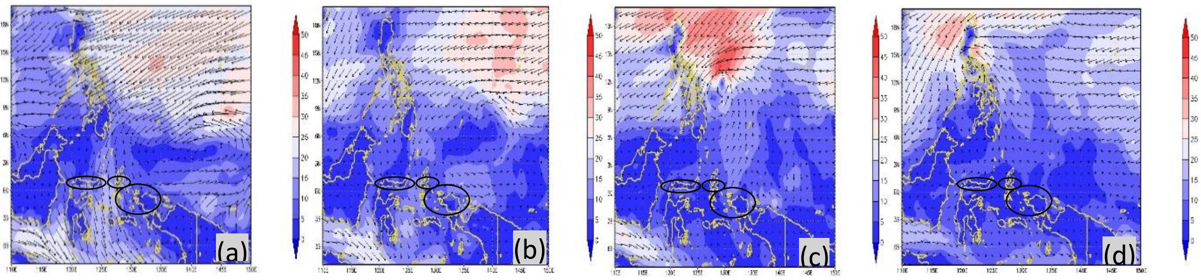

Figure 4. Surface Wind Conditions of GrADS analysis results on **(a)** 21 December 2016, **(b)** 22 December 2016, **(c)** 24 December 2016 and **(d)** 26 December 2016. Gorontalo, Ternate and Sorong regions are shown by black circles.

From the wind surface analysis, the cyclone initial stage of Nock-Ten formation, there is a cyclonic current turnover in the north of West Papua at West Pacific Ocean. This condition results in the formation of convective clouds. Wind condition conditions in parts of Gorontalo, Ternate and Sorong are generally influenced by cyclonic currents and have wind speeds ranging from 5-20 knots. In Ternate it was detected that shear line caused by cyclone generating conventive clouds. The shear line can be an important source of convection as is often associated with strong low-level moisture convergence [1]. The intensification stage shows the condition of the wind patterns in the Sorong area moving cyclonically toward the center of the cyclone with wind velocity between 5-15 knots. It also indicates shear line in all three areas. At a mature stage, air masses in all three regions are attracted toward the centre of the cyclone to the east of the Philippines. Conditions of wind patterns in the three regions generally move with of 5-15 knots velocity. These three areas generally have bright conditions. The depression stage shows the condition of wind patterns in Gorontalo and Ternate generally still influenced by cyclone with speed ≤5 knots. Sorong is generally no longer influenced by the cyclone wind conditions. Wind patterns move to south of Papua at speeds ranging from ≤5 knots.

3.4. Vertical Velocity Analysis

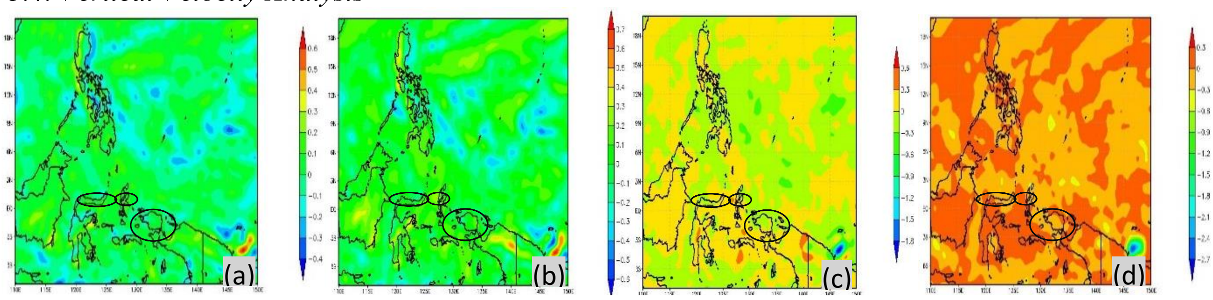

Figure 5. Vertical velocity GrADS analysis results on 21 December 2016 at layers **(a)** 925 mb, **(b)** 850 mb, **(c)** 700 mb and **(d)** 500 mb. The areas of Gorontalo, Ternate, and Sorong are shown in black circles.

At the first stage of Nock-ten Tropical cyclone shown by Figure 5, the GrADS analysis shows in Figure 4 the vertical velocity conditions in (a) 925 mb and (b) 850 mb layers ranging from (-0.2)-0.1 Pa s^{-1} of air mass in the layer is quite low. The pattern indicated by layers (c) 700 mb and layer (d) 500 mb also shows the same value, ranging from (-0.3)-0.3 Pa s^{-1}. Generally, the areas of Gorontalo, Ternate and Sorong have the potential to increase the air mass is quite low and indicate the condition of atmospheric weather in the region is generally bright.

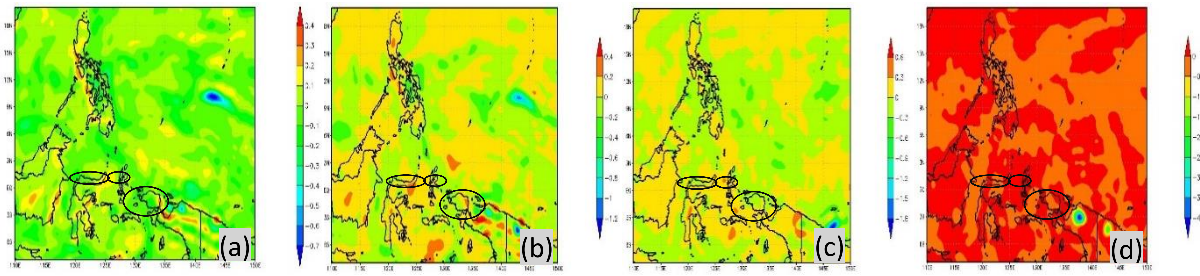

Figure 6. Vertical velocity conditions of GrADS analysis on 22 December 2016 at layers **(a)** 925 mb, **(b)** 850 mb, **(c)** 700 mb and **(d)** 500 mb. The areas of Gorontalo, Ternate, and Sorong are indicated by black circles.

The immature cyclone stage which can be seen from the Figure 6, shows the vertical velocity conditions in the three regions of the (a) 925 mb layer ranging from (-0.1)-0 s^{-1} and layer (b) 850 mb to (-0.2)-0.2 Pa s^{-1}. The negative vertical velocity phase continues until the layer (c) is 700 mb and the layer (d) 500 mb, with each value indicating an average of (-0.3)-0.3 Pa s^{-1} and the number (-0.5)-0 Pa s^{-1}. The pattern of vertical velocity change on a positive to negative scale indicates an indication of the increase in air masses in the region is high enough to indicate the potential for convective clouds in three areas.

The mature stage of the cyclones from Figure 7 shows the vertical velocity at (a) 925 mb layer ranging from 0.3-0 Pa s^{-1}. This indicates a positive vertical velocity condition and air mass decreased. It also occurs in layer (b) 850 mb which shows the value of 0.5-0 Pa s^{-1}. This is also supported by layer condition (c) 700 mb and (d) 500 mb, a decrease of air mass with vertical velocity ≥ 0 Pa s^{-1}. This indicates the potential for the occurrence of convective clouds is quite low in Gorontalo, Ternate and Sorong.

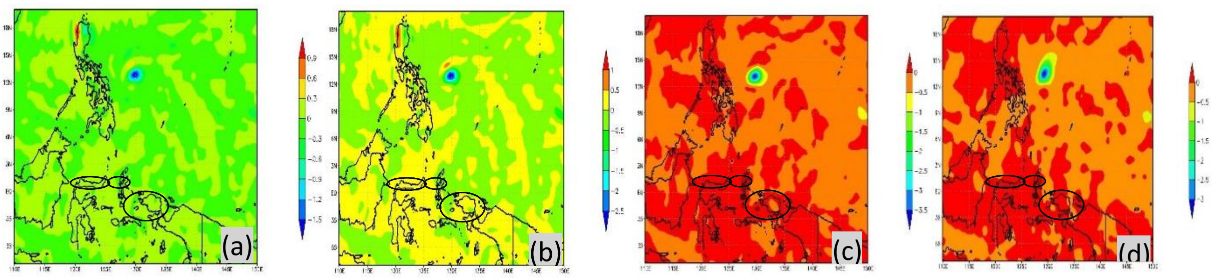

Figure 7. Vertical velocity conditions of GrADS analysis on 24 December 2016 at layers **(a)** 925 mb, **(b)** 850 mb, **(c)** 700 mb and **(d)** 500 mb. The areas of Gorontalo, Ternate, and Sorong are indicated by black circles

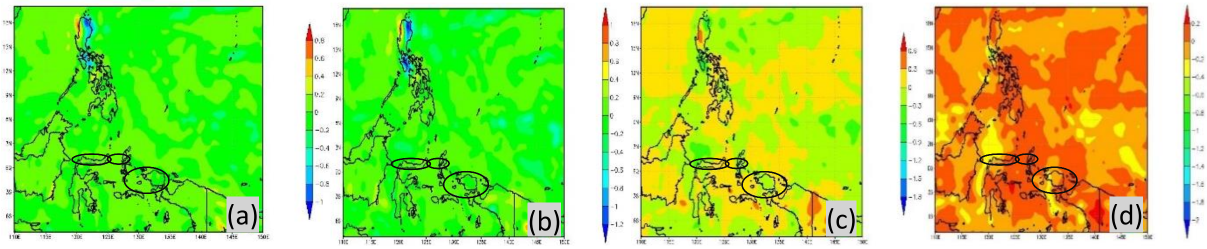

Figure 8. Vertical velocity conditions of GrADS analysis on 26th December 2016 at layers **(a)** 925 mb, **(b)** 850 mb, **(c)** 700 mb and **(d)** 500 mb. The areas of Gorontalo, Ternate, and Sorong are indicated by black circles.

At the tropical depression, the vertical wind velocity conditions of (a) 925 mb and (b) 850 mb range (-0.2)- 0.2 Pa s^{-1}. The potential for air mass increases is quite low in all three regions. The rising pattern continues to layer (c) 700 mb and layer (d) 500 mb with velocity ranging from (-0.3)-0.3 Pa s^{-1} and (-0.4)-0 Pa s^{-1}. Parts of Sorong area are detected to have a vertical velocity of (-0.4) s^{-1} indicating the potential for convective clouds to form. From the analysis result, it can be concluded that there is an increase of active air mass in Sorong city, while Gorontalo and Ternate areas generally have low rainfall potential.

3.5. Relative Vorticity Analysis

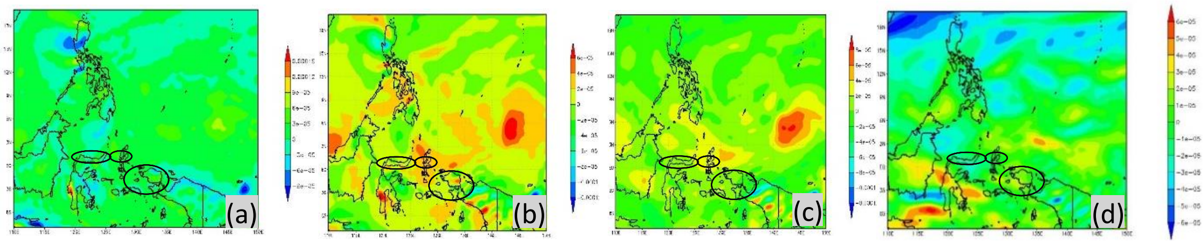

Figure 9. Relative Vorticity GrADS analysis results on 21 December 2016 at layers **(a)** 925 mb, **(b)** 850 mb, **(c)** 700 mb and **(d)** 200 mb. The areas of Gorontalo, Ternate, and Sorong are shown in black circles.

Based on the results of GrADS analysis in the early stages of Nock-Ten tropical cyclone formation, it can be seen that the average relative vorticity condition at 925 mb layer in Gorontalo, Ternate, and Sorong areas shows 3 x 10^{-5} s^{-1} values. This indicates cyclonic wind conditions. Layers of 850 mb and 700 mb show the same relative vorticity values, ranging from 4 x 10^{-5} - (-2 x 10^{-5}) s^{-1}. In the 200 mb layer, the relative vorticity values range from 2 x 10^{-5} - (-2 x 10^{-5}) s^{-1} and indicate that movement is generally anticyclonic. The analysis shows that the weather conditions in the three regions are generally clear.

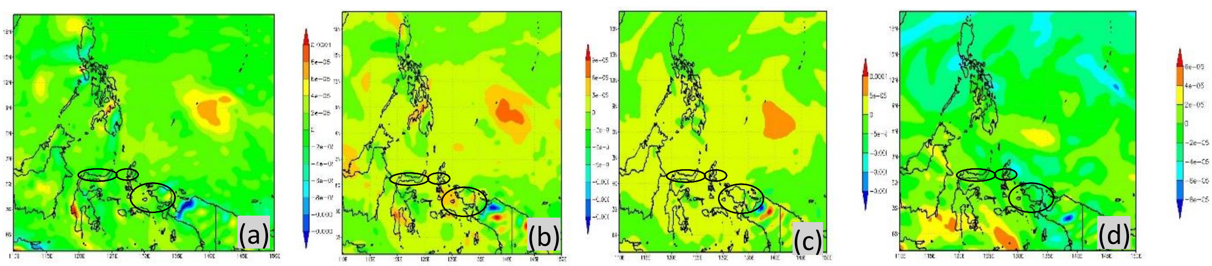

Figure 10. Relative Vorticity GrADS analysis results on 22 December 2016 at layers **(a)** 925 mb, **(b)** 850 mb, **(c)** 700 mb and **(d)** 200 mb. The areas of Gorontalo, Ternate, and Sorong are shown in black circles.

At the cyclone intensification stage, it can be seen in all three regions in 925 mb having an average relative vorticity value of 4 x 10^{-5}-0 s^{-1} except in the northern part of Sorong is -6 x 10^{-5} s $^{-1}$. This indicates a cyclonic condition. The cyclonic wind conditions are also supported on the 850 mb layer of 3 x 10^{-5}-0 s^{-1}, except in northern Gorontalo and Sorong, and the 700 mb layer shows a value of 5 x 10^{-5} s^{-1}. The 200 mb layer shows a value of 2 x 10^{-5} - (-2 x 10^{-5}) s^{-1}. This shows the condition of relative vortices at intensive stage is generally cyclonic.

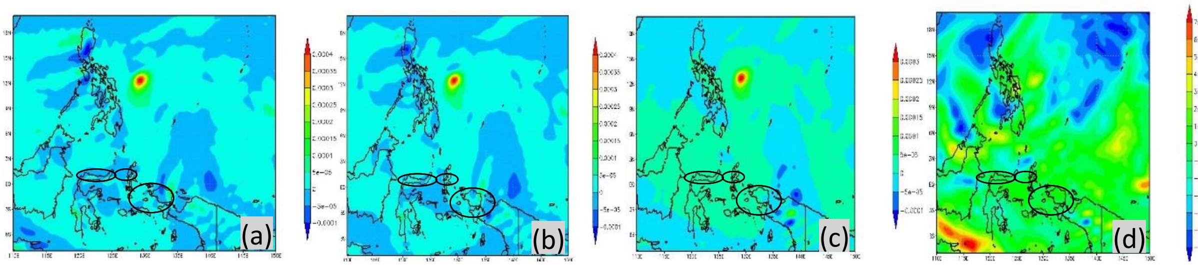

Figure 11. Relative Vorticity GrADS analysis results on 24 December 2016 at layers **(a)** 925 mb, **(b)** 850 mb, **(c)** 700 mb and **(d)** 200 mb. The areas of Gorontalo, Ternate, and Sorong are shown in black circles.

In the Nock-Ten tropical cyclone mature stage which shown in Figure 11, relative vorticity conditions at 925 mb and 850 mb layers show an average value of 5 x 10^{-5} - (-5 x 10^{-5}) s^{-1}. At 700 mb layers, relative vorticity conditions in the three regions are positively 1 x 10^{-4} s^{-1}. This shows the existence of cyclonic movement in all three regions. Cyclones are also shown up to a layer of 200 mb indicating a range of reach (2 x 10^{-5}) - 0 s^{-1}.

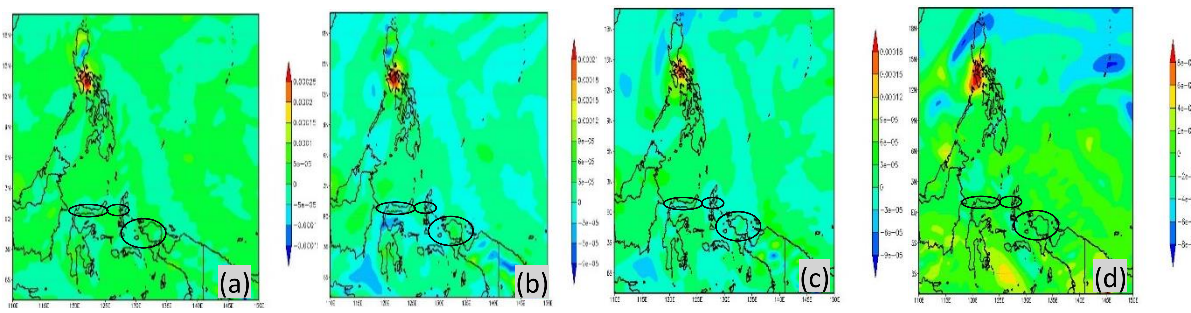

Figure 12. Relative Vorticity GrADS analysis results on 26 December 2016 at layers **(a)** 925 mb, **(b)** 850 mb, **(c)** 700 mb and **(d)** 200 mb. The areas of Gorontalo, Ternate, and Sorong are shown in black circles.

The tropical depression phase of Nock-Ten tropical cyclone is shown in Figure 12. At this stage, the relative vorticity condition indicates a positive value in the 925 mb layer, ie 5 x 10^{-5} s^{-1}, except for the Gorontalo region reaching 5 x 10^{-5} s^{-1}. This condition is also supported by layers of 850 mb and 700 mb, Sorong and Ternate regions show positive values about 6 x 10^{-5} -0 s^{-1}, except Gorontalo reach -3 x 10^{-5} s^{-1}. In the 200 mb layer, the relative vorticity conditions of the three regions show a value of 2 x 10^{-5} - (-2 x 10^{-5}) s^{-1}. From the analysis results on 26 December 2016 it can be concluded that relative vorticity conditions in Sorong and Ternate move cyclonic, except Gorontalo region moves anticyclonic.

3.6. Rainfall Observation Analysis

From the graph of rainfall accumulation, rainfall conditions detected in Gorontalo, Ternate and Sorong generally have the same pattern, except on 26 December having different intensity scale of rainfall. Maximum rainfall conditions generally occur on 26 December 2016, ie the tropical depression, except

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in the Gorontalo region experienced a decrease in intensity. The rainfall conditions during the early stage of cyclones in the three regions ranged from ≤ 10 mm/day. At the intensification stage, the three areas experienced an increase rainfall ranging from 15-35 mm/day, whereas mature stage generally low rainfall distribution ranges ≤ 10 mm/day.

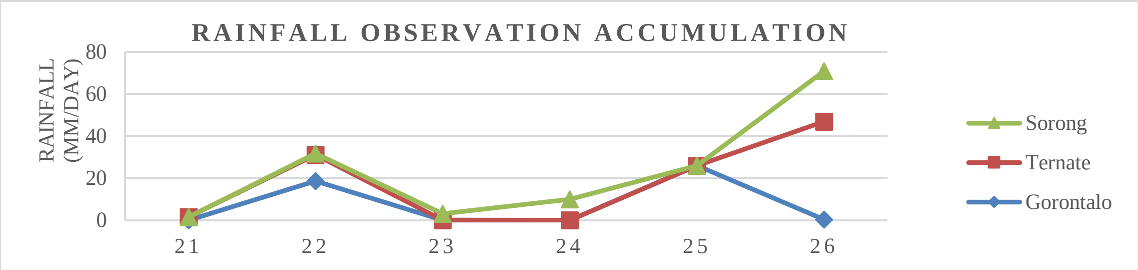

Figure 13. Average accumulated rainfall meteorological station of Gorontalo, Ternate, and Sorong on 21-26 December 2016.

4. Conclusions

Tropical Cyclone Nock-Ten events have an impact on atmospheric events in Gorontalo, Ternate and Sorong. Generally, at the early stage of cyclone growth, the three regions have fairly bright weather conditions with low rainfall intensity caused by the influence of warm air mass to the cyclone trajectory area and is supported by a low enough air mass potential increase and the anticyclonic movement. The intensification stage shows the three regions influenced by the cyclonic condition and the negative vertical velocity value and causing the shear line which contribute to slight-moderate scale rainfall. At the mature stage of tropical cyclones, the regions generally have bright conditions that are also supported by positive vertical velocity except in Sorong area which has slight intensity rain due to air masses in all three areas attracted towards the centre of the cyclone. In the tropical depression, the three regions have different scale of rainfall intensity. Seen from the wind pattern, the weather conditions of Gorontalo and Ternate areas are still affected by the cyclone, except for the Sorong region that is affected by the local scale factors indicated by negative value of vertical velocity. Generally, Gorontalo has clear weather condition which supported by anticyclonic condition in relative vorticity. Sorong and Ternate have moderate to heavy rain which supported by cyclonic movement.

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