Simulation of atmospheric dynamics during heavy rain events on Nias Island using WRF model and Himawari-8 satellite data

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Abstract. Nias is the largest island in the Indian Ocean west of Sumatra. The geographical condition of Nias Island which is a small island surrounded by waters causes strong weather dynamics and high intensity of rainfall. This study was conducted to determine changes in weather dynamics conditions during high rainfall on Nias Island, including the parameters of the vertical profile of air humidity, vorticity, divergence, vertical velocity, reflectivity; and cloud top temperatures. The simulation was carried out on 4 days of heavy rain in 2020, each representing each season period, namely 7 February 2020 for December-January-February (DJF), 30 April 2020 for March-April-May (MAM), 3 August 2020 for June-July-August (JJA), and 8 October 2020 for September-October-November (SON). The data used are Final Analysis Data (FNL) with a spatial resolution of 1°x1° as input data for the Weather Research and Forecast (WRF) model, IR1 data (band#13 – 10.4μm) Himawari-8 satellite, and observational rainfall data from the Binaka and Global Meteorological Stations. Precipitation Measurement – The Integrated Multi-Satellite Retrievals for GPM (GPM IMERG) with a spatial resolution of 0.1°x0.1°. The results showed that the presence of Cumulonimbus convective clouds caused heavy rain, with cloud top temperatures reaching -60°C to -80°C. The relatively humid atmosphere, accompanied by the convection mechanism that occurs, causes the convective activity on Nias Island to be quite intense.

1. Introduction
Nias Island is the largest island among a group of islands on the west coast of Sumatra, which is administratively within the province of North Sumatra. As an area surrounded by waters, Nias Island has a high potential for marine tourism, including Sail Nias activities. In addition, the topographical conditions cause the weather conditions on Nias Island to be very local and dynamic and have very intense convective activity [1]. Intense convective activity causes high rainfall on Nias Island. Cumulonimbus convective clouds can cause extreme weather events, such as heavy rain, strong winds, thunderstorms, and high waves [2]. Extreme weather is one thing that needs attention to support safety in tourism and transportation on Nias Island.

As part of disaster mitigation to support the safety of community activities, accurate weather forecasts are needed to anticipate the occurrence of extreme weather. One method that can be used to improve the accuracy of weather forecasts is to use Numerical Weather Prediction (NWP) [3].
Weather Research and Forecast Model (WRF) is a mesoscale NWP that is open source and flexible so that it can be used for operational weather forecasts or developed for research needs [4–7]. This research was conducted to simulate the weather conditions on Nias Island and its surroundings during heavy rains using the WRF model as NWP product and Himawari-8 as the remote-sensing product. Time-series analysis was carried out on weather parameters from the WRF model output, including surface wind, humidity, vorticity, divergence, and vertical velocity, as well as cloud top temperature (IR1) data from the Himawari-8 satellite.

2. Literature Review

2.1. Rain
Precipitation is a meteorological phenomenon in the form of deposits that fall from the atmosphere to the earth's surface [2,8]. Precipitation can occur in several forms, namely rain, drizzle, snow, and hail [9]. Rain is a hydrometeor in the form of water droplets that fall to the earth's surface and has a diameter of more than or equal to 0.5 mm. Rain occurs when water vapor in the atmosphere condenses into droplets that cannot be held in the air (often referred to as saturated).

The following are the criteria for rain events based on rainfall intensity according to the BMKG:

| Table 1. Rainfall intensity classified according to the rate of precipitation (BMKG) |
|---------------------------------|---------------------------------|
| Rainfall per hour | Accumulated daily rainfall |
| Very light | 0.1-1 mm | < 5 mm |
| Light | 1-5 mm | 5-20 mm |
| Moderate | 5-10 mm | 20-50 mm |
| Heavy | 10-20 mm | 50-100 mm |
| Extreme (violent rain) | > 20 mm | > 100 mm |

2.2. Convective activity
Convective activity or convective cloud growth can be observed using the interpretation of Himawari-8 satellite imagery [10,11]. Interpretation of satellite imagery using cloud top temperature thresholds is used to determine cloud types. The lower the cloud top temperature value indicates the colder the cloud top and the higher the position. Clouds of this type can be identified as high clouds and/or convective clouds. Low clouds generally have warmer cloud tops and their positions are relatively close to the earth's surface. Clouds with low cloud top temperatures can cause rain [12]. Convective clouds in the mature stage with cloud top temperatures around 195-241 K can cause heavy rain [13]. The decrease in the value of the cloud top temperature becoming cooler can be used as an indicator of increasing rainfall intensity, such as -45°C for light rain, -47°C for moderate rain, and -50°C for heavy rain [14].

Cumulonimbus clouds are a type of convective cloud that causes extreme weather events, such as heavy rain, strong winds, and hail. The stages of Cumulonimbus cloud development can be identified based on the cloud top temperature value using IR1 data from the Himawari-8 satellite, consist of the growth stage (Cumulus Stage) with a cloud top temperature value of -30°C to -50°C; mature stage (Mature Stage) with a cloud top temperature value of -60°C to -80°C; and a decay or extinct stage (Dissipating Stage) with a cloud top temperature value of -50°C to -55°C [15].

2.3. Atmospheric dynamic
Atmospheric dynamics are changes in weather conditions that can be seen using several parameters, including wind, humidity, vortices, convergence/divergence, and vertical velocity. Atmospheric dynamics analysis can be done by looking at changes in the vertical profile of weather parameters from time to time (time-series).
a) Vorticity is a vector field (curl) velocity of fluid rotation in microscopic size which has vector dimensions [16,17]. In the Northern Hemisphere (BBU), if the relative vorticity is greater than zero, it indicates a cyclonic movement that causes the air mass to move upward (convection). Circulation and vortices have a relationship and are calculated with the approach that vortices are defined as circulation divided by the area covered [17] so that it can be written in the following equation:

\[
\zeta = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}
\]  

(1)

b) Convergence is the meeting of several different wind patterns where the wind speed is getting weaker. Shady wind conditions support the updraft mechanism which is the main prerequisite for the formation of convective clouds. Divergence is an area of wind spread where the wind speed is getting stronger [9,17,18]. Divergence values can be calculated using the data of the zonal wind (east-west wind; N) and meridional wind (north-south wind; V) using the following equation:

\[
Div V = \nabla_{H,\phi} = \frac{\partial u}{\partial v} + \frac{\partial v}{\partial v}
\]  

(2)

c) Vertical velocity is a parameter to measure an air mass movement in a vertical plane. There are two methods that can be used to determine vertical or omega motion, namely the kinematic method which is based on the continuity equation, and the adiabatic method which is based on the thermodynamic energy equation [17,18]. In the calculation used in this study, the positive vertical velocity value indicates an increase in the value of pressure per second in a vertical plane or there is a downward movement of an air mass. Here's the equation for the vertical velocity in (x, y, z) coordinates:

\[
\omega = - \rho g w
\]  

(3)

3. Methodology

3.1. Research data
The research was conducted on several case studies of heavy rains on Nias Island for the 2020 period, namely 7 February 2020, 30 April 2020, 3 August 2020, and 8 October 2020. The following are some of the data used in this study:

a. Rainfall measurement data per 3 hours from the Binaka Meteorological Station;

b. Daily rainfall accumulation data from GPM IMERG final precipitation with a spatial resolution of 0.1°x0.1° downloaded from NASA's Earth Data webpage at https://disc.gsfc.nasa.gov/;

c. IR1 data (band#13 with a wavelength of 10.4µm) Himawari-8 satellite from BMKG;

d. FNL (Final Analysis) data with a spatial resolution of 1°x1° downloaded from the NCEP FNL Operational Model Global Tropospheric Analyses webpage at https://rda.ucar.edu/datasets/ds083.2/. In each case study, 36 hours of FNL data were used, with the first 12 hours on the previous day being used as a spin-up of the WRF model.

3.2. Research Methods
The following steps are conducted out in this research:

1) Determining the time of the case study based on rainfall measurement data for the 2020 period from the Binaka Meteorological Station. The case study selected was one day of heavy-very heavy rain (rainfall > 50 mm/day) to represent the four seasons. Based on these criteria, case studies were selected on 7 February 2020 for December-January-February (DJF), 30 April 2020 for
March-April-May (MAM), 3 August 2020 for June-July-August (JJA), and 8 October 2020 for September-October-November (SON).

2) Processing the IR1 data using SATAID software, which displays a time-series graph of cloud top temperatures at coordinates 97.70°E 1.16°N (Binaka Meteorological Station) and displays the spatial map of cloud top temperatures in the Nias Island and surrounding areas.

3) WRF model simulation using FNL data in four case studies. This stage consists of pre-processing in the WRF Pre-processing System (WPS) including geogrid.exe on static geographical data; ungrib.exe on gridded meteorological data; and metgrid.exe, numerical processes in WRF-ARW (real.exe and wrf.exe); and WRF Post-processing using ARWpost.exe.

4) Plotting the WRF model output data using the GrADS software.

5) Analysed the convective evolution and changes in atmospheric conditions in each case study.

The following is a workflow diagram in research:

![Workflow Diagram](image)

**Figure 1.** Research flow chart

### 3.3. WRF-ARW model configuration

Numerical simulations were conducted using the WRF Version 4.1.2 model with three-domain nesting (Figure 2) applying horizontal resolutions of 27, 9, and 3 km and the configuration as shown in Table 2.

| WRF configuration | D01 | D02 | D03 |
|-------------------|-----|-----|-----|
| Run Hours         | 36  |     |     |
| Time Step         | 18  |     |     |
| Center Latitude   | 1.16°N |     |     |
| Center Longitude  | 97.70°E |     |     |
| geog_data_res     | 10 m | 5 m | 5 m |
| dx                | 27 km | 9 km | 3 km |
| dy                | 27 km | 9 km | 3 km |
| e_we and e_sn     | 100 | 88  | 76  |
| e-vert            | 34  |     |     |

**Parameterization Scheme**

TROPICAL physics scheme
Figure 2. WRF model domain map; D01 = first domain, D02 = second domain, and D03 = third domain

4. Results and Discussions

The following is the time-series rainfall data based on observational data from the Binaka Meteorological Station in each case study:

| Observation Time (UTC) | 7 Feb 2020 | 30 Apr 2020 | 3 Agu 2020 | 8 Okt 2020 |
|------------------------|------------|-------------|------------|------------|
| 00.00-03.00            | 0.0        | TTU         | 0.0        | 1.0        |
| 03.00-06.00            | 0.0        | 16.0        | 0.0        | 8.2        |
| 06.00-09.00            | 0.0        | 16.5        | 55.5       | 0.2        |
| 09.00-12.00            | 0.0        | 0.5         | 16.5       | 16.3       |
| 12.00-15.00            | 0.9        | TTU         | 0.0        | 33.1       |
| 15.00-18.00            | 32.0       | TTU         | 0.0        | 1.4        |
| 18.00-21.00            | 20.0       | 10.4        | 0.0        | 1.2        |
| 21.00-24.00            | 1.0        | 44.4        | 0.0        | 2.9        |
| 00.00-24.00            | 53.9       | 87.8        | 72.0       | 67.5       |

Time-series data of 3-hour rainfall shows variations in the period of heavy rain. On February 7, 2020, heavy rain occurred at 15-18 UTC hour intervals; 30 April 2020 at 21-24 UTC; 3 August 2020 at 06-09 UTC; and 8 October 2020 at 12-15 UTC. Heavy rains on 30 April 30, 2020, and 8 October 8, 2020, started with light-moderate rain, in contrast to heavy rains on February 7, 2020, and August 3, 2020, which did not start with light rain. This indicates that intense convective activity occurs in a relatively short time.

4.1. Analysis for February 7, 2020

The spatial distribution of rainfall on 7 February 2020 (Figure 3) shows that there were heavy rain areas on Nias Island at 06-09 UTC, but not observed at the Binaka Meteorological Station (GNS). At 15.00 UTC, rain areas were seen forming in the eastern waters of Nias Island which moved westward. Rainfall at 15-18 UTC in GNS is about 15-25 mm. IMERG GPM data shows the accumulation of daily rainfall in the GNS is around 25-35 mm. This shows that the WRF model is able to capture the time of the rain event on February 7, 2020, but the rainfall value is lower (under-estimate) than the observation data.
The time-series graph of cloud top temperature (TBB) on 7 February 2020 (Figure 4) shows two periods of convective cloud growth around the GNS. The first period, starting at around 02.00 UTC, reaches the mature phase at around 03.00 UTC, and undergoes a decay phase until around 05.00 UTC. The lowest cloud top temperature in the first period was around -55ºC. The second period, starting at around 09:00 UTC, reaches the mature phase at about 14:30 UTC, and decays until around 24:00 UTC. The lowest cloud top temperature in the second period reached -84ºC.

There is a match between convective activity that occurs with the distribution of rain output from the WRF model on February 7, 2020. Heavy rain that occurs at intervals of 06-09 UTC is caused by convective activity that occurs at intervals of 02-05 UTC. Heavy rains that occur at intervals of 15-18 UTC are caused by convective activity that occurs at intervals of 09-24 UTC.
Based on the time-series analysis of cloud top temperatures, cloud top temperatures were mapped in the Nias Island and surrounding areas (Figure 5). Seen at 08.00 UTC there are seeds of convective clouds in the waters west of Nias Island. This convective cloud cluster is developing, and at 14.00 UTC it reaches the mature phase with the widest cloud coverage area (red color), even covering the entire area of Nias Island. The fading of the red color indicates an increase in the temperature of the cloud top, which means that the convective cloud is undergoing a decay phase.

![Figure 5](image)

The vertical profile of air humidity (Figure 6.a) shows humid air conditions, namely in the lower layer (1000-800 hPa) with a humidity value of around 75-95%, in the middle layer (700-400 hPa) with a value of around 50-85 %, and in the upper layer (300-100 hPa) with a value of about 40-60%. The vertical velocity profile (Figure 6.b) shows that in the interval of 03-06 UTC there is a positive vertical velocity value in the lower layer, which means that there is an upward vertical movement of air (updraft). The updraft phenomenon is part of the convective cloud growth phase. At intervals of 12-15 UTC, it is seen that there is a negative vertical velocity value in all layers, which means that there is a downward vertical movement of air. The downdraft phenomenon is an indication that convective clouds have reached a mature phase. The vertical vorticity profile (Figure 6.c) shows that at intervals of 03-24 UTC there is a positive vorticity value in the lower layer, which means that there is a lifting of air masses to the top layer (lifting). This phenomenon means that there is intense convection activity on February 7, 2020. At the 12-18 UTC interval, there is a negative vorticity value in the middle layer, which means that the air mass is moving downwards. This phenomenon shows the mass of water vapor that falls into precipitation or rain. The vertical divergence profile (Figure 6.d) shows that at intervals of 12-15 UTC there is a negative divergence value in the lower layer and a positive divergence value in the upper layer. This means that there is a convergence at the bottom layer along with divergence at the top layer. This pattern of air circulation indicates the occurrence of convective activity.
4.2. Analysis for April 30, 2020

The spatial distribution of rainfall on April 30, 2020 (Figure 7) shows that there are rain areas in the waters east-south of Nias Island in the morning, at intervals of 00-03 UTC. This rain was measured in GNS at intervals of 03-06 UTC with a rainfall value of 16.0 mm. At night, at intervals of 12-15 UTC, there is a rainy area in the waters west of Nias Island. At intervals of 18-21 UTC, rain areas were seen forming in the waters east of Nias Island, around the GNS. The daily accumulated rainfall value based on the output of the WRF model in GNS is in the range 4-8 mm, while based on IMERG GPM data it is in the range 35-45 mm. This shows that the WRF rainfall model is not able to capture the time of the heavy rain that occurred on April 30, 2020.

The time-series graph of cloud top temperature (TBB) on April 30, 2020 (Figure 8) shows intense convective activity around the GNS. The first convective cloud growth begins at around 00.30 UTC, reaches the mature phase with a cloud top temperature of -60°C at 01.00 UTC, and decays until 02.30 UTC. The growth of the second convective cloud begins at 02.40 UTC, reaches the mature phase with a cloud top temperature value of around -65°C at 04.10 UTC to 06.00 UTC, and decays to 08.00 UTC. At 11.00 UTC there was a third convective cloud growth, reaching the mature phase with a cloud top temperature value of around -65°C at 17.00 UTC to 18.00 UTC, and decaying up to 20.00 UTC. This convective cloud decay was followed by further convective cloud growth which reached a cloud top temperature of -77°C at 21.40 UTC. There is a match between the convective activity that occurs with the distribution of rain on April 30, 2020. Intense convective activity occurs followed by rain that occurs throughout the day.

The convective activity that occurred on April 30, 2020, is mapped spatially (Figure 9). At 01.30 UTC, the seeds of convective clouds were seen in the waters east of Nias Island. This convective cloud cluster developed and reached the widest coverage area of convective clouds (red color) 02.30 UTC and then decayed (fading red color) until 04.00 UTC. At 06.00 UTC, convective cloud seeds were seen growing in the south of Nias Island until 08.00 UTC. At 14.30 UTC, convective cloud seeds were seen growing in the waters east of Nias Island and moving westward. The process of developing convective clouds is very fast and is followed by the growth of several seeds of convective clouds in the vicinity. At 17.30 UTC it was seen that some of the convective cloud seeds had merged to form a convective cloud cluster with a relatively wide cloud area coverage. The decay of this convective cloud cluster was followed by the growth of several convective cloud seeds which then formed a convective cloud cluster that covered the northern part of Nias Island.
Figure 7. 3-hour rainfall distribution map and daily accumulation from IMERG WRF and GPM models on April 30, 2020

Figure 8. Time-series graph of cloud top temperature at coordinates 97.70°E 1.16°N on April 30, 2020
Figure 9. IR1 image of Himawari-8 satellite in Nias Island and surrounding areas on February 7, 2020

The vertical profile of air humidity (Figure 10.a) shows humid air conditions, namely in the lower layer (1000-800 hPa) with a humidity value of 75-95%, in the middle layer (700-400 hPa) with a value of 50-90%, and in the upper layer (300-100 hPa) with a value of 30-70%. The vertical velocity profile (Figure 10.b) shows that at intervals of 03-06 UTC there are positive vertical velocity values in all layers, which means that there is an upward vertical movement of air. The updraft phenomenon indicates the growth phase of convective clouds. At intervals of 09-24 UTC, it can be seen that there is a negative vertical velocity value in all layers, which means that there is a vertical downward movement of air (downdraft). This negative vertical velocity value is still accompanied by a positive value, which means that new convective cloud growth occurs when the previous convective cloud decays or convective continuity activities. The vertical vorticity profile (Figure 10.c) shows the values of positive and negative vortices spread across layers throughout the day. This indicates that there is a process of moving air masses up and down simultaneously. This is following the convective activities and rain that occurs throughout the day. The vertical divergence profile (Figure 10.d) shows that at intervals of 09-24 UTC there is a negative divergence value in the lower layer and a positive divergence value in the upper layer. This means that there is a convergence at the bottom layer along with divergence at the top layer. This pattern of air circulation indicates the occurrence of convective activities.
4.3. Analysis for August 3, 2020

The spatial distribution of rainfall on August 3, 2020 (Figure 11) shows that there are heavy rain areas in the eastern part of Nias Island at 06-09 UTC, with rainfall values in GNS in the range of 10-25 mm. The highest rainfall in this period occurred at 08.00 UTC. The daily accumulated rainfall value around the GNS based on the output of the WRF model is in the range of 20-35 mm, while based on IMERG GPM data it is in the range of 20-45 mm. This shows that the WRF model can capture the time of heavy rain on August 3, 2020, even though the rainfall value is lower (under-estimate) than the observation data.

The time-series graph of cloud top temperature (TBB) dated August 3, 2020 (Figure 12) shows the growth of convective clouds occurring from 05.00 UTC to 08.00 UTC with cloud top temperatures in the range of -10°C to -20°C. At 09.00 UTC, the cloud top temperature value decreased and reached a relatively stable condition from 11.00 UTC to 24.00 UTC, with values in the range of -30°C to -50°C. This cloud cluster is indicated not to be a convective cloud, but a stratiform cloud with a high cloud top (Cirrus cloud). Heavy rains that occurred on August 3, 2020, were indicated to be caused by convective clouds growing at intervals of 05-09 UTC.

The spatial map of cloud top temperatures (Figure 13) shows that at 06.30 UTC there were convective cloud seeds on the west coast of Nias Island, and moving east. This convective cloud cluster has developed until it reaches the mature phase at 08.10 UTC with the coverage of the convective cloud area (red color) is not too wide. The limited coverage of the convective cloud area formed indicates that this convective cloud is a single cell Cumulonimbus cloud.
Figure 11. Hourly, 3-hour and daily accumulation rainfall distribution maps from IMERG’s WRF and GPM models dated August 3, 2020.

Figure 12. Time-series graph of cloud top temperature at coordinates 97.70°E 1.16°N on August 3, 2020.
The vertical profile of air humidity (Figure 14,a) shows that in moderately humid air conditions, namely in the lower layer (1000-800 hPa) with a humidity value of 70-90%, in the middle layer (700-400 hPa) with a value of 50-70%, and in the upper layer (300-100 hPa) with a value of 30-60%. The vertical velocity profile (Figure 14,b) shows that at intervals of 03-06 UTC there is a positive vertical velocity value in all layers, which means that there is an upward vertical movement of air (updraft). The updraft phenomenon is part of the convective cloud growth phase. This updraft phenomenon is then followed by a downdraft phenomenon (negative vertical velocity value) which is not too strong because the convective clouds formed have relatively small cloud area coverage. The vertical vorticity profile (Figure 14.c) shows negative vorticity values in the lower layers throughout the day. The negative vorticity value indicates that the air is difficult to lift so that convective activity is difficult to occur. The vertical divergence profile (Figure 14.d) shows the dominant positive divergence values occurring in all layers throughout the day. This divergence condition causes the dissolution of air masses so that convective activity is difficult to occur.

Figure 13. IR1 image of Himawari-8 satellite in Nias Island and surrounding areas on August 3, 2020

Figure 14. Vertical profile of atmospheric parameters on August 3, 2020; (a) humidity, (b) vertical velocity, (c) vorticity, (d) divergence
4.4. Analysis for October 8, 2020

The spatial distribution of rainfall on October 8, 2020 (Figure 15) shows that at intervals of 09-12 UTC, rain areas formed on the east coast of Nias Island around the GNS, with rainfall values of 6-10 mm. At intervals of 12-15 UTC, rain areas formed in the waters west of Nias Island, while at intervals of 15-18 UTC also formed in the western and eastern waters of Nias Island. The daily accumulated rainfall value in the area around the GNS based on the output of the WRF model is around 6-20 mm, while based on IMERG GPM data it is in the range of 45-60 mm. This shows that the WRF model is able to capture the time of the rain event on October 8, 2020, but the rainfall value is lower (under-estimate) than the observation data.

The time-series graph of cloud top temperature (TBB) on October 8, 2020 (Figure 16) shows that at 03.00 UTC there was a convective cloud growth, reaching the mature phase at around 04.20 UTC with a cloud peak temperature reaching -72°C, and then decaying until 06.00 UTC. The decay of the first convective cloud continued with the growth of the second convective cloud, which lasted until around 09.20 UTC, reached the mature phase at 10.00 UTC with the cloud top temperature reaching -60°C, and then decayed until 15.00 UTC. At 22.00 UTC, there was a growth of convective clouds that reached the mature phase at around 23.40 UTC with a cloud peak temperature reaching -60°C.

There is a correspondence between convective activity that occurs with the distribution of rainfall on October 8, 2020. Rain measured at intervals of 03-06 UTC is indicated to be caused by the first convective cloud, which develops at intervals of 03-06 UTC. A second convective cloud that developed at intervals of 09-15 UTC resulted in rain measured at intervals of 09-15 UTC, with the highest value reaching 33.1 mm. Convective activity that still occurs causes rain to still occur until 24.00 UTC, although with low rainfall intensity.
The spatial map of cloud top temperatures on October 8, 2020 (Figure 17) shows that at 03.00 UTC there were convective cloud seeds around Nias Island. Convective cloud clusters continue to develop, although the cloud area coverage is relatively small.

Figure 16. Time-series graph of cloud top temperature at coordinates 97.70°E 1.16°N on October 8, 2020

Figure 17. IR1 image of Himawari-8 satellite in Nias Island and surrounding areas on October 8, 2020
The vertical profile of air humidity (Figure 18.a) shows humid air conditions, consisted of in the lower layer (1000-800 hPa) with a humidity value of 80-95%, in the middle layer (700-400 hPa) with a value of 70-90%, and in the upper layer (300-100 hPa) with a value of 40-70%. The vertical velocity profile (Figure 18.b) shows that at intervals of 03-08 UTC there is a positive vertical velocity value in the lower layer, which means that there is an upward vertical movement of air. The updraft phenomenon is part of the convective cloud growth phase. At intervals of 12-15 UTC, it is seen that there is a negative vertical velocity value in all layers, which means that there is a downward vertical movement of air. The downdraft phenomenon is an indication that convective clouds have reached a mature phase. The vertical vorticity profile (Figure 18.c) shows that in the interval of 06-09 UTC there is a positive vorticity value in the middle layer, which means that there is a lifting of air masses to the top layer (lifting). The positive vorticity value that is not too dominant indicates that the convective activity that occurs is not too strong so that the convective cloud formed only has a relatively small cloud area coverage. The vertical divergence profile (Figure 18.d) shows that at intervals of 09-18 UTC, there are negative divergence values in the lower layer and positive divergence values in the middle to upper layers. This means that there is a convergence in the lower layer along with a divergence in the middle layer. This pattern of air circulation indicates the occurrence of convective activity. The divergence that occurs in the middle layer indicates that the convective clouds that are formed have a cloud top height that is not too high, only reaching the height of 800-700 hPa.

5. Conclusions
Convective activities that occur on Nias Island and its surroundings causes rain with varying intensity. Heavy rains are generally caused by convective clouds that have relatively wide cloud coverage areas or are included in the category of multi-cell convective. Heavy rain caused by convective clouds needs to be anticipated because it can occur in a relatively fast and sudden time. In general, the growth phase of convective clouds on Nias Island can reach a duration of 2-3 hours, then reach a mature phase of about 1-2 hours. The relatively humid atmosphere, accompanied by the convection mechanism that occurs, causes the convective activity on Nias Island to be quite intense. Convective cloud growth is characterized by positive vertical velocity values and positive vorticity values in the lower layers (1000-800 hPa), as well as circulation patterns of convergence in the lower layers and divergence in the upper layers (300-100 hPa) and/or intermediate layers (700-500 hPa). Several case studies in this study show the occurrence of several cycles of convective cloud growth in one day or the so-called continuity convective system. The mature phase of convective clouds that form generally reaches a cloud top temperature in the range of -60ºC to -80ºC. This convective cloud is a Cumulonimbus cloud. In general,
from the four case studies, the WRF model is able to capture the timing of the occurrence of rain on Nias Island, but the rainfall intensity is lower (under-estimate) than the observation data.

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