

Analysis of Extreme Weather in the Waters of West Kalimantan using the WRF-ARW Model (Case Study 13-14 July 2021)

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Abstract

On 13 July 2021, there was an extreme weather phenomenon in the waters of West Kalimantan. The extreme weather resulted in several fishing boats sinking and causing 136 casualties. This study aims to analyze atmospheric conditions during extreme weather on July 13-14, 2021. In running the WRF-ARW model, verification is carried out using the dichotomy method (Accuracy, POD, FAR) and RMSE to determine the model's accuracy in simulating extreme weather events. The RMSE verification results show an error value of 4,97. The results of the WRF-ARW model output show that the extreme weather that occurs is caused by the presence of a convergence wind zone with a maximum wind speed of 18 m/s, causing the formation of cumulonimbus clouds. OLR simulations show a low value of 122 watts/m², indicating a lot of cloud cover with the potential for rain. The emergence of this convection zone causes strong winds, which cause high waves, thus contributing to ship accidents.

Keywords: Extreme Weather; West Kalimantan; WRF.

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Introduction

West Kalimantan's coastal and marine areas play an essential role in economic activities, transportation, and the lives of local communities. However, this region's unique geography and meteorology make it prone to a range of extreme weather events (Taufik et al., 2019). Weather is the state of the air at a particular time and in a particular area that is relatively narrow and in a short period (Puspita & Yulianti, 2016). Extreme weather is an event of natural phenomena characterized by conditions of rainfall, wind direction and speed, air temperature, air humidity, and visibility that can cause losses, especially the safety of life and property (BMKG, 2022). Many factors can influence extreme weather, one of which is climate change, which is a factor in increasing the frequency of extreme

weather events such as strong winds and high waves (Nurlatifah et al., 2023). Another impact of extreme weather is the increase in wave height throughout the Indonesian Sea (Rizal et al., 2020). Changes in rainfall patterns and increases in sea surface temperature have the potential to produce large ocean waves that hurt fishermen (Afifah et al., 2024). In addition, extreme weather also impacts the smooth running of land, sea, and air transportation.

In analyzing extreme weather events, many methods can be used, one of which is numerical weather modeling. Numerical weather modeling systems are currently widely used by the world's meteorologists. One of the weather modeling systems developing in the world today is Weather Research Forecasting (WRF). WRF-ARW is a numerical weather model program that

can model atmospheric conditions in a region to help study a meteorological event better (Wisnawa et al., 2019). Research using WRF-ARW modeling was conducted by Putra & Rifani (2016), which analyzed the extreme rain that occurred on 19 August 2014. The results showed that the WRF-ARW model output had good results in showing atmospheric conditions during extreme rainfall.

In 2021, extreme weather has caused the loss of ships in the waters of West Kalimantan. As revealed by Tribunnews.com, there was bad weather that resulted in 14 boats reportedly sinking in three different locations, namely in Muara Jungkat, Muara Kubu, and Muara Pemangkat, which claimed 136 lives. Based on the analysis issued by BMKG, there have been extreme weather in the form of heavy to extreme category rain, reaching >100 mm/day on July 13, 2021, in most areas of West Kalimantan.

Based on the impact caused by extreme weather in the waters of West Kalimantan, this is the basis of the research conducted. Analyzing atmospheric conditions using the WRF-ARW model is expected to get representative results that can describe atmospheric conditions when extreme weather occurs. This research is also expected to provide preliminary information to mitigate extreme weather.

Materials and Methods

The location of this research is the waters of West Kalimantan. This research was conducted for 2 days starting from July 13-14, 2021 which is located at coordinates 5°N to 6°S and 104°BT to 112°BT. The study areas used as samples to analyze wind speed, rainfall, and Outgoing Longwave Radiation (OLR) are the Pemangkat, Jungkat, and Kubu areas because these three areas were reported as the areas where the loss of the ship occurred.

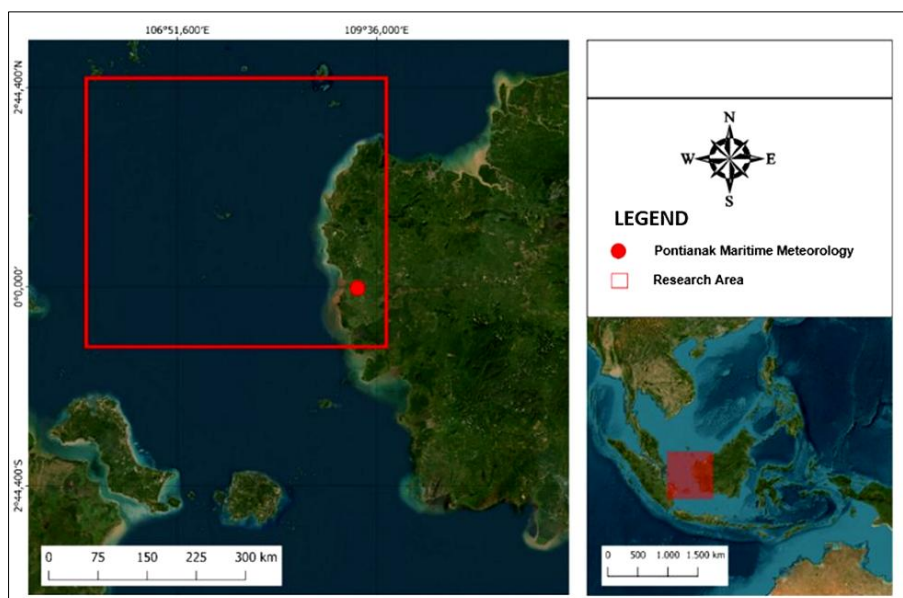


Figure 1. Study location.

Data Used

1. Data FNL (Final Global Data Assimilation System)

Initial condition data and model boundary data were used FNL (Final Global Data Assimilation System) data from 12 July 2021 at 18.00 UTC to 14 July 2021 at 18.00

UTC with a data resolution of $0.25^\circ \times 0.25^\circ$ or $27.75 \text{ km} \times 27.75 \text{ km}$ with a temporal resolution of 6 hours (Liu et al., 2022). The data was obtained by downloading via the link <https://rda.ucar.edu/datasets/ds083.3/dataaccess/>.

2. Data GSMAP (Global Satellite Mapping Precipitation)

Observation data for rainfall parameters using GSMAP (Global Satellite Mapping Precipitation) data of Himawari 8 Satellite obtained from Pontianak Maritime Meteorological Station from 12 July 2021 at 18.00 UTC to 14 July 2021 at 18.00 UTC with data resolution of 0.1° x 0.1° or 11 km x 11 km (Pratama et al., 2022).

3. Wind Speed Data of Pontianak Maritime Meteorological Station

Observation data for wind speed parameters were obtained from Pontianak Maritime Meteorological Station with coordinates 0.02022° N and 109.33778° E on July 12, 2021, at 18:00 UTC to July 14, 2021, at 18:00 UTC.

Work Procedure

1. Preparation/ identification of extreme weather events

The first step is to collect information such as the date and time of the incident related to the loss of ships due to extreme weather. Next, identify suitable initial data as an identifier of extreme weather that causes the loss of vessels in West Kalimantan waters.

2. Data Collection

After identifying the event, the next step is to collect data at that time and location for analysis, model input and comparison.

3. Running Model WRF

There are several stages in the WRF model running process. The WRF model (version 4.5.1). The first stage is to carry out the

downscaling and nesting process to get two domains. Downscaling is a technique to increase model resolution by downscaling the grid scale of a global model to a regional scale in the domain of interest (Maraun and Widmann, 2018). After that, the WRF Pre-Processing system (WPS) consists of three stages: running the geogrid, ungrib, and metgrid processes. At this stage, input files will be obtained, running the ./real.exe and ./wrf.exe commands to get WRF output. The results of WRF are then processed into ARWpost post-processing to produce files in .ctl and .dat formats, which are then visualized.

4. Display The Output of the WRF-ARW Model

The results of running the WRF-ARW model are then visualized. The model output results are displayed with various parameters, so a two-dimensional profile related to extreme weather parameters in the study area is obtained.

5. Conducting Accuracy Tests on the WRF-ARW Model

After obtaining the output results of the next model, a comparison with observational data is carried out. For rainfall parameters, a comparison of rainfall distribution maps between WRF-ARW model output and GSMAP data is carried out to see the accuracy of the WRF-ARW model spatially. Verification of model output also uses the dichotomy method with the contingency table in Table 1. The contingency table method is used to determine the quality of dichotomous forecast data (the result is a yes/no decision) (Sulistiyono & Fadli, 2023).

Table 1. Contingency table 2x2 (Sulistiyono & Fadli, 2023)

Frequency	Satellite Observation (GSMAP)		Total Estimation Data	
	Yes	No		
<i>WRF Model Output Rainfall Data</i>	Yes	a (Hits)	c (False Alarms)	a + b
	No	b (Misses)	d (Correct Negatives)	c + d
Total Observation	a + b	c + d	n = a + b + c + d	

The test results of the contingency table method produce values for Probability of Detection (POD), False Alarm Ratio (FAR), and accuracy (fraction correct). POD measures the number of “YES” events correctly predicted by the satellite data, FAR calculates the forecast error of rainfall products that do not match the observed data, and accuracy indicates the proportion of correct forecasts, with values between 0 and 1, where perfect accuracy is achieved when the value is 1. The equations used to calculate these verification parameters are used in Equations 1, 2, and 3 (Mahubessy & Purnama, 2022).

$$Accuracy = \frac{Hits + Correct\ Negatives}{Total} \quad (1)$$

$$POD = \frac{Hits}{Hits + Misses} \quad (2)$$

$$FAR = \frac{False\ Alarms}{Hits + False\ Alarms} \quad (3)$$

Wind speed parameters are verified using RMSE (Root Mean Square Error). RMSE has a range of values from 0 to infinity, which depends on the error values obtained from the parameters being compared. An element of the WRF-ARW scheme results can be considered good if it has a small error value against the observed weather elements, then the RMSE value will be close to 0. The following is an equation for determining the RMSE value (Wisnawa et al., 2019).

$$RMSE = \sqrt{\frac{\sum (y_i - \hat{y})^2}{n}} \quad (4)$$

With information, \hat{y} is the value of observation data and, y_i is the value of model data, n is the amount of data.

6. Data Analysis

At this stage all the parameters that have been determined are then analyzed to obtain hypotheses that are by atmospheric conditions during extreme weather.

Results and Discussion

Validation Analysis of WRF Model and Observation Data

Rainfall verification results from the WRF-ARW model in Table 3 show three dichotomous parameters for the three ship loss regions.

Table 3. Rainfall verification results from the WRF-ARW model.

Statistics	Observation Area		
	Pemangkat	Jungkat	Kubu
Accuracy	0,6	0,6	0,7
POD	0,05	0,42	0,33
FAR	0,50	0,47	0,33

From Table 3, the results of the verification of WRF model data and observation data, a good accuracy value is owned by the Kubu area because the value is close to 1. The Jungkat area owns a good POD value because the value is pretty close to 1. The Kubu area owns a good FAR value because the value is close to 0. Wind speed verification has an RMSE value with an error of 4.97.

Spatial Analysis of WRF-ARW Model Rainfall

Figure 2 shows the WRF model output for 6 hours before the extreme weather occurred. During this period, it shows stable rainfall with a rainfall intensity of 3 mm/hour. Rainfall is the amount of rainwater that falls during a certain period which is measured using units of height above horizontal ground level (Ruswanti, 2020). One millimeter of rainfall means that one square meter of flat area contains one millimeter of water or one liter of water (Ajr, 2019). There was an increase in rainfall intensity at 13:00 WIB near Bangka Belitung Island, and it began to decline around 16:00 WIB. Meteorological conditions such as evaporation, humidity, wind speed, air temperature, and solar radiation intensity can affect rainfall in an area (Ramadhan, 2018; Wang & Zheng, 2022).

Figure 3 is the output of the WRF-ARW model of rainfall distribution patterns during extreme weather that is expected to occur from the 13th night until the 14th

morning. The visualization results are displayed for 10 hours, from 19:00 WIB until 04:00 WIB. At 23:00 WIB, high rainfall began to be seen in the sea near the coast of West Kalimantan with a maximum intensity reaching 27 mm/hour, then at 24:00 WIB, rainfall with high intensity began to be seen spreading in the sea near the coast of West Kalimantan. The rainfall pattern in the previous hour shows that the intensity increases within an hour, which is indicated by several areas having high rainfall. At 01.00 am, the rainfall intensity increases with a maximum intensity of 30 mm/hour with a broader range of areas. A similar pattern continues at 02:00 am, with

the rainfall area moving further to the coast of West Kalimantan.

Figure 4 shows the visualization results of the WRF-ARW model output rainfall after the extreme weather event. The image is displayed in a period of 6 hours after the event. In general, the rainfall has an intensity of 3 mm/hour with a coverage area around the South China Sea and West Kalimantan Island. However, in the northern part of West Kalimantan Island, there is a high rainfall intensity with a maximum intensity of 30 mm/hour. Entering 06.00 WIB, the high rainfall intensity decreased with a maximum intensity of 21 mm/hour.

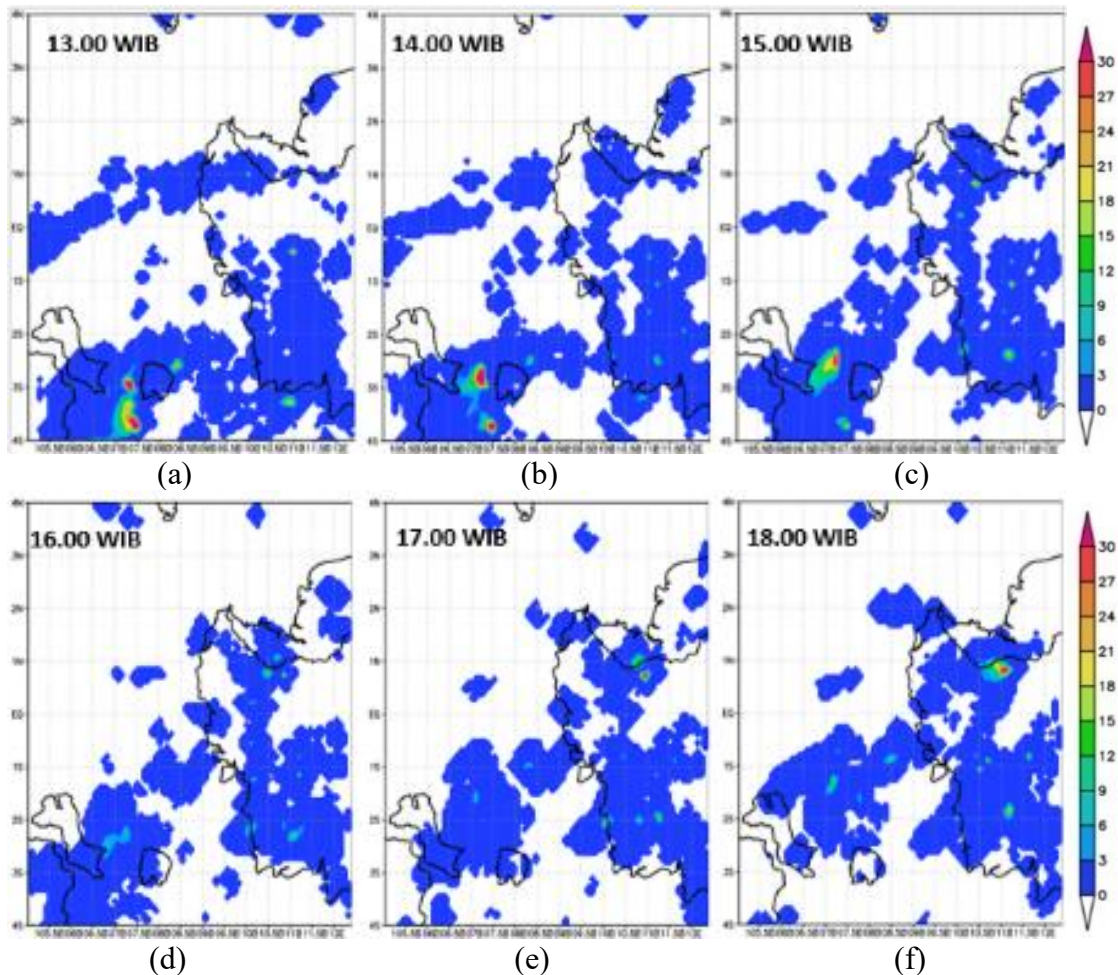


Figure 2. Rainfall distribution map before extreme weather in West Kalimantan waters on July 13, 2021
 (a)13.00 WIB, (b) 14.00 WIB, (c) 15.00 WIB, (d) 16.00 WIB, (e) 17.00 WIB, (f) 18.00 WIB.

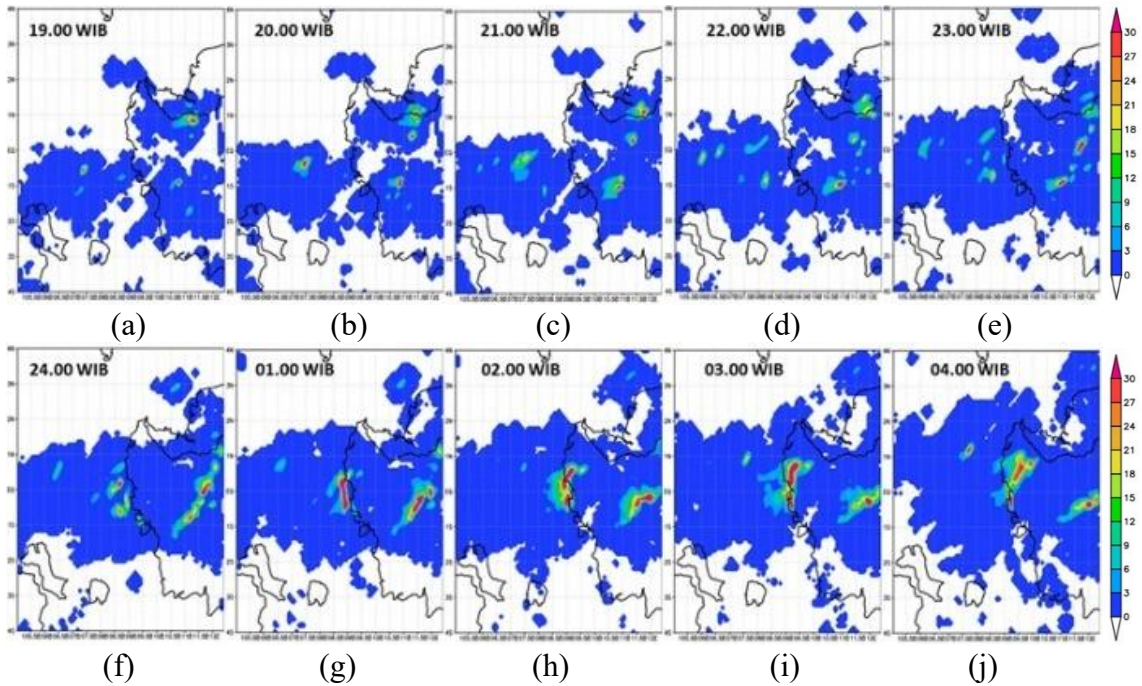


Figure 3. Rainfall distribution map during extreme weather in West Kalimantan waters on July 13-14, 2021 (a) 19.00 WIB, (b) 20.00 WIB, (c) 21.00 WIB, (d) 22.00 WIB, (e) 23.00 WIB, (f) 24.00 WIB, (g) 01.00 WIB, (h) 02.00 WIB, (i) 03.00 WIB, (j) 04.00 WIB.

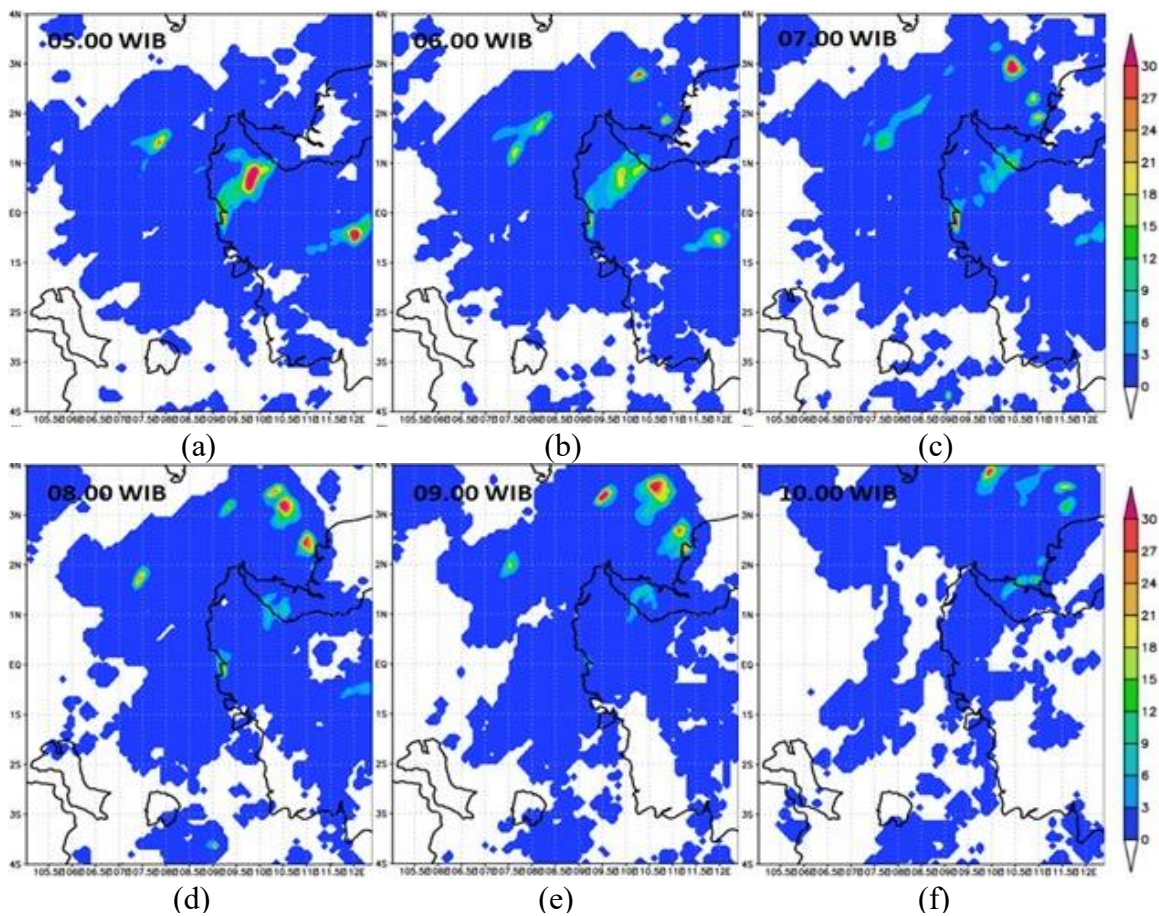


Figure 4. Rainfall distribution map after extreme weather in West Kalimantan waters on July 14, 2021 (a) 05.00 WIB, (b) 06.00 WIB, (c) 07.00 WIB, (d) 08.00 WIB, (e) 09.00 WIB, (f) 10.00 WIB.

Figure 5 displays the WRF-ARW model output for 6 hours before the extreme weather. Overall, the wind speed on the West Kalimantan coast and sea was 8 - 10 m/s. Wind speed is the speed of air moving horizontally which is influenced by the barometric gradient of the location, height, and topography of a place (Suwarti et al., 2017; Minola et al., 2024). The wind speed pattern continues to move northward from Bangka Belitung Island to Kalimantan Island. The wind movement comes from an area of high pressure to an area of low pressure (Miftahuddin, 2016; Siagian, 2022). At 18.00 WIB, the wind vector pattern shows the presence of wind convergence; the wind vector looks spread or away from one center point, which indicates convergence. Wind speed is influenced by various micro and macro factors, one of which is hurricanes, monsoons, and tornadoes can affect wind

speed both regionally and locally (Abdy & Sanusi, 2020).

Figure 6 shows the wind speed and direction during extreme weather, which is expected to occur in the evening of July 13, 2021, until the early morning of 14 July 2021. The wind speed begins to increase every hour, as indicated by the pink vector in the figure as well as the wind direction shown by the wind vector; at 19.00 WIB, the wind direction pattern is already visible above Bangka Belitung Island with a maximum speed of 16 m/s, the wind vector looks increasingly spread or away from a central point indicating convergence. In this condition, the area has the potential for convective cloud growth due to the mass of air that gathers, which will allow severe weather conditions to occur (Wisnawa et al., 2019).

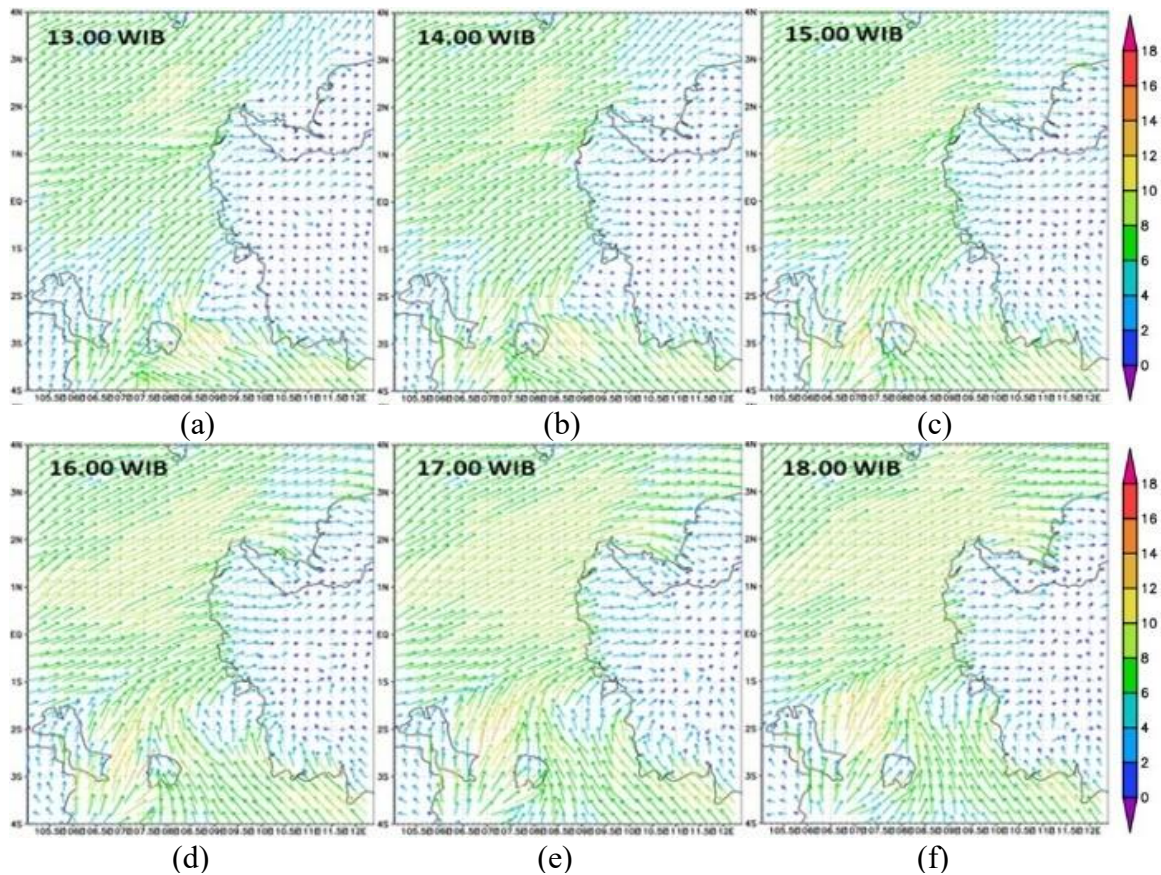


Figure 5. Spatial map of wind speed in West Kalimantan waters before extreme weather on July 13, 2021 (a) 13.00 WIB, (b) 14.00 WIB, (c) 15.00 WIB, (d) 16.00 WIB, (e) 17.00 WIB, (f) 18.00 WIB.

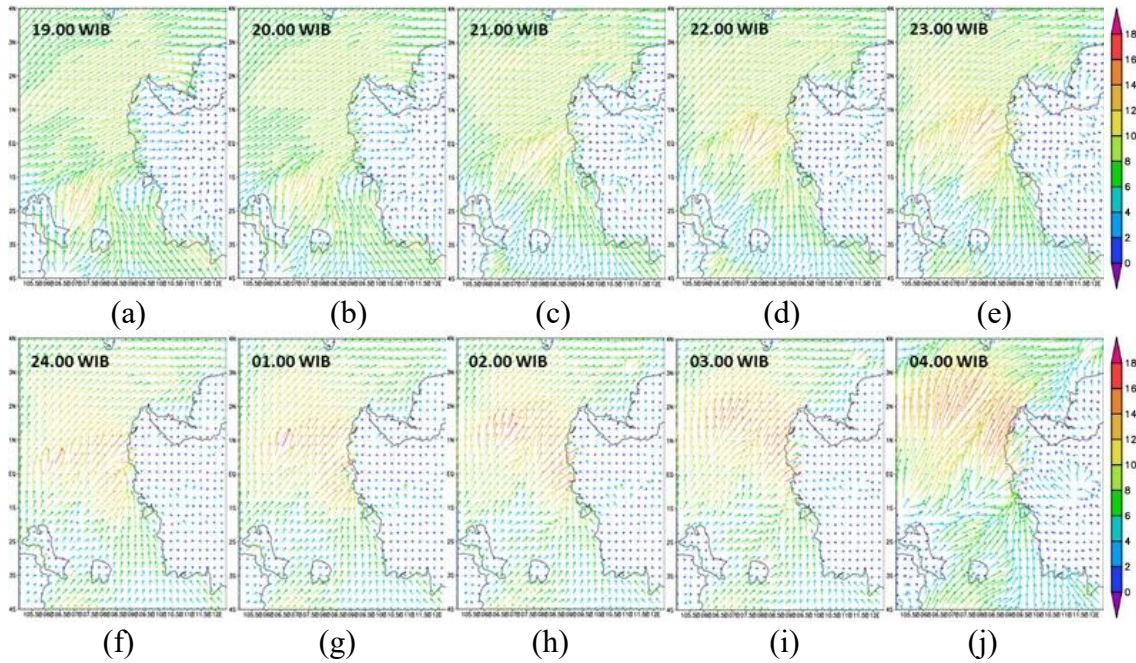


Figure 6. Spatial map of wind speed during extreme weather in West Kalimantan waters on July 13-14, 2021 (a) 19.00 WIB, (b) 20.00 WIB, (c) 21.00 WIB, (d) 22.00 WIB, (e) 23.00 WIB, (f) 24.00 WIB, (g) 01.00 WIB, (h) 02.00 WIB, (i) 03.00 WIB, (j) 04.00 WIB.

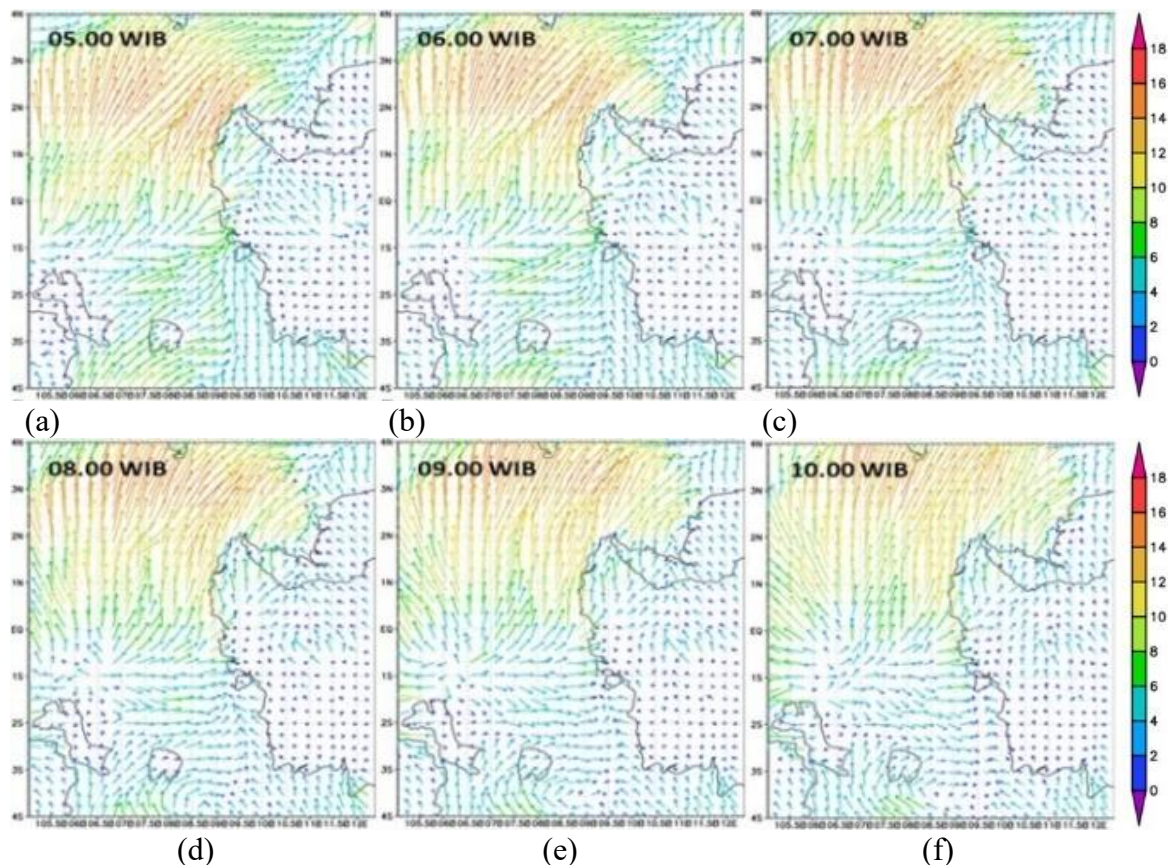


Figure 7. Spatial map of wind speed after extreme weather in West Kalimantan waters on July 14, 2021 (a) 05.00 WIB, (b) 06.00 WIB, (c) 07.00 WIB, (d) 08.00 WIB, (e) 09.00 WIB, (f) 10.00 WIB.

Figure 7 shows the wind speed for 6 hours after the extreme weather. Overall, the wind

speed has decreased from 05.00 WIB to 10.00 WIB, with the direction of the wind

vector heading north or to the South China Sea. At 05.00 WIB, the wind speed on the coast of West Kalimantan, precisely in the North, has a wind speed that is still relatively high, reaching 16 - 18 m / s. The

wind speed is still quite high for the coast of West Kalimantan in the lower part. The coast of West Kalimantan at the bottom of the wind speed is relatively stable, namely 4 – 8 m/s.

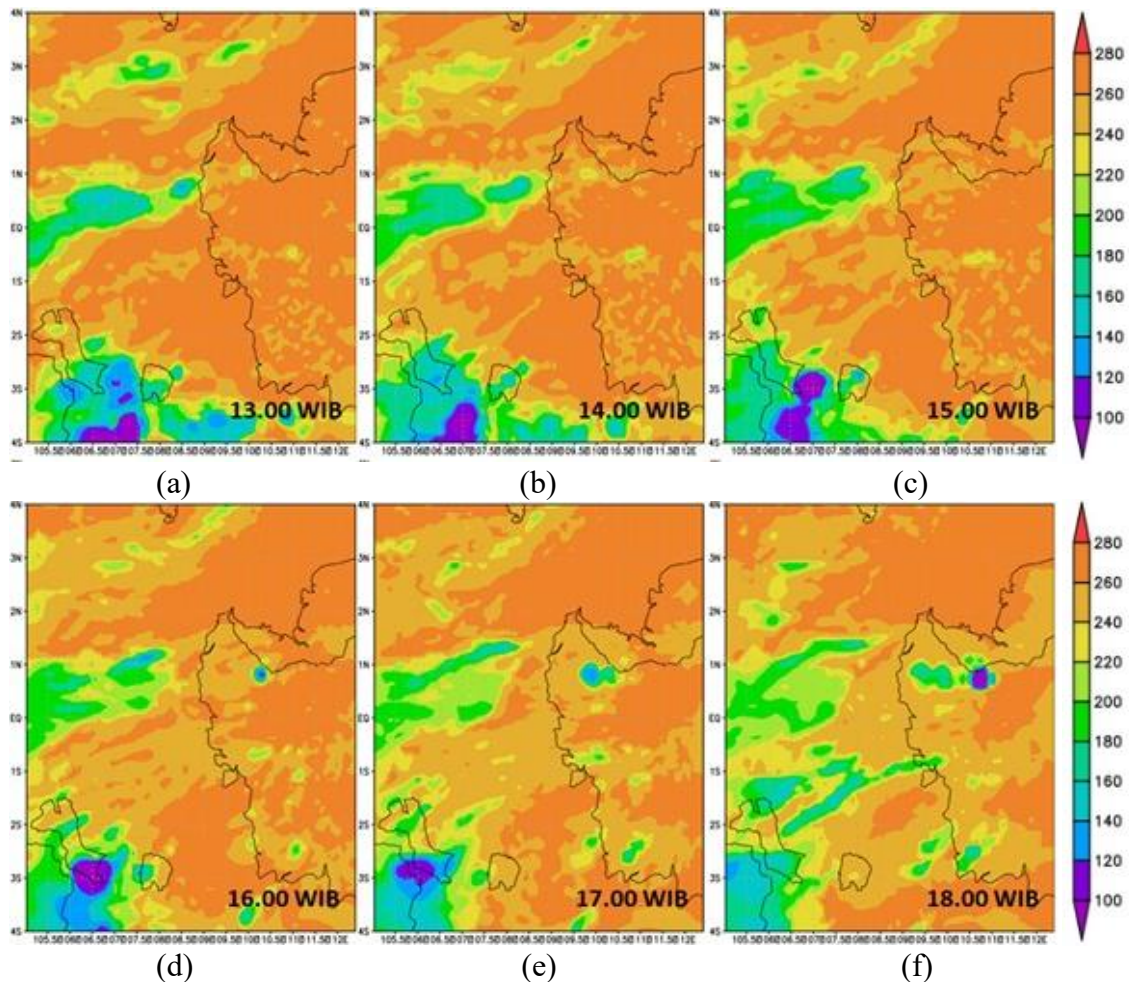


Figure 8. Spatial map of OLR in West Kalimantan waters before extreme weather on July 13, 2021 (a) 13.00 WIB, (b) 14.00 WIB, (c) 15.00 WIB, (d) 16.00 WIB, (e) 17.00 WIB, (f) 18.00 WIB.

Outgoing Longwave Radiation (OLR) is the longwave return radiation at the top of the atmosphere observed by polar-orbiting satellites in watts/meter² (Loeb et al., 2018). Figure 8 shows the OLR for 6 hours before the extreme weather. Overall, the OLR value on the coast of West Kalimantan Island is pretty high, at 250 – 270 Watt/m². However, on the North side of West Kalimantan, precisely around the Singkawang area, the OLR value looks relatively low at 13.00 WIB, around 230 -

130 Watt / m². From 14.00 WIB until 15.00 WIB, OLR began to move westward in West Kalimantan, as indicated by the decrease in OLR value. The low OLR value suggests that more cloud cover allows rain to occur. OLR shows the amount of cloud cover that exists; if OLR is low, then it can be indicated that many clouds are formed because the outgoing long waves are held back by the clouds and vice versa (Prayuda & Alfuadi, 2015; Schreck et al., 2018).

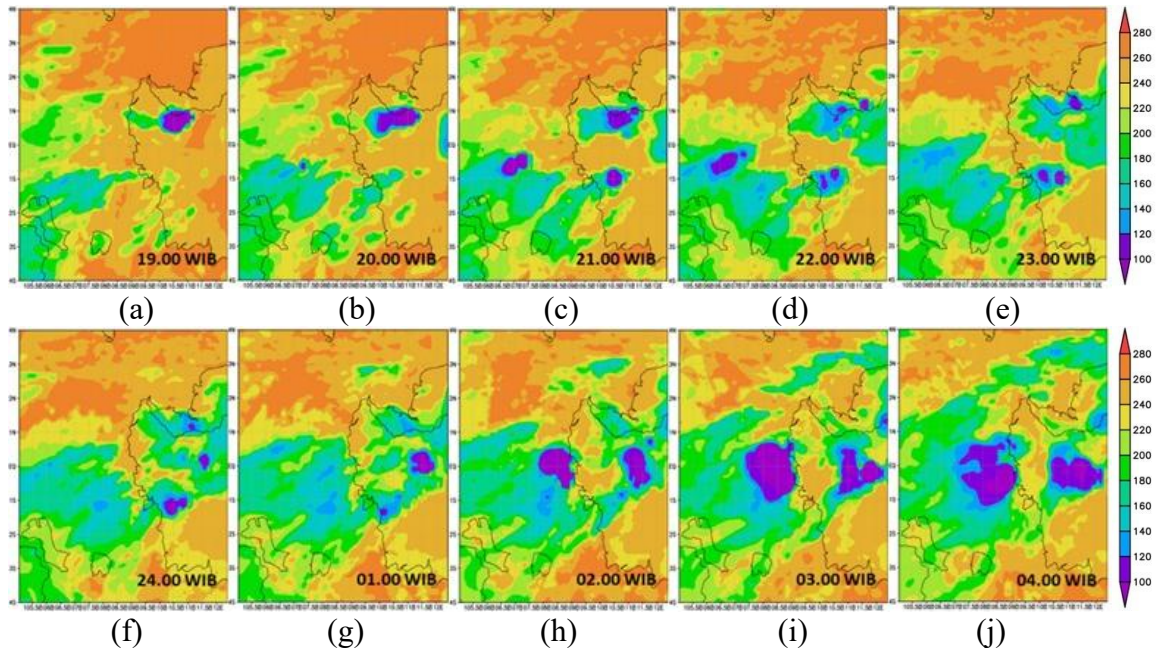


Figure 9. Spatial map of OLR during extreme weather in West Kalimantan waters on July 13-14, 2021 (a) 19.00 WIB, (b) 20.00 WIB, (c) 21.00 WIB, (d) 22.00 WIB, (e) 23.00 WIB, (f) 24.00 WIB, (g) 01.00 WIB, (h) 02.00 WIB, (i) 03.00 WIB, (j) 04.00 WIB.

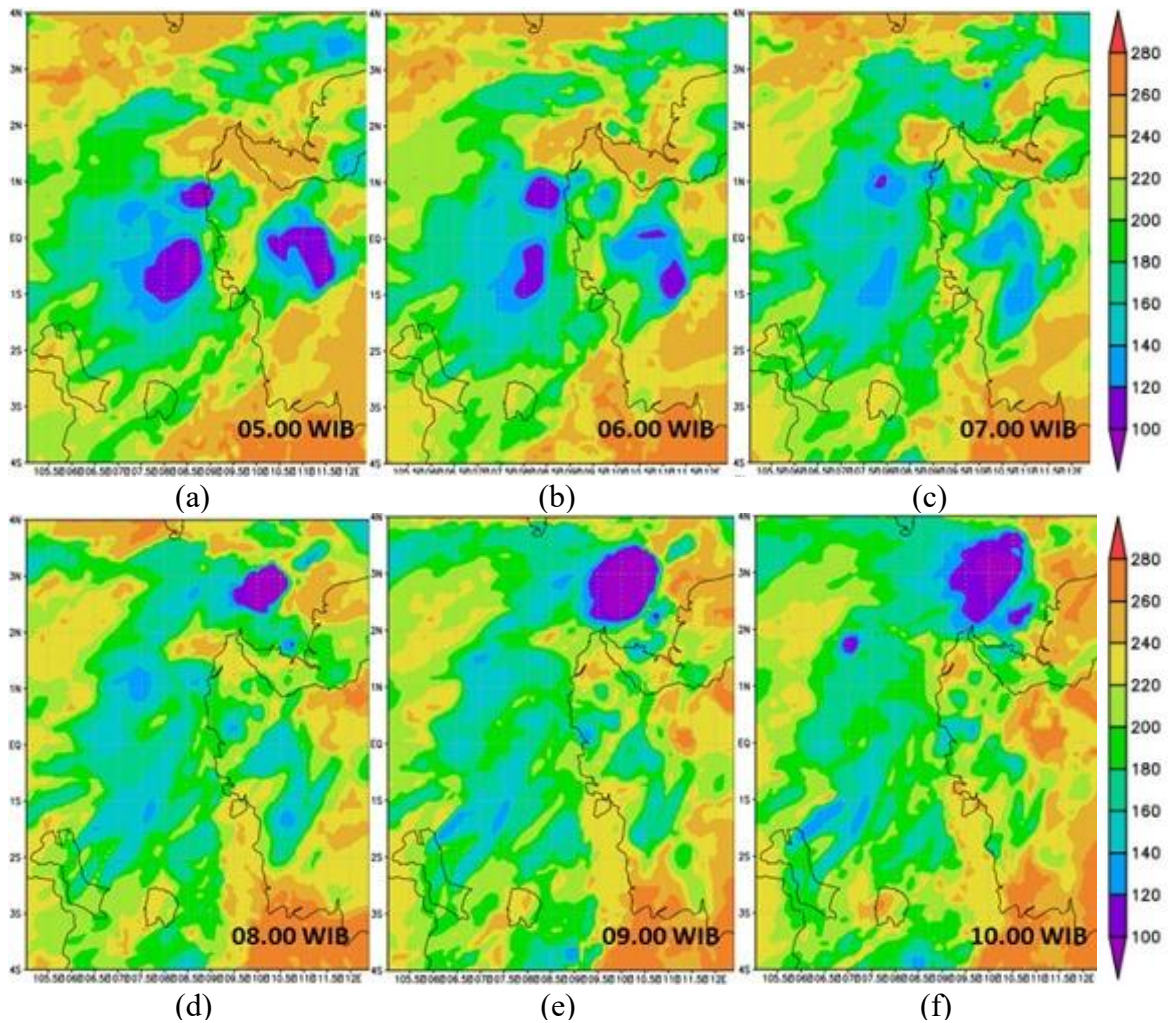


Figure 10. Spatial map of OLR after extreme weather in West Kalimantan waters on July 14, 2021 (a) 05.00 WIB, (b) 06.00 WIB, (c) 07.00 WIB, (d) 08.00 WIB, (e) 09.00 WIB, (f) 10.00 WIB.

Figure 9 shows OLR for 10 hours when extreme weather occurs. At 19:00 WIB, OLR with low values began to spread over the coast of West Kalimantan with an OLR value of around 180 Watt/m²; this continued until 20:00 WIB. At 21:00 WIB, the OLR value decreases until it reaches a value of 150 Watt / m². It is found around the coast of West Kalimantan, but if seen in the picture, there is OLR with a minimum value of 100 Watt / m² on the island. This shows that there is a lot of cloud cover in the area, which makes it cooler. Low or minimum OLR values indicate cold temperatures, while high or maximum values indicate hot temperatures. (Handayani et al., 2016; Koll & Cronin, 2018). This low OLR value indicates a large cloud cover potentially containing convective clouds that can cause rain. The OLR value at the top of the Earth's atmosphere is a function of two things: the number of clouds and the temperature of the cloud surface, both of which are related to rainfall (Natasha et al., 2021). The study of the relationship between OLR and rainfall has been studied by Morrissey (1986), which states that if OLR is high, rainfall is low and vice versa (Prayuda & Alfuadi, 2015; Rasch et al., 2019). This aligns with the WRF-ARW model's output rainfall, which shows that the same time and region have high rainfall.

Figure 10 shows the OLR for 6 hours after the extreme weather. At 05.00, WIB, OLR is still at the minimum value of 100 Watt/m², which is located around Singkawang and in the sea near the Jungkat estuary. For coastal areas from 07.00 WIB to 10.00 WIB, it has OLR with a value of 190 - 230 Watt/m², indicating that cloud cover in the coastal areas of West Kalimantan is not too large or small.

Conclusion

Based on the results of the research, it can be concluded that the rainfall output of the WRF-ARW model is underestimated

against GSMAP data. Kubu region has the best accuracy value of 0.7, Kubu has a good prediction with a FAR value of 0.33, and Jungkat has the highest POD value of 0.42. The RMSE value shows a small error value for wind speed verification with a value of 4.97.

The WRF model output showed a low OLR value, indicating high rainfall at the time of the ship loss. High wind speeds with a maximum speed of 20 m/s and low OLR values of 100 watts/m² also indicate the influence of convective clouds that support high rainfall with a maximum intensity of 30 mm/hour. In a sense, meteorological conditions during extreme weather are characterized by cumulonimbus clouds formed due to wind convergence, which causes high rainfall at the study site.

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Author Contribution

Tarisya Juliana: conceptualized, data curation, formal analysis, visualization and writing original draft. Riza Adriat: supervision, validation, and writing review editing. Randy Ardianto: supervision, validation, and writing review editing. Andi Ihwan: supervision and visualization. Yuris Sutanto: supervision and visualization.

Conflict of Interest

The authors declare no conflict of interest.

References

- Abdy, M., & Sanusi, W. (2020). Karakteristik Kategori Kecepatan Angin di Kota Majene dengan

- Pendekatan Rantai Markov. *Saintifik*, 6(1), 85–90. <https://doi.org/10.31605/saintifik.v6i1.305>
- Afifah, D., Chusni, A., Nahar, A. N., Sirojuddin, M. A., & Fatmawati, N. (2024). Persepsi Masyarakat Nelayan Dalam Menghadapi Perubahan Iklim Studi Desa Ujung Batu Kawasan Pesisir Utara Pulau Jawa (Ditinjau Aspek Sosial Ekonomi). *UTILITY: Jurnal Ilmiah Pendidikan dan Ekonomi*, 8(1), 42–58. <https://doi.org/10.30599/utility.v8i1.3107>
- Ajr, E. Q., & Dwirani, F. (2019). Menentukan Stasiun Hujan dan Curah Hujan dengan Metode Polygon Thiessen Daerah Kabupaten Lebak. *Jurnal Lingkungan Dan Sumberdaya Alam*, 2(2), 139–146. <https://ejournal.lppm-unbaja.ac.id/index.php/jls/article/view/674/387>
- Badan Meteorologi Klimatologi dan Geofisika (BMKG). (2022). *Penyediaan dan Penyebarluasan Peringatan Dini Cuaca Ekstrem*. 1–19.
- Handayani, D., Asrul, A., & Nugroho, S. (2016). Analisis Angin Zonal dan Outgoing Longwave (OLR) Untuk Inisialisasi Kemunculan Fenomena Medden Julian Oscillation (MJO) di Kota Padang. *Pillar of Physics*, 8, 9–16.
- Koll, D. D. B., & Cronin, T. W. (2018). Earth's outgoing longwave radiation linear due to H₂O greenhouse effect. *Proceedings of the National Academy of Sciences*, 115(41), 10293–10298. <https://doi.org/10.1073/pnas.1809868115>
- Liu, J., Song, X., Long, W., Fu, Y., Yun, L., & Zhang, M. (2022). Structure Analysis of the Sea Breeze Based on Doppler Lidar and Its Impact on Pollutants. *Remote Sensing*, 14(2), 324. <https://doi.org/10.3390/rs14020324>
- Loeb, N. G., Doelling, D. R., Wang, H., Su, W., Nguyen, C., Corbett, J. G., Liang, L., Mitrescu, C., Rose, F. G., & Kato, S. (2018). Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) Top-of-Atmosphere (TOA) Edition-4.0 Data Product. *Journal of Climate*, 31(2), 895–918. <https://doi.org/10.1175/JCLI-D-17-0208.1>
- Mahubessy, R., & Purnama, D. R. (2022). Uji Skema Parameterisasi Kumulus Untuk Prediksi Hujan Penyebab Banjir Di Kota Ambon Tanggal 11 Juli Test of Cumulus Parameterization Schemes for Prediction of Rain That Causes Floods in Ambon City on 11 July 2021. *Preprints, Open Science Framework*. <https://doi.org/10.31219/osf.io/cz93f>
- Maraun, D., & Widmann, M. (2018). *Statistical Downscaling and Bias Correction for Climate Research*. Cambridge University Press.
- Miftahuddin, M. (2016). Analisis Unsur-unsur Cuaca dan Iklim Melalui Uji Mann-Kendall Multivariat. *Jurnal Matematika, Statistika Dan Komputasi*, 13(1), 26–38. <https://journal.unhas.ac.id/index.php/jmsk/article/view/3476>
- Minola, L., Zhang, G., Ou, T., Kukulies, J., Curio, J., Guijarro, J. A., Deng, K., Azorin-Molina, C., Shen, C., Pezzoli, A., & Chen, D. (2024). Climatology of near-surface wind speed from observational, reanalysis and high-resolution regional climate model data over the Tibetan Plateau. *Climate Dynamics*, 62, 933–953. <https://doi.org/10.1007/s00382-023-06931-3>
- Morrissey, M. L. (1986). A Statistical Analysis of the Relationships among Rainfall, Outgoing Longwave Radiation and the Moisture Budget during January–March 1979. *Monthly Weather Review*, 114(5), 931–942. <https://doi.org/10.1175/1520->

- 0493(1986)114<0931:ASAOTR>2.0.CO;2
- Natasha, I., Putra, Y. S., & Adriat, R. (2021). Keterkaitan Outgoing Longwave Radiation dengan Intensitas Curah Hujan di Paloh Kabupaten Sambas Kalimantan Barat. *Prisma Fisika*, 9(2), 160. <https://doi.org/10.26418/pf.v9i2.49490>
- Nurlatifah, A., Hatmaja, R. B., & Rakhman, A. A. (2023). Analisis Potensi Kejadian Curah Hujan Ekstrem di Masa Mendatang Sebagai Dampak dari Perubahan Iklim di Pulau Jawa Berbasis Model Iklim Regional CCAM. *Jurnal Ilmu Lingkungan*, 21(4), 980–986. <https://doi.org/10.14710/jil.21.4.980-986>
- Pratama, A., Agiel, H. M., & Oktaviana, A. A. (2022). Evaluasi Satellite Precipitation Product (GSMaP, CHIRPS, dan IMERG) di Kabupaten Lampung Selatan. *Journal of Science and Applicative Technology*, 6(1), 32. <https://doi.org/10.35472/jsat.v6i1.702>
- Prayuda, S. S., & Alfuadi, N. (2015). Pengaruh Convective Available Potential Energy (CAPE) dan Outgoing Longwave Radiation (OLR) Terhadap Curah Hujan di Cengkareng. *Prosiding Seminar Nasional Fisika dan Aplikasinya*, 47–55.
- Puspita, E. S., & Yulianti, L. (2016). Perancangan Sistem Peramalan Cuaca Berbasis Logika Fuzzy. *Jurnal Media Infotama*, 12(1), 1-10. <https://doi.org/10.37676/jmi.v12i1.267>
- Putra, R. M., & Rifani, A. (2016). Analisis Hujan Ekstrem Menggunakan Model WRF-ARW. *Prosiding Seminar Nasional Fisika Dan Pendidikan Fisika*, 105–114.
- Ramadhan, F. D. (2018). *Analisis Pola Curah Hujan pada Kondisi Cuaca Ekstrem Bulan Oktober hingga Desember 2017 melalui Citra Modis Level 1B di Provinsi Jawa Timur*. Institut Teknologi Sepuluh Nopember.
- Rasch, P. J., Xie, S., Ma, P-L., Lin, W., Wang, H., Tang, Q., Burrows, S. M., Caldwell, P., Zhang, K., Easter, R. C., Cameron-Smith, P., Singh, B., Wan, H., Golaz, J-C., Harrop, B. E., Roesler, B., Bacmeister, J., Larson, V. E., Evans, K. J., Qian, Y., Taylor, M., Leung, L. R., Zhang, Y., Brent, L., Branstetter, M., Hannay, C., Mahajan, S., Mamejtanov, A., Neale, R., Richter, J. H., Yoon, J-H., Zender, C. S., Bader, D., Flanner, M., Foucar, J. G., Jacob, R., Keen, N., Klein, S. A., Liu, X., Salinger, A. G., Shrivastava, M., & Yang, Y. (2019). An Overview of the Atmospheric Component of the Energy Exascale Earth System Model. *Journal of Advances in Modeling Earth Systems*, 11, 2377–2411. <https://doi.org/10.1029/2019MS001629>
- Rizal, A. S., Widada, S., Ismanto, A., Handoyo, G., & Purwandana, A. D. P. (2020). Analysis of extreme wave heights in Indonesian waters using satellite altimetry data. *IOP Conference Series: Earth and Environmental Science*, 530(1), 012002. <https://doi.org/10.1088/1755-1315/530/1/012002>
- Ruswanti, D. (2020). Pengukuran Performa Support Vector Machine Dan Neural Netwok Dalam Meramalkan Tingkat Curah Hujan. *Gaung Informatika*, 13(1), 66–75. <https://jurnal.usahidsolo.ac.id/index.php/GI/article/view/455>
- Schreck, C. J., III, Lee, H.-T., & Knapp, K. R. (2018). HIRS Outgoing Longwave Radiation—Daily Climate Data Record: Application toward Identifying Tropical Subseasonal Variability. *Remote Sensing*, 10(9), 1325. <https://doi.org/10.3390/rs10091325>
- Siagian, P. (2022). Wind Resource for Electrical Energy of Tourism and Micro Small and Medium Enterprises (MSMEs) in Coastal Areas After the

- COVID-19 Pandemic. *Adpebi International Journal of Multidisciplinary Sciences*, 1(1), 175–186.
<https://doi.org/10.54099/aijms.v1i1.272>
- Sulistiyono, W., & Fadli, M. (2023). Verifikasi Produk Estimasi Curah Hujan GSMAP, GPM-IMERG, dan HIMAWARI-8 Pada Wilayah Serang, Pekanbaru, dan Ambon. *OPTIKA: Jurnal Pendidikan Fisika*, 7(2), 270–283.
<https://doi.org/10.37478/optika.v7i2.3119>
- Suwarti, S., Mulyono, M., Prasetyo, B., Rifa'i, A., Diastiara, I. R., Indriyani, L., & Putro, W. P. (2017). Pembuatan Monitoring Kecepatan Angin Dan Arah Angin Menggunakan Mikrokontroler Arduino. *Seminar Nasional Pendidikan, Sains Dan Teknologi*, 05(01), 56–64.
<https://jurnal.unimus.ac.id/index.php/psn12012010/article/view/3152>
- Taufik, M., Setiawan, B. I., & Van Lanen, H. A. J. (2019). Increased fire hazard in human-modified wetlands in Southeast Asia. *Ambio*, 48, 363–373.
<https://doi.org/10.1007/s13280-018-1082-3>
- Tribunnews.com (2021). *BMKG: Peringatan Cuaca Buruk Selasa 13 Juli 2021, Waspada Hujan Lebat Disertai Petir dan Angin*. Accessed on 27 January 2024.
<https://lombok.tribunnews.com/2021/07/12/bmkg-peringatan-cuaca-buruk-selasa-13-juli-2021-waspada-hujan-lebat-disertai-petir-dan-angin>
- Wang, H., & Zheng, J. (2022). Assessing the Effects of Surface Conditions on Potential Evapotranspiration in a Humid Subtropical Region of China. *Frontiers in Climate*, 4, 813787.
<https://doi.org/10.3389/fclim.2022.813787>
- Wisnawa, G. G., Utami, A. D., Prayudhi, S. A., & Sari, F. P. (2019). Pemanfaatan Model WRF-ARW untuk Simulasi Hujan Sangat Lebat di Bandara I Gusti Ngurah Rai Bali (Studi Kasus Tanggal 12 Januari 2019). *Prosiding Seminar Nasional Fisika Dan Pendidikan Fisika 2019*, 5, 56–63.
<https://eprints.uny.ac.id/68452/1/57-end.pdf>