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SPATIAL INFORMATION ON THE RELATIONSHIP BETWEEN IOD AND TOTAL COLUMN WATER VAPOR IN CLOUD FORMATION IN THE WESTERN WATERS OF ACEH IN 2022

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ABSTRACT

The Indian Ocean Dipole (IOD) phenomenon is one of the important factors affecting climate variability in western Indonesia, particularly in the waters west of Aceh. This study aims to analyze the relationship between negative IOD events and atmospheric water vapor represented by Total Column Water Vapor (TCWV) as well as cloud formation that could potentially affect weather conditions. The research method used is a descriptive qualitative method utilizing ECMWF/ERA-5 reanalysis data for TCWV and HIMAWARI-8 EH infrared channel satellite image data. The analysis focused on the daily period of September 25–26, 2022. The results of the study show that on September 25, 2022, relatively high TCWV values correlated with increased convective cloud formation that had the potential to produce light rain in the waters west of Aceh. Meanwhile, on September 26, 2022, TCWV values and cloud formation intensity tended to be lower, so no significant rain potential was identified. These results indicate that the negative IOD phenomenon affects atmospheric water vapor distribution and cloud formation processes in the waters west of Aceh. This study is expected to contribute to the understanding of regional climate dynamics and serve as a basis for efforts to mitigate the risk of extreme weather in the coastal areas of Aceh.

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1. INTRODUCTION

The Indonesian region is known in atmospheric science terminology as the Maritime Continent. This term was first put forward by Ramage (1968) who showed that the vastness

of Indonesia's territory is like a continent, but is dominated by water (sea), and is also bordered by two oceans (Indian and Pacific) and two continents, Asia in the north and Australia in the south. Under these conditions, the atmosphere in most parts of Indonesia is relatively humid throughout most of the year due to the high amount of water vapor in the air, facilitating the formation of cumulonimbus (Cb) clouds known as Super Cloud Clusters (SCC), which indicate the magnitude of energy changes that drive the Earth's overall surface circulation (global circulation). This energy drives the factors that control the climate system in Indonesia and surrounding regions.

The main factor affecting Indonesia's climate is not air temperature or air pressure, but rainfall. The average humidity in Indonesia ranges from 65% to 90%. Wind speeds around Indonesia are moderate, with wind directions predicted to be influenced by monsoon winds, namely the East Monsoon blowing from the southeast from May to September and the West Monsoon blowing from the west and northwest from November to March. In a number of regions in Indonesia, the symptoms of change are increasingly being felt, especially during the dry and rainy seasons. The dry season is becoming longer each year, while the rainy season is becoming more intense, shorter in duration, and shifting from its usual timing (Naylor *et al*., 2007).

Early indications of the dry season in several regions of Indonesia are reflected by a decline in rainfall intensity on daily, ten-day, and monthly scales, with more pronounced impacts in eastern Indonesia and the northern coast of Java. The general public often equates the arrival of a hot and long dry season with the presence of the El Niño phenomenon. There are other phenomena that are no less important, namely the Monsoon and the Indian Ocean Dipole Mode (IOD). This last phenomenon, although still relatively unknown among most of our society, has been found to cause prolonged droughts and floods similar to El Niño and La Niña.

Indonesia is a tropical country that only has two seasons, the rainy season and the dry season. In general, the rainy season in Indonesia occurs during the west monsoon, while the dry season occurs during the east monsoon (Koesuma *et al.*, 2021). Although seasons occur periodically, they are shifting, with the rainy season becoming longer and the dry season becoming shorter. One factor causing seasonal shifts in Indonesia is a phenomenon known as the Indian Ocean Dipole (IOD). The IOD phenomenon occurs due to differences in sea surface temperature anomalies between the western and eastern Indian Ocean (Saji *et al*., 1999).

Indonesia is geographically located between two continents, Asia and Australia, and between two oceans, the Pacific and Indian Oceans. Experts believe that the Indian Ocean plays a very important role in controlling the global climate, particularly in the western part of Indonesia, Sumatra, which includes the waters of West Sumatra. These waters lie just below the equator and directly face the Indian Ocean, so they are greatly influenced by the Indian Ocean Dipole (IOD) phenomenon, which controls sea surface temperature (SST) fluctuations. The IOD is identified as one of the main modes of variability in tropical climate (Sahu *et al*., 2012).

The Indian Ocean Dipole phenomenon is divided into three phases: neutral phase, positive phase, and negative phase. The neutral phase of the IOD does not have a significant effect on climate change, and the SPL value is close to normal. The positive phase of the IOD is indicated by an index value above +0.35, while the negative phase of this phenomenon is indicated by an index value below -0.35 (Li *et al*., 2003).
IOD (+) occurs when the western coast of Sumatra experiences high pressure, while the eastern coast of Africa experiences low pressure, causing air to flow from western Sumatra to eastern Africa, resulting in the formation of convective clouds over Africa and producing above-normal rainfall. In contrast, western Sumatra experienced drought after its water vapor failed to precipitate as rain. Conversely, when the IOD is negative, the western region of Sumatra, including West Sumatra, experiences a rainfall surplus, while eastern Africa experiences drought. This occurs based on the assumption that high pressure in Eastern Africa and low pressure in Western Indonesia cause convective clouds formed in the Indian Ocean to move from Africa to Indonesia, resulting in high rainfall in Indonesia, especially in Western Indonesia here, there is a clear link between the IOD phenomenon and rainfall patterns in western Indonesia.

The IOD has a significant influence on sea surface temperature distribution and rainfall patterns in West Sumatra. In general, if there is a positive IOD, the impact on rainfall in western Indonesia is reduced. Conversely, when there is a negative IOD, rainfall in Indonesia is quite high (Khaldun et al., 2018).

According to Ahrens (2001) in his book on meteorology, clouds are large collections of water droplets or fine ice crystals in the atmosphere. During the dry season, we rarely see clouds in the sky because there is little evaporation, but during the rainy season, we see many clouds because there is a lot of water vapor in the air. However, not all types of clouds produce rain, therefore it is very important to recognize the types, shapes, and properties of clouds. Clouds are not all the same type and are constantly changing shape. Clouds depend on altitude and temperature, and are distinguished by their shape and height, with higher clouds being higher up.

This study aims to conclude the relationship between the Indian Ocean Dipole and cloud formation that causes extreme weather during negative IOD events in the waters and oceans west of Aceh. Through analysis of total column water vapor data and HIMAWARI 8 EH satellite products, their relationship with climate and extreme weather, cloud formation distribution, and other climate information, we seek to understand the relationship between these factors and the presence of negative IOD. The results of this study are expected to provide further insight into the dynamics of climate change in the region. This study is expected to contribute to the understanding of regional climate dynamics and their potential impact on the waters west of Aceh during negative IOD events. This research also serves as an important reference or basis for the formulation of adaptation and mitigation policies against climate change, such as extreme weather, and in efforts to manage natural resources in the region, making it very important to study.

2. RESEARCH METHODOLOGY

Time and Place

This research was conducted from July 27 to November 15, 2023, at the Sultan Iskandar Muda Class 1 Meteorological Station office located at Sultan Iskandar Muda International Airport Complex, Cot Mancang, Kuta Baro, Aceh Besar (Figure 1). The research was conducted on weekdays, from Monday to Friday, between 8:00 a.m. and 6:00 p.m., by analyzing data during the daily period on September 25, 2022, in the waters west of Aceh, Aceh Province.

Figure 1. Research Location

BMKG Banda Aceh (SIM) https://maps.app.goo.gl/VAcyhMBA7u5yifqK6

Research Method

This study conducted an analysis using qualitative methods to conclude the correlational relationship between the Indian Ocean Dipole (IOD) and total column water vapor (TCWV) on cloud formation in the waters west of Aceh. Qualitative methods are descriptive in nature and tend to use analysis (data processing).

Research Data

The data used in this study are as follows.

1. ECMWF/ERA-5 (format .nc)
   This data is processed using the Grads application to view total column water vapor (TCWV) data in map/spatial form. Grads, quoted from the official Grid Analysis and Display System (GrADS) website, is an interactive desktop tool that facilitates access, manipulation, and visualization of earth science data. The OpenGrADS project aims to develop advanced interfaces and extensions based on the main GrADS engine. The following is a link to data from ECMWF.
   https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single levels?tab=form.

2. HIMAWARI-8/9 satellite data (Z format)
   This data was processed using the SATAID (SATellite Animation and Interactive Diagnosis) application, where the data used came from Himawari-8/9 satellite data on channel 13, which functions to observe cloud top temperatures using infrared (IR) waves with the accumulation of several data points.

Data collection and observation of the IOD observation index (https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/dmi.had.long.data.) were conducted daily on September 25-26, 2022, in the waters west of Aceh, Aceh Province. Processing and analysis of total column water vapor (TCWV) data was also carried out during the daily period on September 25-26, 2022.

3. RESULTS AND DISCUSSION

Data Processing Results TCWV

Total Column Water Vapor is a climate variable that shows a correlation between the Indian Ocean Dipole (-) and water vapor in 2022. If there is a positive IOD, it will have a reduced impact on rainfall in western Indonesia. Conversely, a negative IOD will result in significant rainfall in Indonesia (Khaldun et al., 2018).

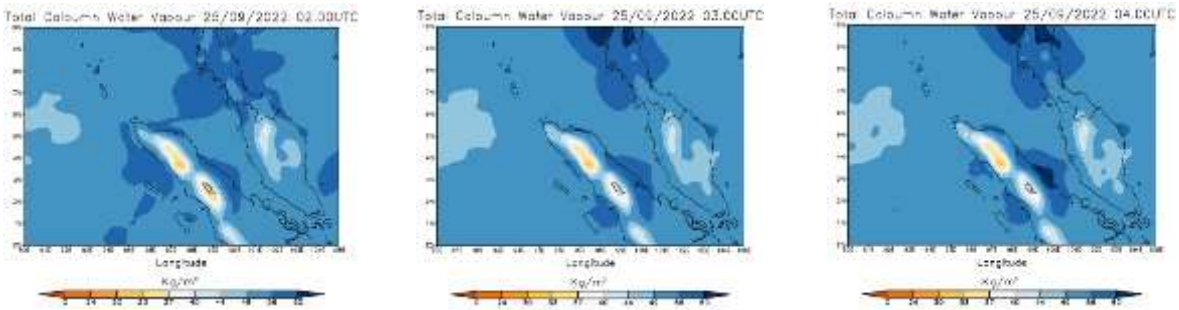

Figure 2. TCWV data results at 02:00-04:00 UTC in the waters west of Aceh on September 25, 2022.

The results of TCWV data processing on September 25, 2022 are shown in Figure 2. At 02:00 UTC, the TCWV value was above 40 kg/m3, at 03:00 UTC the TCWV value was above 44 kg/m3, while at 04:00 UTC the TCWV value was around 49 kg/m3.

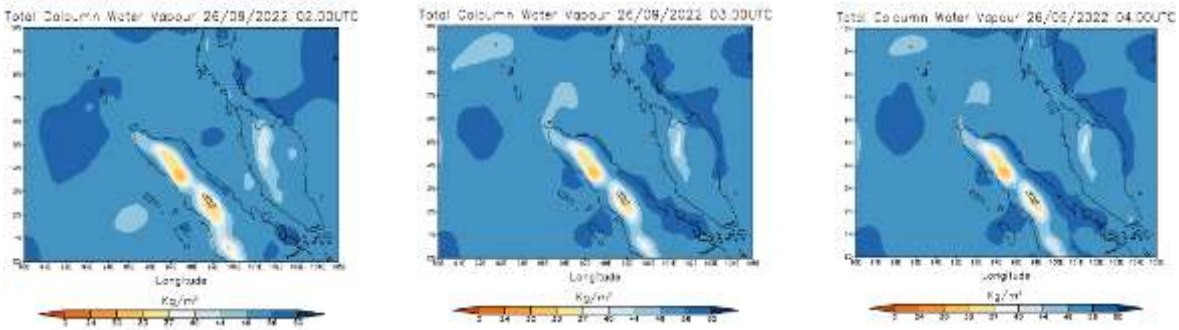

Figure 3. TCWV data results in the waters west of Aceh on September 26, 2022.

The results of TCWV data processing on September 26, 2022 are shown in Figure 3. At 02:00 UTC, the TCWV value was above 40 kg/m3, at 03:00 UTC the TCWV value was around 44 kg/m3, while at 04:00 UTC the TCWV value was around 44 kg/m3.

Data from the Himawari-8 EH Satellite

Himawari-8 EH product data shows peak cloud temperatures obtained from radiation observations at a wavelength of 10.4 micrometers, which are then classified using specific colors. Blue indicates no significant cloud formation (clear skies), while colder cloud top temperatures, where colors range from orange to red, indicate significant cloud growth and the potential formation of cumulonimbus clouds. Cumulonimbus clouds are thick clouds that grow vertically and generally bring heavy rain, lightning, and even hail.

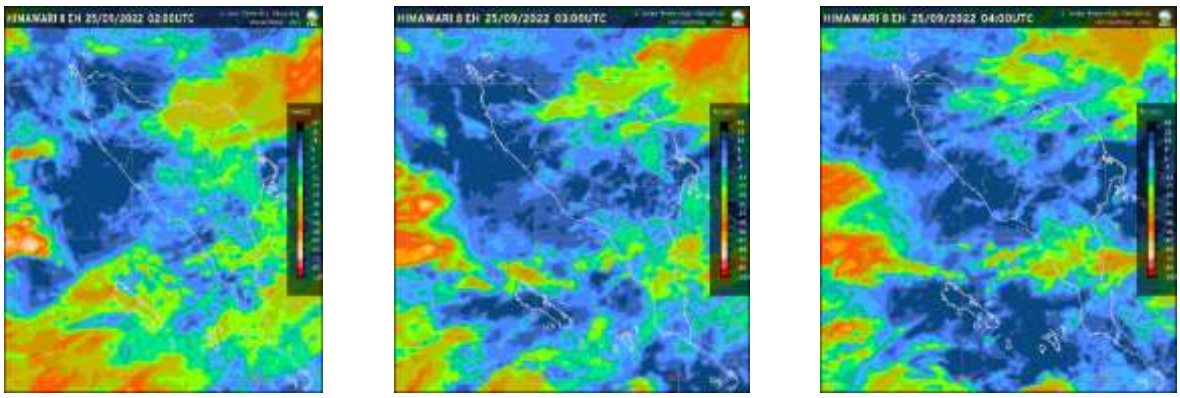

Figure 4. HIMAWARI 8 EH data results in the waters west of Aceh on September 25, 2022.

The data from the HIMAWARI-8 EH satellite on September 25, 2022, is shown in Figure 4. At 02:00-04:00 UTC, conditions in the waters west of Aceh showed that the peak cloud temperature obtained from HIMAWARI 8 EH satellite radiation observations indicated cloud formation with higher cloud intensity in the eastern and southern waters of Aceh.

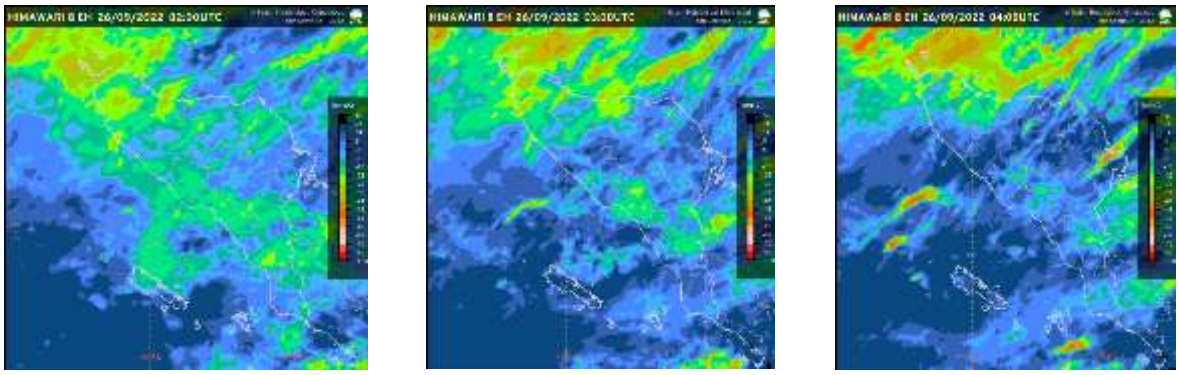

Figure 5. HIMAWARI 8 EH data results in the waters west of Aceh on September 26, 2022.

The data from the HIMAWARI-8 EH satellite on September 26, 2022, is shown in Figure 5. At 02:00-04:00 UTC, conditions in the waters west of Aceh showed that the peak cloud temperature obtained from HIMAWARI 8 EH satellite radiation observations indicated cloud formation with less intense clouds (clear skies) in the waters and coastal areas west of Aceh.

Figure 2, 3, 4, and 5 show the UTC time zone. When converted to WIB format, 02:00 UTC is 09:00 WIB, 03:00 UTC is 10:00 WIB, and 04:00 UTC is 11:00 WIB. From Figure 2, 3, 4, and 5, when clouds become very heavy, they cannot hold water. Therefore, the water in the clouds slowly melts and falls to the ground. This stage is called precipitation, which is the process of clouds melting into droplets. Water droplets from clouds that fall to the ground are called rain. The results of TCWV data and Himawari satellite data from BMKG produce output on the potential for extreme weather at a specified time. The potential for extreme weather has an impact on the occurrence of floods, landslides, tornadoes, and a number of other natural disasters. The statement regarding the potential for extreme weather in the western coastal region of Aceh is due to the Dipole Mode Index (DMO). The DMO factor also causes tornadoes, storms, and other potential natural disasters resulting from high water evaporation in the air, which leads to rainfall or extreme weather.

Data analysis on September 25 and 26 shows weather information. Based on the TCWV data and HIMAWARI 8 EH satellite image product output on September 25, 2022, there was potential for light to moderate rainfall in the waters west of Aceh. However, based on the TCWV data and HIMAWARI 8 EH satellite image product output on September 26, 2022, there was no potential for heavy or light rainfall between 02: 00-04.00 UTC or 09.00-11.00 WIB in the waters west of Aceh.

4. CONCLUSIONS

The relationship between IOD and water vapor (total water vapor column) TWCV on cloud formation in the waters west of Aceh is directly proportional to the accumulation of two data points on September 25, 2022, and September 26, 2022. The IOD has a significant influence on sea surface temperature distribution and rainfall patterns in western Aceh. High rainfall is directly proportional to cloud thickness, resulting in high rainfall data on September 25, 2022, and extreme rainfall on September 26, 2022, around the western waters of Aceh. Total Water Vapor Column is a climate variable that shows a correlation between the Indian Ocean Dipole (-) and water vapor in 2022, which describes cloud formation in the waters west of Aceh.

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