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RESEARCH ARTICLE

The Characterization of Warm Temperature in the Central part of Java during the Monsoon Transition in April 2019

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Abstract In 2019, a warm temperature was observed in the central part of Java Island-Indonesia during the monsoon transition. Therefore, this research aims to characterize temperature anomaly and explain the contributing factors in terms of radiation balance and latent heat flux to explain the environmental process related to temperature variability. The data from two meteorological stations in the Indonesian Bureau of Meteorology, Climatology, and Geophysics (BMKG) and the National Centers for Environmental Prediction (NCEP/NCAR) Reanalysis Project were used to explain the temperature anomaly. Furthermore, the reanalysis data were used to obtain several parameters, such as near-surface air temperature and humidity, cloudiness, solar and longwave radiation, as well as latent heat flux. Also, descriptive time-series data analysis was used to explain the factors contributing to the April 2019 temperatures. The results showed the effect of the Madden–Jullian Oscillation (MJO) on weather anomalies, where the study area traversed by the MJO causes an increase in humidity followed by an intensive cloud formation and the release of latent heat. This latent heat contributes significantly to the increase in temperature than the short and longwave radiation balance. Therefore, further study on atmospheric phenomena in the tropics especially warmer temperatures is needed because they significantly affect by climate change.

1. Introduction

In the last two decades, disastrous events, such as heat waves (Kalkstein & Smoyer, 1993; You & Wang, 2021), forest fires (Turk & Xian, 2013), river flooding (Loo et al., 2015; Marfai et al., 2015), coastal flooding (Kirshen et al., 2008), and extreme rainfall (Grimm & Tedeschi, 2009; Sekaranom & Masunaga, 2019) occurred frequently, causing major losses globally. These occurrences indicate what the future holds, where climate change causes frequent and severe extreme events. This is in line with the Intergovernmental Panel on Climate Change (IPCC) scenarios that analyze future changes in the mean and extreme climate at multiple spatial scales and estimate the future consequences toward the environment. According to the IPCC scenarios, the global temperature is predicted to rise between 1.41° C to 4.09° C, which is the moderate and worst scenarios, respectively (IPCC, 2014; Mach et al., 2016; Rhodes, 2016). Additionally, a rise in temperature to 1.5° C globally causes increasing magnitude and frequency of disasters (Allen et al., 2019; IPCC, 2018; Tollefson, 2018). The IPCC report on the warming of 1.5°C (IPCC, 2018) states that the frequency and amplitude of climate extremes will escalate in 100 years. During the end of the 21st century, the extremely warm temperature rose in magnitude and frequency, and vice versa for cold extremes. Also, there is an increase in extreme rainfall in different parts of the world (Loo et al., 2015).

Heat waves are one of the effects of rising temperatures on global regions (Ossola et al., 2021; You & Wang, 2021), occurring frequently in subtropical regions during the boreal summer in the northern hemisphere (boreal winter for the southern hemisphere) and causes heart disease in humans, agricultural drought, forest fires, and damage to infrastructure, hydroelectric power plants, and cultural heritage (García-Herrera et al., 2010; Prodhomme et al., 2021). Also, several parts of the world have experienced an increase in heatwave intensity, duration, and frequency (IDF) since the mid-twentieth century (Ossola et al., 2021). Presently, heat waves are significant hazards, exacerbated by shifting climate variability due to increasing Green House Gases (GHG) in the atmosphere (Das & Umamahesh, 2022). According to recent analysis and projections, the episodes escalated in many parts of the world, especially on a spatial and temporal scale. The temperature rise due to anthropogenic climate change is responsible for the IDF properties of heat waves (Robinson et al., 2021).

Generally, the tropics have a more stable temperature than the subtropics and heat waves have little impact, hence a temperature increase due to climate change is considered because it is related to thermal comfort, especially in urban areas (Nikolopoulou & Lykoudis, 2006). The balance of radiation entering and leaving the ground surface influences temperature rise (Mach et al., 2016). For example, high GHG in the atmosphere prevent outgoing longwave radiation (OLR) from escaping the earth. Consequently, the surface reabsorbs the longwave radiation reflected by GHG in the atmosphere, causing an increase in temperature (IPCC, 2014). This is exacerbated in urban areas by land cover, which absorbs radiation and raises the temperature above its surroundings, known as the urban heat island effect (Leichenko, 2011; Mayer & Höppe, 1987). The increase in GHG and changes in land use cause a significant rise in temperature (Leichenko, 2011).

The central region of Java Island–Indonesia is characterized by a tropical warm climate and is close to the Indian Ocean in the southern part. Furthermore, due to the high landscape dynamics, changes in land use associated with fast urbanization, and the loss of valuable agricultural land many researchers are interested, especially in urban heat islands in the cities (Partoyo & Shrestha, 2013). The local climate characteristics in the surrounding area are affected by the variability of sea surface temperature over the Indian Ocean. In addition, the influence of Madden–Julian Oscillation (MJO) on the intra–annual variability is noted. In the tropics, the MJO is an atmospheric oscillation propagating eastward every one to three months and is responsible for the periodical variation in precipitation (Sekaranom & Nurjani, 2019; Zhou et al., 2011). Furthermore, the MJO propagation forces the air upwards, causing intensifying convection and cloudiness, which is associated with latent heat and temperature-related processes, while at the other location, a reversed condition occurs. The MJO influence on the temperature has been identified across regions. For example, an increase in surface temperature has been identified in part of the United States when MJO enhances the convection over the Maritime continent (Zhou et al, 2011). Conversely, the same condition affects colder temperatures in the continental East Asia region (Kim et al., 2020; Song and Wu., 2019). These above conditions occur because of the interaction between MJO and other processes, such as anticyclonic activities and the Rossby Wave.

In this region, high-temperature variability has been observed during the transition between the rainy to dry seasons, especially in April (Chang et al., 2005; Sekaranom & Nurjani, 2019). Figure 1 showed the variation in air temperature from 1950 to 2019. Furthermore, the temperature in April was selected to be presented in the figure instead of the annual variation because it has a higher variability compared to other months. Also, there are more temperature data above the mean value, around 26.9°C – orange line, in the month of April after the 2000s compared to the previous five decades. The process affecting the warmer temperature is identified by analyzing recent years of information available in 2019. This research addresses what process causes the temperature to be warmer than average after the 2000s and a case study in April 2019 was used. Following this, the research aims to characterize the warmer temperature during the April monsoon transition in 2019 and identify the dynamics of the atmosphere in terms of radiation balance and latent heat flux. In addition, the case study will help in understanding future research .

2. The Methods

2.1. Data

This research was conducted based on temperature data from the Indonesian Bureau of Meteorology, Climatology, and Geophysics (BMKG). Also, the daily temperature data from Yogyakarta and Semarang Stations were analyzed from January to April 2019, using additional information from the National Centers for Environmental Prediction (NCEP/NCAR) Reanalysis Project, conducted by The United States. The reanalysis product contains a global dataset of the major atmospheric parameters from field measurement data and climate models. Furthermore, the end product generated gridded data that is spatially and temporally uniform, 2.5° × 2.5° in spatial resolution around 250 km in the tropics and 6 hours temporal resolution (Kalnay et al., 1996). Several parameters from the product were used, such as air temperature near the surface, relative humidity, and cloudiness. The relative humidity is associated with precipitation, which lowers the temperature after rain and the water evaporates into the atmosphere. Also, the cloud can block solar radiation from the sun and re-radiating longwave emissions from the earth back to the surface, hence affecting the temperature.

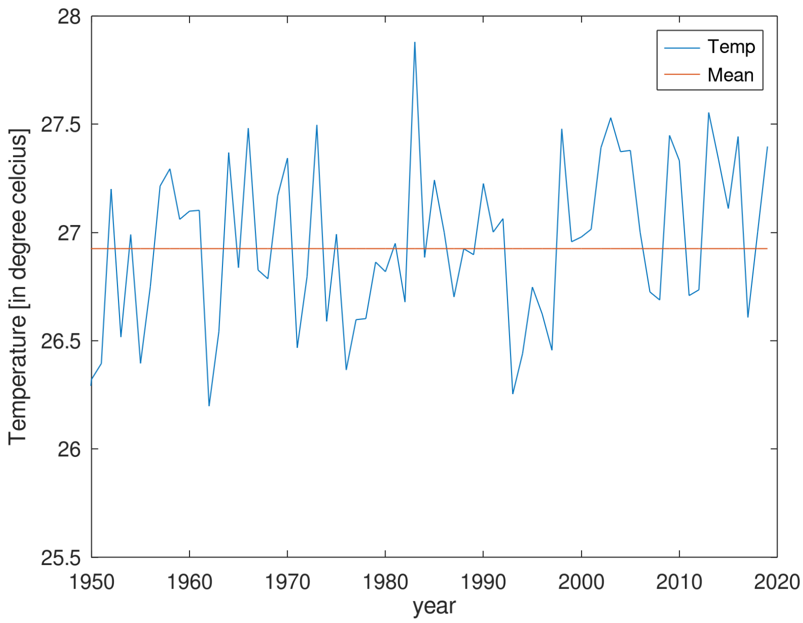

Figure 1. Variation of air temperature selected only for the month of April from 1950 to 2019 (Source: data processing of NCEP/NCAR Reanalysis Project)

Table 1. Description of parameters from the NCEP/NCAR Reanalysis Project used in this research

Short name	Description	Level
air	Near Surface Air Temperature	Sig995
rhum	Near Surface Relative Humidity	Sig995
tcdc	Total Cloud Cover	EATM
ulwrf	Upward longwave radiation flux	sfc
uswrf	Upward solar radiation flux	sfc
dlwrf	Downward longwave radiation flux	sfc
dswrf	Downward solar radiation flux	sfc
lthfl	Latent heat flux	sfc

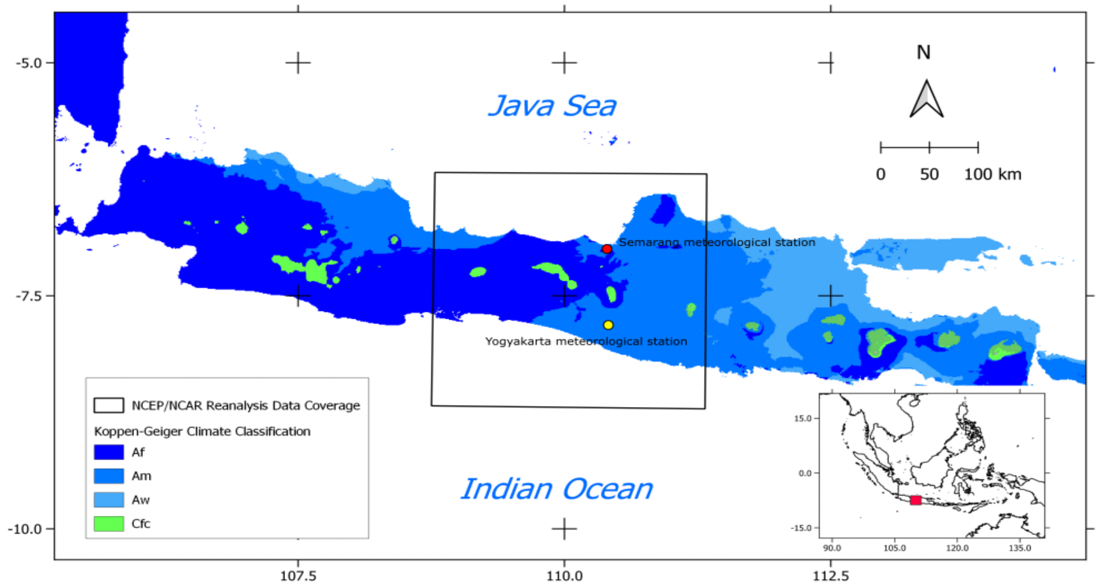

Figure 2. Study area location and the corresponding meteorological stations (Yogyakarta-yellow dot; Semarang-red dot) and NCEP/NCAR Reanalysis Data Grid (Black color rectangle) used in this study (Source: Data Processing, climate classification data are obtained from Beck et al., 2018)

The surface temperature is a product of net radiation received from the sun, shortwave radiation, and emitted by the surface in longwave radiation. Furthermore, increasing net radiation causes higher temperatures and vice versa with decreasing net radiation. The downward and upward shortwave and longwave radiations are used to calculate the radiation balance. Finally, latent heat flux data, associated with radiation released during the condensation process inside clouds, explains the factors contributing to the warm anomaly. Table 1 shows the detail of each parameter.

The reanalysis product contains gridded data at the resolution above and covers approximately 250 km × 250 km of the research area. Therefore, it extends across two provinces, namely Central Java and Yogyakarta. Based on the Koppen–Geiger Climate Classification, the area is dominated by a tropical humid climate as shown in Figure **2**, with tropical rainforest (Af) and monsoon climates (Am) in the western part. The top of the mountainous region has a subpolar climate (Cfc) due to the cold temperature. The research area is characterized by urban area development at several locations, especially Yogyakarta and Semarang. Additionally, the growing population changed the land cover which resulted in the development of urban heat islands (UHI). This condition indicates a warmer temperature compared to the past, which affects the thermal comfort of the local population in the long run. The warm temperature anomaly decreases the comfort level, spread vector-borne diseases, such as dengue fever, and reduces agricultural production.

2.2. Methods

This research focuses on descriptive analyses related to the atmospheric dynamics that may affect the warm temperature anomaly. Also, the information related to the development of warm temperature anomalies in the study area was described and interpreted using graphical analysis. First, changes in basic atmospheric characteristics particularly temperature, relative humidity, and cloud coverage are plotted using the time series data. The emphasis is on the dynamics from the beginning of the year, which is the peak of the rainy season, to the monsoon transition in April.

Furthermore, the result above is elaborated with the radiation-related processes using outgoing longwave radiation (OLR) data and net radiation balance calculation. The space-time distribution of OLR at the research area was characterized using the Hovmoller diagram, particularly at 6.25° to 8.75° South Latitude and 90° to 150° East Longitude which is the Maritime Continent area (Ramage, 1968). Additionally, the low OLR values indicate that dense clouds reflect the longwave radiation, which comes back to the earth's surface, hence the clouds are similar to greenhouse gases that warm the earth's surface and keep the temperature stable at night. The net radiation balance is calculated to obtain a detailed explanation of the warm temperature anomaly and the formula is as follows:

Net Radiation = DSWRF+DLWRF-USWRF-ULWRF

where DSWRF, DLWRF, USWRF, and ULWRF are the downward and upward shortwave and longwave radiation as shown in Table 1. Finally, the latent heat flux data were analyzed to determine the contribution of clouds in terms of latent heat release. In addition to the longwave radiation reflectance, the latent heat release is an important parameter because it transfers more heat to the surface due to the cloud's condensation process. The latent heat analysis is based on a time series plot, particularly the anomaly since the peak of the rainy season in January.

3. Result and Discussion

3.1. Characteristic of the temperature, humidity, and cloud during the warm temperature anomaly

The first part of the results is related to the atmospheric characteristics associated with the warmer temperature in April 2019, this includes near-surface temperature, relative humidity, and cloud fraction. The temporal analysis was conducted from early January to April 2019, when the temperature began to

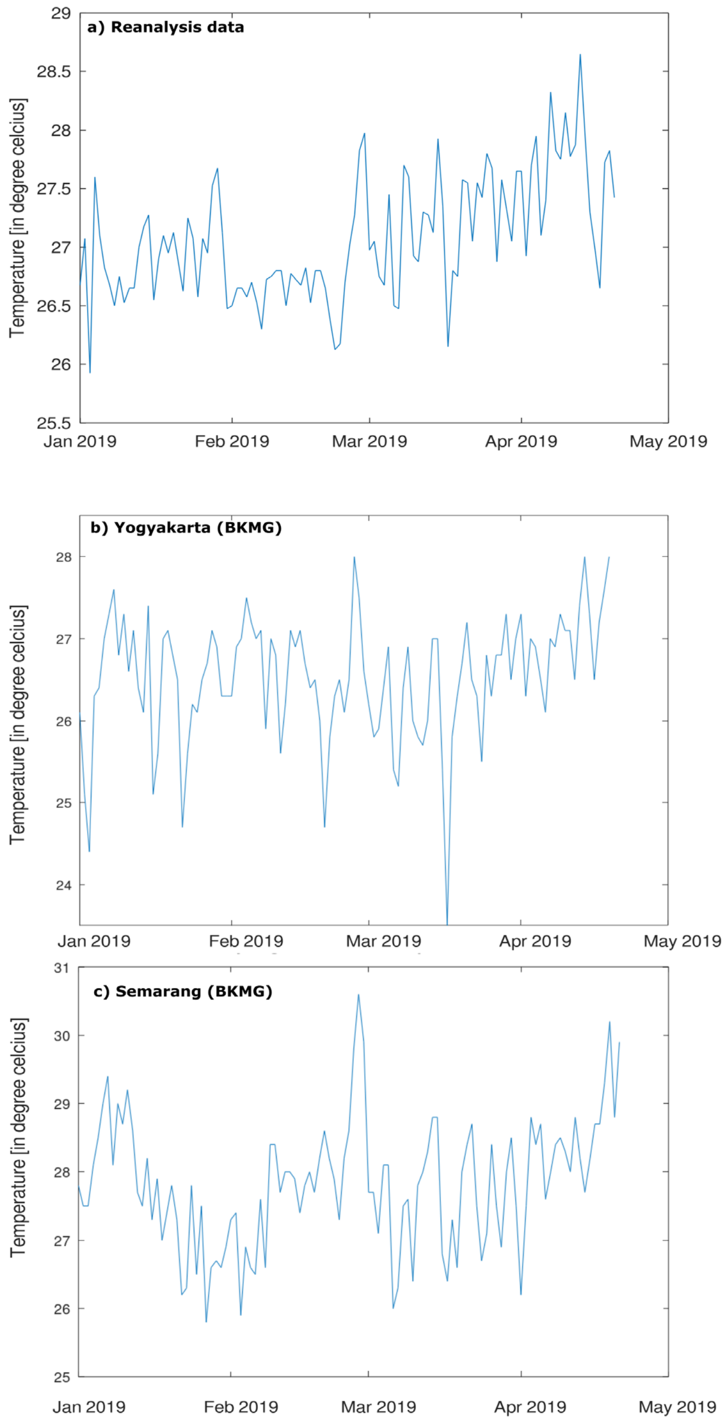

Figure 3. Temperature variability from January to April 2019 which shows a period of warmer temperature in April 2019 from a) reanalysis data, b) Yogyakarta meteorological station, and c) Semarang meteorological station (Source: data processing from BMKG and NCEP/NCAR Reanalysis Project)

rise. Figure 3 shows a significant increase in temperature from January to April using the reanalysis data and meteorological stations in Yogyakarta and Semarang. According to the reanalysis data, the peak temperature in January 2019 was about 27.5° Celsius, and this exceeded to around 28° Celsius in late February and early March. The highest peak of 28.5° Celsius is reached in April, and the variability shows that this temperature is also observed from Yogyakarta meteorological station. The temperature at the Yogyakarta station matches the reanalysis data, with the minimum occurring in mid-March 2019. Furthermore, the maximum temperature in Semarang is warmer than in the region, reaching up to 30° Celsius. The meteorological station data showed the maximum temperature in both areas is similar at the end of February 2019. This variability is explained later in the discussion section.

This analysis focuses on the short-term variability, where the temperature increases by about 1° Celsius compared to January 2019. The temperature varies after that due to many factors, including seasonal changes. Furthermore, it is not directly connected to climate change-related processes, particularly the global increase of temperature between 1.5° to 4° Celsius in 2100. The process that occurred during the analysis period can help explain the mechanism of temperature increase in the future, for example, due to the increasing magnitude of ENSO and/or other tropical phenomena, MJO in this case – will be explained in the discussion section. Figure 1 infers that various processes affect April's temperature, it has a more dynamic than constant pattern.

Additional data are analyzed to understand the mechanism. In the next step, relative humidity and cloud fraction data are used to analyze temperature increase as shown in Figure 4. Figure 4a shows the temporal dynamics of relative humidity for the same period as the temperature data. The air humidity at the end of the analysis period in April was lower than at the beginning of January. This is due to the period between the rainy season, which occurs from January to February, and the transitional season from March to May. The high relative humidity at the beginning is associated with rainfall at the peak of the rainy season. In March-April, relative humidity decreases and is associated with less rainfall, with the minimum value in early April. However, there is an increase in humidity in mid–April.

Figure 4b shows the variability of cloud cover, which aims to confirm the dynamics of the atmosphere that occurred during that period. There was a high cloud cover in mid–January, accompanied by a peak relative humidity of about 90%. Also, February and March are characterized by similar cloud cover compared to January. The maximum value is reached in early March, though only for a short period before it decreases. In March, the peak cloud cover is not accompanied by a high relative humidity, as the humidity in early March is lower than in the previous month. Therefore, the increase in cloud cover was not accompanied by a rise in rainfall in March, though this was temporary and cloud cover intensified in early to mid–April.

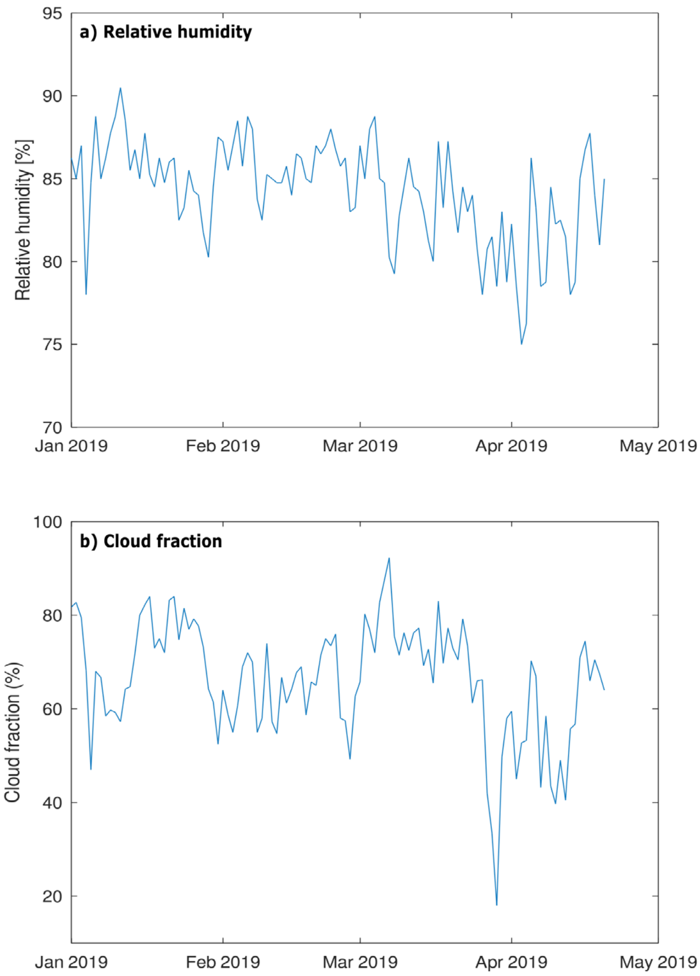

Figure 4. Relative humidity and cloud fraction from January to April 2019 which corresponds to warmer temperatures (Source: data processing of NCEP/NCAR Reanalysis Project)

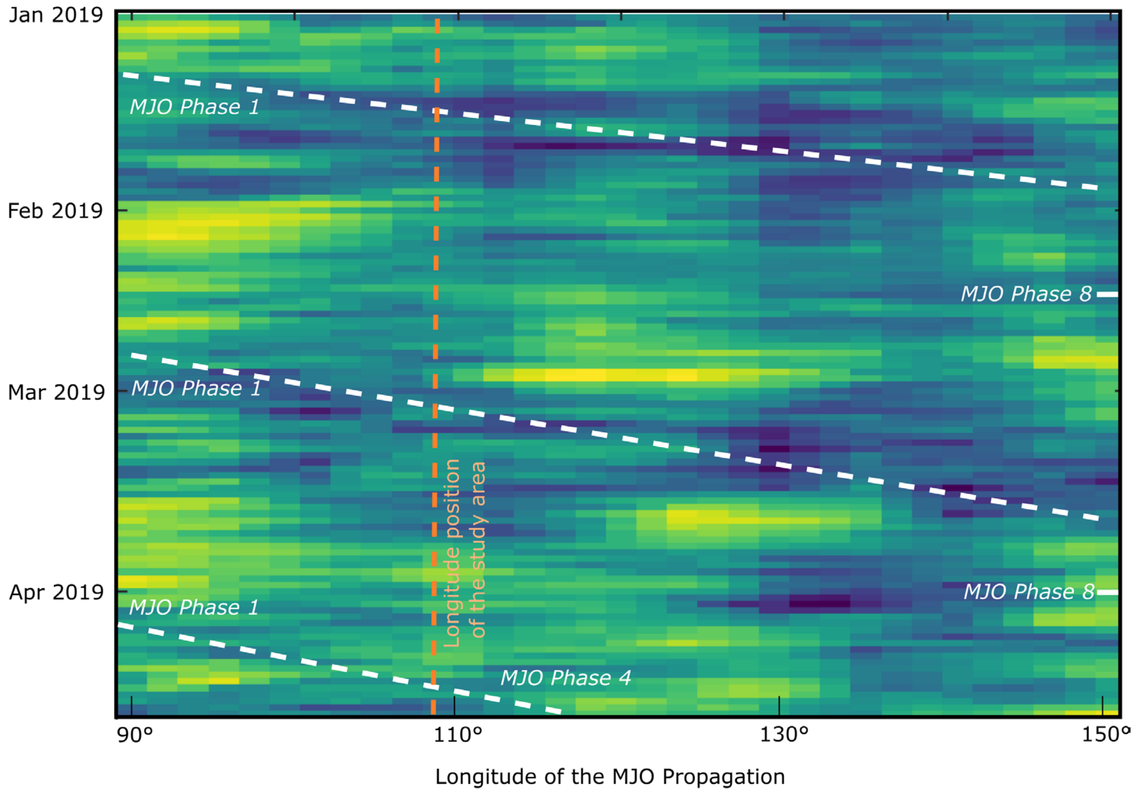

Figure 5. Hovmoller diagram of the Outgoing Longwave Radiation (OLR) from January–April 2019 that indicates the influence of Madden–Jullian Oscillation (Source: data processing of NCEP/NCAR Reanalysis Project)

3.2. Radiation Balance and the Influence of Latent Heat

Temporal characteristics of temperature, humidity, and cloud cover data are analyzed to determine their relationship to the radiation balance. The Outgoing Longwave Radiation (OLR) value is an important factor related to cloud cover. Therefore, the less cloud cover, the higher the longwave radiation released from the atmosphere, hence affecting the increasing OLR value. Figure 5 depicted the propagation of the OLR on the Maritime Continent from west to east, 90° – 150° East Longitude. The short–term propagation is related to the dynamics of the Madden-Julian Oscillation (MJO), which moves from east to west starting from Phases 1 to 8 in the Indian and Pacific Oceans, respectively. Additionally, this propagation carries high humidity from the Indian Ocean to the Pacific and is associated with rainfall anomalies. The MJO began development at the beginning of April (Phase 1). Furthermore, when the temperature anomaly reaches its peak, the MJO reaches phases 3 and 4, having a significant impact on atmospheric dynamics in the research area, which is located at longitude coordinates of approximately 110° East Longitude, hence the MJO influences the temperature anomaly.

Figure 6 shows the temporal dynamics of the radiation balance which includes shortwave radiation from the sun, long-wave from the earth, and the total radiation balance. The results demonstrtates that there is no change related to the shortwave radiation balance, except the end of March to April. This is due to an increase in cloud cover which is also affected by the MJO. The rise in cloud cover reflects shortwave radiation from the sun, hence less solar radiation reaches the Earth's surface and it also affects the longwave radiation emitted by Earth. In addition, there is a decrease in the intensity of long-wave radiation that escaped the Earth's atmosphere from the end of March to mid–April due to absorption by cloud cover. An increase in cloud cover reduces the amount of shortwave radiation that reaches the earth's surface, while long-wave radiation is trapped by clouds to a greater extent. This results in a lower total radiation balance in mid-April than at the end of March.

The analysis shows that the radiation characteristics are balanced from January to March, while there is a decrease in the net radiation balance from the end of March to April. However, a decrease in the net radiation balance does not imply a decrease in temperature. The temperature increases from late March to mid–April and this may be triggered by higher cloud cover and humidity. Also, when condensation occurs in the cloud, these processes contribute to the release of latent heat. Figure 7 shows the temporal variability of latent heat for the same period as the previous analysis. The latent heat is higher in January than in February and this is due to high rainfall in January accompanied by the peak humidity. February is characterized by lower latent heat, associated with lower temperature, humidity, and cloud cover. Meanwhile, March is distinguished by lower humidity, increased cloud cover, and higher latent heat. March experienced less precipitation which reduced surface evaporative cooling and the latent heat release was not balanced. This triggered a temperature rise which peaked higher than in February. Also, there was a sharp increase in latent heat from the beginning to the middle of April due to the cloud cover and humidity during the MJO propagation, which has an impact on the temperature. Figure 8 shows the interrelationship of the factors that contribute to the temperature anomaly.

According to this analysis, MJO influences the warmer temperature variability in April 2019. The direct impact of the higher temperature may be less significant compared to the subtropical region. For example, MJO is responsible for

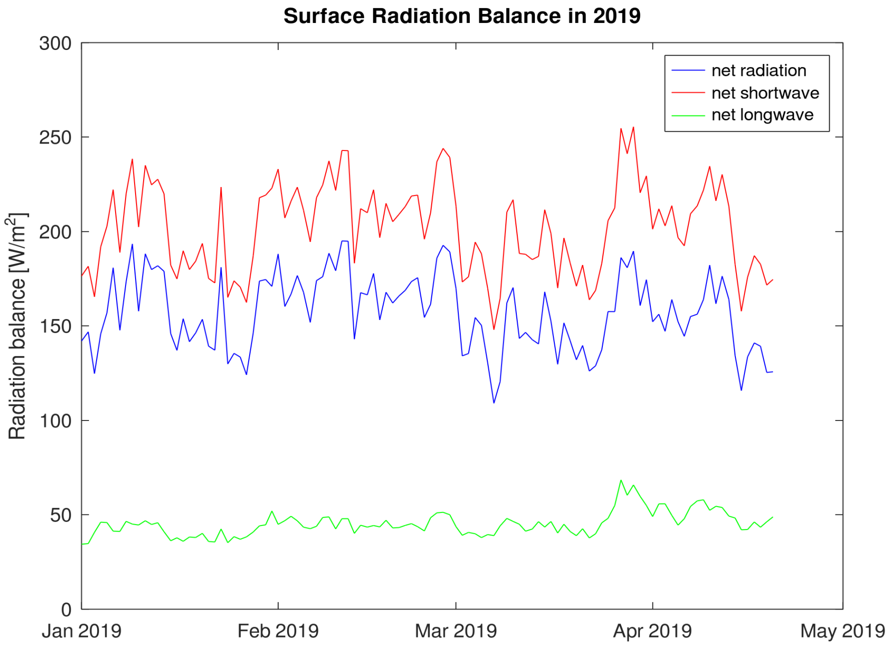

Figure 6. Radiation balance in terms of net shortwave radiation, net longwave radiation, and total radiation balance before and during the temperature extreme in April 2019 (Source: data processing of NCEP/NCAR Reanalysis Project)

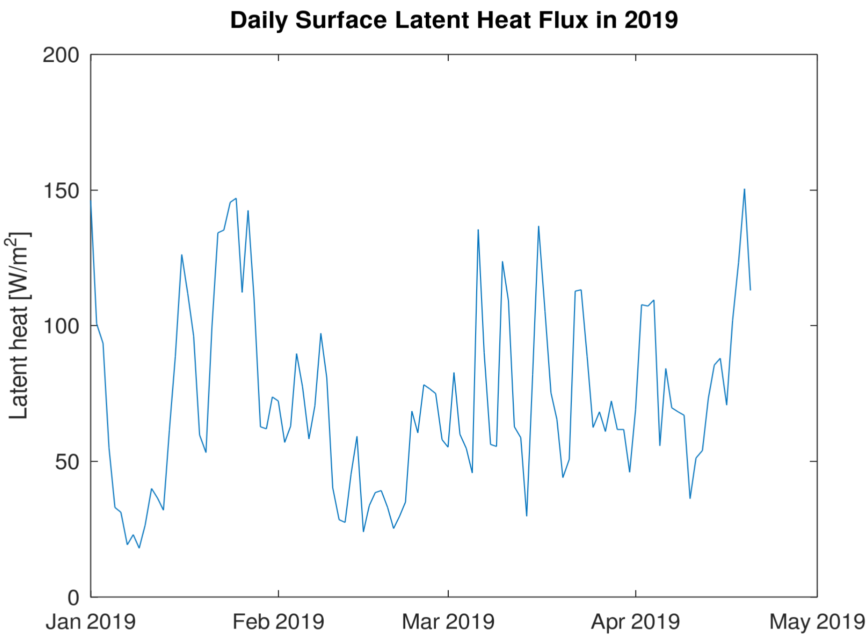

Figure 7. Latent heat flux of the study area before and during the temperature extreme in April 2019 (Source: data processing of NCEP/NCAR Reanalysis Project)

the record-breaking heat waves in parts of Japan, Korea, and North Eastern China in 2018 (Hsu et al., 2020). The recorded temperatures at the three locations were higher than 39°C, hence warmer than this research. Also, the MJO was responsible for the record-breaking marine heat waves over the Yellow Sea in 2016, which caused SST anomalies more than 2°C higher at the center (Li et al., 2022). The above phenomenon is a complex process that affected by the interaction between MJO, cyclonic activities, subtropical high, cloudiness, radiation, and wind. The warmer temperature variability in the research area is more simple to explain than the other two locations, because of the direct impact of MJO on the increasing convective activity in the passed area.

4. Conclusion

This research examines the short–term temperature variability which has different properties compared to climatological studies. Also, it reported that short-term variability has higher fluctuations than the long-term mean, which covers 30 years or more in climatological studies. For example, this research shows that from January to April 2019, the temperature increased by about 1° Celsius. According to the climatological average, this increase will be achieved in the next few decades, with a global average of 1° to 4° Celsius by the end of 2100. Although the above short-term variability is unrelated to the long-term increasing global average temperature, this condition depicted that the threat

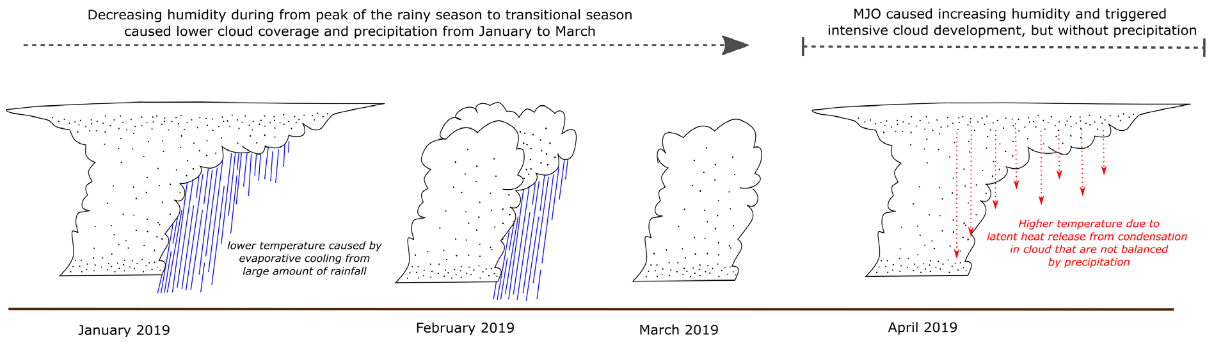

Figure 8. The conceptual result related to the influence of MJO and the contribution of latent heat release during the warmer temperature in April 2019

of increasing variability of meteorological components in the short term should be considered in addition to the long-term change. The impact of short-term increase in variability can be significant in the present time. For example, a rise in drought events caused an extremely high temperature during the dry season in some parts of the research area.

The results of the short–term temperature variability indicate that the atmospheric phenomenon in the tropics, including the MJO, can affect the occurrence of extreme temperatures. Therefore, future temperature variability can be influenced by complex factors. The increase in temperature is influenced by the balance of short-wave radiation from the sun, long-wave radiation from the earth, the dynamics of clouds, and water vapor in the atmosphere. This research shows that the availability of water vapor and cloudiness affect temperature variability. The MJO can trigger a rise in water vapor in the atmosphere, leading to a higher cloud cover and increased latent heat release in the clouds through the condensation process.

Atmospheric dynamics concerning temperature increase in the tropics require further study, especially with climate change and disaster risk reduction. Currently, extreme temperatures are equated with thermal comfort in various parts of Indonesia. The higher temperatures due to climate change in the future will produce a more severe impact and will spread across regions. However, the mechanism by which temperature extremes affect significant sectors, such as agriculture and health, is unclear. Most research focuses on changes in mean values, while a few focus on changes in extreme values due to climate change. Additionally, changes in the extreme range are more significant than the statistical average. This influences the impacts of climate change, making it difficult to overcome in the future, especially if the changes in these extreme values are not carefully considered.

Acknowledgment

Temperature data presented in this research were obtained from the Indonesian Bureau of Meteorology, Climatology, and Geophysics (BMKG) Online Portal Website (https://dataonline.bmkg.go.id), while the reanalysis data were accessed from NCEP/NCAR reanalysis data website (https://psl.noaa.gov/data/gridded/data.ncep.reanalysis .html). The authors are grateful to Radio Republic Indonesia (RRI) Pro 1 for the first idea regarding the research through an interview process. This research is not affiliated with any grants in the submission process and will be proposed for the grant of “Hibah Penghargaan Karya Ilmiah Sudah Terbit pada Jurnal Internasional Bereputasi” by “Badan Penerbit dan Publikasi (BPP) Universitas Gadjah Mada” after publication.

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