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Atmospheric Dynamics Analysis of Extreme Rain Events Using Radiosonde Observation Method (Case Study of Extreme Rain for The Period Of 21-31 March 2024 in Probolinggo (Paiton), East Java

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A B S T R A C T

Rain extreme is one of phenomenon weather extreme that can cause disaster like flood and land landslide. Understanding about dynamics the atmosphere that causes the occurrence Rain extremes are very important to predict and anticipate possibility the occurrence disaster This study aims to analyze dynamics the atmosphere that causes incident Rain extreme in Probolinggo (Paiton), East Java in the period 21-31 March 2024 using method radiosonde observations. Research methods used covered rainfall data collection Rain daily, radiosonde data (temperature, humidity, wind), and real data from the numerical model global weather / climate. Data analysis was carried out using method statistics, visualization of skew-T log-P diagrams, analysis pattern wind, distribution humidity, convergence / divergence, and analysis dynamics atmosphere use equality movement and continuity. Expected results from This research is better understanding deep about dynamics the atmosphere that causes Rain extremes in the study area, such as pattern circulation wind, source water vapor, lifting processes, and mechanisms formation Rain extreme. This research can also give contribution in development system warning early and mitigation disaster related Rain extreme in the study area and other areas with similar characteristics.

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1. INTRODUCTION

Rain extreme is one of phenomenon weather extreme that can cause disaster like flood and land landslide. Understanding about dynamics the atmosphere that causes the occurrence Rain extremes are very important to predict and anticipate possibility the occurrence disaster The radiosonde observation method is one of the methods that can used to analyze condition atmosphere in a way vertical, such as profile temperature, humidity, and wind [1].

Case study Rain extreme events that occurred in Probolinggo (Paiton), East Java in the period 21-31 March 2024 became object interesting research to study. By analyzing radiosonde data during period said, it is expected can obtained information about dynamics the atmosphere that causes the occurrence Rain extreme, such as pattern circulation wind, distribution humidity, and conditions layer atmosphere other. On March 21-31, 2024, it has been happened Rain extreme in a number of districts in the East Java Province area starting at noon day until Evening day with intensity tall during more from one hour since Afternoon day and estimated until reaches (>100 mm/ day). Rain extremes that have occurred so far Indonesia, the majority preceded by the existence of rainfall heavy rain (rain dense) and long in the location and surrounding areas event. High rainfall need condition supportive atmosphere like atmosphere that is not stable so that push the occurrence growth the clouds convective. Factors that can influence condition atmosphere own global scale up to in addition, flooding is also influenced by regional conditions, especially on the surface. like size area flow river (DAS), DAS topography and type use or cover land. Probolinggo City is one of the buffer areas Mother city province Java East in all aspect electricity so that get attention If happen a disaster like flood, land landslides, etc. This writing aims to find out and study condition dynamics atmosphere moment incident Rain extreme in the Probolinggo area cause concern public local.

According to Prof. Samsuri Haryadi, Professor of Meteorology Institute Bandung Institute of Technology (ITB), analysis dynamics atmosphere using radiosonde data is very important in learn phenomenon weather extreme like Rain extreme. Radiosonde data provide information vertical about condition atmosphere like temperature, humidity, and wind can used to analyze the atmospheric processes that cause Rain extreme[2]. Dr. Ardhasena Sopaheluwakan, researcher from the National Institute of Aeronautics and Space (LAPAN), stated that Rain extreme in East Java region often associated with the El Nino-Southern Oscillation (ENSO)[3] phenomenon and the pattern wind monsoon. Therefore that, analysis dynamics atmosphere related pattern circulation wind and distribution humidity become very important in understand incident Rain extreme in the region. According to Dr. Reni Sumarni, a researcher from the Meteorology, Climatology and Geophysics Agency (BMKG), rain extreme in the East Java region can also caused by interaction between system weather local and regional. Therefore that, analysis dynamics atmosphere No only limited to a regional scale, but also necessary consider factors local like topography and conditions surface.

This study aims to address the analytical gap in understanding the atmospheric processes triggering extreme rainfall in the area, particularly related to wind circulation patterns, humidity distribution, and atmospheric instability. Previous studies have focused more on global-scale phenomena such as ENSO or monsoons but have not thoroughly examined the interaction of global factors with local conditions like topography or land use. Therefore, this research provides a significant contribution by exploring these relationships and offering insights for the development of early warning systems and disaster mitigation strategies in the region. The objective of this study is to analyze the atmospheric dynamics leading to extreme rainfall in Probolinggo using radiosonde data and global numerical models. This research is expected to provide an in-depth understanding of wind circulation patterns, sources of water vapor, lifting processes, and the mechanisms behind convective cloud formation.

2. RESEARCH METODE

In the analysis dynamics this atmosphere we use study of existing data in bulk data Rain daily from station climatology Malang East Java case during period 21-31 March 2024 to identify incident Rain extreme. Observation data (temperature, humidity, wind) from station Meteorology Juanda East Java during period Rain extreme. Reanalytical data (reanalysis data) from numerical models global weather / climate such as university data wyoming or raob to get information about condition atmosphere on a regional and global scale. And using BMKG Radar Imagery as foundation main condition atmosphere period mentioned.

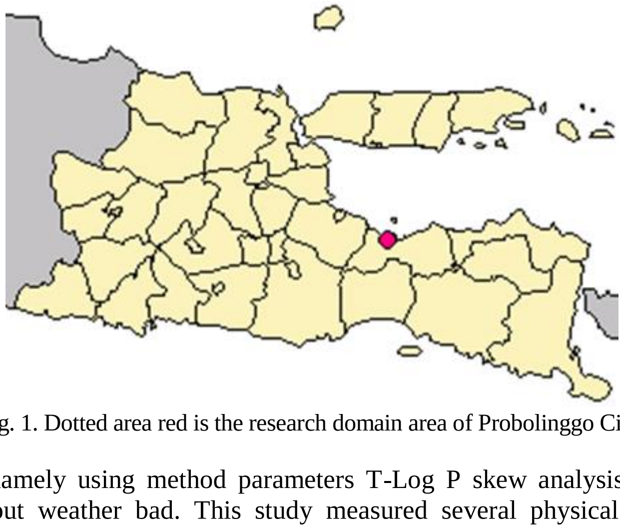

Fig. 1. Dotted area red is the research domain area of Probolinggo City.

The index we use namely using method parameters T-Log P skew analysis where can know A indication or parameters about weather bad. This study measured several physical variables, including atmospheric temperature at various altitudes, relative humidity, wind speed and direction, and daily rainfall intensity. These measurements aimed to provide a comprehensive analysis of the atmospheric conditions leading to extreme rainfall in the study area [4]. Radiosonde data from the Juanda Meteorological Station were utilized to observe vertical atmospheric profiles. These observations included parameters such as temperature, humidity, and wind at different altitudes [4]. Additionally, reanalysis data from global numerical models, such as RAOB or datasets provided by the University of Wyoming, were employed to understand regional and global atmospheric conditions. Rainfall data from the Malang climatology station were also collected to assess local precipitation patterns, while radar imagery from BMKG was used to visualize and validate rainfall distribution.

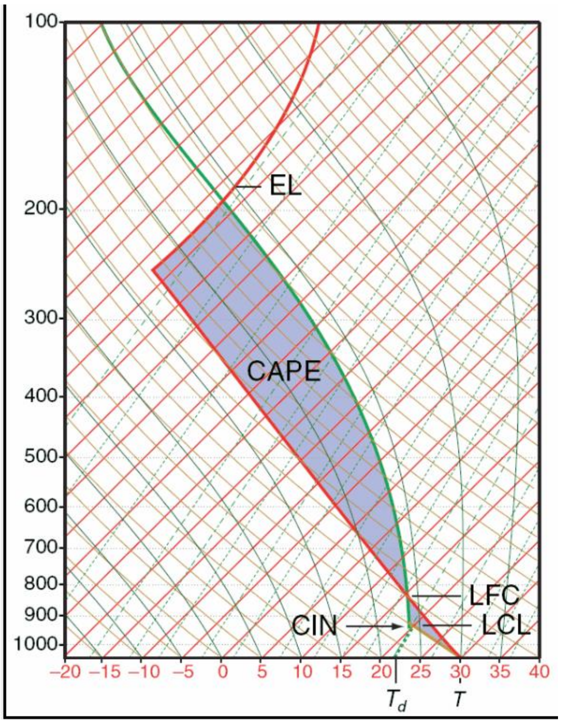

Fig. 2. Example SKEW T-Log P Indeks

The Skew-T Log-P diagram is a powerful tool for analyzing atmospheric thermodynamics. It provides a graphical representation of temperature, dew point, and wind speed profiles at various atmospheric levels. Key components analyzed using this method include:

- Atmospheric Stability: The difference between the environmental lapse rate and the adiabatic lapse rate reveals whether the atmosphere is stable, unstable, or neutral. High CAPE values, calculated from the diagram, indicate substantial energy for convection, leading to intense cloud formation and rainfall.
- Wind Shear: By observing wind barbs on the diagram, changes in wind direction and speed with altitude can be assessed, identifying potential shear zones that enhance storm severity.
- Moisture Content: The dew point temperature curve provides insight into the humidity levels at different altitudes, indicating layers conducive to condensation and cloud development.

Data processing and interpretation included several analytical techniques. The Skew-T Log-P diagrams were used to evaluate atmospheric instability and the potential for convection. Rainfall distribution maps were created to highlight areas most affected by extreme precipitation. Weather systems associated with surface weather conditions were identified using radiosonde data and radar imagery. Finally, statistical analyses were conducted to validate the relationship between radiosonde measurements and the extreme rainfall occurrences [5].

Key Calculation Formulas:

1) *Convective Available Potential Energy (CAPE): where:*
   - virtual temperature of the air parcel (K).
   - virtual temperature of the environment (K).
   - gravitational acceleration (9.8 m/s).
   - Level of Free Convection (height where the parcel becomes buoyant).
   - Equilibrium Level (height where the parcel loses buoyancy).

2) *Vertical Wind Shear: where:*
   - change in the zonal wind component (m/s).
   - change in the meridional wind component (m/s).
3) *Moisture Flux Convergence (MFC): where:*
   - specific humidity (kg/kg).
   - horizontal wind vector (m/s).
   - divergence operator.

These formulas represent the critical relationships between physical variables such as temperature, wind, and humidity, which collectively influence the processes leading to extreme rainfall. Key formulas were applied to quantify specific atmospheric dynamics. Convective Available Potential Energy (CAPE) was calculated to measure the energy available for convection, while vertical wind shear was assessed to evaluate changes in wind speed and direction with altitude. These calculations provided critical insights into the mechanisms driving extreme rainfall in the study area.

3. RESULT AND DISCUSSION

Observations are made by relying on all available data, there are radiosonde observations in the surrounding area and related to conditions at the existing point. To support the analysis, the following processes were employed to enhance data visualization:

3.1 Vertical Humidity Trends:

- Radiosonde data from the 0-6 km atmospheric layer were processed to extract relative humidity values at different altitudes.
- A line graph was generated to depict changes in humidity, highlighting peaks in the 2-4 km range during the event period.
- This visualization aids in identifying atmospheric layers with maximum moisture content that contribute to convective activity.

3.2 Correlation Diagrams:

- CAPE values, calculated using radiosonde temperature and dew point data, were plotted against daily rainfall intensity recorded at climatology stations.
- The scatter plot revealed a positive correlation, demonstrating the role of atmospheric instability in extreme rainfall occurrences.

3.3 Surface Pressure Maps:

- Data from global weather models were used to create isobar maps of the research region during the event.
- Low-pressure systems driving wind convergence were clearly identified, providing insights into surface weather dynamics.

3.4 Rainfall Distribution:

- Rainfall data from regional stations were interpolated to produce spatial distribution maps.
- These maps highlighted regions experiencing the highest rainfall intensities, aligning with areas of significant atmospheric instability.

3.5 Profile Vertical Atmosphere

In this discussion, we will discuss about profile vertical the atmosphere of course related to temperature and humidity as well as the wind where according to WMO guidelines on observation that is Temperature layer lower atmosphere (0-3 km) shows existence significant warming, which is accompanied with humidity high in the layer This. In the layer medium (3-6 km), found existence decline sufficient temperature sharp, showing existence instability atmosphere. Layer on atmosphere (>6 km) tends to dry with very low temperature. At height low (0-2 km), wind blowing from direction southeast with speed moderate (5-10 m/s). At the height medium (2-5 km), occurs change direction wind to the southwest with increasing speed (10-15 m/s). In the layer above (>5 km), wind blowing from west direction with speed high (15-20 m/s). [1] After process existing data then, the result from observation temperature and humidity as well as wind at the station meteorology closest is as following, The Skew-T Log-P analysis reinforced these findings, indicating substantial atmospheric instability with high CAPE values. The diagrams also highlighted the existence of significant wind shear, which further amplified the potential for severe weather conditions. These observations were consistent with the identified patterns of convective activity in the study area.

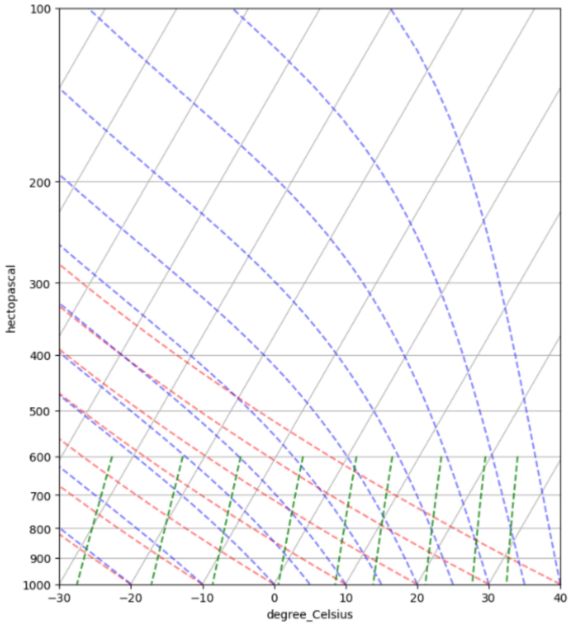

Fig. 3. T Log P Skew Analysis of Case Study.

Monsoon activity in East Java during March 2024 played a pivotal role in enhancing atmospheric instability and moisture availability in Probolinggo. The interaction between large-scale weather systems, such as monsoons, and local topographical factors contributed significantly to the occurrence of extreme rainfall. The radiosonde data confirmed the influence of these interacting factors, providing a clear link between regional atmospheric dynamics and localized extreme weather events. In the analysis above can known that heating in the layer lower high atmosphere and humidity create very bad condition stable, supportive formation cloud intense convective. And also change direction and speed wind with height show existence wind significant shear, which contributes to the formation and intensity storm Rain.[6]

3.6 Rainfall Distribution Map

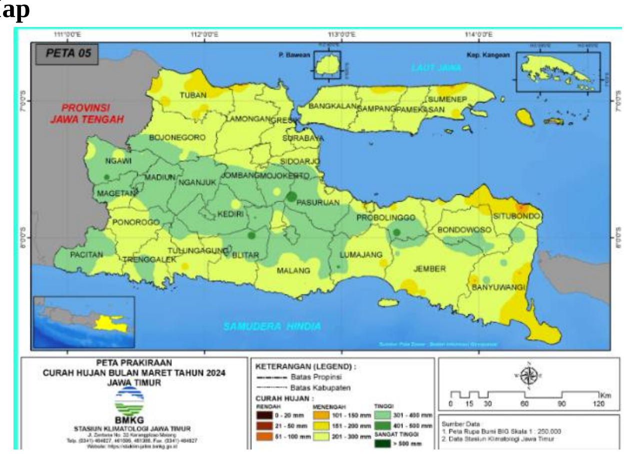

Fig. 3. Map of March Rain Forecast in January

Observations are certainly carried out with precision in order to achieve perfect results, by using a rainfall distribution map, it will be possible to find out some of the impacts that will occur in the next disaster. This rainfall distribution map is to make conclusions that will later be correlated with the next observation. With rainfall parameters in certain areas, it will certainly make observations close to the word perfect. And here is a rainfall distribution map carried out in the study area,

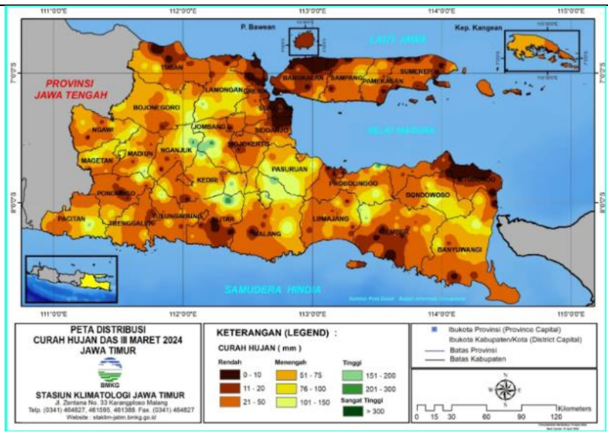

Fig. 4. Rainfall distribution map according to the study,

According to the data we got, there is bulk data Rain show that intensity Rain extreme highest occurred on March 25-27, 2024, with rainfall Rain reaching 150-200 mm per day . The decrease pressure significant surface observed on March 24-26, 2024, which correlates with an increase activity convective . It can be concluded that the observations made are by relying on radiosonde as a parameter. We can see together that observations and observations of current weather changes need to be considered so that estimates and predictions regarding future disasters can be addressed properly [7].

3.7 Identifying Weather Systems That Correlate With Surface Weather Data

Rainfall data from the climatology station in Malang shows very high rainfall values during the event period, in line with humidity and atmospheric instability data detected by radiosonde. Also, Decrease pressure significant surface during period the indicates existence activity intense weather, such as storm convective or system pressure low. Furthermore, analysis of radiosonde data from January to March 2024 demonstrated a progressive increase in humidity and atmospheric instability, culminating in the extreme rainfall event in late March. Statistical analyses validated that the atmospheric profiles observed earlier in the year were predictive of the extreme weather conditions that followed. In analyzing the relationship between weather systems and surface data, radiosonde observations and surface measurements were integrated to provide a comprehensive view of atmospheric dynamics during the event. Radiosonde data revealed significant instability in the lower and mid-level atmosphere, characterized by high CAPE values and steep temperature gradients. These findings corresponded closely with surface weather data, which indicated persistent high humidity and fluctuating surface pressure.

A detailed examination of surface pressure maps showed the development of a pronounced low-pressure system over the Java Sea, which enhanced wind convergence and moisture transport into the Probolinggo region. This low-pressure system was further supported by monsoonal winds, creating a dynamic environment conducive to convective activity. Surface humidity levels remained elevated throughout the period, sustaining the moisture supply necessary for continuous cloud formation and rainfall. The integration of radiosonde profiles with surface weather station data allowed for the identification of key patterns linking atmospheric instability, wind convergence, and surface conditions. This holistic approach confirmed that the extreme rainfall event was driven by a combination of regional and local atmospheric processes, underlining the importance of coordinated observational strategies in extreme weather studies.

4. CONCLUSION

Analysis dynamics atmosphere at the event Rain extreme in Probolinggo (Paiton), East Java, during the period 21-31 March 2024, using method radiosonde observations. That in the period was driven by unstable atmospheric dynamics, characterized by complex wind circulation patterns, high humidity, and significant wind shear.

Based on the findings of this research, several implementation steps are recommended:

- Integration of Early Warning Systems: Develop an early warning system using radiosonde data combined with global weather prediction models to improve detection accuracy for extreme rainfall.
- Strengthening Inter-Agency Collaboration: Enhance cooperation between BMKG, local governments, and research institutions to accelerate responses to potential disasters.
- Public Education and Awareness: Conduct educational programs for communities on recognizing extreme weather signs and independently taking mitigation steps.
- Enhancing Disaster-Resilient Infrastructure: Develop adaptive drainage systems and water management infrastructure to mitigate the impact of high-intensity rainfall and reduce flooding risk.

Identified that happen condition supportive atmosphere Rain extreme in certain areas. In addition, the influence system regional and local weather in the area which correlates with existing surface dat. These findings can support the development of early warning systems for similar disaster events in the future.

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