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UTILIZATION OF RADIOSONDE DATA TO PREDICT LLWS EVENTS IN THE JUANDA AIRPORT AREA

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Abstract

Low-Level Wind Shear (LLWS) is one of the dangerous atmospheric phenomena that can interfere with flight safety, especially during takeoff and landing phases. This study aims to evaluate the potential of radiosonde data processed using RAOB software as a tool to predict the occurrence of LLWS in the Juanda International Airport area. The study used a correlational descriptive method with radiosonde data and LLWS incidence data from the LLWAS system for the 2023–2024 period. The results of the analysis showed that atmospheric parameters such as TPW, LCL, LI, and KI had a significant relationship with LLWS occurrence. The model produces a high precision value (0.99), but a low recall (0.35), which suggests that although the model is able to accurately identify LLWS, there are still many undetected LLWS events. Thus, radiosonde data has potential as an aid to LLWS prediction, but it needs to be further developed to improve its sensitivity and effectiveness in early warning systems.

Keywords : LLWS, radiosonde, RAOB, aviation safety, Juanda Airport

INTRODUCTION

Flight safety is a key element in the air transportation system that is affected by meteorological conditions. Stable and supportive weather can improve the efficiency and safety of flight operations, while extreme weather conditions can cause a variety of serious disruptions, including delays, flight cancellations, and air accidents (Putri et al., 2025; Fatkhuroyan & Wijayanto, 2019; Andarini et al., 2023). One of the weather phenomena that often causes flight disruptions is Low Level Wind Shear (LLWS), which is a sudden change in wind speed and/or direction in the lower layers of the atmosphere (less than 2,000 feet). This phenomenon is very dangerous, especially in critical phases such as takeoff and landing, as it can affect the stability and lift of the aircraft suddenly (Golding, 2005; Sasmito et al., 2020).

LLWS is closely related to convective activity in the atmosphere, such as the formation of cumulonimbus clouds and the emergence of microburst phenomena that produce intense downdrafts in a short period of time. Microbursts can trigger sudden changes in wind speed and direction in the lower layers of the atmosphere, thus giving rise to the potential for LLWS (Sasmito et al., 2020).

Several studies have been conducted to detect the occurrence of LLWS, one of which is using weather radar. Research by Manurung et al. (2024) shows that Doppler weather radar is effective in detecting strong winds in the lower layers of the atmosphere, including early indications of LLWS. In addition to the use of radar technology, there are other alternatives that can be used to detect LLWS. Another approach that has now been developed is to use upper air data as a predictor tool for atmospheric conditions that can be used to detect atmospheric conditions that have the potential to cause LLWS (Juaeni et al., 2022; Andarini et al., 2023; Fatkhuroyan & Wijayanto, 2019).

The use of upper air data as a predictor tool for LLWS can provide important information about atmospheric dynamics that occur and the potential for LLWS to form. To do this, the upper air data is processed using a software instrument called The Universal RAwinsonde OBservation program (RAOB). RAOB is a weather balloon-based observation system that carries sensors to record the vertical profile of temperature, humidity, pressure, and wind from the surface to the upper layers of the atmosphere. The data from these observations is released twice a day and plays an important role in the analysis of atmospheric stability as well as the forecast of significant weather phenomena.

Through the use of RAOB products, various important atmospheric parameters can be obtained, such as wind shear index, CAPE, as well as the distribution of wind direction and speed in the surface atmospheric layer. This information is useful for identifying conditions that support the formation of extreme weather conditions such as LLWS (Stull, 2017). The use of RAOB as a tool to observe LLWS has previously been researched by Zamreeg and Hasanean (2024), in this study RAOB has been successfully used to analyze the amount and intensity of Windshear at 6 Saudi Arabian Airports.

By utilizing upper air data processed using RAOB, this study aims to examine the potential of upper air data for the prediction of LLWS occurrence in the Juanda International Airport area. The use of the upper air is expected to make a real contribution to improving flight safety.

METHODS

This study uses a quantitative method with a correlational descriptive design, which aims to analyze the relationship between atmospheric parameters from radiosonde data and the occurrence of Low-Level Wind Shear (LLWS) and microburst at Juanda Airport. The data used is in the form of 00 UTC radiosonde data from BMKG Juanda and windshear event data recorded by the LowLevel Wind Shear Alert System (LLWAS) system during the 2023–2024 period. Radiosonde data was processed using RAOB software to obtain atmospheric lability parameters such as CAPE, and Lifted Index (LI), as well as vertical wind profiles at 0–3 km plateau.

Downdraft Convective Available Potential Energy (DCAPE) is a measure of the potential energy available to accelerate descending air parcels in the atmosphere. Unlike Convective Available Potential Energy (CAPE), which quantifies the energy available for upward motion, DCAPE represents the energy associated with downward air movement. This parameter is particularly important in deep convective systems, such as thunderstorms, where strong downdrafts can produce damaging surface winds or microbursts. DCAPE is calculated from the difference in potential energy between the environmental air at higher and lower atmospheric levels and is expressed in joules per kilogram (J/kg).

In addition to using a measure of air movement energy, it is also used as a Lifted Index (LI) which is an indicator of atmospheric stability and prediction of convection potential. LI is calculated by measuring the temperature of the air lifted from the surface and comparing it to the air temperature present at a certain altitude. The smaller the LI value (to the negative), this indicates the presence of atmospheric instability, which means there is a potential for strong convection formation and could lead to thunderstorms.

To correlate weather events such as LLWS (Low-Level Wind Shear), microburst, rain, sunny, and combination with RAOB (Radio Acoustic Observation Balloon) data, the first step is to collect RAOB data that includes wind speeds across different layers of the atmosphere as well as other meteorological parameters such as temperature, humidity, and atmospheric lability index (e.g. LI, KI, CAPE). RAOB data is an accurate and important source of atmospheric data for weather analysis, although its spatial coverage is limited, so it is often combined with reanalysis data such as ERA-Interim to extend spatial coverage with maintained quality through 4D space-time statistical models (Xu & Wang, 2021).

After data collection, the identification of weather events is carried out based on established meteorological criteria, e.g. changes in wind speed and direction for LLWS, or threshold values of the lability index for microbursts and rain. Basic statistical analysis was carried out by calculating the frequency and percentage of weather events in each category of wind speed recorded in the RAOB data. To test the relationship between weather events and wind speeds, the Chi-Square Test method can be used for categorical data, but this method only tests the association without demonstrating the strength of the relationship. Therefore, for a more comprehensive and predictive analysis, logistic regression is recommended because it can model the probability of weather events based on RAOB parameters and take into account several variables at once. If the category of weather events is more than two, multinomial logistic regression can be applied.

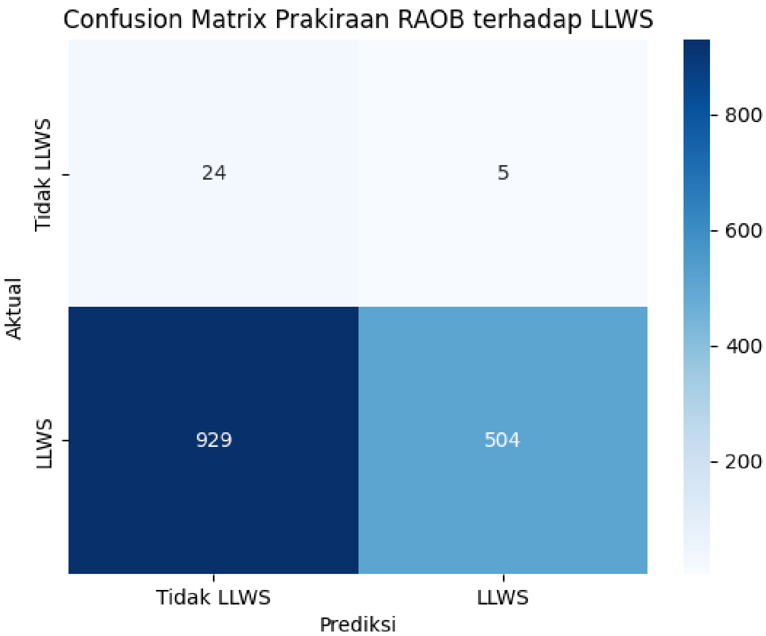
In addition, to measure the correlation between numerical variables such as the index of lability and frequency of events, the Pearson correlation coefficient is the appropriate method. The evaluation of the prediction model was carried out using a confusion matrix which included True Positive, False Positive, True Negative, and False Negative, so that it could assess the accuracy of weather event predictions. This approach allows for a better understanding of the relationship between wind speed parameters and weather events and improves the predictability of high-quality RAOB observational data-driven predictions, making it useful for accurate and practical evaluation and warning of extreme weather.

The data collection procedure is carried out by downloading radiosonde data and LLWAS data from official sources, then radiosonde data is processed to obtain relevant parameters. Pearson correlation analysis is used to measure the relationship between radiosonde parameters and windshear events, as well as to assess the ability of these parameters to predict microburst and LLWS phenomenon. The results of this analysis are expected to provide an overview of the effectiveness of using radiosonde data as a tool for early prediction of these dangerous phenomena.

This method allows for a better understanding of the vertical atmospheric dynamics that trigger convective and windshear phenomena, as well as provides a scientific basis for the development of more effective early warning systems in the tropics.

RESULTS AND DISCUSSION

To be able to find out how accurate the RAOB product is for LLWS forecasting, several error matrix methods are used where there are several parameters used, namely True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN) which are used to show the correlation between the 2 file types used.



Gambar 1. Confussion Matrix

After processing, the Confusion Matrix data was obtained as shown by Figure 1 where the True Negative (TN) value was 24, False Positive (FP) 5, False Negative (FN) 929 and True Positive (TP) 504. With the results of the Confusion Matrix, the Evaluation Matrix calculation is then carried out which can be used for data evaluation parameters. Some of the evaluation matrices used are:

- Accuracy: Used to measure the extent to which a data or model makes predictions correctly.

  Accuracy = (TP+TN) / (TP+FP+FN+TN) ..... (1)

- Precision: Precision is able to measure the extent of positive predictions that have been made by the model
  Precision = TP / (TP+FP) ..... (2)
- Recall: Recall measures the model's ability to detect true positive events, which is LLWS in this case.
  Recall=TP / (TP+FN) ..... (3)
- Specificity: Specificity measures the extent to which the model can identify a true negative event, i.e. not LLWS.
  Specificity = TN / (TN+FP) ..... (4)
- Specificity: Specificity measures the extent to which the model can identify a true negative event, i.e. not LLWS.
  Specificity = TN / (TN+FP) ..... (4)

Tabel 1 Hasil Evaluation Matrix.

Akurasi	0.36
Presisi	0.99
Recall	0.35

From the results of the evaluation matrix calculation in Table 1, it can be analyzed that the RAOB product has a high precision of 0.99, which means that the model has a dominant True Positive (TP) of 504 events out of the total LLWS prediction. This shows that when the model predicts the occurrence of LLWS, the prediction is correct according to the event. However, despite having a high precision value, the model has a low Recall, which is 0.35. This indicates that the number of False Negatives (FN) is large at 929, indicating that the model fails to detect most of the actual LLWS events.

RAOB products are less sensitive to LLWS occurrences and often mispredict LLWS as "No LLWS". Although the model is quite accurate in predicting "LLWS" when it exists, it is less effective at capturing all LLWS events that occur.

To improve the ability to analyze the upper air data, visualization was also carried out for the distribution of each parameter value. Featured Distribution

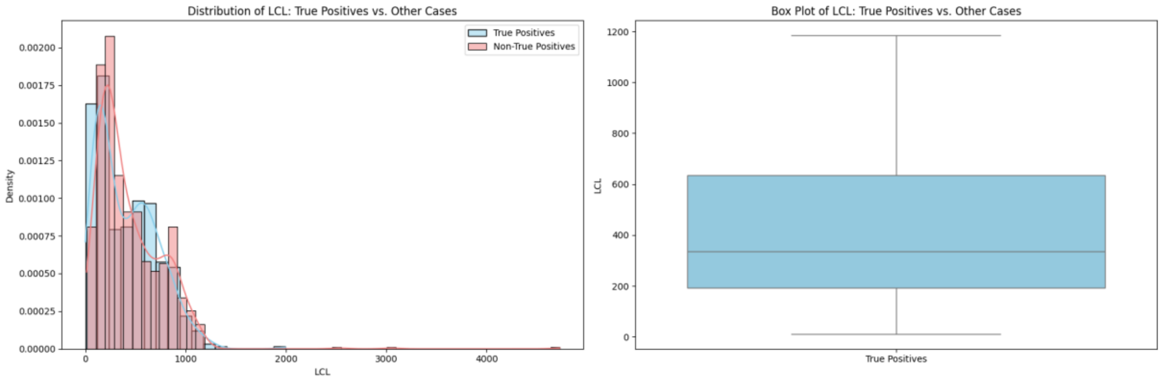


Figure 2. Visualization of LCL True Positives value distribution

LCL values for True Positives tend to be lower than Non-True Positives, as can be seen from the boxplot showing a smaller range and a lower median. This is in accordance with the physics of clouds that form closer to the surface, increasing the chances of rain.

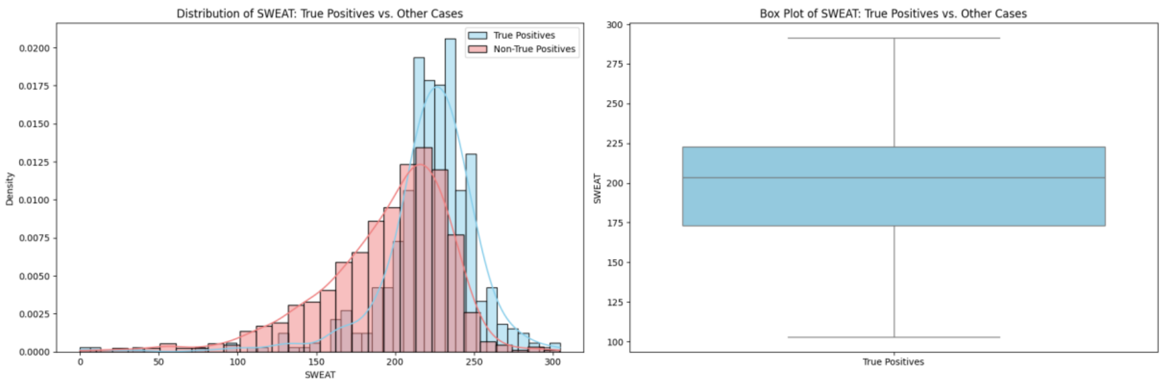


Figure 3. Visualization of the True Positives SWEAT value distribution

The distribution of SWEAT between True Positives and Non-True Positives has a difference, but not too much contrast. True Positives tend to have higher SWEAT values, but overlapping is quite large. This suggests SWEAT is more sensitive to extreme weather, rather than just light to moderate rain.

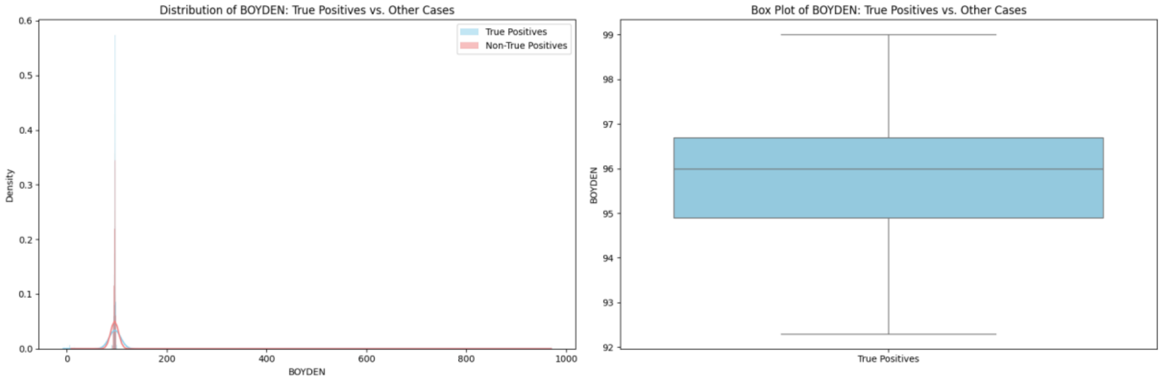


Figure 4. Visualization of the True Positives value distribution BOYDEN

There is no significant difference between True Positives and Non-True Positives, so this parameter is less effective for distinguishing rainfall events in the context of this analysis.

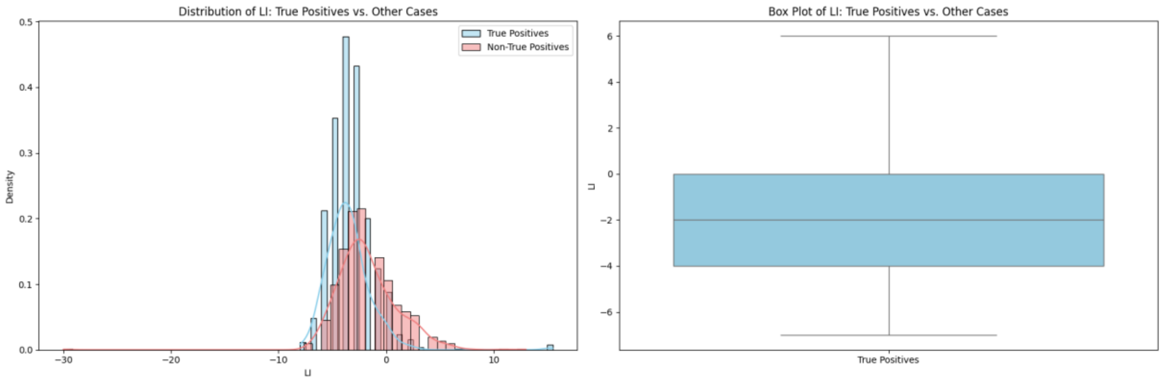


Figure 5. Visualization of the True Positives LI value distribution

LI values on True Positives tend to be more negative than Non-True Positives, according to meteorological theory. The boxplot shows a clearly lower distribution on True Positives, confirming the relevance of LI as a key parameter in detecting potential rainfall.

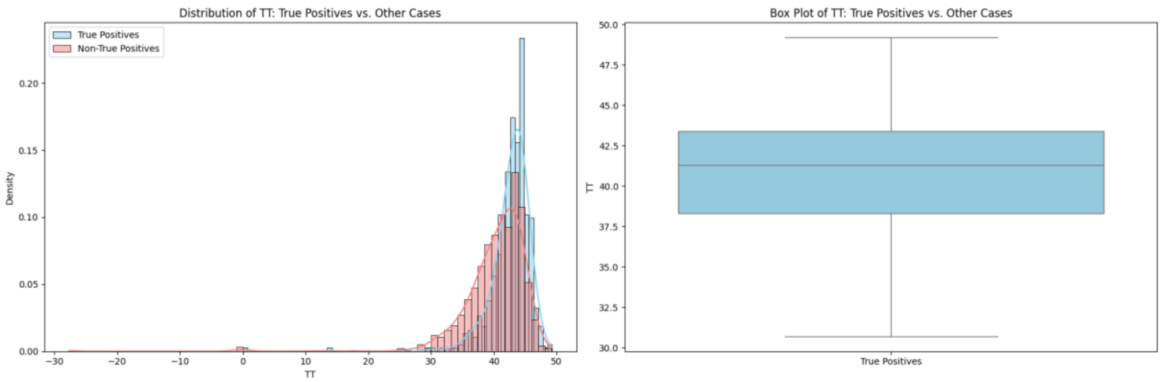


Figure 6. Visualization of TT True Positives value distribution

The median TT value for True Positives is higher than for Non-True Positives. However, the overlapping distribution is still quite large, so TT can be said to have a moderate contribution in detecting rain.

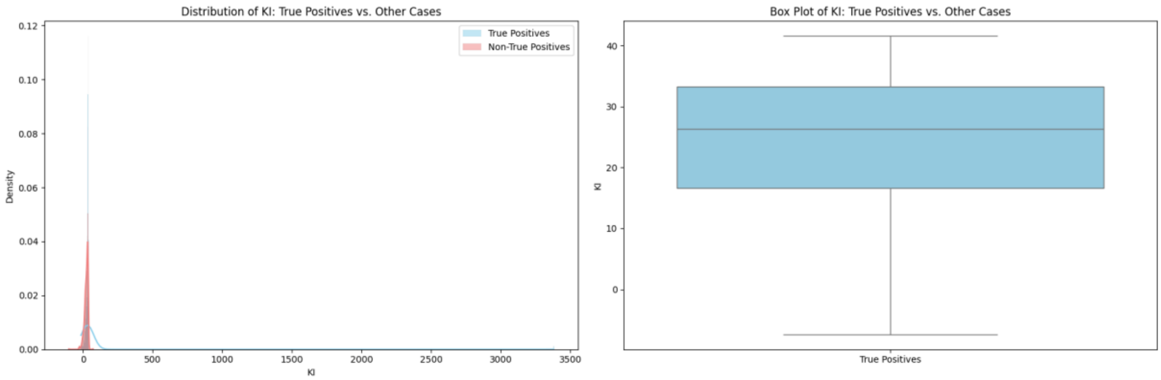


Figure 7. Visualization of the Distribution of True Positives KI values

The IP value for True Positives is clearly higher than for Non-True Positives. This distribution supports the understanding that KI is relevant to separate rain and non-rain events, especially for rain with convective character.

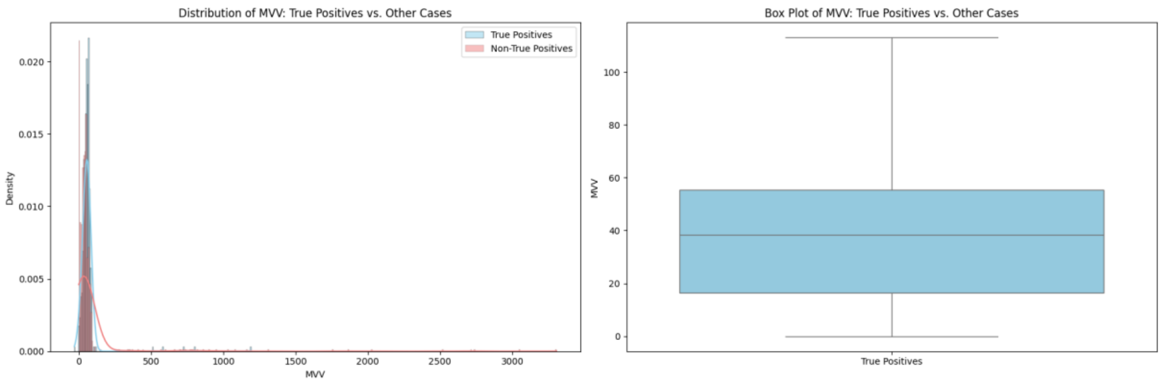


Figure 8. MVV True Positives Value Distribution Visualization

The range of MVV values is very wide, but True Positives generally show higher MVV values than Non-True Positives. However, high variability makes interpretation require caution, and may require further normalization or processing.

CONCLUSION

This study evaluated the potential of radiosonde data processed using the RAOB software for predicting Low-Level Wind Shear (LLWS) events at Juanda International Airport during the 2023–2024 period. The results indicate that several atmospheric stability parameters derived from radiosonde observations, particularly Lifted Index (LI), K Index (KI), and Lifted Condensation Level (LCL), show good potential for identifying atmospheric conditions favorable for LLWS occurrence. In contrast, the BOYDEN Index and Maximum Vertical Velocity (MVV) contributed less effectively to distinguishing LLWS events. The prediction model achieved a high precision (0.99), indicating that LLWS predictions generated by the model were highly reliable. However, the low recall (0.35) demonstrates that a considerable number of LLWS events were not successfully detected, suggesting that the model is still limited in its sensitivity. Therefore, radiosonde-derived atmospheric parameters should be considered as supporting indicators rather than standalone predictors for operational LLWS forecasting.

Overall, radiosonde observations processed using RAOB have the potential to support aviation weather forecasting and improve situational awareness for flight safety. Future studies are recommended to incorporate additional atmospheric parameters, such as Downdraft Convective Available Potential Energy (DCAPE) and vertical wind shear indices, as well as integrate radiosonde observations with weather radar, numerical weather prediction (NWP), and machine learning approaches to improve the accuracy and sensitivity of LLWS early warning systems.

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