E ISSN : 3024 - 9961
JOURNAL OF CLIMATE CHANGE SOCIETY
JCCS
https://jccs.ppj.unp.ac.id rccc.lp2m.unp.ac.id

Analysis Of Cape Index And Total Index Thresholds Towards Cumulonimbus Cloud And Thunderstorm Events At Minangkabau International Airport

Indah Yoseva Effendi[1*], Nofi Yendri Sudiar[2], Ratnawulan[3], Harman Amir[4]

[1,2,3,4] Department of Physics, Universitas Negeri Padang

CORRESPONDENCE

Email : yosevaindah926@gmail.com
Phone : 089525024042

ARTICLE INFORMATION

DOI : 10.24036/jccs/Vol4-iss1/83
Page : 1 - 10

Received : May 12, 2026
Revised : May 25, 2026
Accepted : May 27, 2026

ABSTRACT

Indonesia located along the equator and dominated by oceanic areas, is highly vulnerable to atmospheric dynamics and extreme convective weather. Minangkabau International Airport (BIM), situated in a coastal region of West Sumatra, is frequently affected by cumulonimbus (Cb) clouds and thunderstorms (TS), which pose risks to aviation safety. This study aims to determine the threshold values of the Convective Available Potential Energy (CAPE) index and the Total Totals Index (TT) that are appropriate for local conditions, based on radiosonde and synoptic observation data from 2019–2023, and verified using 2024 data. The CAPE and TT values were analyzed using Sturges' method to determine frequency intervals and dichotomous analysis to establish threshold effectiveness. Results indicate that CAPE thresholds for Cb clouds range from 495 to 2679 J/kg, while TT thresholds for thunderstorms range from 43.5 to 47.4, depending on the seasonal variation (DJF, MAM, JJA, SON). These thresholds demonstrated strong performance in identifying convective weather events, thus serving as a useful reference for forecasting and enhancing flight safety at BIM.

KEYWORDS : CAPE, Total Totals Index, cumulonimbus, thunderstorm, Minangkabau International Airport.

INTRODUCTION

Indonesia is the largest archipelagic country in the world, located along the equator and dominated by oceanic areas. These geographical characteristics make Indonesia highly vulnerable to atmospheric dynamics and extreme convective weather events, particularly during transitional and rainy seasons [1], [2]. Convective clouds such as cumulonimbus (Cb) and associated thunderstorms (TS) are severe meteorological disturbances that can cause heavy rainfall, lightning, strong winds, and turbulence—posing serious threats to aviation operations [3], [4].

Minangkabau International Airport (BIM), located on the western coast of Sumatra, is one of the airports frequently affected by such phenomena. Its proximity to the equator, adjacency to the Indian

Ocean, and nearby hilly terrain to the east contribute to a highly dynamic atmospheric environment that promotes convective cloud development [5], [6]. According to data from PT Angkasa Pura II, in 2020 alone, more than 1,700 flight delays occurred due to extreme weather conditions, significantly impacting airport operations [7].

To forecast convective weather potential, several atmospheric stability indices derived from radiosonde observations are utilized. Among the most commonly used indices are the Convective Available Potential Energy (CAPE) and the Total Totals Index (TT). CAPE estimates the amount of energy available for convection in a rising air parcel, while TT reflects vertical atmospheric instability based on differences in temperature and moisture across pressure levels [8], [9].

However, the current threshold values used for these indices are largely based on studies conducted in subtropical or mid-latitude regions, which may not be appropriate for tropical environments such as Indonesia. The distinct thermodynamic and dynamic characteristics of tropical atmospheres necessitate the development of localized thresholds to ensure accurate convective weather prediction [10], [11].

This study aims to analyze radiosonde and synoptic data collected at Minangkabau International Airport from 2019 to 2023, in order to determine localized threshold values for CAPE and TT that correlate with Cb and TS occurrences. The proposed thresholds are validated using 2024 data and dichotomous verification methods. This research is expected to contribute to the enhancement of early warning systems and aviation safety in West Sumatra and similar tropical regions.

METHODS

This research employed a quantitative descriptive approach to analyze the atmospheric stability indices associated with the occurrence of cumulonimbus clouds and thunderstorms at Minangkabau International Airport (BIM). The study used secondary meteorological data obtained from the Minangkabau Class II Meteorological Station, including both upper-air (radiosonde) and surface synoptic observations. The main objective was to determine threshold values of the Convective Available Potential Energy (CAPE) and Total Totals Index (TT) based on local climatic characteristics.

The study area is located at Minangkabau International Airport, Padang Pariaman, West Sumatra, Indonesia. Geographically, BIM lies at 00°47'12" South Latitude and 100°16'50" East Longitude, near the Indian Ocean and approximately 23 kilometers northwest of Padang city. The surrounding region includes coastal plains and the Bukit Barisan mountain range to the east, which influences local convective dynamics. The map of the study location (Figure 1) illustrates the geographic and topographic setting that contributes to the development of convective clouds. This setting highlights the airport's vulnerability to maritime and orographic atmospheric interactions, which are essential to consider when interpreting atmospheric stability indices.

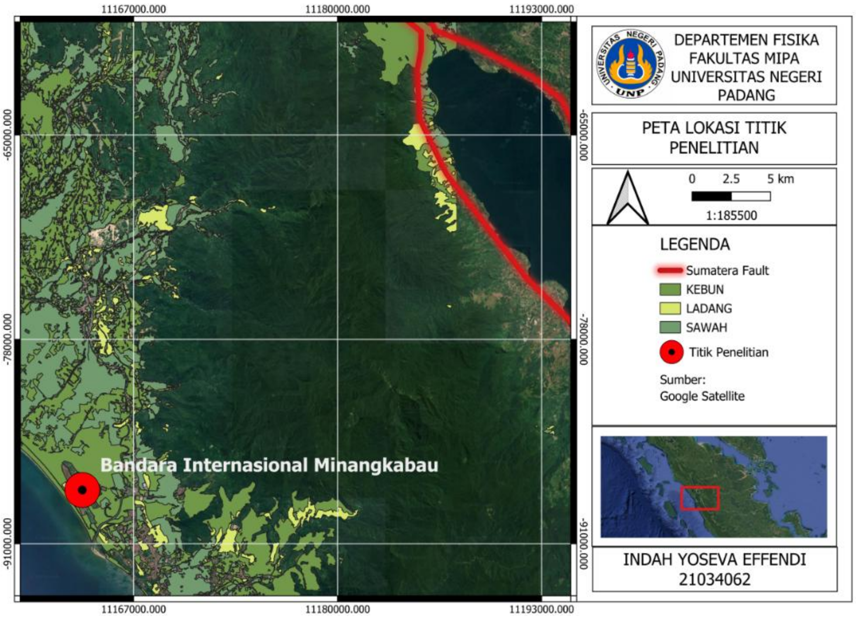

Fig. 1. Research location map.

The data used in this study consisted of radiosonde measurements recorded at 00 UTC (07:00 local time) and 12 UTC (19:00 local time) from January 2019 to December 2023. These data were processed using the Radiosonde Observation Program (RAOB) version 5.7, which generated key stability parameters, including CAPE and TT. The TT index was calculated based on temperature and dew point data at 850 hPa and temperature at 500 hPa, using the following equation [17]:

$$TT = T_{850} + Td_{850} - 2T_{500}$$

where T850 is the temperature at 850 hPa, Td850Td is the dew point temperature at 850 hPa, and T500 is the temperature at 500 hPa. Meanwhile, CAPE values were obtained by integrating the area between the temperature of an ascending air parcel and the environmental temperature on a skew-T diagram (Air Weather Service, 1999).

Surface synoptic data were also collected for the same period. Observations included cloud types and present weather phenomena, specifically the occurrence of cumulonimbus clouds and thunderstorms, which were coded based on SYNOP observation standards [12]. These surface data were used to validate the timing and presence of convective events in relation to the atmospheric stability indices.

In this study, an event was defined as the occurrence of cumulonimbus clouds (Cb) or thunderstorm (TS) reported in synoptic observations within a 3 hour window of the radiosonde observation time (00 UTC or 12 UTC). Observations that did not meet these criteria were classified as non-events.

To address the issue of multiple events occurring within a single day, a singel-event-day approach was applied. All convective occurrences within one calender day were treated as a single event. If events were recorded at both observation times (00 UTC and 12 UTC), the maximum value of the stability index (CAPE or TT) was selected to represent the most unstable atmospheric condition of that day. This approach minimizes bias due to repeated counting of similar events.

To determine the threshold values of CAPE and TT, the data were analyzed using Sturges' method to create frequency distributions and interval classes [13]. The resulting intervals were then subjected to dichotomous analysis, which categorized index values into binary outcomes—"event" or "no event"—based on the presence or absence of cumulonimbus clouds and thunderstorms. The performance of the thresholds was evaluated using verification metrics such as hit rate, false alarm rate, and critical success index[13][14] [15].

In addition to descriptive analysis, statistical tests were conducted to strengthen the analysis. A correlation test (Pearson or Spearman) was used to assess the relationship between CAPE/TT values and convective events. Furthermore, a difference test (independent t-test or Mann–Whitney U test) was applied to evaluate whether there were statistically significant differences in index values between event and non-event groups.

The performance of the derived threshold values was evaluated using a 2×2 contingency table approach. Several verification metrics were calculated, including Probability of Detection (POD), False Alarm Ratio (FAR), Bias, Threat Score (TS), Heidke Skill Score (HSS), and Accuracy. These metrics were used to assess the predictive capability and reliability of the stability indices in detecting convective events [16]

Table 1. 2×2 Contingency Table

		OBSERVATION		
		Yes	No	Total
PREDICTION	Yes	Hits (H)	False Alarms (FA)	Forecast Yes
	No	Misses (M)	Correct Negatives (CN)	Forecast No
	Total	Observed Yes	Observed No	Total

This methodological framework enables a localized calibration of atmospheric stability thresholds for operational forecasting at BIM, considering both seasonal variations (DJF, MAM, JJA, SON) and geographical influences unique to the region.

RESULTS AND DISCUSSION

Analysis of radiosonde and synoptic observation data from 2019 to 2023 revealed clear seasonal patterns in the occurrence of cumulonimbus (Cb) clouds and thunderstorms (TS) at Minangkabau International Airport. These convective weather phenomena were found to be closely associated with variations in atmospheric instability, particularly in the CAPE and Total Totals Index (TT) values.

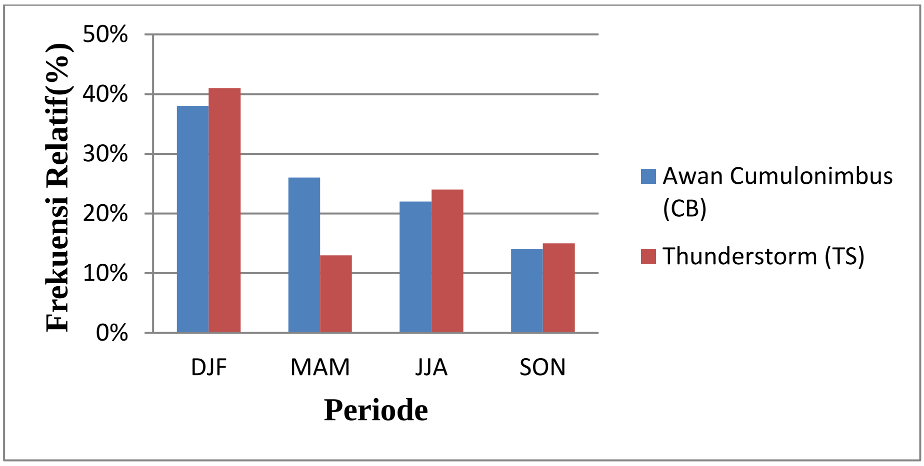

Fig. 2. Frequensy of Cb and TS events

Fig. 1 presents the geographical location of Minangkabau International Airport, which lies along the western coast of Sumatra and is directly influenced by maritime and orographic factors. The convergence of sea breeze from the Indian Ocean and upland winds from the Bukit Barisan Mountains plays a critical role in enhancing convective activity, making the area particularly prone to extreme weather.

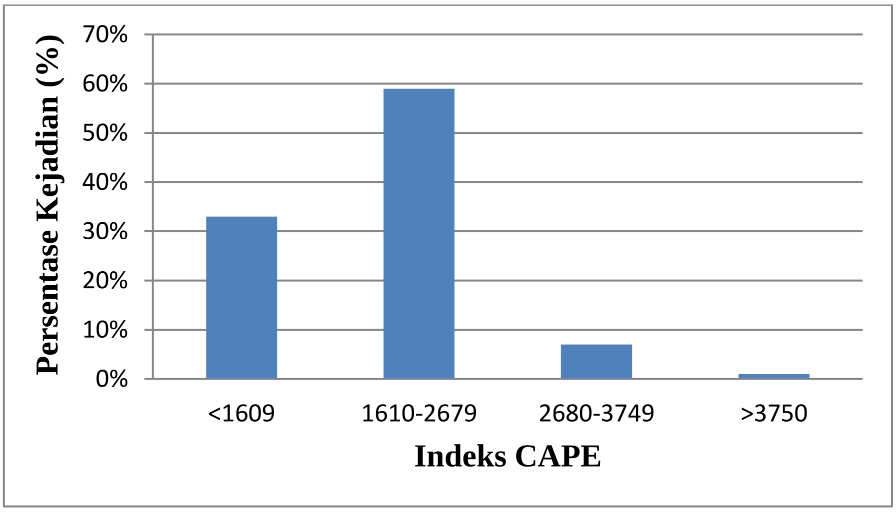

Fig. 3. CAPE distributions DJF

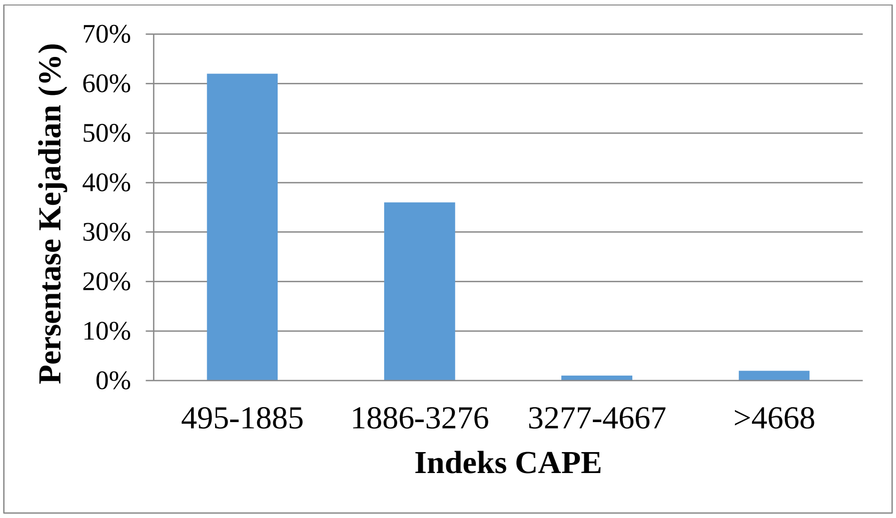

Fig. 4. CAPE distributions MAM

Seasonal distribution of Cb and TS occurrences is shown in Figure 2. The wet season (DJF) recorded the highest number of convective events, with 38% of total Cb and 41% of TS cases, followed by SON. These results confirm that convective activity at BIM is dominated by seasonal moisture availability and diurnal heating, which drive instability.

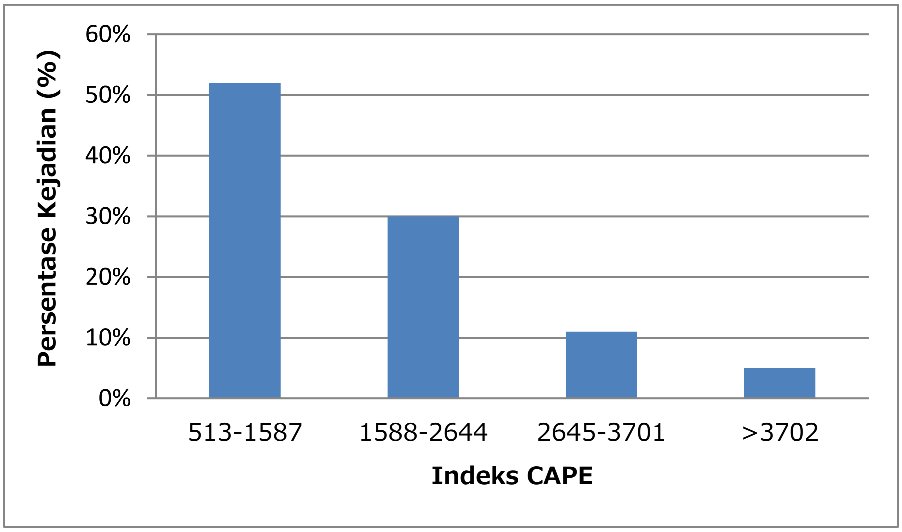

Fig. 5. CAPE distributions JJA

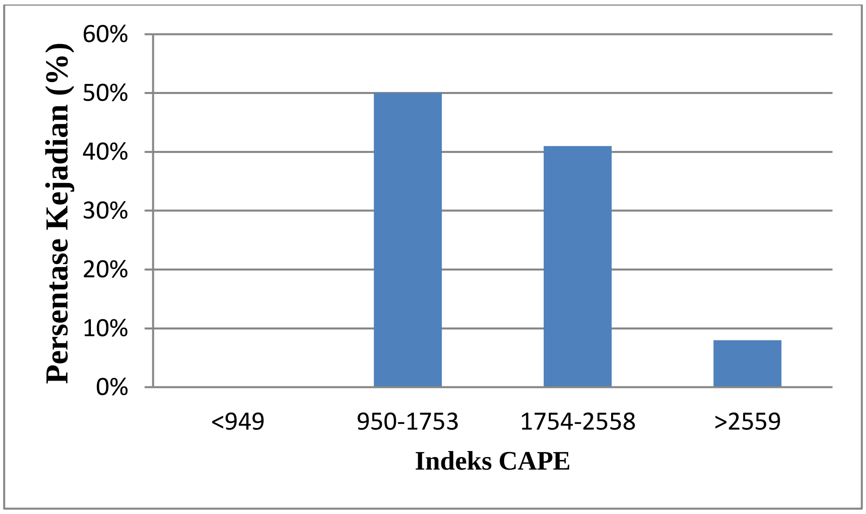

Fig. 6. CAPE distributions SON

To assess the relationship between atmospheric indices and convective events, CAPE and TT values were grouped by season using the Sturges method. Fig 3 to 6 show the frequency distribution of CAPE values during Cb occurrences for each season. Notably, Cb clouds formed in the DJF season with CAPE values ranging from 1200 to 2500 J/kg, while in JJA, Cb could develop even at values as low as 495 J/kg. This suggests that convective development at BIM is not solely dependent on high instability but also on dynamic lifting factors.

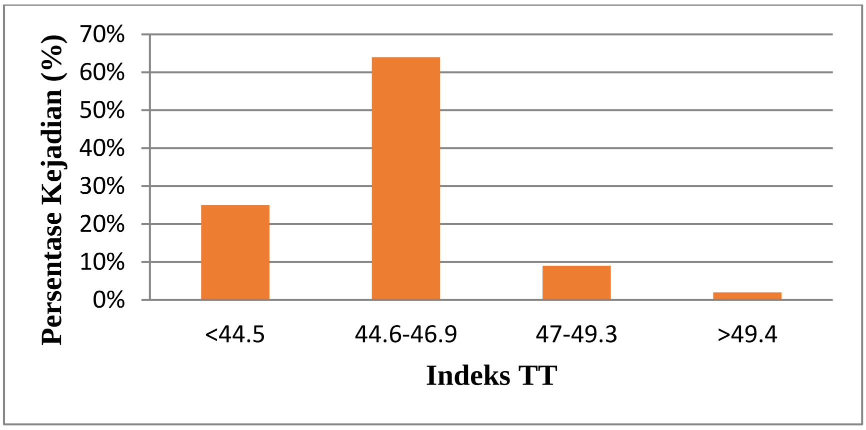

Fig. 7. TT index distributions DJF

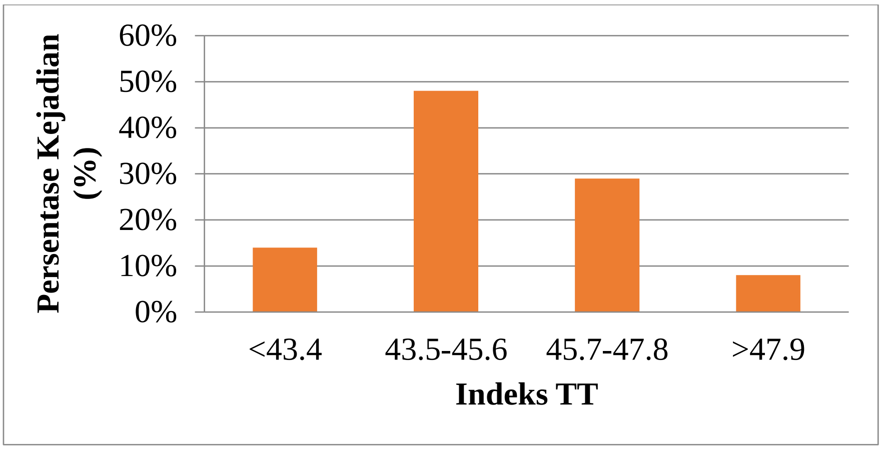

Fig. 8. TT index distributions MAM

A similar analysis was conducted for the TT index. Fig. 7 to 10 illustrate that TT values associated with TS events ranged between 43.5 and 47.4, with the highest occurrences found in DJF and SON seasons. These thresholds are consistent with previous studies in other Indonesian regions [9], [10], but have been refined here to reflect the local climatological characteristics of BIM.

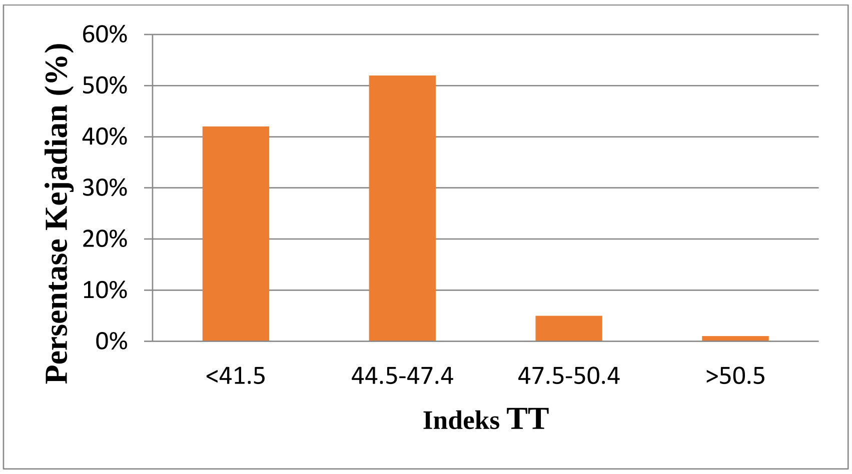

Fig. 9. TT index distributions JJA

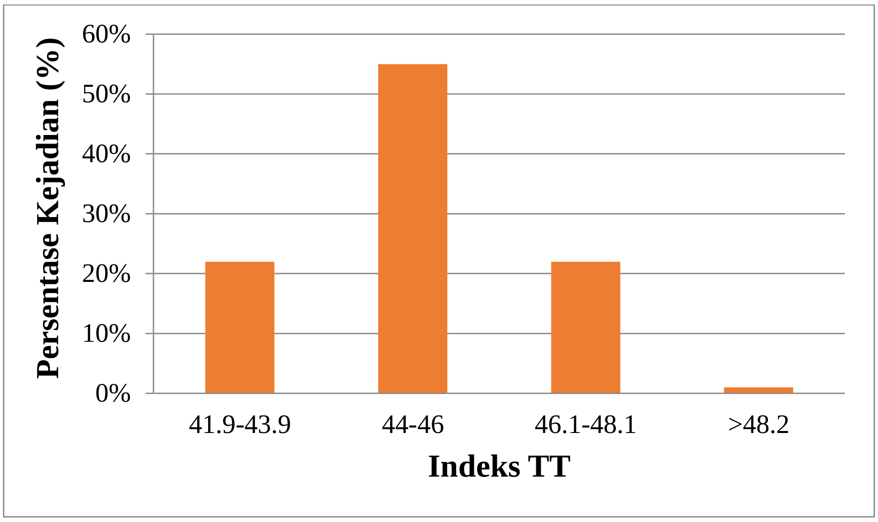

Fig. 10. TT index distributions SON

The summary of seasonal threshold values for both CAPE and TT indices is presented in Table 2. These values serve as preliminary thresholds for anticipating the potential of convective cloud formation and thunderstorm development at BIM. The ABL Index (old Threshold) represents the initial threshold used as a baseline or comparison, generally derived from the overall dataset without considering seasonal variations. In contrast, the seasonal indices are divided into four periods: DJF (December–January–February), which represents the main rainy season in Indonesia characterized by high convective activity; MAM (March–April–May), which corresponds to the transition period from the rainy season to the dry season (Transition I); JJA (June–July–August), which represents the dry season with relatively more stable atmospheric conditions and lower convective activity; and SON (September–October–November), which corresponds to the transition period from the dry season to the rainy season (Transition II), often marked by an increase in convective activity.

Tabel 2. Threshold ranges for CAPE and TT

Indeks	Indeks ABL	Indeks DJF	Indeks MAM	Indeks JJA	Indeks SON
CAPE	>1000	>1610	>495	>513	>949
TT	>50	>44.6	>43.5	>44.5	>44

To validate the effectiveness of these thresholds, dichotomous verification was conducted using 2024 data. Fig 11 displays the performance of CAPE thresholds in detecting Cb events across the seasons. The verification results indicate high accuracy (>80%) and low false alarm rates, especially in DJF and SON. This confirms that the proposed thresholds have strong predictive capability and can support short-term forecasting.

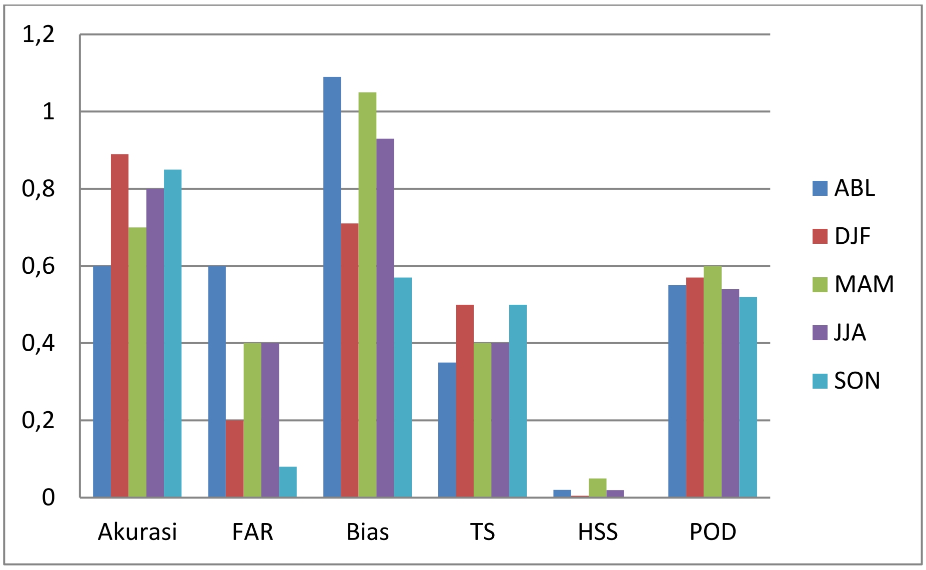

Fig. 11. Verification of CAPE performance

Overall, the results highlight the importance of local and seasonal calibration of atmospheric instability indices. Universal thresholds may not capture the nuanced convective behavior in tropical regions like West Sumatra. It is therefore recommended that meteorological services apply seasonally-adjusted CAPE and TT thresholds at BIM to improve early warning systems and flight safety.

CONCLUSION

This study has successfully determined seasonal threshold values of two key atmospheric stability indices Convective Available Potential Energy (CAPE) and Total Totals Index (TT) that are associated with the occurrence of cumulonimbus clouds (Cb) and thunderstorms (TS) at Minangkabau International Airport (BIM). The results show that convective activity at BIM is strongly influenced by seasonal variations in thermodynamic instability, with DJF and SON exhibiting the highest frequency of Cb and TS events.

The optimal CAPE thresholds for Cb formation ranged from 495 to 2679 J/kg, while TT thresholds for thunderstorm detection ranged from 43.5 to 47.4, depending on the season. These thresholds, validated using 2024 data, demonstrated high predictive performance, especially during the rainy season, with accuracy values exceeding 80% and false alarm rates below 10%.

The findings highlight the importance of using season-specific, location-based thresholds for convective weather forecasting in tropical regions. Unlike generalized thresholds developed for subtropical or mid-latitude areas, localized parameters such as those presented in this study offer more accurate and operationally useful predictions. This is particularly critical for aviation meteorology, where early warnings of convective weather can significantly enhance flight safety and efficiency.

Future research is encouraged to expand this threshold analysis by including additional indices such as the Lifted Index (LI), K-Index, and Showalter Index, and by applying the approach to other airports across Indonesia to develop a national-scale convective weather forecasting system.

REFERENCES

[1] A. Sulistiyono and B. I. Samiaji, "The Influence of Indonesian Throughflow on the Dynamics of Climate and Waters in the Indonesian Region," pp. 134–144, 2024.

[2] A. A. Rusdin, P. Palloan, S. Subaer, and A. Prasetiyo, "Uji Akurasi Ambang Batas Indeks Stabilitas Atmosfer Terhadap Pembentukan Thunderstorm dan Awan Cumulonimbus di Stasiun Meteorologi Kelas I Sultan Hasanuddin," J. Fis. Unand, vol. 12, no. 2, pp. 269–275, Apr. 2023, doi: 10.25077/jfu.12.2.268-274.2023.

[3] B. Tjasyono, MIKROFISIKA AWAN DAN HUJAN. Jakarta: BMKG, 2007.

[4] M. Chaeran and H. Harcici, "Pedoman Menentukan Daerah Cuaca Buruk Bagi Para Nahkoda," Din. Bahari, vol. 1, no. 2, pp. 116–121, Oct. 2020, doi: 10.46484/db.v1i2.234.

[5] D. Y. Mugihono, D. E. Nuryanto, and D. Septiadi, "Studi Pola Awan Cumulonimbus di Indonesia pada Musim Basah (Desember s.d. Februari)," War. Penelit. Perhub., vol. 35, no. 1, pp. 59–66, Aug. 2023, doi: 10.25104/warlit.v35i1.1962.

[6] A. WICAKSONO, "ANALISA CUACA EKSTRIM DI PARIGI MOUTONG (STUDI KASUS HUJAN LEBAT TANGGAL 8 FEBRUARI 2006 DAN TANGGAL 25 AGUSTUS 2012)," Akad. Meteorol. Dan Geofis., pp. 1–23, 2016.

[7] P. A. P. I. (Persero) Angkasa, "Laporan Tahunan Kementerian Perhubungan 2020," KEMENTERIAN PERHUBUNGAN, 2020.

[8] M. Budiarti, M. Muslim, and Y. Ilhamsyah, "Studi Indeks Stabilitas Udara Terhadap Prediksi Kejadian Badai Guntur (Thunderstorm) Di Wilayah Stasiun Meteorologi Cengkareng Banten," J. Meteorol. dan Geofis., vol. 13, no. 2, Aug. 2012, doi: 10.31172/jmg.v13i2.125.

[9] A. Nugraha, Y. S. Putra, and R. Adriat, "Analisis Potensi Terjadinya Thunderstorm Menggunakan Metode SWEAT di Stasiun Meteorologi Supadio," Prism. Fis., vol. 9, no. 1, p. 55, Apr. 2021, doi: 10.26418/pf.v9i1.45380.

[10] R. M. Putra, A. Zakir, C. A. D. Permata, L. F. Aiqiu, and Azzahra A. N, "Penentuan Batas Ambang Cape Dan K Indeks Terhadap Prediksi Awan Cumulonimbus Dan Badai Guntur Di Surabaya Periode 2010-2014," Pros. Semin. Hari Meteorol. Dunia 2016, pp. 96–108, 2016.

[11] Soejitno, Dasar-dasar Pengamatan Meteorologi Permukaan. Jakarta: AMG, 1973.

[12] H. A. Sturges., "the Choice of a Class Interval Case I. Computations Involving a Single Series," J. Am. Stat. Assoc., vol. Vol. 21 No, no. 153, pp. 65–66, 1926.

[13] K. Hachemi, F. Grecu, D. M. Constantin, and G. Ioana-Toroimac, "Extraction and mapping of downpour impact and their Cumulonimbus origin, 20 May 2020, Vâlcea (Romania) via Sentinnel-1 SAR dual polarization," Sci. Rep., vol. 12, no. 1, p. 19490, Nov. 2022, doi: 10.1038/s41598-022-22909-3.

[14] K. V. Yousefnia, T. Bölle, and C. Metzl, "Increasing NWP Thunderstorm Predictability Using Ensemble Data and Machine Learning," no. Ml, pp. 1–12, 2025, [Online]. Available: http://arxiv.org/abs/2502.13316

[15] D. S. Wilks., Statistical methods in the atmospheric sciences, second edition, vol. 91. 2007.

[16] Zakir, A., Sulistya, W., & Khotimah, M. K. (2010). Perspektif operasional cuaca tropis. Badan Meteorologi Klimatologi dan Geofisika, Jakarta.

[17] Wei, J., Shi, Y., Ren, Y., Li, Q., Qiao, Z., Cao, J., ... & Wang, G. (2021). Application of ground-based microwave radiometer in retrieving meteorological characteristics of Tibet Plateau. Remote Sensing, 13(13), 2527. https://doi.org/10.3390/rs1313252.