

Assessment of Atmospheric Stability Indices for Thunderstorm Forecasting over Absheron Peninsula

Huseynov, N.¹  | Bashirova, A.¹ 

1. Department of Aviation Meteorology, National Aviation Academy of AZAL CJSC, Baku, Azerbaijan.

Corresponding Author E-mail: aygun.agayeva1990@gmail.com

(Received: 29 Dec 2024, Revised: 26 July 2025, Accepted: 18 Oct 2025, Published online: 17 March 2026)

Abstract

This study examines the application of various thunderstorm indices to predict the occurrence of thunderstorms over the Absheron Peninsula. By considering thermodynamic indices such as the K index, lifted index (LI), Showalter index (SI), Thompson index, S index, Total Totals (TT) and SWEAT, and comparing their ability to forecast thunderstorms, more insight is gained into the vertical thermodynamic structure over the Absheron Peninsula.

Numerical weather prediction (NWP) models corresponding to the territory of Heydar Aliyev International Airport (UBBB) were used to calculate the indices. To facilitate the calculations, a software tool was developed in the C# programming language, which automates the process of selecting the required meteorological parameters. The generated data series are used as input for calculating the indices. The implementation of this software enhances the efficiency of the forecasting process, significantly reducing the time required by meteorologists. Based on the results of the study, a number of the indices produced relatively high skill scores and can serve as an initial guide for forecasters in determining the occurrence of thunderstorms. Among the indices, the SWEAT index demonstrated the highest forecasting skill, followed by LI, Thompson, S, SI, and TT. The K index, however, showed the lowest skill scores. These results are comparable to those of other studies that have examined thunderstorm occurrence.

Keywords: Stability indices, thunderstorms, convection, cumulonimbus clouds, unstable environment.

1. Introduction

Although the Absheron Peninsula constitutes only a small portion of Azerbaijan, it exhibits distinct physical and geographical characteristics compared to the rest of the country (Figure 1). The west and southwest of the peninsula consist of highlands, 300-500 m in elevation, while the eastern part is a lowland below sea level (Babayev & Telesca, 2016). Atmospheric processes and the formation of synoptic-climatic features over the Absheron Peninsula are significantly influenced by the above-mentioned orographic features of Azerbaijan and the proximity of the Caspian Sea (Pashayev et al., 2007). The Main Caucasian Range is the main obstacle to the invasion of cold air masses from the north into the territory of

Azerbaijan, due to the insufficient power of cold air when it reaches the North Caucasus. Cold air accumulating in front of the Main Caucasian Range flows around it from the east and comes as a powerful stream along the western coast of the Caspian Sea to the Absheron Peninsula. The convergence of flows when flowing around the obstacle contributes to the strengthening of the wind (Madatzade & Shikhlinsky, 1968). Heydar Aliyev International Airport (UBBB) is considered the research site in this article. It is located in the central part of the Absheron Peninsula, 20 km northeast of Baku. An automatic weather station (AWOS) has been installed at this airport, and the data from which were used to compile this aviation climate.

Cite this article: Huseynov, N., & Bashirova, A. (2026). Assessment of Atmospheric Stability Indices for Thunderstorm Forecasting over Absheron Peninsula. *Journal of the Earth and Space Physics*, 51(4), 125-131. DOI: <http://doi.org/10.22059/jesphys.2025.387703.1007658>

E-mail: (2) dr.nazim@azans.az



© Authors Retain the Copyright and Full Publishing Rights.
Publisher: University of Tehran Press.
DOI: <http://doi.org/10.22059/jesphys.2025.387703.1007658>

Print ISSN: 2538-371X
Online ISSN: 2538-3906



Figure 1. The Absheron Peninsula, illustrating its geographic location and contrast with the rest of Azerbaijan.

Thunderstorms over the Absheron Peninsula are mainly of frontal origin, while ultra-mass thunderstorms are observed very rarely. Thunderstorms usually form under three types of synoptic positions:

- Thunderstorms most often occur in the warm season, when cold air masses advected from the sea in the middle troposphere in the presence of relatively high pressure in the warm air masses over North Africa.

- Thunderstorms often occur when cold air masses invade the territory, accompanied by the passage of a cold front.

- Throughout the year, especially in spring, the transfer of warm air masses accompanied by warm fronts can cause the development of thunderstorm activity (Pashayev et al., 2007). Usually, on the territory of Heydar Aliyev International Airport (UBBB), thunderstorms are observed throughout the year, except from January to March. The highest number of thunder days occurs in May and September (6 days), and the lowest (1 day) in November and December (Bashirova, 2022).

Thunderstorms have a negative impact on many sectors of the national economy, especially aviation, energy, etc. Electrical discharges that occur during thunderstorms often cause forest fires, destruction of various structures, disruption of communication and power lines, loss of life, and dangerous situations for aviation. Therefore, the study of the physical nature and climatological aspects of such phenomena is of great scientific and practical interest (Safarov, 2012).

Thunderstorms are characterized by a short but intense spell of rain, enormous lightning, and gusts of strong winds associated with

cumulonimbus clouds (Doswell, 1987). Thunderstorms are convective storms that form with rising air. Thus, the birth of a thunderstorm often begins when warm, moist air rises in a conditionally unstable environment (Ahrens et al., 2012). The prediction of thunderstorms is one of the most difficult challenges in weather forecasting (Kunz, 2007).

In most cases, dangerous atmospheric phenomena associated with convective processes are associated with cumulonimbus clouds formed as a result of intensively developing convective processes extending from the middle layer of the troposphere to the tropopause level. Depending on the intensity of convection, its impact on aviation operations can be more or less significant. Low-intensity convection does not cause significant difficulties for aircraft takeoff, landing, or flight. These clouds may produce turbulence and reduce visibility. When flying over Cu clouds, there are no serious complications. Powerful cumulus clouds already pose a significant danger; at subzero temperatures, moderate and severe icing may occur in these clouds. The most dangerous conditions for flights are associated with cumulonimbus clouds. The horizontal extent of cumulonimbus clouds varies from several kilometers to several tens of kilometers (Shakina & Ivanova, 2016).

Previous studies on thunderstorm forecasting in Azerbaijan, including those by Pashayev et al. (2007), Huseynov and Agayeva (2019), and Bashirova (2022), have documented the synoptic conditions conducive to thunderstorm formation and evaluated the general applicability of selected atmospheric

instability indices such as the K Index and the Lifted Index. However, these works often relied on limited observation periods or did not extensively calibrate index thresholds for local conditions. This study builds upon that foundation by using model data spanning 2005–2020 to calculate and assess the performance of a wider set of thermodynamic indices, including the SWEAT, S, TT, and Thompson indices. Furthermore, our work introduces regionally optimized threshold values for the most effective indices, thereby enhancing forecasting accuracy specifically for the Absheron Peninsula and the aviation-sensitive area around Heydar Aliyev International Airport (UBBB).

2. Methodology

Since the late 1940s, meteorologists have utilized indices and parameters derived from vertical profiles of temperature, moisture, and wind to assess the risk of thunderstorms. Despite decades of research, thunderstorms continue to pose significant challenges to forecasters due to their complex and localized nature (Perler & Marchand, 2009). Atmospheric instability is one of the important requirements for cloud development. Stability indices have been widely used in the meteorological field to evaluate the atmospheric instability, which is a fundamental factor in the development of thunderstorms.

These stability indices are generally numerical values calculated from various parameters such as temperature, moisture and wind in a vertical column of the atmosphere at a specific location.

The present study evaluates the predictive performance of several commonly used stability indices — namely, the K-Index, the Total Totals Index and the Lifted Index— in forecasting thunderstorm occurrence. The selected indices were chosen based on their established use in convective forecasting literature and their ability to incorporate different thermodynamic and dynamic parameters relevant to the synoptic and mesoscale conditions of the Absheron Peninsula (Fernando et al., 2021).

According to K and Total Totals indices, the probability of thunderstorms is determined by the vertical gradient of temperature and humidity in the lower layers of the atmosphere.

$$K = (t_{850} - t_{500}) + t_{d850} - d_{700} \quad (1)$$

$$TT = t_{850} + t_{d850} - 2 \times (t_{500}) \quad (2)$$

These indices are used to estimate the probability of thunderstorm occurrence by evaluating the vertical gradients of temperature and humidity in the lower troposphere. Specifically, t_{850} , t_{500} represent the air temperatures at the 850 hPa and 500 hPa isobaric levels, respectively; t_{d850} is the dew point temperature at 850 hPa; d_{700} indicates the dew point depression at 700 hPa. Thunderstorms are unlikely when both the K index is below 20 and the TT index below 44.

The Showalter and Lifted indices are used to estimate atmospheric instability in the mid-troposphere based on the difference between the ambient temperature at 500 hPa and the temperature of a rising air parcel. However, since the starting levels of the unstable rising air parcel are different (850 hPa and 950 hPa, respectively), the values of indices are different (Showalter, 1953).

$$SI = T_{500} - T_{p850} \quad (3)$$

$$LI = T_{500} - T_{p950} \quad (4)$$

The Lifted index is a modification of the Showalter Index and strongly resembles it, except for the determination of the level from which the parcel is lifted and the fact that the Lifted Index is used for forecasting, whereas the Showalter Index is an observed static index (Pepler, 1988). Both indices provide insight into mid-tropospheric instability: values of LI or SI greater than 0 indicate a stable atmosphere, although weak convection may still be possible. Values ranging from 0 to -3 °C suggest a marginally unstable atmosphere with an increased likelihood of convective activity (Fernando et al., 2021).

The Severe Weather Threat (SWEAT) Index integrates several meteorological factors, including low-level humidity, the degree of atmospheric instability, warm air advection between the 850 hPa and 500 hPa levels, as well as wind speed and directional shear in the lower and middle troposphere. SWEAT values exceeding +250 are typically associated with a heightened potential for strong convective activity.

$$SWEAT = 12 \times t_{d850} + 20 \times (TT - 49) + 2 \times (V_{850} + V_{500}) + 125 \times (\sin(dd_{500} - dd_{850}) + 0.2) \quad (5)$$

TT refers to the Total Totals Index, t_{d850} is the dew point temperature at the 850 hPa level, V_{850} and V_{500} denote the wind speeds at 850 hPa and 500 hPa, respectively, while dd_{850} and dd_{500} indicate the wind directions at these respective pressure levels. When calculating the Severe Weather Threat (SWEAT) Index, the following conditions must be strictly satisfied:

- * $TT > 49$;
- * The wind direction at 500 hPa must fall within the range of 210° to 310° ;
- * The wind direction at 850 hPa must fall within the range of 130° to 250° ;
- * The directional shear ($dd_{500} - dd_{850}$) must be positive;
- * Wind speeds at both 850 hPa and 500 hPa (V_{850} and V_{500}) must be ≥ 7.5 m/s.

In the calculation of the S Index, several parameters are utilized, including the value of the Total Totals (TT) Index, the temperature and dew point temperature at the 700 hPa level, and a temperature difference coefficient, referred to as Coefficient A, which is derived from the temperature gradient between the 850 hPa and 500 hPa levels. The S Index is primarily used to assess thunderstorm potential. If the S index is below 36, the likelihood of thunderstorms is less than 11 percent.

$$S = TT - (t_{700} - t_{d700}) - A \quad (6)$$

Coefficient A is defined based on the temperature difference between the 850 hPa and 500 hPa surfaces. When the temperature difference between 850 hPa and 500 hPa ($t_{850} - t_{500}$) exceeds 25°C , Coefficient A is assigned a value of 0. If the temperature difference falls within the range of 22 – 25°C , then $A = 2$. When $t_{850} - t_{500} < 22$, the value of Coefficient A is set to 6 (Huseynov & Agayeva, 2019).

Thompson Index (TI) is another diagnostic tool used to estimate the potential intensity of lightning associated with convective storms. Thunderstorm activity is generally not expected when the TI value is below 25. The index is computed using the following formula:

$$TI = K - LI \quad (7)$$

This index integrates the effects of both moisture and instability by incorporating the values of the K Index and the Lifted Index.

3. Results

Atmospheric stability indices are calculated

using data obtained from sounding or numerical weather forecast models. Considering the irregular conduct of aerological observations on the territory of the republic, we used model data (2005–2020) for the first time when calculating stability indices for the area of Heydar Aliyev International Airport (UBBB). Parameters such as air temperature, dew point temperature, wind speed, wind direction, and geopotential height at standard pressure levels (e.g., 850 hPa, 700 hPa, 500 hPa) are extracted automatically by the program. Once the data are ingested, the software calculates the selected instability indices (K, LI, SI, TT, S, SWEAT, and TI) for each day on which cumulonimbus cloud presence is identified. Information on wind speed and direction at different altitudes, air temperature, dew point temperature, and geopotential height was used from the web server of the Air Resources Laboratory, which is supported by the National Oceanic and Atmospheric Administration - NOAA (<https://www.ready.noaa.gov/index.php>). NOAA's Air Resources Laboratory (ARL) routinely uses NCEP model data for air quality transport and dispersion modeling calculations

(<https://www.nco.ncep.noaa.gov/pmb/products/>). Since several years of data are stored on a web server in archive form, analyzing a sufficient amount of data is necessary. Accurate data processing is only possible through automation. For this purpose, software was developed in the C Sharp (C#) programming language. The program selects the meteorological parameters required for index calculation. The prepared data series are used as input for calculating indices. Using these models, it is possible to obtain data on wind speed and direction, air temperature, dew point temperature, pressure, and geopotential height from the station level to the 20 hPa level (Rolph, 2017). This automation greatly improves the efficiency and reproducibility of the forecasting process while minimizing manual data handling errors.

Considering the importance, this study focuses on identifying threshold values for several stability indices such as the K-Index, Lifted index, Total Totals Index, S index, Showalter index, and SWEAT index in the context of the Heyder Aliyev International

airport.

In the article, based on model data, instability indices for the territory of Heydar Aliyev International Airport (UBBB) for 2005-2020 were calculated. According to Figure 2, the SWEAT index (94.7%), followed by the Lifted index (85.2%) and the Thompson index (74.8%), all showed high scores over the period. The S and Showalter indices demonstrated skill scores of 69.5% and 65.2%, respectively, while the Total Totals index was 55.5%. The K index showed the lowest skill scores (37.2%). This is because, despite the separate forecast of isolated lightning at index values of 20 to 25, lightning in the study area most often occurs when the index reaches values greater than 25 (Huseynov & Agayeva, 2019).

Further research was conducted to further evaluate the effectiveness of the K, TT and S indices. For the K index, the threshold value for the lightning prediction was taken $K \geq 25$. An analysis of thunderstorm occurrences in relation to K Index values indicates that 78% of thunderstorm days were associated with K Index values ≥ 25 , while 15% occurred when the index ranged from 20 to 25, and only 7% when it was below 20. This distribution underscores the strong predictive capability of a K Index threshold of 25 for thunderstorm activity in the Absheron Peninsula. The relief, orography, surface diversity, and physical and geographical conditions of the region influence the activity of synoptic processes, and, in contrast to higher latitudes, it is more appropriate to forecast lightning in the study area using values of $K \geq 25$ (Huseynov & Agayeva, 2019).

By changing the criterion values of the S

index ($S \geq 45$) and TT index ($TT \geq 46$) for the Heydar Aliyev International Airport (UBBB) area, the effectiveness of thunderstorm forecasting was increased. These adjusted values resulted in improved detection rates of thunderstorm events. The decision to raise the thresholds reflects the unique thermodynamic and synoptic environment of the study area, where maritime influence from the Caspian Sea and local orographic effects lead to slightly more stable baseline conditions. Therefore, stronger instability is generally needed to trigger convection compared to other mid-latitude regions. Adjusting the thresholds improved the indices' performance and made them more reliable for operational use in this region.

The C# software developed as part of this study has been actively integrated into the daily operations of the Aviation Meteorological Center of Azeraeronavigation ATD, CJSC "Azerbaijan Airlines" since September 2019. Each day, forecasters use the software to automatically retrieve model-based meteorological data from the NOAA READY system, including temperature, dew point, wind speed and direction, and geopotential height at standard pressure levels. The software processes this data and computes seven key atmospheric instability indices: K, LI, SI, TT, S, SWEAT, and TI. Based on pre-defined thresholds — some of which have been locally optimized by this study — the software highlights potential thunderstorm days.

The degree of predictive effectiveness of the method developed in this study is shown in Figure 3.

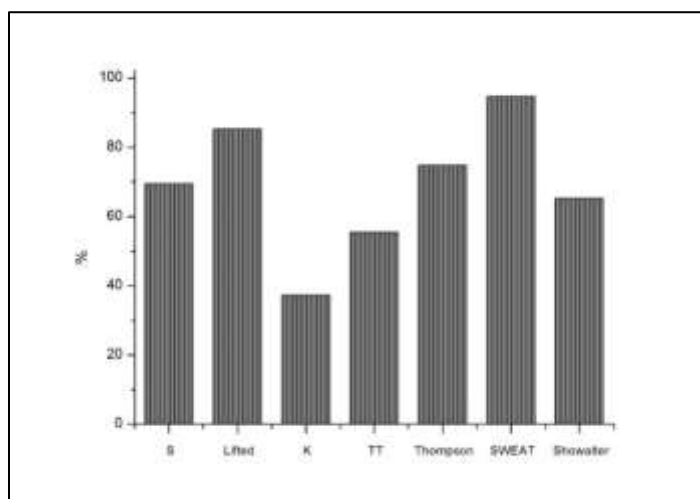


Figure 2. Effectiveness of stability indices for the 2005-2020 period.

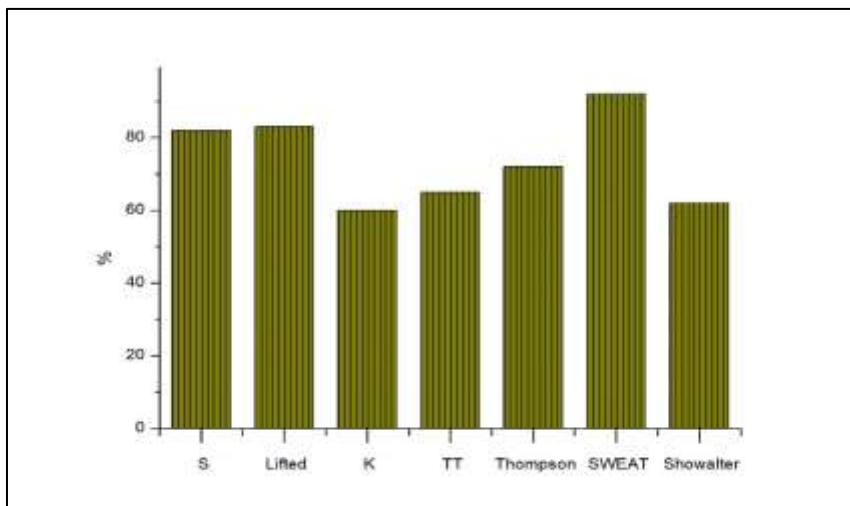


Figure 3. The degree of predictive effectiveness of the method developed by the author in practice. By tailoring thunderstorm indices to the local climatic conditions, this study enhances predictive accuracy, potentially minimizing the socioeconomic impact of such high-risk weather phenomena.

4. Conclusions

This study has demonstrated the critical role of atmospheric stability indices in improving thunderstorm forecasting over the Absheron Peninsula, with particular relevance to operations at Heydar Aliyev International Airport (UBBB). Through a comparative analysis of several indices, the SWEAT, Lifted (LI), and Total Totals (TT) indices were identified as the most reliable predictors of convective activity in the region. By establishing optimal threshold values for $K \geq 25$, $SWEAT \geq 45$, $TT \geq 46$ indices, the research provides a validated, operationally applicable framework that enhances both the precision and responsiveness of thunderstorm forecasts.

The successful integration of these findings into the forecasting practices of the Aviation Meteorological Center of Azeraeronavigation ATD since 2019 underscores their practical value and operational viability. This advancement not only supports aviation safety and efficiency, but also contributes to the broader meteorological understanding of convective systems in complex coastal environments.

Future work will focus on extending this methodology to other regions of Azerbaijan to assess spatial variability in index performance. Additionally, incorporating emerging forecasting technologies—such as satellite-derived convective parameters and real-time radar observations—offers promising avenues to further refine and modernize thunderstorm prediction

capabilities. Overall, this study represents a foundational step toward the development of a more comprehensive and regionally adaptive convective weather forecasting system.

Acknowledgements

The authors would like to express their gratitude to the NOAA Air Resources Laboratory, from whose web-site they downloaded the sounding data, as well as “Aviation Meteorological Center” of Azeraeronavigation ATD, CJSC “Azerbaijan Airlines for the data they provided.

All authors contributed to the material preparation, data collection and analysis. The first draft of the manuscript was written by Aygun Bashirova, and the other authors commented on previous versions of the manuscript.

Declaration of competing interest

The authors did not receive support from any organization for the submitted work.

References

- Ahrens, C., Jackson, P., & Jackson, C. (2012). *Meteorology Today: An Introduction to Weather, Climate, and The Environment*. Hardcover. Nelson Education Ltd.
- Bashirova, A. (2022). Statistical analysis of hazardous atmospheric phenomena associated with convective processes. *Geography and natural resources*, 3(18), 8-13.

- Babayev, G., & Telesca, L. (2016). Site Specific Ground Motion Modeling and Seismic Response Analysis for Microzonation of Baku, Azerbaijan. *Acta Geophysica*, 64. 10.1515/acgeo-2016-0105
- Doswell III, Ch. (1987). The Distinction between Large-Scale and Mesoscale Contribution to Severe Convection: A Case Study Example. *Weather and forecasting*, 2(1), 3-16. [https://doi.org/10.1175/1520-0434\(1987\)002<0003:TDBLSA>2.0.CO;2](https://doi.org/10.1175/1520-0434(1987)002<0003:TDBLSA>2.0.CO;2).
- Fernando, M., Millangoda, M., & Premalal, S. (2021). *Multi-Hazard Early Warning and Disaster Risks: Analyze and Comparison of the Atmospheric Instability Using K-Index, Lifted Index Total Totals Index Convective Availability Potential Energy (CAPE) and Convective Inhibition (CIN) in Development of Thunderstorms in Sri Lanka During Second Inter-Monsoon*. Springer, Cham. 603-614. https://DOI:10.1007/978-3-030-73003-1_41
- Huseynov, N., & Agayeva, A. (2019). Application of atmospheric instability indices for operational thunder forecasting based on the model data. *Proceedings of the Russian State Hydrometeorological University*, 56, 30-37.
- Huseynov, N., & Agayeva, A. (2019). Evaluation of thunderstorm conditions over the Absheron Peninsula. *Scientific Proceedings of the National Aviation Academy*, 21(2), 98-102.
- Kunz, M. (2007). The skill of convective parameters and indices to predict isolated and severe thunderstorms. *Natural Hazards and Earth System Science*, 7, 327-342. doi.org/10.5194/nhess-7-327-2007.
- Madatzade, A., & Shikhlinisky, E. (1968). *Climate of Azerbaijan*. Baku. Publishing House of the Academy of Sciences of the Republic of Azerbaijan.
- Pashayev, A., Imanov, F., Huseynov, N., & Guliyev, G. (2007). *Climate characteristics of Heydar Aliyev Airport*. Baku. National Aviation Academy.
- Perler, D., & Marchand, O. (2009). A study in weather model output postprocessing: Using the boosting method for thunderstorm detection. *Weather and Forecasting*, 24(1), 2011-2022. <https://doi.org/10.1175/2008WAF2007047.1>
- Peppler, R. A. (1988). *A review of static stability indices and related thermodynamic parameters*. Illinois State Water Survey. SWS Miscellaneous Publication. Retrieved from <https://www.ideals.illinois.edu/handle/2142/48974>.
- Rolph, G. (2017). *Real-time Environmental Applications and Display System: READY. Environmental Modelling & Software*. Elsevier Ltd, - 2017. 95, 210-228.
- Safarov, S. (2012). *Thunderstorms and mudflows in the territory of Azerbaijan and radar methods for their forecasting*. Baku. ELM.
- Shakina, N., & Ivanova, A. (2016). *Weather forecasting for aviation*. Moscow. Triada Ltd.
- Showalter, A. K. (1953). A stability index for forecasting thunderstorms // - Washington: Bulletin American Meteorological Society, 34, 250-252.