Atmospheric indices for predicting weather phenomena with a significant impact on the airport in Ngaoundéré, Adamaoua, Cameroon

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Abstract

This study aims to identify meteorological phenomena and establish their predictability at Ngaoundéré airport using stability indices. The investigation was based on literature review, analysis of 12H00 UTC radiosonde data, and 12H00 UTC SYNOP messages. The results show that stability indices vary much more during the months without thunderstorms than during the months with thunderstorms. They reveal that the lowest median value during the dry season, in the absence of thunderstorms, is observed in most cases in February. Finally, the most suitable indices for forecasting thunderstorms at Ngaoundéré Airport are CAPE, SHOWALTER, the SWEAT index and CIN. These results allow weather forecasters at the Ngaoundéré station to better refine their forecasts, and consequently, to meet the expectations of pilots operating at the Ngaoundéré Airport.

Résumé

La présente étude se propose d'identifier à partir des indices de stabilité les phénomènes météorologiques et d'établir leur prévisibilité sur l'aéroport de Ngaoundéré. L'investigation s'est basée sur la recherche documentaire, l'exploitation des radiosondages du réseau de 12H00 TU et des messages SYNOP de 12H00 TU également. Les résultats obtenus montrent que les indices de stabilité varient beaucoup plus au cours des mois sans orages qu'au cours des mois avec orages. Ils révèlent que la valeur minimale de la médiane pendant la saison sèche en l'absence d'orages s'observe pour la plupart des cas en Février. Enfin, les indices les plus indiqués pour la prévision des orages à l'aéroport de Ngaoundéré sont la CAPE, SHOWALTER, la SWEAT index et la CIN. Ces résultats permettent aux prévisionnistes du temps sur la station de Ngaoundéré de mieux affiner leurs prévisions, par conséquent de répondre aux attentes des pilotes en mouvement sur l'aéroport de Ngaoundéré.
Mots clés : Indices de stabilité, orages, radiosondage, phénomènes météorologiques, Ngaoundéré, Adamaoua.

Introduction

Air navigation has always been intimately linked to meteorology since its inception. Despite technological breakthroughs of all kinds, with better aircraft and constantly improving navigation systems, meteorology remains a significant challenge in air transport. Meteorology is one of the most important factors to consider, due to the multiple implication, not only flight safety, which is a priority, but also for customer satisfaction in terms of punctuality and flight regularity, and for the economic health of airlines (World Meteorological Organization, 2011). Meteorology is therefore at the very heart of the decision-making process for any airline that consider itself reputable. While air transport has seen remarkable technical progress and development in recent decades, it remains extremely sensitive to

weather phenomena. This is why Chi-Ming (2017) aptly stated that "aviation is among the economic sectors most sensitive to weather conditions".

In Cameroon, air navigation faces disruptions such as flight delays or cancellations due to weather conditions. Almost all flight delays or cancellations at Ngaoundéré Airport are partly attributable to adverse weather conditions. Ngaoundéré airport serve as astopovers for both domestic and international flights. Accurate weather forecasting is essential for flight preparation and scheduling. The Adamaoua region, located on a central plateau with a strong orographic influence, experiences high atmospheric variability characterized by intense convective storms, sudden and heavy rainfall, fog and low visibility, particularly during the rainy season and seasonal transitions. These extreme weather events are particularly frequent in Ngaoundéré, where the altitude and geographical position promote atmospheric instability. This situation makes the airport highly exposed to rapidly changing weather conditions, which are often difficult to anticipate using conventional forecasting methods. At Ngaoundéré Airport, weather conditions are one of the main factors disrupting air traffic, particularly through flight delays and cancellations, aircraft diversions, and increased risks during the critical phases of take-off and landing. Good weather forecasts are essential for preparing and scheduling flights. Air safety relies on the quality of the forecasts used before and during the flight, as well as on observations. Ngaoundéré airport lacks navigation aids such as VOR, NDB, ILS or MLS. Pilots are therefore forced to navigate visually, which makes the task particularly challenging and even extremely dangerous with the slightest deterioration in weather conditions. In March 2015, an incident occurred in which the Cameroon Defense Forces aircraft TJXCF narrowly avoided an accident during a failed landing attempt in heavy rain and thunderstorms. Given the deteriorating weather condition shortly before landing, the

meteorological service sent a special message to the control tower at exactly 14:40 local time. The message indicated winds of 12 Knots, severe thunderstorms accompanied by heavy rain, visibility of 2000 meters, and a sky covered by 6/8 low clouds at an altitude of 400 meters.

The aircraft rolled twice during landing due to wind shear, forcing the pilot to abort the landing and return to Garoua. Therefore, it become extremely important for pilots to have regular real-time updates on the precise weather conditions prevailing at Ngaoundéré airfield, and to obtain the most accurate forecasts possible on the occurrence of different weather phenomena. Flight cancellations due to poor visibility caused by dry fog are also significant, with the most recent occurring in March and April 2018 (with a record visibility of 300 meters recorded on March 30th), unfortunately leading to a series of cancellations. The economic impact of these multiple delays and cancellations is considerable, not only for the airlines, but also for the passengers, many of whom are business travelers. In this context, meteorological information is crucial for preventing accidents, delays and last-minute flight cancellations that passengers often face, and for identifying the most impactful weather phenomena, particularly at the airport. The objective of this article is to identify, using relevant indicators, the most impactful weather phenomena to improve predictability at Ngaoundéré airport.

1. Material

Located in the Adamaoua region, Ngaoundéré airfield is situated in the north of the city (Figure 1). Commissioned in the 1950s and it is a secondary civil aerodrome, with ICAO and IATA codes FKKN and NGE, respectively. It lies approximately 3,700m to the north-west of the city. Its altitude is 1114m and its geographical coordinates are 07°21'32" North Latitude and

013°33'36" East Longitude. Its runway is 2,700m long and 45m wide. It is administered by the Cameroon Civil Aviation Authority (CCAA), which oversees the activities of ASECNA, represented on the airfield by the Secondary Meteorological Center (CMS). The Ngaoundéré station has an observation room, a radiosonde room, a hydrogen preparation room and a METEO park, all equipped with properly calibrated meteorological instruments using appropriate observation and measurement techniques.
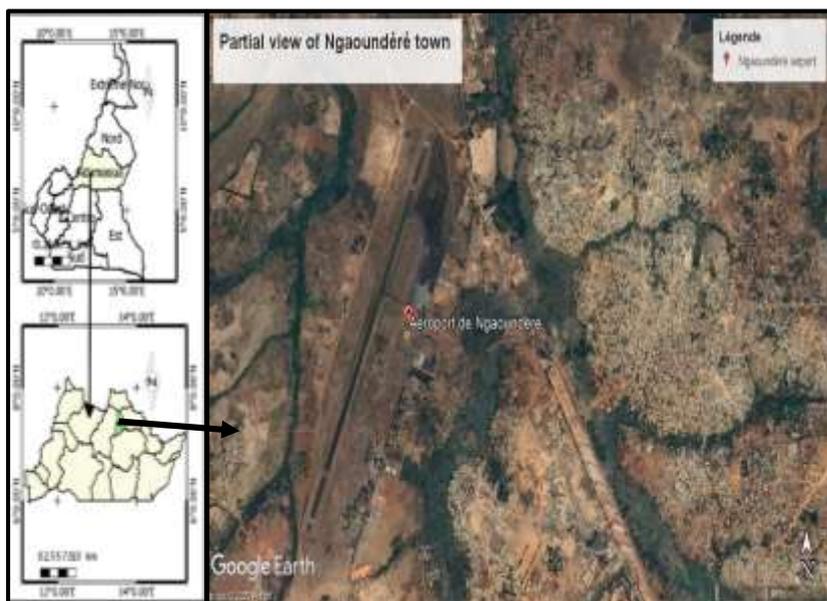
Source: *SOGEFI & Image Digital Globe de Google Earth (2025)   By Mobara, july 2025*

Figure 1. **Localization of area study**

2. Methods

The methodology is based on literature review and the use of synoptic reports. The data used in this study come from two sources: the radiosonde data come from the University of Wyoming database (www.weather.uwyo.edu) and the thunderstorm data come from the OGIMET database, SYNOP from the 12:00 UTC network from the Ngaoundéré station (www.Ogimet.com). This data originates from upper-air and surface observations made at the Ngaoundéré weather station. The atmospheric stability indices present in the various radiosonde data were selected using a methodical approach. The study relies on observational meteorological data obtained from two main sources like Upper-air data were obtained from the University of Wyoming database (www.weather.uwyo.edu). These data originate from regular upper-air soundings conducted at the Ngaoundéré meteorological station. The radiosonde profiles provide vertical measurements of key atmospheric parameters such as temperature, dew point temperature, pressure, wind speed, and wind direction from the surface to the upper troposphere. Thunderstorm occurrence and surface meteorological conditions were extracted from the OGIMET database (www.ogimet.com), using SYNOP messages recorded at 12:00 UTC for the Ngaoundéré station. These observations include weather phenomena codes, visibility, wind, precipitation, cloud cover, and pressure, allowing for the identification of thunderstorm events and associated hazardous weather conditions. The analytical approach was carried out to assess the relationship between atmospheric stability indices and the occurrence of significant weather phenomena affecting the airport. This involved on comparing index values during thunderstorm days and non-thunderstorm days, identifying threshold values associated with

severe weather occurrence and evaluating the predictive performance of each index in the context of Ngaoundéré airport operations.

3. Results

This study identifies atmospheric indices of predictability for meteorological phenomena with significant impacts on the Ngaoundéré aerodrome. These stability indices are studied according to the seasons and thunderstorms.

3.1. Convective Potential Energy (CAPE)

CAPE exhibits an average monthly fluctuation that allows us to measure of instability throughout the depth of the atmosphere. The whisker boxes show the dispersion of the CAPE as a function of storms. During the dry season, they show a greater dispersion of CAPE in the months of January, February and March with storms than in January, February and March without storms. During the rainy season (particularly between April and September), the dispersion of CAPE is much more pronounced in the months without storms than in the months with storms. The very low CAPE values observed in January, February and March without storms are consistent with the CAPE predictability criteria, unlike the abnormally low values (practically zero) observed in the rainy season during the months with storms. July, however, show a value reaching almost 2000 J/Kg (Figure 2).
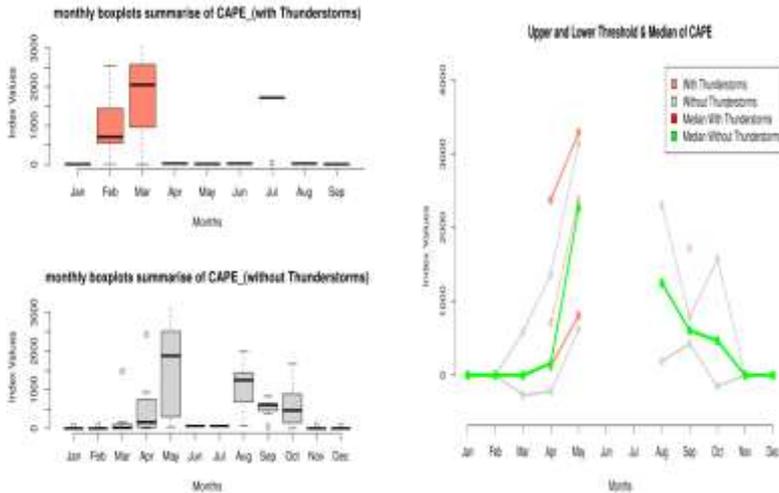
Figure 2. Average monthly variation in CAPE

Figure 2 shows the average monthly variation in CAPE. The average fluctuation thresholds of CAPE during the first two months of the rainy season (April and May) range approximately between 100 and 3500 in the presence of thunderstorms. During the dry season, in the absence of thunderstorms, a negative lower threshold is observed, while the upper value is around 500. Between April and May with thunderstorms, the minimum and maximum values of the CAPE are respectively around 700 and 2500; for the same period, these values range from 100 and 2400 in the absence of thunderstorms. For the last three months of the rainy season (August, September and, October) the minimum and maximum values of the median value are around 500 and 1400, indicating high instability and the risk of severe weather phenomena such as storms, which are very dangerous for navigation. CAPE would not be sufficient to predicting

thunderstorms during the months of April, May, June, August and September.

3.2. Convection Inhibition (CIN)

The analysis of the Convection Inhibition (CIN) present the fluctuation thresholds (Figure 3). During the dry season, the whisker boxes show a slightly greater dispersion of CIN in January, February and March with thunderstorms than in January, February and March without thunderstorms; it can also be seen that CIN values are significantly lower in February and March with thunderstorms than in the same months without thunderstorms.
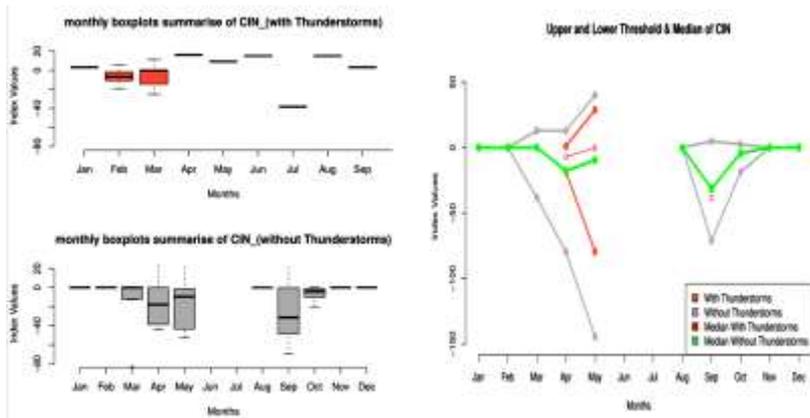

Figure 3. Dispersion of CIN thresholds

Figure 3 shows that the average CIN values are almost all above 0 between April and September for months with thunderstorms, with the exception of July, which has a value of around -40. This is probably explained by the development of convection, as convection is delayed for a CIN of -20 J/Kg or higher, but when it develops, it can lead to fairly violent thunderstorms. For June with thunderstorms, we have a median of almost 20, i.e. a value

that predicts showers, which is logical, as we are almost in the middle of the rainy season. We can therefore estimate that the CIN would be an indicator for forecasting thunderstorms at Ngaoundéré airport for the month of June. Observation of the figure 3 shows that the average CIN fluctuation thresholds during the first two months of the rainy season are approximately between -75 and 25 in the presence of a thunderstorm, and between -150 and 40 in the absence of thunderstorm. For the last two months of the dry season, the average fluctuation thresholds are between -40 and 20 in the absence of thunderstorms.

For the first two months of the rainy season (April and May) with thunderstorms, the median minimum and maximum values are around -10 and 0 respectively. For the last three months of the rainy season (September and October), the minimum and maximum values of the median, in the absence of thunderstorms, are -30 and 0 respectively. Based on the CIN values, thunderstorms are unlikely, therefore navigation is possible.

3.3. Convection Inhibition using Virtual Temperature (CINV)

The Convection Inhibition using Virtual Temperature (CINV) is a modified form of CIN calculated based on virtual temperature. Figure 4 shows the box plots and monthly fluctuation thresholds for the CIN calculated based on virtual temperature.
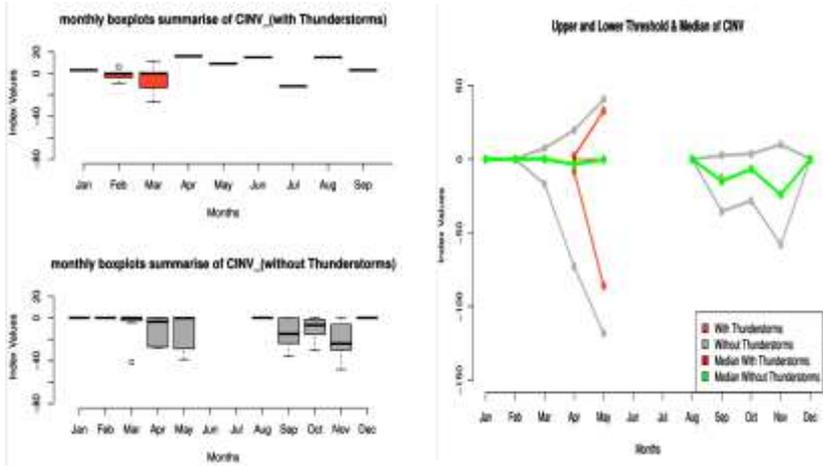
Figure 4. Dispersion of the CINV

3.4. Cross Total (CRT)

The box plots and the average monthly fluctuation thresholds for the Climate Reduction Time of the (CRT) shows the dispersion of the CRT as a function of thunderstorms (Figure 5). The box plots show a lower dispersion of the TRM during months with thunderstorms than during months without storms, for both the dry and rainy seasons. However, high values are observed that deviate from predictability criteria, values observed during the months of June and July without storms. Indeed, CRT values above 25 already indicate the occurrence of severe thunderstorms and tornadoes, which are very dangerous for aerial surveillance.
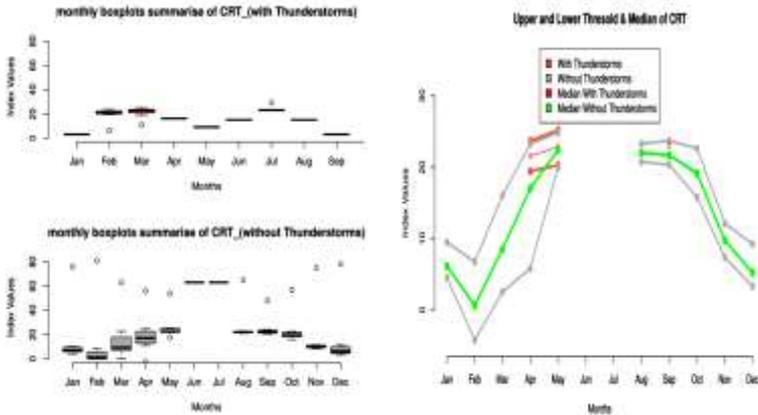
Figure 5. Dispersion of phenomena and monthly CRT thresholds

The CRT does not appear to be relevant indicator for forecasting during June and July. During the dry season, the lower threshold for mean TRC fluctuation in the absence of thunderstorms is negative, while the upper threshold is around 10. For the first two months of the rainy season, the average CRT fluctuation thresholds range between 18 to 25 in the presence of thunderstorms and between 7 to 25 in the absence of thunderstorms. During this period, the minimum value of the median is observed in February in the absence of thunderstorms. It is also observed that during the first two months of the rainy season, the maximum median values (with or without thunderstorms) are identical. The absence of curves during the months of June and July is due to lack of data.

3.5. *Middle Layer Mixing Ratio (MMLMR)*

The Middle Layer Mixing Ratio (MMLMR) shows that the median values of the thickness vary more in the presence of

thunderstorms than in the absence of thunderstorms during the dry season (Figure 6). This variation in layer thickness during the dry season could be due to the warming of the air mass in the lower layers of the atmosphere, thus promoting convection current. When air layers heat up under the effect of strong sunlight, they become unstable and updraft are created, leading to turbulence effects on the aircraft when it encounters strong winds. The consequence is airframe fatigue, pilot fatigue and loss of control.
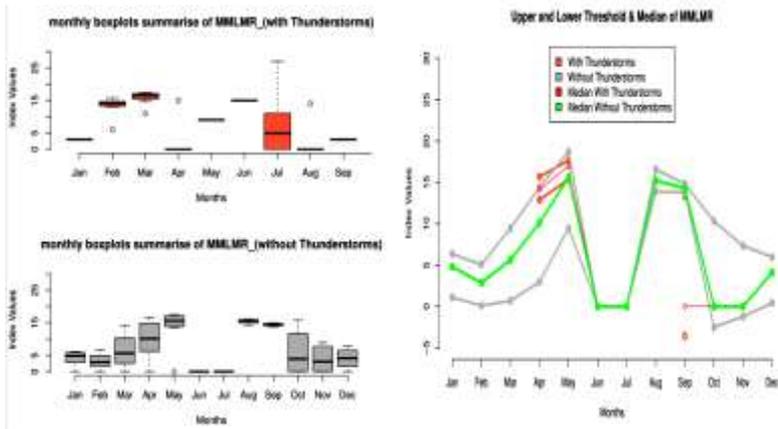

Figure 6. Dispersion of MMLMR thresholds

The medians thickness of the middle layer is relatively stable in the presence of thunderstorms during July, August and September, i.e. during part of the rainy season. This is explained by the influx of moisture from the monsoon into the lower and middle layers of the atmosphere, thus creating saturation. During the dry season, the average fluctuation thresholds of the MMLMR vary between 0 to 10 in the absence of thunderstorms, while they range from -3 to almost 20 during the rainy season. For the first two months of the rainy season, the average

fluctuation thresholds of the MMLMR are between 13 to 17 in the presence of thunderstorms and between 10 to 15 in the absence of thunderstorms. During the dry season, the median minimum value in the absence of a storm is observed in February (as with the CRT), while during the rainy season the maximum value is observed in August.

3.6. Precipitable Water (PWES)

Monthly fluctuations of the amount of rainfall shows that the dispersion in the absence of thunderstorms is significantly greater than in the presence of thunderstorms, regardless of the season (Figure 7). However, the highest values are observed in March with thunderstorms. During the dry season, the average fluctuation thresholds for PWES are between 10 to 28 in the absence of thunderstorms. This indicates that the sky is not overcast and flying is indeed possible.
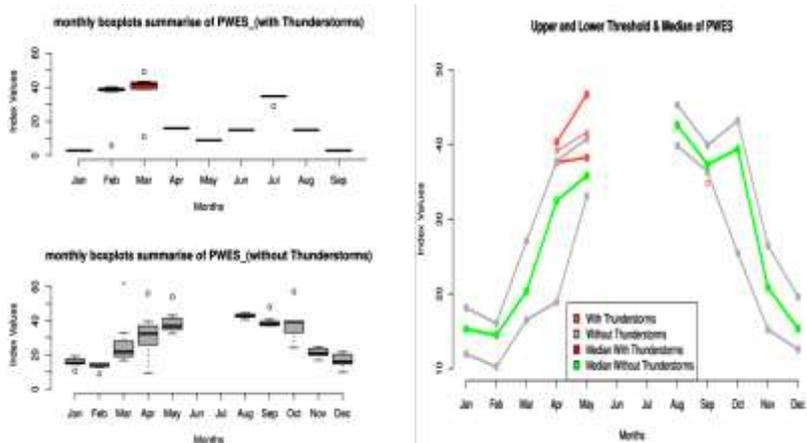

Figure 7. Dispersion of PWES

It can be seen that during the first two months of the rainy season, the mean fluctuation thresholds are between 38 to 48 in

the presence of thunderstorms and between 18 to 40 in the absence of thunderstorms. During the dry season, the minimum value of the median in the absence of thunderstorms is still observed in February. It is therefore important to navigate in the absence of thunderstorms.

3.7. Showalter (SHO)

The Showalter (SHO) index shows a more pronounced dispersion for months without thunderstorms than for months with thunderstorms. SHO values are higher in January, February and March without storms than in the same period with storms (Figure 8). This clearly confirms Showalter criteria.
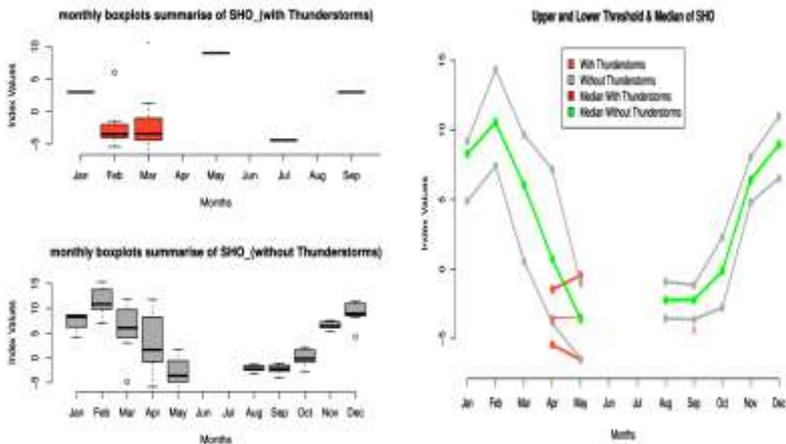

Figure 8. Dispersion of phenomena and monthly SHO thresholds

The curve clearly shows an evolution in the non-occurrence of thunderstorms throughout the year, which corroborates the thunderstorms climatology at the station. Based on the evolution of the SHO median curve, we observe values between 0 and - 5

between August and September (towards the end of the rainy season), then an increase from September until reaching its peak in February (which is logical, as this is the dry season), and for SI >3 no thunderstorms or showers are expected), we then observe a decrease in values after February (i.e. towards the start of the rainy season, which is again logical, as the more negative the SI, the greater the probability of thunderstorms occurrence) until May. The Showalter index would therefore be quite relevant for the predicting thunderstorms over Ngaoundéré throughout the year, except for the months of June and July when it seems difficult to draw a conclusion due to the lack of curves, probably due to insufficient data. The average SHO fluctuation thresholds during the dry season and in the absence of thunderstorms are between 1 to15.

3.8. Sweat (SWT)

The Sweat (SWT) as a function of thunderstorms shows a significantly greater dispersion for months without thunderstorms than for months with thunderstorms, and this is true for both seasons (Figure 9). The high SWT value observed during July, a month with thunderstorms clearly confirms the thunderstorm climatology at the Ngaoundéré station.
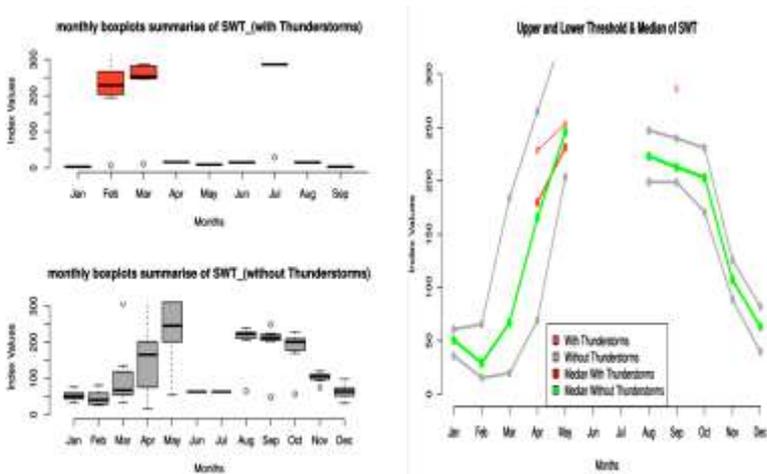
Figure 9. Dispersion of phenomena and monthly SWT thresholds

The average SWT fluctuation thresholds during the dry season and in the absence of thunderstorms are between 20 to 190. The minimum median value during the dry season in the absence of thunderstorms is still observed in February. This index is quite useful for forecasting during the month of July.

3.9. Total Total Index (TTI)

The Total Total Index (TTI), illustrated by the box plots, shows the dispersion of the SWT as a function of thunderstorms. Generally, a relatively stable dispersion is observe during the months without storms, throughout the year. However, the months of June and July without thunderstorms, stand out with their higher median values (60), which is an anomaly, given that the TTI criteria typically predict thunderstorms and tornadoes at such a value. This could be explained by the lack of data, also probably justifying the absence of most of the curves for the months with thunderstorms.
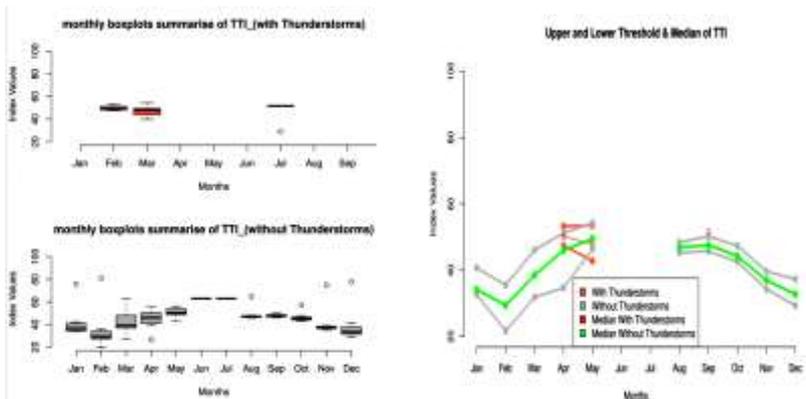
Figure 10. Dispersion of TTI

The average TTI fluctuation thresholds during the dry season and in the absence of thunderstorms are between 20 to 50. The minimum median value during the dry season in the absence of thunderstorms is still observed in February. For the first two months of the rainy season, the minimum median value in the presence of thunderstorms is slightly lower than the maximum value in the absence of thunderstorms.

3.10. Vertical totals index (VET)

Figure 11 show the dispersion of the VET as a function of thunderstorms. Generally, very little dispersion is observe during the months without storms, and this is consitent throughout the year.
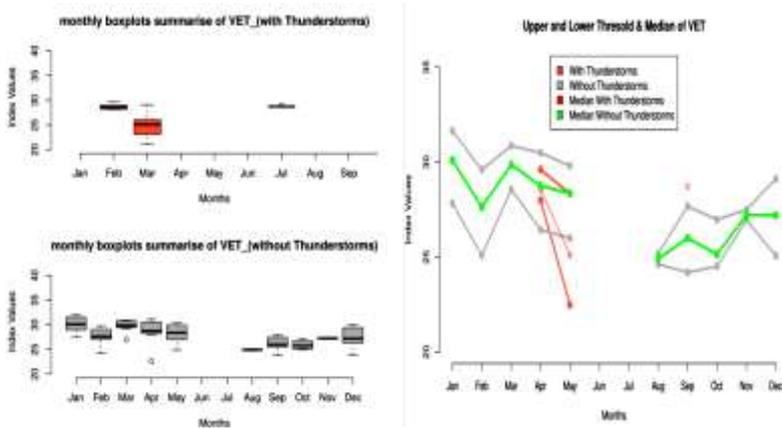
Figure 11. Dispersion of ETV

Analysis of the dispersion of phenomena and monthly ETV thresholds reveals that February (the dry season) with thunderstorms is an anomaly in that its maximum value is close to 30, indicating the occurrence of numerous moderate thunderstorms and a few tornadoes. The mean thresholds of fluctuation of the ETV during the dry season and in the absence of thunderstorms are between 25 and 32. The minimum value of median during the dry season in the absence of thunderstorms is also observed in February. For the first two months of the rainy season, the minimum values of median in the presence and absence of thunderstorms are almost identical. The absence of most of the curves in the presence of thunderstorms can be explained by the lack of data.

3.11. Mean mixed layer potential temperature (MMLPT)

The dispersion of Mean mixed layer potential temperature (MMLPT) indices is more or less stable throughout the year in the presence and absence of thunderstorms (Figure

12). This could be due to a small variation in the potential temperature in the middle layer in the presence and absence of thunderstorms. However, relatively significant differences are observe for June and July without thunderstorms and for February and March with thunderstorms.
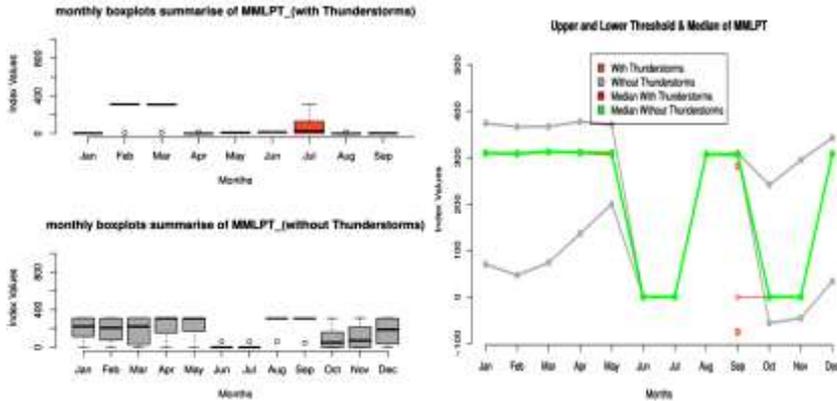

Figure 12. Dispersion of the MMLPT

The value of MMLPT shows that it is not only very stable, but also very low throughout the year (except for February and March) for months with thunderstorms; this could be explained by weak diurnal warming. During the dry season, the average fluctuation thresholds of the MMLPT in the absence of thunderstorms are approximately between -50 and 390. It can also be seen that throughout the year, the median values are between 0 and 300 in the absence of thunderstorms. The absence of curves in the presence of thunderstorms could be explained by the lack of data.

3.13. Bulk Richardson Number (BRN)

Bulk Richardson Number (BRN) values are higher in the absence of thunderstorms than in the presence of thunderstorms,

particularly in July, August and September (Figure 13). Another observation that stands out is the very low values of the index (almost zero) for February and March without thunderstorms, in contrast to February and March with thunderstorms, where the median values reach 100.
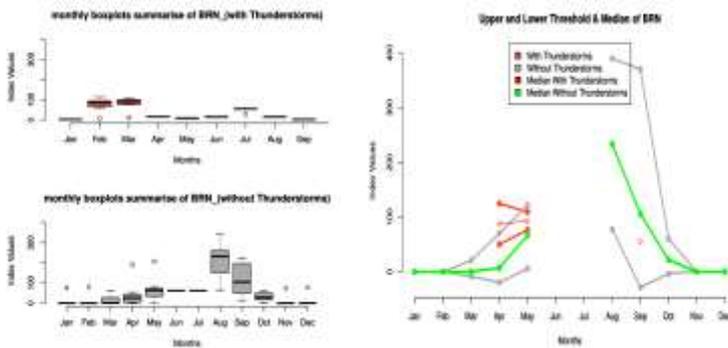

Figure 13. Dispersion of BRN

The dispersion of BRN thresholds shows that, during the first two months of the rainy season, the average BRN fluctuation thresholds range from 50 to 140 in the presence of thunderstorms, while in the absence of thunderstorms, the lower threshold is negative. The upper threshold is around 140. The value of the upper fluctuation threshold during the last three rainy months without thunderstorms stands out, peaking at around 400. Table 1 summarizes the indices corresponding to the different periods.

Jan.	Feb.	Mars	April	May	Ju	July	Aug	Sept.	Oct.	Nov.	Dec.
CAPE	CAPE/ SHO	CAPE/ SHO	SHO	SHO	CIN	CAPE/ SWEAT	SHO	SHO	SHO	SHO	SHO

The monthly distribution of thunderstorms observed at the Ngaoundéré station between 2015 and 2017 reveals that the three stormiest months correspond to the last three months August, September and October of the rainy season (which generally runs from April to October), namely August, September and October, with the peak occurring in September. The minimum rainfall recorded during December, January and February falls squarely within the heart of the' dry season (which extends from November to March).

Discussion

The results obtained show that the most suitable indices for forecasting thunderstorms at Ngaoundéré airport are the CAPE, SHOWALTER, SWEAT index and CIN. An examination of all the box plots and curves representing the monthly thresholds of the different indices reveals that the minimum median value during the dry season, in the absence of thunderstorms is observed in most cases in February. Stability indices vary much more during the months without thunderstorms than during

months with storms. This can be explained by the thermodynamics of air masses. During thunderstorms periods, unstable conditions are generally maintained for certain time; when an index reaches values that trigger thunderstorm phenomena, these values are remain for certain period. Conversely, periods without thunderstorms are marked by very high variability in parameters such as temperature and pressure. Furthermore, the most relevant stability indices for forecasting at Ngaoundéré station are: CAPE, Showalter, Sweat index and CIN. The SHO indices at Ngaoundéré airport meet the criteria defined by Showalter.

In light of the results obtained, the monthly distribution of thunderstorms recorded at Ngaoundéré airport confirms that thunderstorms significantly impact air traffic at this airport. These results corroborate those obtained by Thibaut (2016), which show that a thunderstorm is an atmospheric disturbance that manifests as a cumulonimbus. Furthermore, the study of the variability of the stability indices in relation to thunderstorm occurrence generally establishes a consistency between the criteria for thunderstorms predictability, using these indices and the actual occurrence of thunderstorms in the field for each season. The results obtained on thunderstorms climatology are confirmed by those published on the website infoclimat, which specializes in climate information. However, the results have limitation, as the data collected do not cover the entire period continuously. This is due to the ono-conduct of radiosonde soundings during certain months, primarily because of technical failures in the sounding equipment.

Conclusion

In summary, this article has shown that atmospheric stability indices allow for better forecasting of high-impact weather phenomena. The results obtained have established greater

variability in the indices during periods of no thunderstorm compared to periods with thunderstorms. It has enabled the establishment of the climatology of thunderstorms, the variability of stability indices according to the occurrence of thunderstorms and the determination of average monthly fluctuation thresholds for the various indices. The most important indices for forecasting weather phenomena are CAPE, SHOWALTER, SWEAT INDEX and CIN at Ngaoundéré airport. Based on the results, the SHOWALTER index remains the best index for forecasting weather phenomena regardless of the month or season. Thus, the study of atmospheric indices as tools for forecasting weather phenomena with a significant impact on Ngaoundéré Airport is a scientific and operational response to a major local issue that has not yet been sufficiently explored in Cameroon. It offers a concrete opportunity to strengthen forecasting capabilities, reduce risks and improve aviation safety in an increasingly challenging climate context.

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