



STORM CHARACTERIZATION IN THE CANARY ISLANDS

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Curso 2021-2022

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Presentado en cumplimiento de los requisitos para:
GRADO EN CIENCIAS DEL MAR
en
UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

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En Las Palmas de Gran Canaria a 3 de junio de 2022

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1. Introduction

This is a study of the convective activity in an area surrounding the Canary Islands. These islands are under the influence of the Azores High Pressure Centre, which sends the Trade Winds from the Northeast. The result is a prevalence of atmospheric stability. However, polar fronts and tropical disturbances also affect the islands. These episodes can leave important amounts of rainfall and sometimes lightning. There are registers that show very severe episodes of this kind.

Some authors have studied the relationship of the weather in the Canary Islands with teleconnection patterns (García Herrera et al., 2001). Regarding precipitation, it seems that some patterns affect the islands, but probably the most important factors are very local scale phenomena, enhanced by the complex orography of the islands. Regarding lightning activity, the intensity of the perturbation seems to be the leading factor.

To the best of our knowledge, this is the first study of convective environments around the Canary Islands. Data from the highly valued ERA5 reanalysis from 1979 to 2021, in combination with lightning observations from 2007, are used. The study includes correlations between significant variables for convection, time series analysis of these variables, two lightning episodes, seasonal and diurnal variability of relevant variables. In addition, we have also studied the relation of these variables with teleconnection patterns (atmospheric circulation indices).

2. Study area and datasets

2.1 Study area

The Canary Islands are an archipelago located in the subtropical Eastern North Atlantic region, called Macaronesia, between 27° N - 30° N and 13° W - 20° W. These coordinates are the limits of our study area. This archipelago consists of seven main islands covering a total area of about 7447 km^2 . Canary Islands are greatly influenced by the Azores high pressure system and associated trade wind belt (Cropper and Hanna, 2014), performing a subsidence inversion usually founded between 700 and 1500 m.a.s.l. (meters above sea level), which does not allow the convective development (Suarez Molina et al., 2020). The western Islands (La Palma, El Hierro, La Gomera, Tenerife and Gran Canaria) present a more complex orography than the eastern islands (Fuerteventura and Lanzarote).

Due to this complex orography, the small-scale atmospheric processes play an important role in this archipelago.

There are three kinds of weather that define the characteristic climate of the Canary Islands (Marzol y Máyer, 2012). The first and most important is the regime of the trade winds coming from the north-easterly, which dominates during approximately two-thirds of the year and brings humidity and atmospheric stability to the islands; in second place, we have the unstable weather coming from the north, where the storms detached from the Polar Front of the Atlantic Circulation causes great precipitation and storms in the islands. In third place we find the southern weather, coming from the Sahara in a south-easterly direction, which brings warm and dry air to the islands, besides the dust coming from the Sahara. The succession of these three kinds of weather, together with the transitions between them, define the climate in the Canary Islands. However, this work does not mention the influence of the southern tropical weather type, along with disturbances of tropical origin.

This work aims to characterize the thunderstorm regime in the Canary Islands area, in addition to trying to relate storm events with atmospheric circulation patterns. The climatic variables chosen for our study (CAPE, total precipitation, K index and Total Totals index) were downloaded from Copernicus (the European project) ERA5 Reanalysis.

Reanalysis combines observations made in the past and data from old models. This is a complex process that is the input for a contemporary weather model. The execution of this model through these past times delivers a complete, consistent and more accurate estimate. This delivers a global picture of the weather and climate of the past as close to reality as possible.

The ERA5 atmospheric reanalysis data has a spatial resolution of 31km (0.28125 degrees), but data has been regridded to a regular latitude-longitude grid of 0.25 degrees between each grid point for the reanalysis. The model runs on 137 vertical levels, but the most significant 37 levels are offered to use¹.

¹ <https://confluence.ecmwf.int/display/CKB/ERA5%3A+data+documentation#ERA5:datadocumentation-Instantaneousparameters>

2.2 Convective Available Potential Energy (CAPE)

The convective available potential energy (CAPE) measures the maximum buoyancy of a parcel of air, indicating the instability (or stability) of the atmosphere, related to the potential strength of the updraft of thunderstorms. Large positive values of CAPE indicate that an air parcel would be much warmer than its surrounding environment and therefore, it will continue to rise. On a thermodynamic diagram this is called positive area and can be seen as the region between the lifted parcel process curve and the environmental sounding, from the parcel's level of free convection to its level of neutral buoyancy. CAPE may be expressed as follows:

$$CAPE (J Kg^{-1}) = \int_{p_f}^{p_n} R_d (T_{vp} - T_{ve}) d \ln p$$

Where T_{vp} is the virtual temperature of the lifted parcel moving upward moist adiabatically from the level of free convection to the level of neutral buoyancy, T_{ve} is the virtual temperature of the environment, R_d is the specific gas constant for dry air, p_f and p_n are the pressure at the level of free convection, and the pressure at the level of neutral buoyancy, respectively. The calculation of this parameter assumes: (i) the parcel of air does not mix with surrounding air; (ii) ascent is pseudo-adiabatic (all condensed water falls out) and (iii) other simplifications related to the mixed-phase condensation heating.

Thunderstorm environments in the Canary Islands are observed to have lower CAPE than the ones observed in other places like China (Li et al., 2018), United States (Brooks et al., 2003) and Europe (Brooks et al., 2007; Tuovinen et al., 2015). Following Suárez Molina et. al 2020, CAPE values were below $1000 J kg^{-1}$ in more than 75 percent of the cases on the Canary Islands. This characteristic low CAPE values may be due to the atmospheric stability caused by the Azores High Pressure System (AHPS) and associated Trade Wind Belt (TWB).

Monthly averaged data by hour of day from ERA5 Reanalysis were computed to compare the lightning data supplied by the State Meteorological Agency of Spain (AEMET) with the CAPE values in the archipelago.

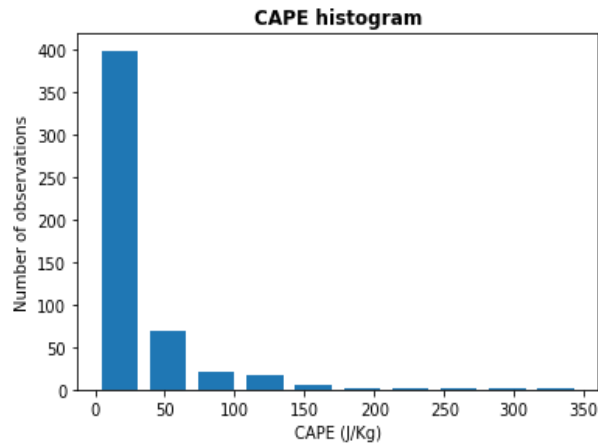


Figure 1. CAPE histogram at coordinates $15,43^{\circ} W - 28,121^{\circ} N$ (Parque Doramas, Las Palmas de Gran Canaria).

The operational experience of the AEMET prediction staff in the Canary Islands gives almost all the importance to the CAPE, while other instability indices like the K Index (KI) or the Total Totals Index (TTI) lack that importance in this area.

2.3 Total Precipitation

This parameter is the sum of large-scale precipitation and convective precipitation. We choose total precipitation instead of convective precipitation because the first one contemplates the accumulated liquid and frozen water that falls to the Earth's surface (comprising rain and snow). The Total Precipitation (TP) is accumulated over a period, in our case we downloaded the monthly averaged reanalysis (1979-2021), where the accumulation period is one day. Originally, the units of this parameter were depth in metres of water equivalent per grid area, but we made the conversion to millimetres per grid area (31 km x 31 km).

We must take care with the interpretation of this parameter, because a large precipitation event does not mean that a convective episode is developing.

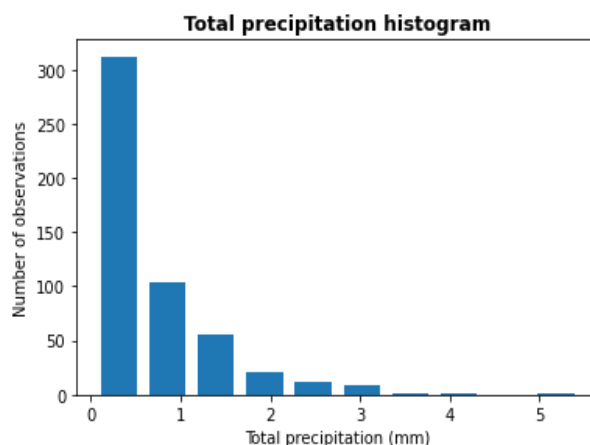


Figure 2. Total precipitation histogram at coordinates 15,43° W – 28,121° N (Parque Doramas, Las Palmas de Gran Canaria).

2.4 K index

This variable is a parameter that measures the thunderstorm potential, calculated from the temperature lapse rate and dewpoint temperature of the lower troposphere. The KI has the following expression:

$$K (K) = (T_{850} - T_{500}) + D_{850} - (T_{700} - D_{700})$$

Where T is the temperature at different pressure levels (850, 700, and 500 hPa), and D is the dewpoint at the pressure levels of 700 and 850 hPa.

Positive values of the KI indicate greater likelihood of thunderstorm development.

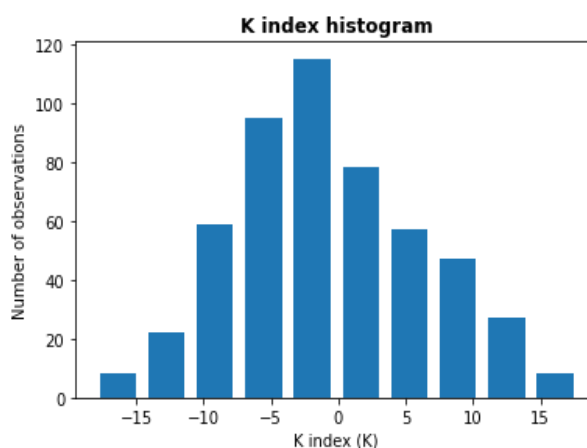


Figure 3. K Index histogram at at coordinates 15,43° W – 28,121° N (Parque Doramas, Las Palmas de Gran Canaria).

2.5 Total totals index

This parameter also measures the probability of occurrence of a thunderstorm, like the KI. It is calculated by the following expression:

$$TT (K) = (T_{850} - T_{500}) + (D_{850} - T_{500})$$

Where T is the temperature at the pressure levels of 850 and 500 hPa, and D is the dewpoint at the levels pressure of 850 hPa. On the other hand, as in the case of KI index, this parameter only considers ambient and dewpoint temperatures (it measures only thermodynamic parameters).

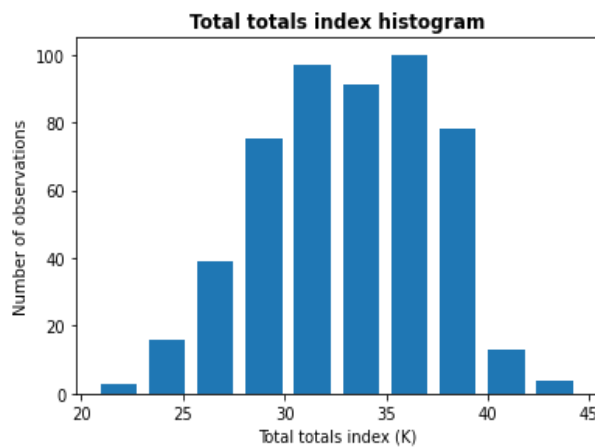


Figure 4. Total Totals Index histogram at coordinates $15,43^{\circ} W - 28,121^{\circ} N$ (Parque Doramas, Las Palmas de Gran Canaria).

2.6 Lightning data

Lightning data observations were supplied by Agencia Estatal de Meteorología (AEMET). The dataset consists of a second-by-second breakdown from 2007 to 2021 in our study area. The dataset considers all the lightning observations detected, both those that are cloud-cloud and those that are cloud-ground, also if the sign is positive or negative.

2.7 Atmospheric circulation indices

To study the possible modulation of the thunderstorm's development in Canary Islands by atmospheric circulation patterns, five atmospheric circulation indices were chosen to describe the thunderstorm's behaviour. All the indices' periods cover from January 1979 to December 2020, at one-month intervals.

The first one is the North Atlantic Oscillation index (NAO; Jones et al. 1997), based on the normalized surface sea-level pressure difference between the Azores High and the Subpolar Low (Reykjavik). Secondly, we study the Atlantic Multidecadal Oscillation index (AMO), which shows the variability of the sea surface temperature (SST) over the North Atlantic basin (0-70°N) on several decades. The AMO index was download from the NOAA data base². Third, we choose the East Atlantic Index (EAI), which is structurally like the NAO index, consisting of a North-South dipole displaced south-eastward to the NAO pattern dipole. Fourth, we study the South Oscillation Index (SOI), which indicates the development and the intensity of El Niño and La Niña events. The SOI is calculated using the pressure differences between Tahiti and Darwin (Australia). Positives values tends to represent La Niña events, and negative values tends to represent El Niño events. Finally, the last circulation pattern studied is the Trade Wind Index (TWI; Cropper and Hannah 2014), calculated with the normalized surface sea-level pressure between Azores and Cape Verde. The TWI has a great influence in the study area because it is useful to study the Trade Winds intensity.

3. Results

3.1 Variable statistical analysis

As previously stated, the operational experience of lightning forecasting in the Canary Islands have shown the importance of CAPE, so the analysis performed in this work have considered CAPE as the main descriptor variable of the thunderstorm activity.

First, we study the relationship between the climatic variables calculating the correlation coefficient between them. As we see at the CAPE and TP histograms (Fig. 1 and Fig. 2), the dataset doesn't follow a normal distribution, which forced us to use statistical analysis without that assumption. Spearman rank-order correlation was used to describe this relationship, because we are examining the monotonic relationship between two datasets, and it varies between -1 and +1, with 0 implying no correlation. Correlations of -1 or +1 imply an exact monotonic relationship. A negative correlation implies that the relationship between the two

² <https://psl.noaa.gov/data/timeseries/AMO/>

variables is opposite, while a positive correlation implies a synchronous relationship.

To explain the total linear correlation between variables, Pearson correlation coefficient between variables with the mean values of the total area is shown in Fig. 5.

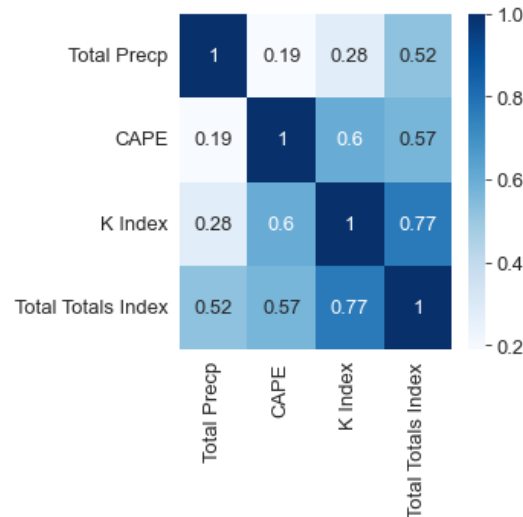


Figure 5. Heatmap with the correlation coefficient between variables.

The low value of the correlation coefficient between CAPE and TP reinforces the idea that, although a large precipitation event occurs, it does not mean that a thunderstorm episode is developing. The higher correlation coefficient value it's found between TTI and KI, which have a lot of sense, because the difference between these two variables is that they have only one difference term in their formula.

TP values correlate well with TTI and KI because these indices measure changes in temperature at certain levels and, when precipitation occurs, these changes occur in part as a consequence of precipitation: precipitation usually involves thermal descent by 1) dragging air downwards at a certain altitude and 2) evaporation of droplets. Correlation coefficients between CAPE, TTI and KI values are high because all of them are instability indices. See that all the correlation coefficients between variables are positive.

Seasonal correlation coefficient maps of the instability indices versus total precipitation are shown in figures 6, 7, 8. The maximum correlation coefficient values are in the centre of Tenerife, showing the importance of its orography.

Seasonal CAPE-TP correlation coefficient

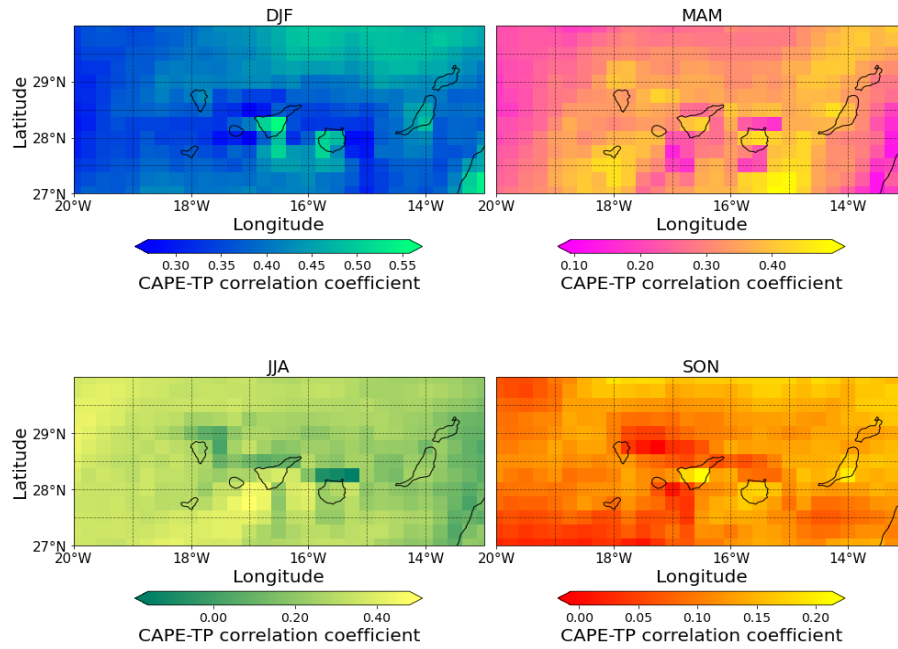


Figure 6. Seasonal Spearman correlation coefficient map between CAPE-TP.

Seasonal K Index-TP correlation coefficient

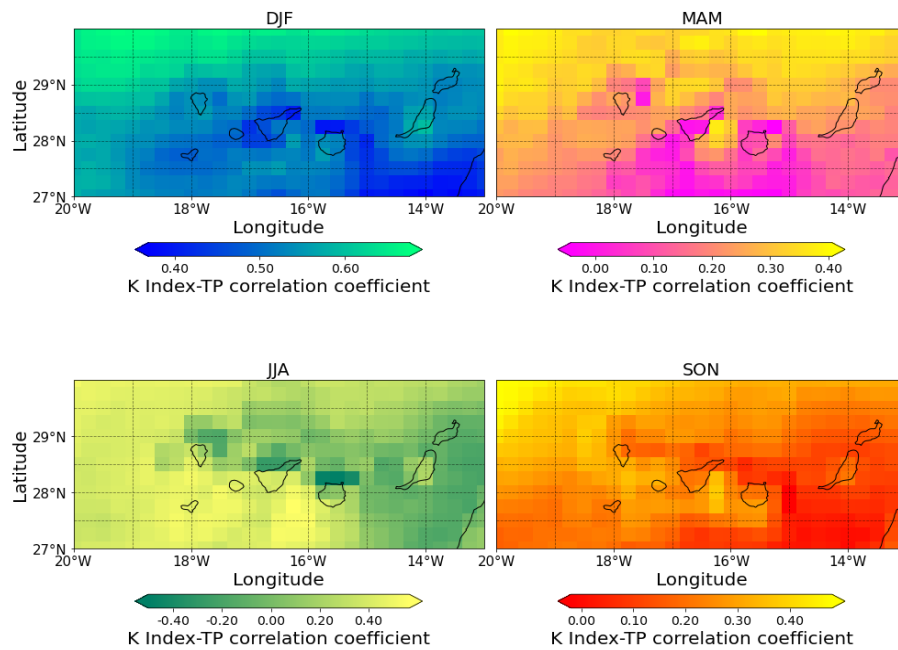


Figure 7. Seasonal Spearman correlation coefficient map between KI-TP.

Seasonal Total Totals Index-TP correlation coefficient

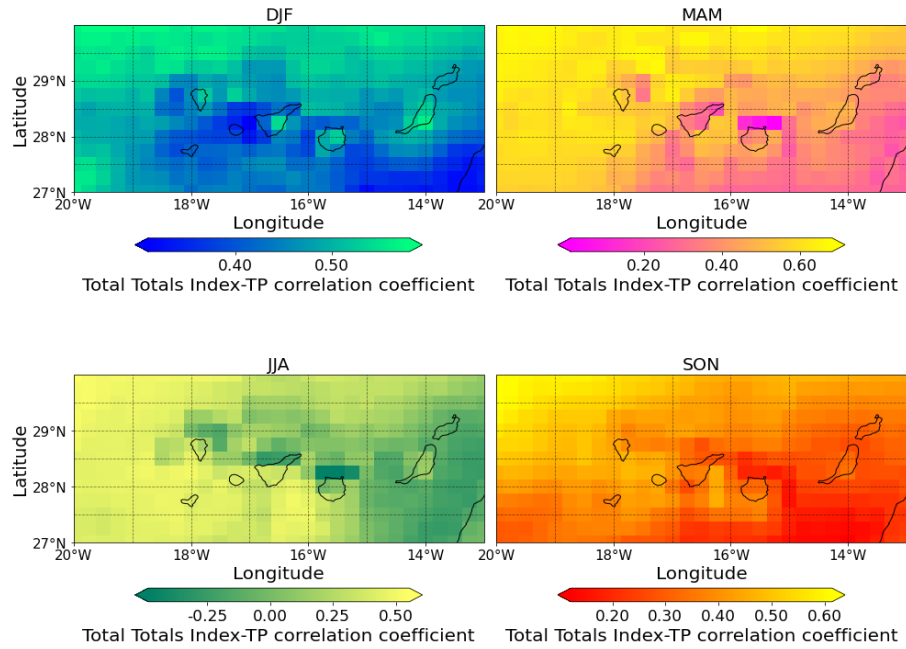


Figure 8. Seasonal Spearman correlation coefficient map between TTI-TP.

3.2 Seasonal variability

Monthly averaged reanalysis data from ERA5 Reanalysis were downloaded for the 1979-2021 period to study the storm’s seasonal behaviour in the Canary Islands. Data has been grouped by season and represented in a grid box map over the study area.

Seasonal CAPE

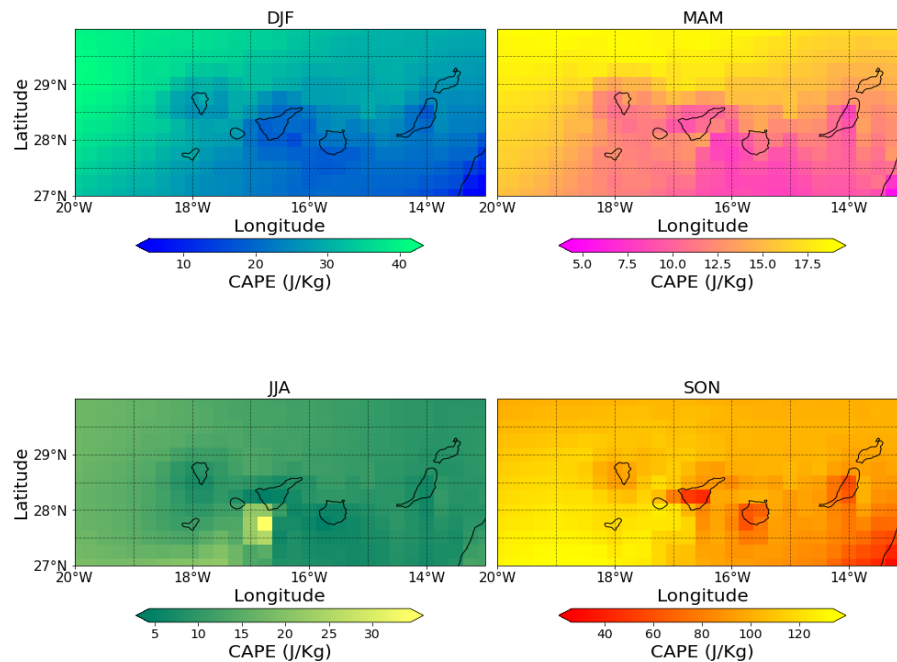


Figure 9. Seasonal CAPE mean values in Canary Islands from 1979 to 2021.

Analysing the seasonal variability of the CAPE (Fig. 9), we can observe the minimum values in spring (March, April and May) and summer (June, July and August), and the maximum values in autumn (September, October and November). The low CAPE values in spring and summer coincide with the intensification of the trade winds (TW) in this season (Azorín-Molina et al., 2016), which brings stability to the lower levels of the troposphere and inhibit the convection. The highest CAPE values in spring are in the North of the Islands, coinciding with the TW direction.

The maximum CAPE values were found in autumn, in a southwest direction, when the weakening of the TW occurs, the tropical disturbances affecting the archipelago and the sea surface temperature (SST) reach their maximum value. Observing the position of the maximum CAPE values of winter (December, January and February), these may be due to the Polar Lows that affect the Canary Islands in this season.

TP does not show as clear a seasonal variability (Fig. 10) as that of CAPE, furthermore, the precipitation values are greatly smoothed by the model, and the mean biases the representativeness of these results.

Seasonal Total precipitation

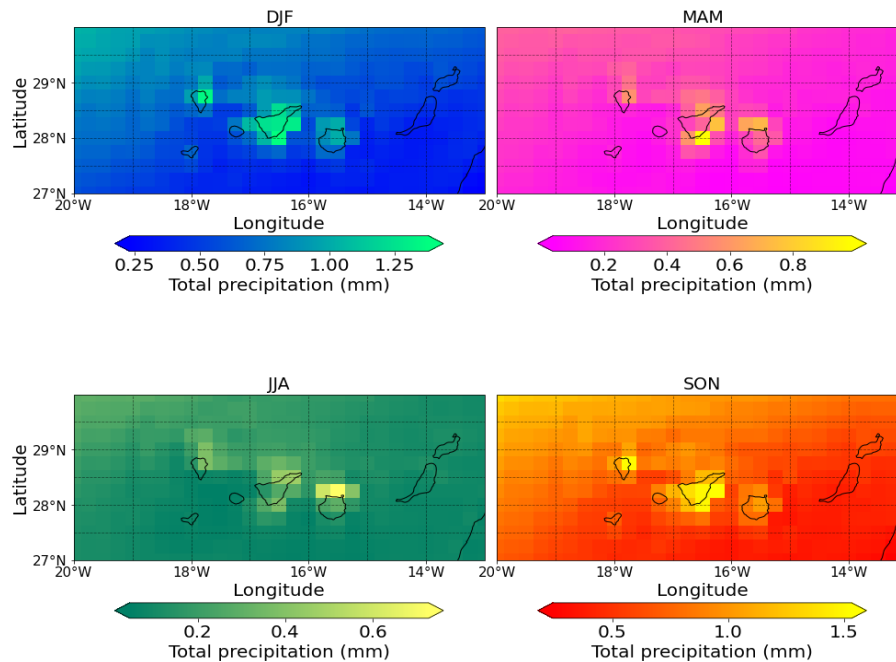


Figure 10. Seasonal TP mean values in Canary Islands from 1979 to 2021.

In figures 9 and 10, we can observe the great importance of the orography in these islands, since the model detects maximum CAPE and TP values in the centre of Tenerife, due to the height of Mount Teide.

3.3 Diurnal variability

CAPE monthly averaged reanalysis by hour of day were downloaded for the 1979-2021 period to study the storm's diurnal variability the Canary Islands. Data has been grouped by 4 times zones (00:00-06:00; 06:00-12:00; 12:00-18:00 and 18:00-00:00 hours). Figure 11 doesn't show any significant variation between the values of the time zones of the day. However, Chi-Square test was applied to check the results. The null hypothesis of the Chi-Square test assumes that there is no variability between the time zones values. The p-value is greater than the typical significance level of 0,05 (0,9795); we fail to reject the null hypothesis and we say that there doesn't seem to be diurnal variability of the CAPE values.

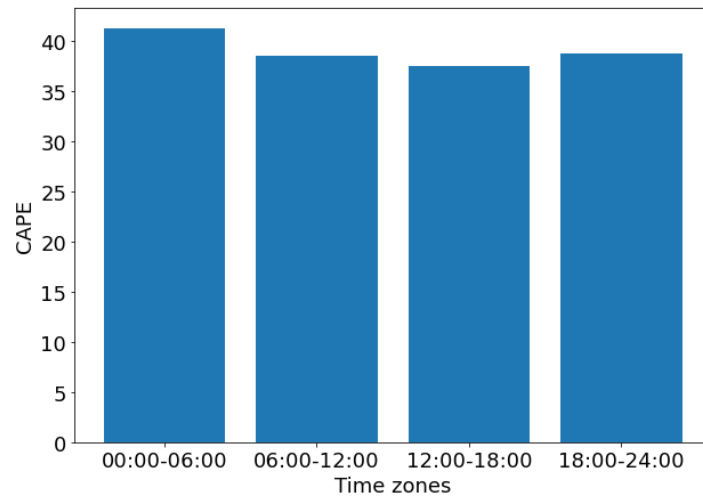


Figure 11. Diurnal CAPE variability histogram.

3.4 Time series analysis

To characterize the thunderstorm variability over the Canary Islands, we compute the CAPE time series data from 1979 to 2021 and made a Seasonal-Trend decomposition procedure based on Loess (STL). STL is a filtering procedure to decompose a time series into trend, seasonal, and residual components (B. Cleveland et al. 1990). STL was applied to all variables time series: climatic variables (CAPE, K index, Total Precipitation and Total Totals index) cover from 1979 to 2021, atmospheric circulation indices cover from 1979 to 2020, and lightning data, which covers from 2007 to 2021³.

³ The boundary years are also included.



Figure 12. CAPE STL decomposition from 1979 to 2021.

No trend is observed in the CAPE values throughout the study period, but an interesting behaviour is observed in the seasonality components (Fig. 12). CAPE values show a sinusoidal behaviour that affects especially in autumn and dampens over the period. This may be related to a synoptic cause, due to the atmospheric circulation indices influence, or to other causes, like complex interactions among many factors. Also, the seasonal variability can be observed, with the maximum values of the year in autumn and the minimum in summer.

When analysing the STL of the atmospheric circulation indices and parameters (not shown), it seems that the rest of the variables have a similar behaviour in the seasonal component to that of the CAPE.

3.5 Influence of atmospheric circulation on CAPE and Total Precipitation

Some papers establish there may be a relationship between some atmospheric circulation indices with meteorological variables in the Canary Islands (García

Herrera et al., 2001). To analyse a monotonic relationship, Spearman Rank Correlation was applied between the atmospheric circulation indices and the climatic variables.

No significant correlations were found between CAPE and TP with all the atmospheric circulation indices, in fact, analysing the results of the Spearman correlation coefficient, no correlation has been found between atmospheric circulation indices and climatic variables in which the correlation coefficient is greater than 0,5. CAPE has a maximum negative correlation coefficient value (-0,42) with NAO in winter and positive (0,26) in spring (Fig. 13). This makes sense, since when the NAO index values are negative (NAO-), the pressure difference between the two stations decreases and the westerly winds are suppressed. This causes an increase in convective activity and precipitation in southern Europe and North Africa. During positives phases in NAO (NAO+), the pressure gradient between the stations is strong, contributing to the strengthening of the westerlies, and causing an increased advection of moist warm air to the northeast, producing warmer conditions over Northern Europe.

Another maximum negative correlation coefficient value (-0,42) is found between CAPE-TWI in summer (Fig. 14). Negative correlation between CAPE-TWI implies that, when the trade winds intensify, the atmosphere stabilizes, and CAPE values decreases.

Seasonal CAPE-NAO correlation coefficient

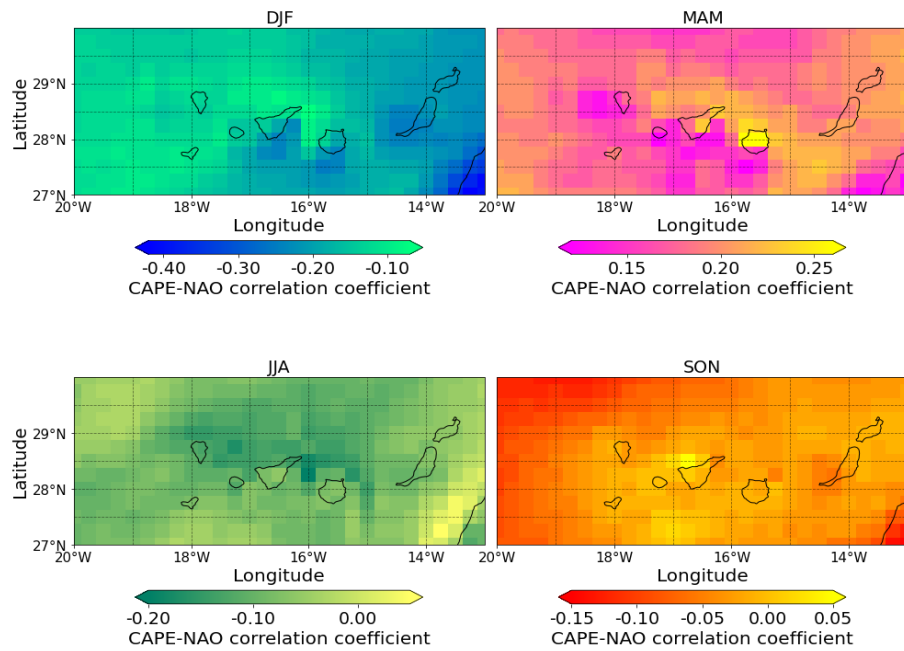


Figure 13. Seasonal CAPE-NAO Spearman correlation coefficient map.

Seasonal CAPE-TWI correlation coefficient

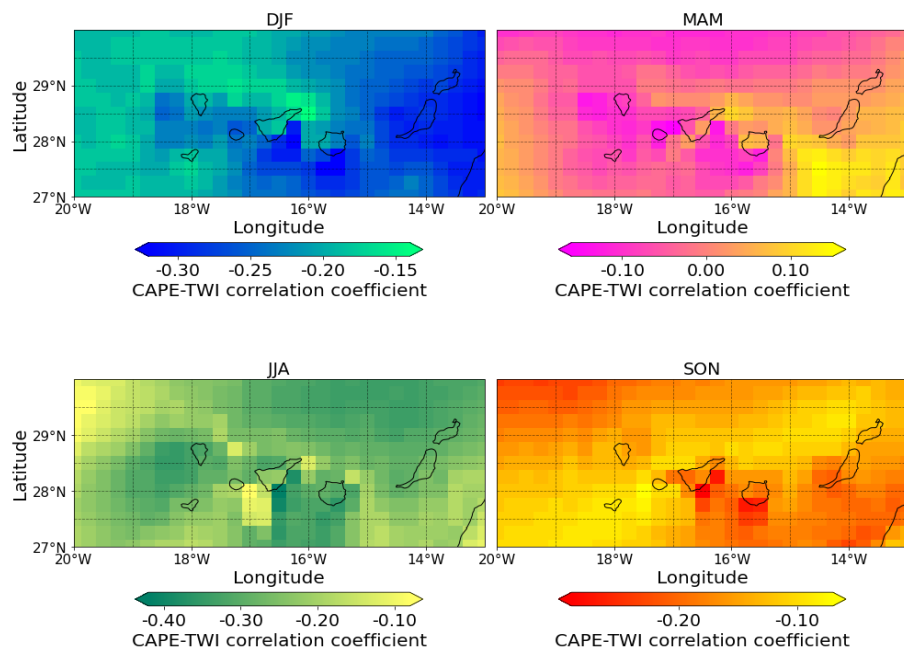


Figure 14. Seasonal CAPE-TWI Spearman correlation coefficient map.

Regarding the TP, the greatest values of the Spearman correlation coefficient were founded in the TP-NAO relationship, with the maximum negative correlation in winter (-0,26) and the maximum positive correlation in spring (0,33).

Seasonal Total precipitation-NAO correlation coefficient

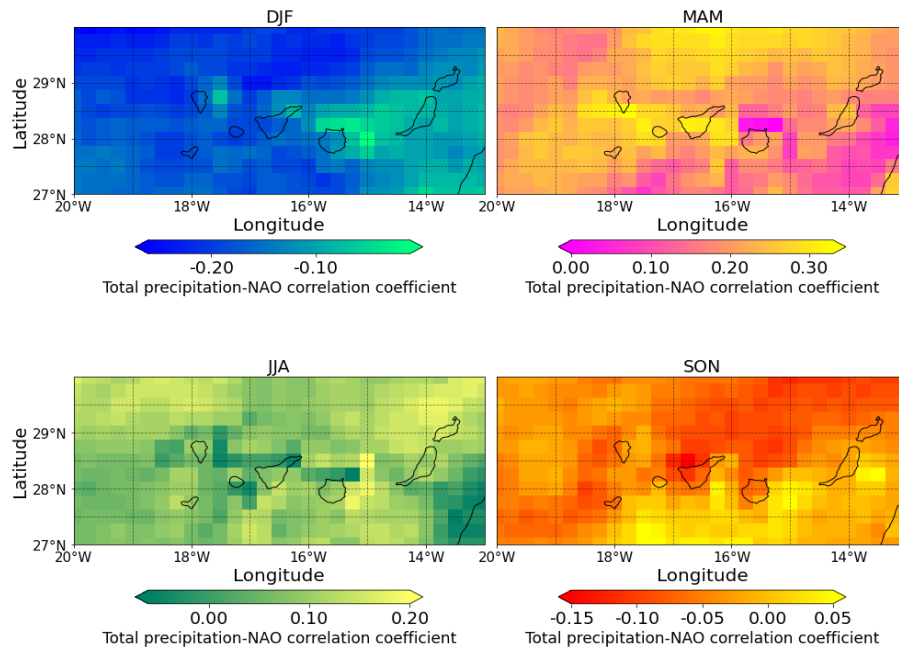


Figure 15. Seasonal Total precipitation-NAO Spearman correlation coefficient map.

To analyse if the variability of an atmospheric circulation index has a delayed effect on the CAPE or the TP variability (i.e., if it exists a “leader-follower” modulation), a cross-correlation was applied between these parameters. The cross-correlation is based on the calculation of the correlation between two time series, so one of them (follower) has a certain lag (max. 1 year in our study) with the other time series (leader). When calculating the cross-correlations, the “leader” variable has been established following the hypotheses that we found to be the most reasonable from a physical point of view. In the statistical package that we have used the leader is the series placed in second position. We want to mention that we are adjusting for the lag, so the denominators are divided by number of points minus the lag, instead by dividing just by the number of points. We want to state the known fact that correlation not necessarily implies causality.

No significant cross-correlations were found between CAPE and TP with almost all the atmospheric circulation indices. Attending CAPE, the maximum cross-

correlation coefficient was found between CAPE-TWI (Fig. 16), with 3 months of lag, which means that as TWI increases, CAPE increase three months later. Regarding TP, the maximum cross-correlation coefficient was found between TWI-TP (Fig. 17), with zero months of lag, which means that, as TWI increase, the likelihood of convective activity. This makes sense, because the strengthening of the Trade Winds decreases the likelihood of a convective environment developing.

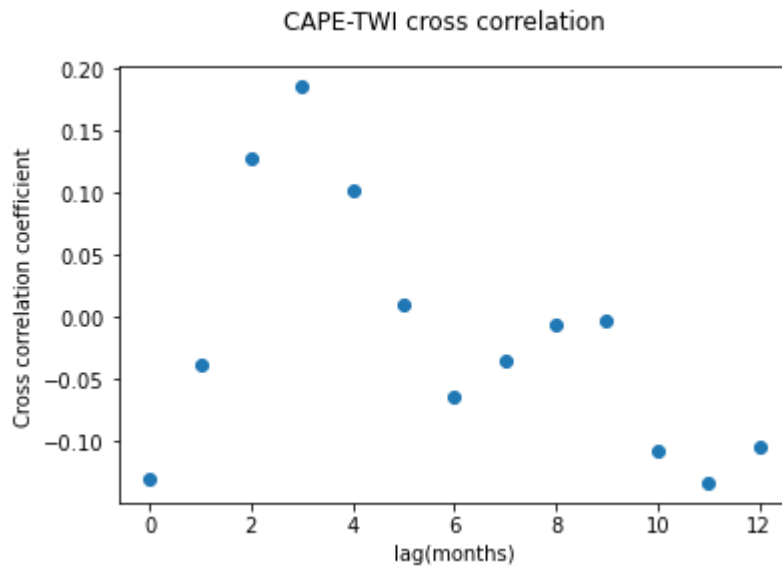


Figure 16. Cross-correlation graph between TWI-CAPE.

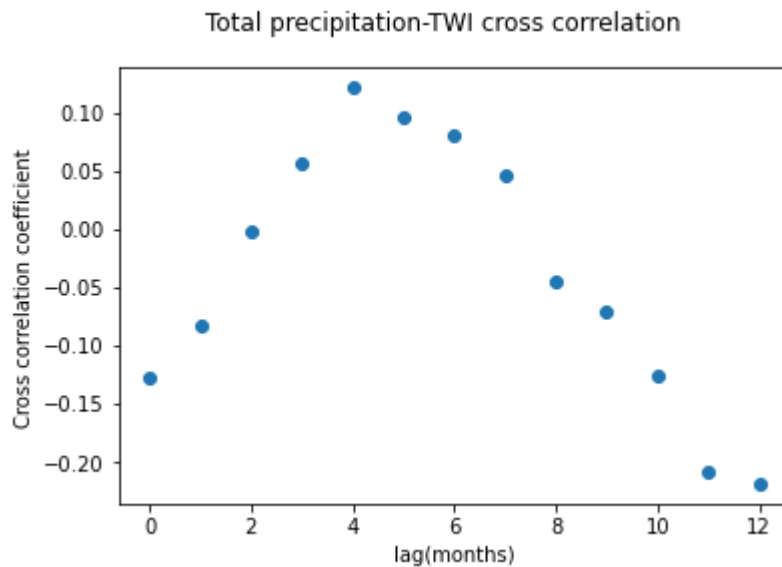


Figure 17. Cross-correlation graph between TWI-Total precipitation.

To understand the modulation of SST on the CAPE and TP variables, a cross-correlation between these variables has also been performed (Fig. 18 and Fig. 19). CAPE and SST have a positive correlation of 0,4 with no lag month, which means that as SST increases, CAPE increases simultaneously. The same is true for the TP-SST correlation at lag 0, where TP increases simultaneously with SST (0,19). The maximum correlation between TP-SST is found with 3 months of lag. This suggest that when SST increases, 3 months later TP will increase.

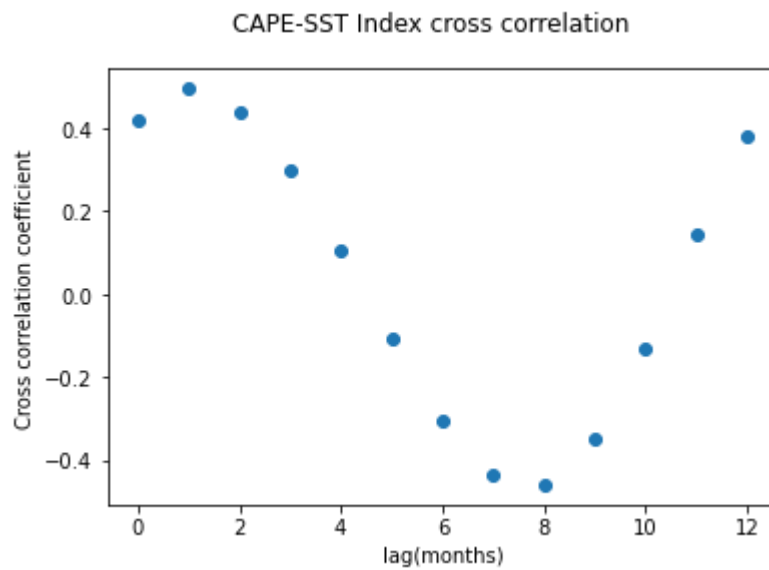


Figure 18. Cross-correlation graph between SST-CAPE.

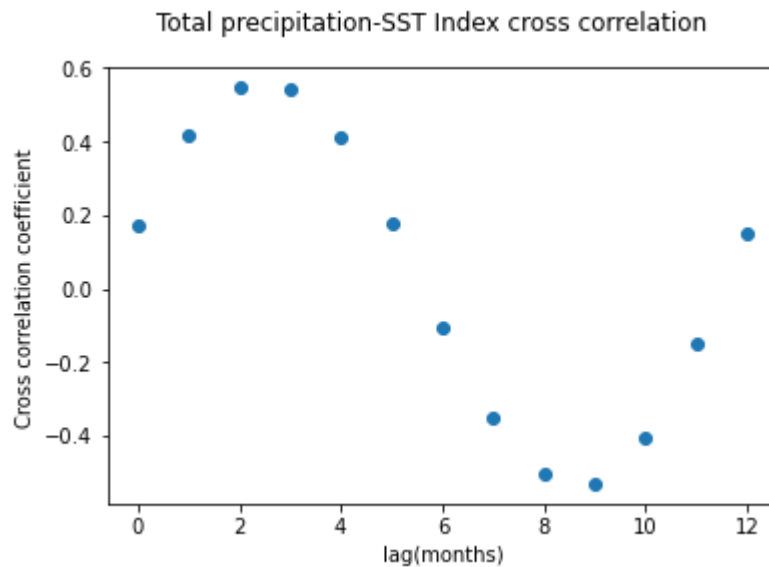


Figure 19. Cross-correlation graph between SST-Total precipitation.

3.6 Lightning data analysis

The lightning data set was computed to analyse the CAPE values on the day with the highest number of lightning events and on a day with few numbers of lightning events, from 2007 to 2021 (both included). The day with the highest number of lightning events was found on October 19, 2014; with 29.402 lightning events, and the chosen day with a few lightning events was on February 19, 2015; with 54 lightning events.

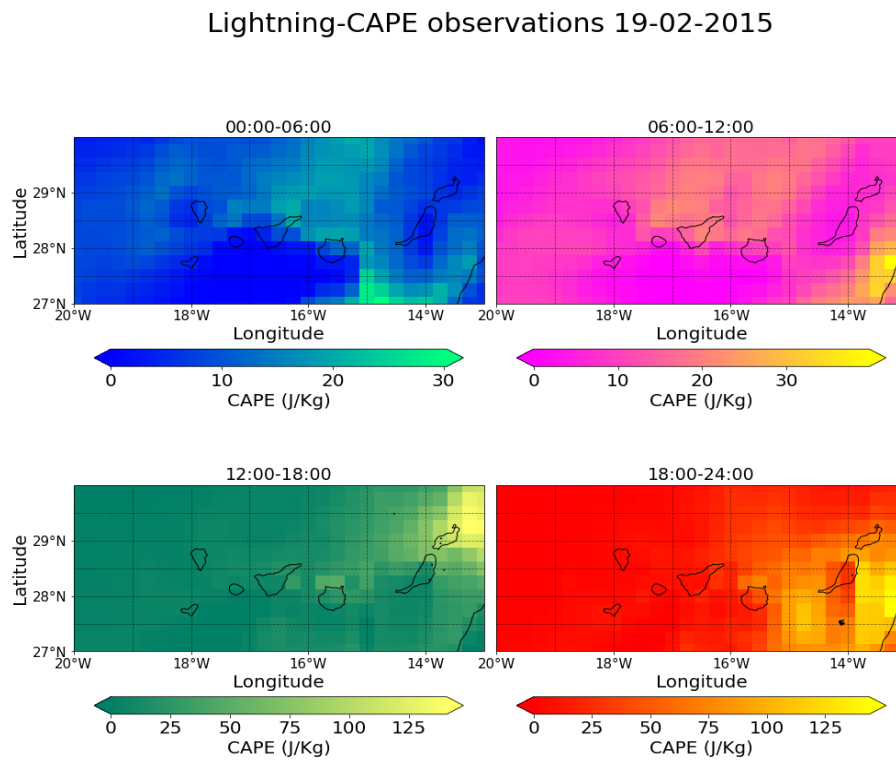


Figure 20. Lightning-CAPE observations from February 19, 2015. The observed lightning discharges are represented with dots on the grid box map.

Lightning-CAPE observations 19-10-2014

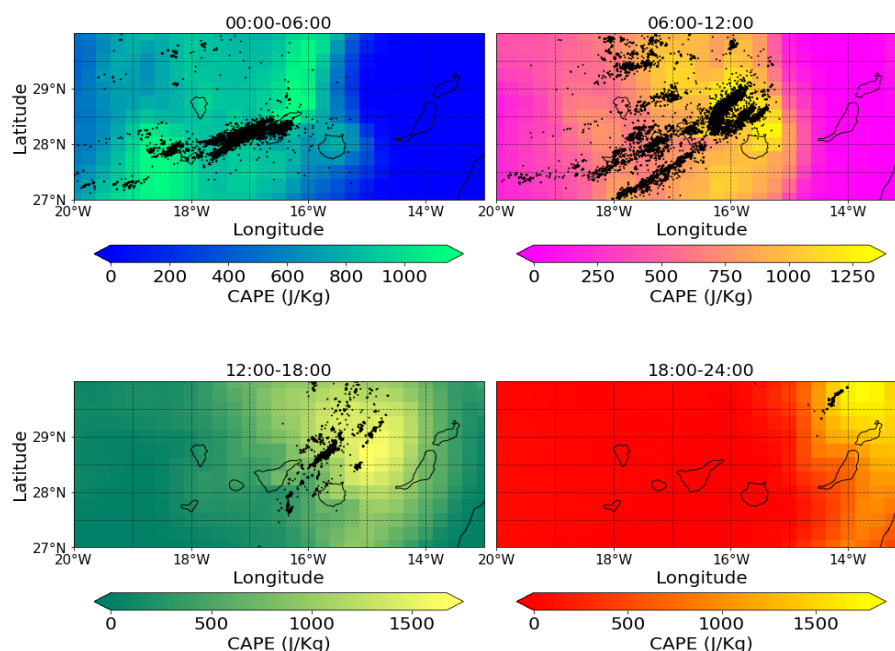


Figure 21. Lightning-CAPE observations from October 19, 2014. The observed lightning discharges are represented with dots on the grid box map.

Figure 21 shows the day with the highest number of lightning events (October 19, 2014). This day belongs to the autumn season, when the tropical disturbances affect the archipelago, and CAPE reaches the maximum values of the year. The thunderstorm direction (Southwestern to Northeastern) can also be observed at this figure. This figure shows very high values of CAPE, with maximum values of 1500 J kg^{-1} .

Figure 20 shows the chosen day with the fewest lightning events (February 19, 2015). CAPE values of this day are not as high as October 19, 2014, highlighting the importance of the CAPE values to develop a thunderstorm environment. Also, the highest CAPE values on this day, seems to have a different origin than the day with the highest number of lightning events. The disturbances of this day may be originated from the African continent.

4. Discussion

Based on the operational experience of AEMET staff and the observations, this work has shown the importance of the CAPE when interpreting the results obtained. TP can

give us an approximate idea of the characteristics of a storm in the Canary Islands, but it does not describe it perfectly. The results suggest that local factors, as orography, play an important role on the extreme precipitation and storm events (García-Herrera et al., 2003).

When analysing the seasonal variability, CAPE shows maximum values of the year in autumn, due to the TW intensity decreasing in this season, and coinciding with the highest SST values. Cross-correlation between CAPE and SST shows a simultaneously modulation between them. TP doesn't seem to have a clear seasonal variability.

The results of the diurnal variability of the CAPE values, doesn't suggest that there are any significant differences between these values in the diurnal cycle.

The STL time series analysis shows an interesting behaviour in the seasonality component of the CAPE series, which seems to follow a sinusoidal behaviour that affects especially in autumn and dampens over the period. The hypothesis is that one or both synoptic causes are the origin, perhaps tropical interactions, or complex behaviour between the indices shown and other indices. We also think that the local factors have an important influence in modulating thunderstorm events.

When working with monthly CAPE averages, no value exceeds the 350 J/Kg, which agrees with the results obtained by Suárez Molina et al. (2020), who establish CAPE values were below 1000 J kg^{-1} in more than 75 percent of the cases on the Canary Islands.

4.1 Study limitations

Throughout this study several factors have been limitations to consider in its interpretation:

- 1) First, the principal parameters in this paper (CAPE and TP) don't have a normal distribution in the datasets. To find out if the lack of normality in its distributions is extreme, kurtosis and skewness tests have been performed on the CAPE and TP variables. The two variables (CAPE and TP) have an extreme lack of normality.

- 2) The second limitation is also related with the dataset's distribution. As the variables have a lack of normality in their dataset distribution, working with monthly means limits the representability of the results, more than if the study is centred on concrete thunderstorm events. Due to the dataset dimension (42 years), working with monthly means was necessary.
- 3) It is important to know which parcel is more representative for the convective potential analysis (Craven et al., 2002). This parameter can be calculated as SBCAPE (Surface Based CAPE), MLCAPE (Mixed Layer CAPE) and MUCAPE (Most Unstable CAPE). The mean-layer parcel is likely more representative of the actual parcel associated with convective development (Craven et al., 2002). ERA-5 ECMWF reanalysis documentation calculate CAPE by considering parcels of air departing at different model levels below the 350 hPa level, which doesn't distinguish between the different CAPE categories mentioned above (SBCAPE, ML CAPE, MUCAPE). It is worth mentioning that high CAPE values have been reported as a known issue of ERA5 for some occasions; how much this can affect to our area is not known, but we conjecture that it is probably not very relevant⁴.
- 4) Another limitation is the ERA5 atmospheric reanalysis spatial resolution. Data has been regridded from a latitude-longitude grid of 0,31 to 0,25 degrees between each grid point. When analysing with this spatial resolution in the Canary Islands, where the convective environments are strongly affected by the orography, microscale effects are not appreciable (Fig. 22).

⁴ <https://confluence.ecmwf.int/display/CKB/ERA5%3A+data+documentation#heading-Knownissues>

Spatial resolution example

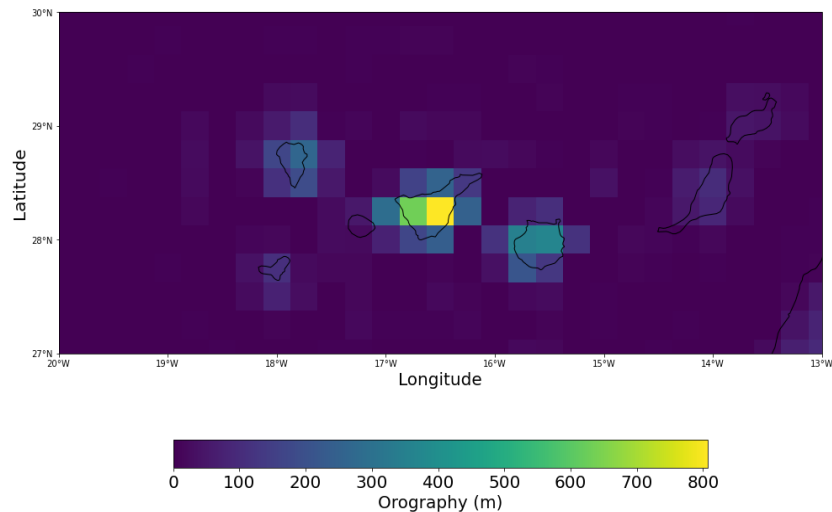


Figure 22. Orography of the Canary Islands with ERA5 atmospheric reanalysis spatial resolution.

- 5) The correlation calculations performed between climatic variables and atmospheric circulation indices don't imply causality. This means that the correlation coefficients found between the variables, besides not having great significance, do not imply a necessary causal relationship between them. Correlations could be considered spurious since they would be essentially caused by trend or autocorrelation in the time series.

5. Conclusion

The results obtained in this work by analyzing reanalysis data of some climatic variables and atmospheric circulation indices for the Canary Islands, from 1979 to 2021, are the following:

- 1) CAPE shows a seasonal variability, reaching maximum values in autumn, and minimum values in spring (Fig. 9). The minimum values in spring-summer are mostly due to the influence of the Azores anticyclone and the associated trade winds, which strengthen the subsidence inversion at these seasons. The maximum values in autumn seem to be due to the weakening of the trade winds and the consequent entry of tropical flow.

- 2) TP does not show as clear a seasonal variability (Fig. 10) as that of CAPE but seems to be more affected by local factors such as orography.
- 3) In the case of the diurnal variability study, the analyses performed suggest that CAPE does not have significant differences between its mean values throughout the day.
- 4) No significant correlations have been found between the atmospheric circulation indices and the CAPE-TP variables. Taking this into account, it seems that the strongest relationship that exists is an opposite relationship between both variables and TWI with a one-month lag, which means that as the trade winds decrease, one month later CAPE and TP increase, or vice versa.
- 5) CAPE and TP show a positive simultaneously correlation with SST. This is notable in autumn, when the SST reaches the maximum value of the year (September, October and November).
- 6) Analyzing STL decomposition of the CAPE time series, an interesting behaviour in the seasonality component was observed. This component shows a sinusoidal behaviour that affects especially in autumn and dampens over the period. We are not sure about the origin of this modulating signal.
- 7) CAPE seems to be the parameter that best describes a convective episode, but some authors state that it is necessary to choose well which CAPE category to use (Craven et al., 2002).
- 8) A clear trend in CAPE time series has not been found. So we can say that the effects of global warming on storm activity in our study area are not clear. However, this should be combined with lightning observations, but unfortunately, this time series is still too short to compare (Fig. 23).

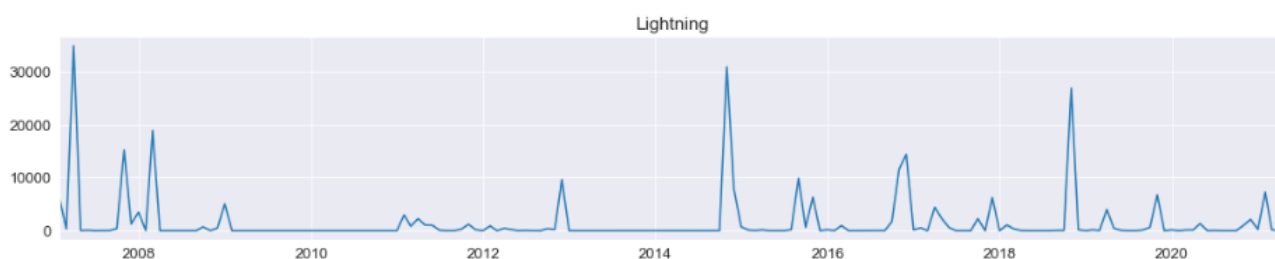


Figure 23. Lightning time series from 2007 to 2021.

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