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MARITIME, COASTAL AND MICROCONTINENTAL THUNDERSTORM ACTIVITY IN INSULAR AREAS. A GEOGRAPHYCAL ANALYSIS IN MALLORCA

Miquel Tomàs-Burguera
Miquel Grimalt Gelabert
Departamento de Ciencias de la Tierra. Universitat de les Illes Balears
miquel.tomas@gmail.com

I. INTRODUCTION

Cloud to ground lightning strikes in Mallorca and its surrounding sea are analyzed for the period 2000-2011, using AEMET (Agencia Estatal de Meteorología) data. We focus on the relationship between inland and oceanic CG lightning to compare our results with those obtained in other regions.

Global studies conclude that the most important part of the activity occurs in continental areas. Christian et al (2003) obtained a ratio 10:1 for the period 4th May 1995 - 21st March 2000. However, studies in some regions of Mediterranean Sea show a big difference with global results. Altaratz et al (2003) obtained a ratio 1.64:1 in Israel.

Temporary differences are also detected by Blakeslee et al (2012). While continental data shows an important diurnal variation with a maximum during the afternoon, oceanic data shows more regularity, with a little maximum during morning hours.

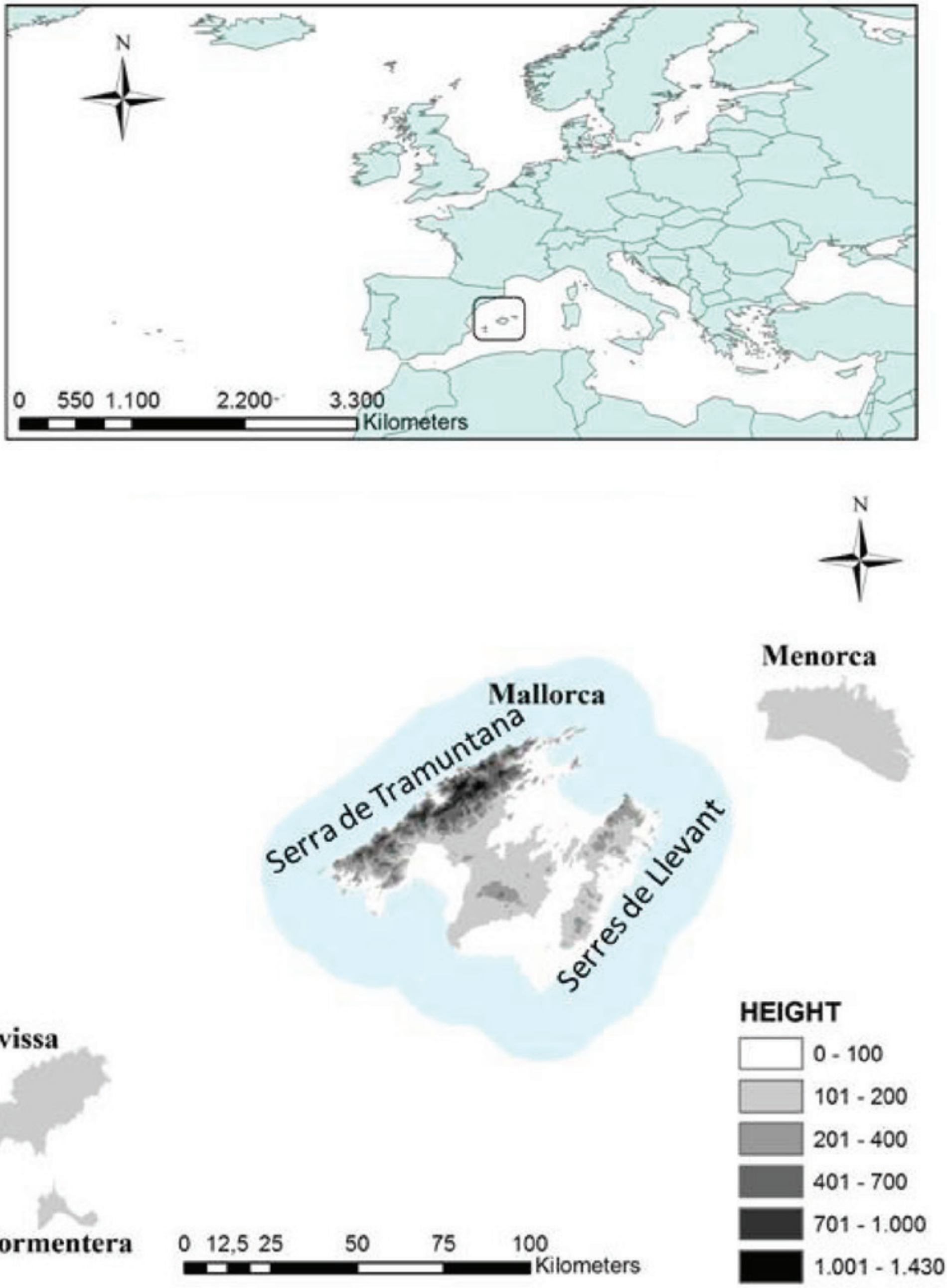
Moreover, in tropical islands, Williams and Chan (2004) detected that those islands bigger than 10^2-10^3km^2 have a lightning activity with a notorious difference between inland and ocean.

In spite of the existence of some previous papers in Mallorca and Balearic Islands (González Márquez, 1996, Guijarro y Heredia, 2004; Ruiz et al 2012) none of them calculates a ratio between inland and oceanic activity.

II. DATA AND METHODOLOGY

The study area (Figure 1) is defined by Mallorca Island and its surrounding sea. By defining a maximum distance of 20km to the shoreline to limit the maritime area we obtain two comparable regions, not for their surface area but for their maximum distance to the shore-

Figure 1
STUDY AREA



line. The total surface area is 10.652,79 km^2, 3.620,02 km^2 of inland surface and 7.032,77 km^2 of maritime surface.

The island has two principal mountain ranges (Serra de Tramuntana and Serres de Llevant), with a maximum height of 1.445m (Puig Major) in the central part of Serra de Tramuntana.

CG lightning data is obtained from AEMET lightning detection network (REDRA), which detects the location and the time of lightning strikes. In spite of starting to operate in 1992 (Perez-Puebla, 1999) only data from 2000 is used in this study, due to some important changes introduced in the network that year. According to López Diaz et al (2012), data between 2000 and 2011 is homogenous to be used in climate analysis.

In order to focus our analysis on the contrast between maritime and terrestrial CG lightning activity we establish two types of spatial divisions:

1. A simple division in two regions, maritime and terrestrial.
2. A more complex division according to the distance to the shoreline (Figure 2). We obtain 12 study regions (6 maritime and 6 terrestrial) by using as distances, 1,2,5,10 and 15km.

In the two cases we do a spatial and temporary analysis. In the terrestrial part, we also study the relation with land cover and elevation by using a 2006 Corine Land Cover shape and an Elevation Digital Model. In the temporary analysis we focus in annual, monthly and hourly data.

Figure 2
BUFFERS FROM SHORE LINE

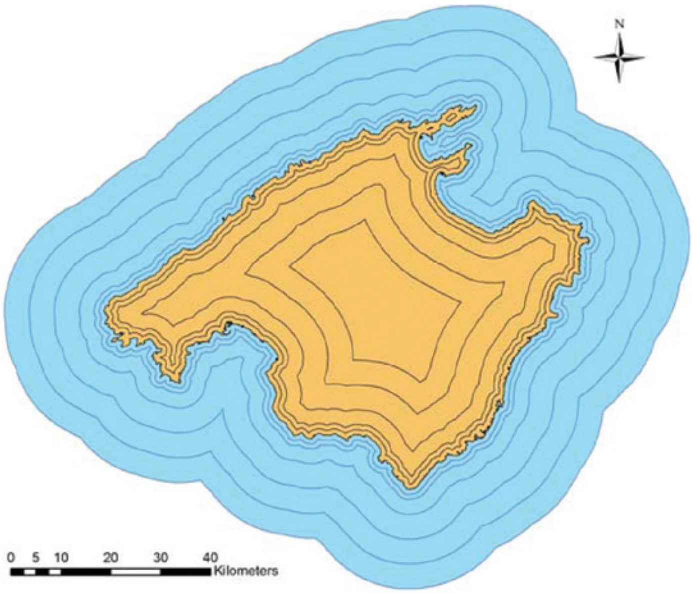
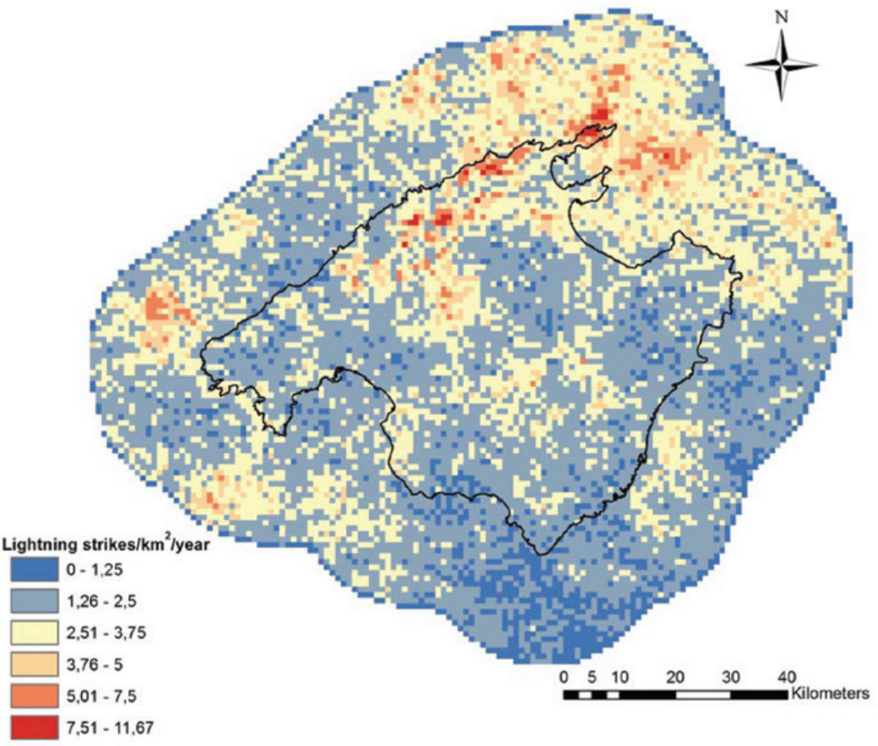


Figure 3
GEOGRAPHICAL DISTRIBUTION OF ANNUAL LIGHTNING DENSITY



Source: compiled using data from AEMET lightning detection network

III. RESULTS AND DISCUSSION

2.1. Spatial analysis

A total number of 318.763 CG lightning strikes were detected in the area (2000-2011) with 106.993 in the inland area and 211.770 in the maritime area. The number of storm days (when at least one CG lightning is detected) are 964 (21,9% over 4.383 total days), with 720 days in the inland area and 889 in the maritime area. The density is 2,49 strikes/km^2/year, being 2,46 in the inland area and 2,51 in the maritime area with an irregular distribution over the area. We obtain a terrestrial/maritime ratio of 0,98:1, far away from 10:1 obtained by Christian et al (2003) and very close to 1,64:1 obtained by Altaratz et al (2003).

The highest density is obtained in the north (Figure 3), with values near 11 strikes/km^2/year in central part of Serra de Tramuntana, where highest mountains are located. In the rest of the island values are much lower, near 2 strikes/km^2/year, except for an inner NW-SE axis with values near 4 strikes/km^2/year. This axis corresponds to an area where some storms due to a sea breeze convergence occur in the warm period of the year (Alomar, 2012; Alomar y Grimalt, 2009; Ramis, 1998).

Another maximum activity is detected in the western part of the study area, but in the martime area.

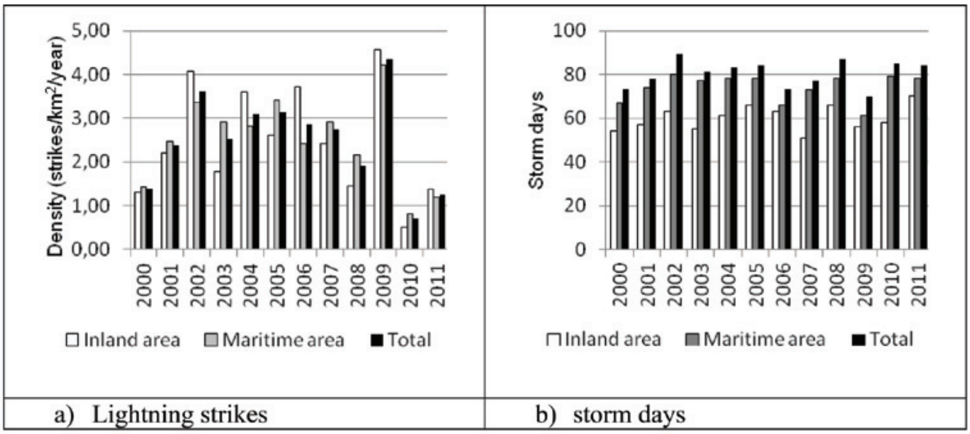
2.2. Temporary analysis

An important annual variation is detected in the total number of CG lightning strikes (Figure 4.a) with a coefficient of variation of 0,41 (medium value of 2,49 strikes/km^2/year and standard deviation of 1,04 strikes/km^2/year). Both maritime and terrestrial area show this kind of variation, and terrestrial/maritime ratio is also affected, appearing some years with higher density values in terrestrial area and another ones in maritime area.

Storm days (Figure 4.b) are more regular from one year to another, with a coefficient of variation of only 0,075 (medium value of 80,3 days/year and standard deviation of 6,08 days/year). Because maritime area is bigger than terrestrial area, storm days are always higher in maritime area.

A possible explanation is that the atmospheric conditions that storms need to develop occur in a regular way, but extreme atmospheric conditions – when a storm with a high number of CG lightning strikes occurs – appear rarely.

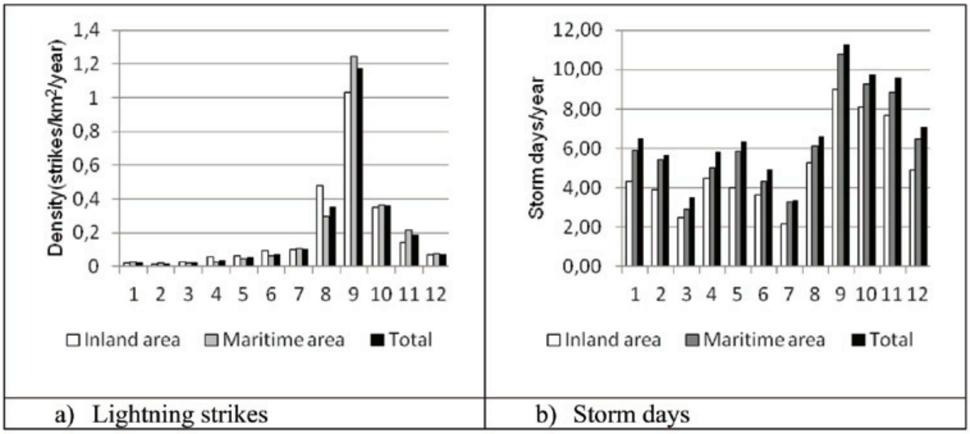
Figure 4
ANNUAL DISTRIBUTION OF LIGHTNING AND STORM DAYS



Source: compiled using data from AEMET lightning detection network

A monthly analysis (Figure 5.a) shows September as the month where most of CG lightning strikes occur, with a 41% of the total inland activity and a 50% of maritime activity. Moreover, in both areas, a 75% of the total activity occurs during the August-September-October period. Our results are similar to those obtained in previous papers in the study area (González Márquez, 1996; Guijarro y Heredia, 2004; Ruiz et al 2012) but slightly different to those obtained by Rivas Soriano et al (2005) for the Iberian Peninsula, where the maximum appears in August and September. In contrast to our study area, continental areas of northern hemisphere show the maximum activity in July and August (Christian et al 2003, Bentley and Stallins 2005).

Figure 5
MONTHLY DISTRIBUTION OF LIGHTNING AND STORM DAYS



Source: compiled using data from AEMET lightning detection network

In continental areas, maximum instability occurs during the summer – when maximum temperatures are recorded. In Mallorca maximum instability occurs during the end of warm period, when sea surface temperature (SST) reaches its highest values and some cold air advections affect Western Mediterranean.

From March to August the lightning density is higher in the inland area than in the maritime, mainly because of the most important diurnal heating of the terrestrial surface than the maritime surface, and the *embat* (sea breeze) and its convergence area in the inner part of the island that with some particular conditions brings on the development of storms.

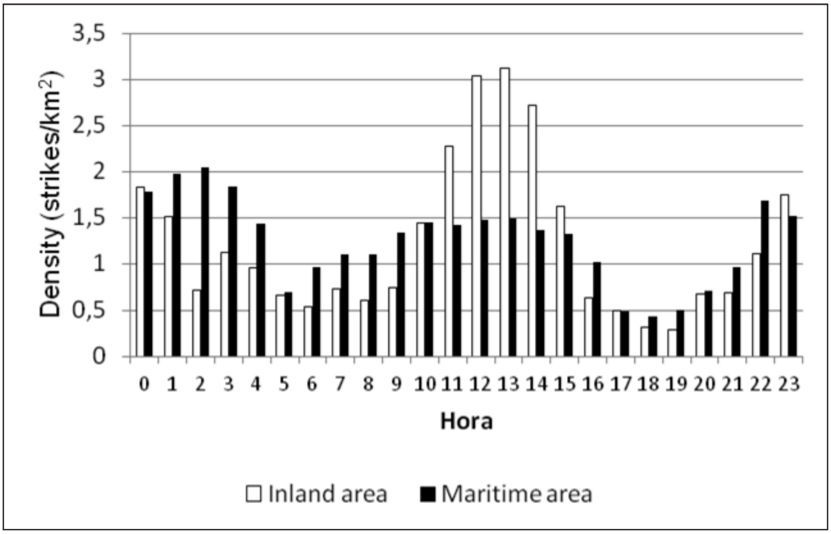
In contrast, from September to February the higher lightning density occurs in the maritime area of the study.

A diurnal oscillation is detected (Figure 6), with two maximums, one at noon (13UTC) and the other at midnight (02UTC). The first one corresponds to a high activity in inland area, and the second one to a high activity in maritime area.

Continental areas show maximum activity during afternoon, some hours later than maximum in Mallorca, when convective available potential energy is higher (William et al 2000) due to the maximum temperatures. Rivas Soriano et al (2005) in Iberian Peninsula and Seity et al (2005) in France obtained results like this.

During the warm period, temperature in Mallorca is regulated by the sea breeze, and maximum temperatures appear earlier than in continental areas, mainly during noon (Alomar, 2012). Therefore, it is at noon when more energy is available to the development of

Figure 6
HOURLY DISTRIBUTION OF LIGHTNING STRIKES



Source: compiled using data from AEMET lightning detection network

storms. Moreover, sea breeze in Mallorca is characterized by the occurrence of some convergence areas that bring on storm development (Alomar, 2012; Alomar and Grimalt, 2009, Ramis, 1998). Those factors explain the earlier apparition of storms in Mallorca than in continental regions.

At night, maritime activity is more important than inland activity, as the higher instability occurs on the sea because of its higher temperature.

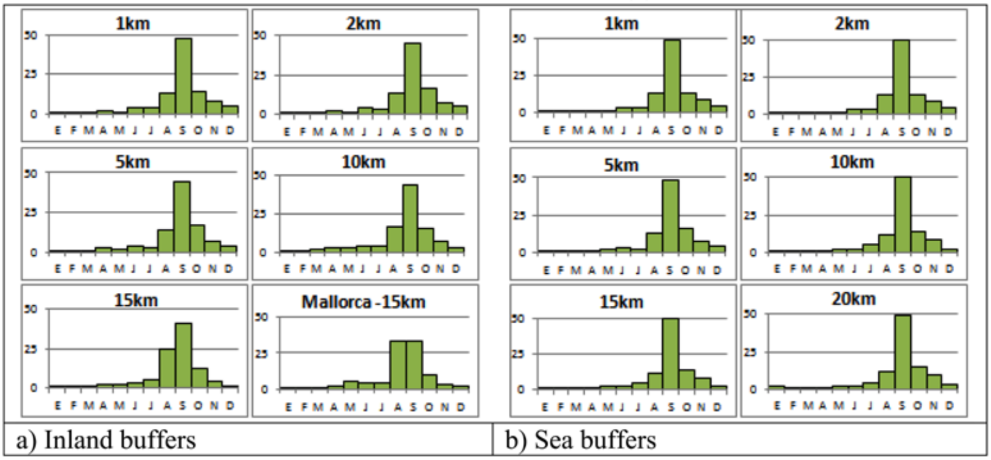
3.3. Geographycal analysis

3.3.1. The distance to the shoreline

A monthly analysis in our proposal of division shows an important variation in August and September activity, mainly in terrestrial area (Figure 7). August percentage of activity tends to grow as we move to the inner part of Mallorca and September percentage tends to decrease. When we analyze the innermost region - where the distance to the shoreline is higher than 15km – August, with 33,1%, accumulates a more important number of CG lightning than September 32,7%.

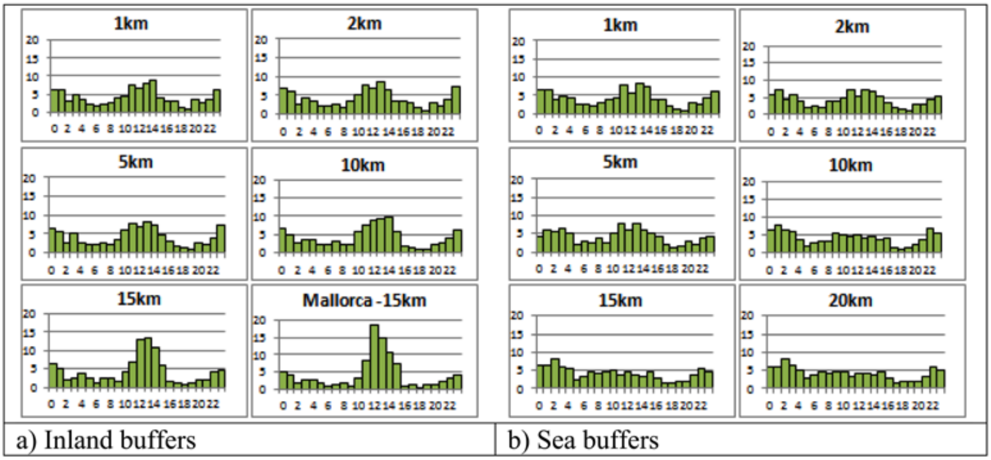
An hourly analysis (Figure 8) shows an important increase of diurnal activity as we move to the inner part of Mallorca, reaching a peak of 56% of the total activity for the 10UTC-14UTC period in the innermost region. At the same time, nocturnal activity tends to decrease. As we go into the maritime area, nocturnal activity tends to grow and diurnal activity tends to decrease

Figure 7
MONTHLY DISTRIBUTION OF LIGHTNING STROKES IN BUFFERS OF INLAND AREA (a) AND SEA AREA (b)



Source: compiled using data from AEMET lightning detection network

Figure 8
HOURLY DISTRIBUTION OF LIGHTNING STROKES IN BUFFERS OF INLAND AREA (a) AND SEA AREA (b)



Source: compiled using data from AEMET lightning detection network

3.3.2. Topography

Some authors have detected an important relation between CG lightning and topography. Pinz et al (2011) concluded that maximum CG lightning activity in an Austrobavarian region occurs at 1800msnm.

In Mallorca this relation has also been detected (Table 1), with a maximum activity above 1000m, where the mean activity increases until 7,87 strikes/km^2/year. An important growth in the phenomenon is detected above 500m.

While north and central part of Serra de Tramuntana shows a maximum activity, Serres de Llevant do not appear as a maximum activity region, probably due to the fact that only some elevations are slightly higher than 500m.

Table 1
LIGHTNING STRIKES DISTRIBUTION DEPENDING ON THE HEIGHT (M)

Height (m)	Lightning strikes/km^2/year
0-100	2,18
100-200	2,41
200-500	2,75
500-1000	3,93
>1000	7,87
Average	2,46

Source: compiled using data from AEMET lightning detection network

IV. CONCLUSIONS

There's an important latitudinal effect in CG lightning number in Mallorca and its surrounding sea, with a maximum at north, decreasing rapidly while we move to the south. Probably because some cold air advections and fronts only affect the north of our study area.

According to hourly analysis we propose a zoning of our study area:

1. Diurnal activity area: The inner part of Mallorca where the distance to the shoreline is higher than 10km. More than 40% of total activity occurs during 10-14UTC period. Moreover, a change in monthly pattern is detected, with an important increase of August activity, at the same time as September activity decreases.
2. Nocturnal activity area: The maritime area where the distance to the shoreline is higher than 10km. More than 30% of total activity occurs during 00-04UTC period.
3. Transition area: The rest of the study area, where two slight maximum are detected.

Although we detect an important increase in diurnal activity in the innermost part of Mallorca, this cannot be understood as microcontinentality because:

1. Maximum hourly activity occurs during noon hours, not during afternoon as in continental regions
2. Negligible activity during June and July, when in continental areas most of the activity occurs.
3. Sea breeze effect instead of heating effect.