Response to comments by reviewer 2 on the manuscript
10.5194/egusphere-2024-704

The World Wide Lightning Location Network (WWLLN) over Spain

First of all, the authors would like to than the reviewer for his valuable comments, which will help us in improving the quality of the manuscript. We include below a detailed response to the Reviewer's comments. We hope you find this response satisfactory.

We would like to note that, according to the Editor's instructions, the revised manuscript must not be prepared at this stage, so specific changes in the paper and final figures are still pending of the Editor's decision about the further handling of the manuscript.

Reviewer's General Comments. *The finding of an unusual unexplained high DE of 38% around Spain may indicate an error. Adding to the puzzle, the DE in sub-regions, Fig 2 green and cyan boxes, was smaller. That requires an even higher DE outside the green and cyan boxes to give an average DE over the full region of 38%. Unfortunately, it is not convenient to check the analysis through independent calculations. Perhaps AEMET data had been over-filtered to eliminate weaker CG strokes. Figure 7 is helpful to address this, although there is not enough information about filtering to eliminate this possibility. There may be a problem with how DE is calculated (see comments about section 4).*

A number of minor errors should be corrected. Several questions popped up, some due to incomplete descriptions, some of which may suggest modifications that would improve the paper, and other questions may be outside the scope of this work. When this review was written, no other comments about this manuscript had been viewed; these comments were independently produced.

Response. As regards the first paragraph, the reviewer is right in noting the high value of the DE obtained and the strange average value which suggest that other subregions must have even higher values for DE. He is also right in noting the existence of a problem with the way we have calculated DE. As he points in comments to Section 4, there was an error on the original manuscript, since we identified which strokes detected by WWLLN were also detected by the reference agency, AEMET. The correct way was to find which AEMET strokes were also detected by WWLLN. We thank the reviewer for noting this error which may lead to an overestimate in the DE.

The DE calculation has been corrected on the revised manuscript, as well as the corresponding sentences throughout the paper and affected figures which have been modified accordingly. The correction causes an average value reduction from 38% to 29% for the whole region of Spain. As regards the two reduced regions presented in section 4.2 of the original manuscript, the DE reduces from 14.5% to 13% for the Spanish Plateau and from 25% to 22% for the Mediterranean Spanish coast at Valencia.

The reviewer also notes that the surprising high DE global value for Spain indicates that there are regions where the DE must be even higher. In this sense, the revised manuscript will include two new regions with usually high intensity storms. The subregions will be indicated by slightly modifying figure 2 as shown below. The first region (with magenta color in the figure below) corresponds to a region including Canary Islands and the West African Atlantic coast covered by AEMET between [27°N, 37°N]x[20W°, 5°W], while the second one corresponds to the Alborán Sea, [35°N, 37°N]x[5W°, 0°W], at the South Mediterranean coast of Spain (with dark blue color in the figure below). The first region includes a transition between the Atlantic Ocean, while the second one is a transition between land areas and a small sea, the Mediterranean Sea, including the Straits of Gibraltar, a region with frequent strong marine currents. The DE obtained for these regions is 49% and 53%, respectively, which justify the high average new value for Spain of 29%.

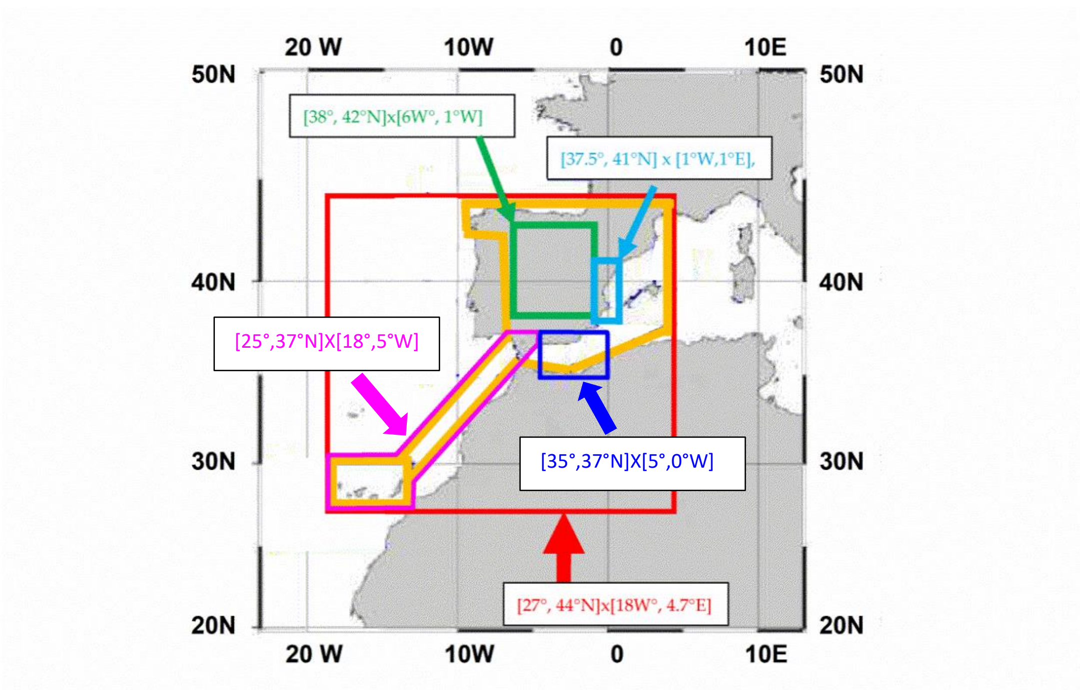
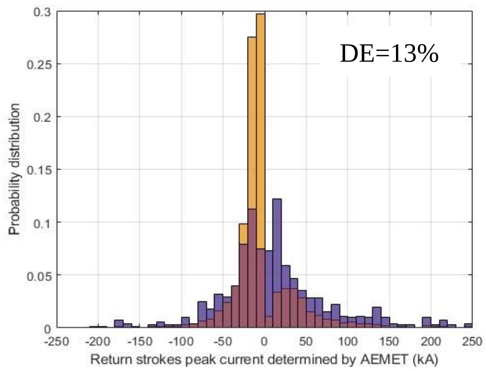
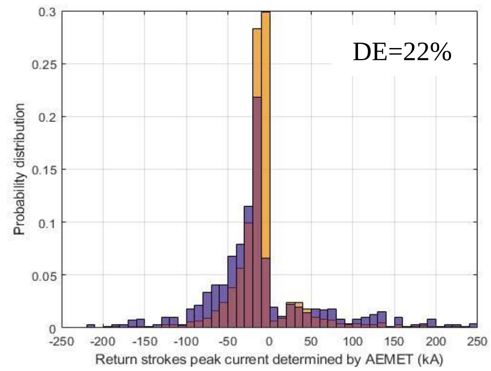


Figure 2. Different areas for the studies presented in this work.

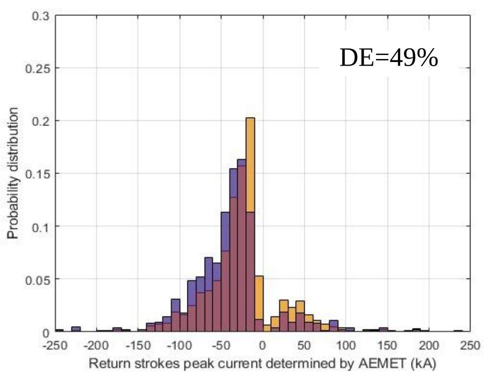
According to figure 8 in the original paper showing the DE for different peak amplitudes, the DE value considerably increases with high energy strokes. In this sense, as kindly suggested by the reviewer and in order to try to explain the origin of the differences in the DE for the different subregions considered, the peak distribution of lightning strokes for each subregion has been calculated for this revised manuscript (similar to figure 7 but limited to the four subregions). The resulting figures are shown below.



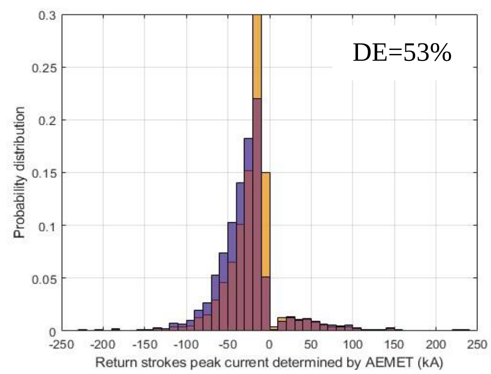
a)



b)



c)



d)

Figure caption: (new figure 10) Distribution of AEMET return strokes also detected by the WWLLN, in blue color, and total AEMET return strokes, in orange color for different subregions: a) Spanish Plateau, b) East Spanish Mediterranean coast, c) West African Atlantic coast, and d) South Spanish Mediterranean coast.

It can be appreciated from them that the continental area at the Spanish Plateau presents an important distribution of lightning strokes at low energies, while the presence of high energy strokes increases in the other three areas containing land-sea transitions in the following order: East Spanish Mediterranean coast, West Atlantic region, and South Spanish Mediterranean coasts. This, combined with the results shown in Figure 8 in the original manuscript, seems to indicate that the DE is higher in land sea transitions influenced by a different energy distribution towards higher peak currents in the storms for those areas.

The revised manuscript will include the study for the two new subregions in section 4.2, the peak current distribution figure shown above will be included and a discussion on the possible link between this energy distribution and the DE values will be addressed.

Reviewer's Specific Comments

Abstract *First sentence is good, but the following text has too much detail for an abstract. Consider deleting sentences after the first down into line 22. Then resume with: This study finds the detection efficiency of WWLLN is around 38% . . . and continue with the remaining text in the abstract.*

Response

The paragraph will be reduced and reorganized to eliminate the excessive details but still providing a brief introduction of the WWLLN to researchers non-directly concerned with this global network.

Tables

Caption on Table 1 declares a date range 2004–2022. However, datasets in the table are from 2003–2015, while publication references are from 2004–2018.

Table 1 has some historical interest, but could be shorter. Much of the contents is not relevant to WWLLN in 2012 or in the 2020s, because algorithms and network station distribution have changed greatly.

Response

The caption has been corrected. As regards the reduction of contents, we think that the items included not only describes the historical evolution of the network performances, showing the differences in the working parameters and resulting DE for different studies, but also facilitates the understanding of the paragraphs describing the WWLLN feature evolution since its initial times (lines 160 and following in the original manuscript).

In this sense and pointing to the interest in including summarizing details in the table, Reviewer 1, in one of his comments, makes reference to a detail in the text that is not in the Table (*L190: "...the best data recorded by WWLLN so far was a DE of 31%...". This value is not even in your Table 1*). It seems that summarizing capability of this table advises maintaining information even when it could be considered as non-relevant for highly specialized readers.

Figures

Figure 2: *Text near line 565 describes the cyan region of Figure 2 as the boundary for study, but Figures 10–12 show strokes outside the Figure 2 region. Is the text wrong? Or do Figures 10–12 show strokes not considered in the analysis?*

Response. The reviewer is right. The region only approximately corresponds to the cyan region of the study un section 4.2. It has been chosen to match the areas covered by the maps provided by AEMET. The text will be changed accordingly and the areas of the original figures 10b, 11b, and 11c will be adjusted to match the regions of AEMET shown in figures 10a, 11a, and 12a, respectively.

Figure 5A: *horizontal axis label is wrong. West should be negative, but the label has west is positive.*

Response. Thank you for noting the mistake. The figure caption will be corrected.

Figure 8: *shows a point above DE=1. Isn't that impossible? The method for calculating uncertainties cannot be correct, for an uncertainty bar extending above DE=1 is wrong. The smoothed blue line is difficult to see behind the red circles. If the blue line were plotted on top of the circles, both would be visible.*

Response:

As regards the point above DE=1, it was due to the mistake in calculating the DE the reviewer mentions in section 4, which provides an overestimate of the DE. This calculation has been corrected and the DE values are now below 1 as expected.

As regards uncertainties, the values above DE=1 result from direct statistical operations using the set of available data, which may lead to unphysical solutions. Of course, these statistical operations must be completed with the condition that DE is lower or equal than unity. In the figure of the revised manuscript, the vertical axis has been redefined to avoid unphysical solutions and the blue line has been plotted on top of the circles to better appreciate it.

Reviewer's Comments on Section 1, Introduction

Comment: *lines 69–75: The method for calculating DE seems to be incorrect (see comments for Section 4).*

A CG stroke is not a vertical column above a point on Earth's surface. The path of a stroke often has a large horizontal displacement. Given this behavior of strokes, what is meant by stroke location? For a VLF stroke detection, this is an effective point for the transmitting antenna location. That point is unlikely to be the stroke contact point on the ground, and it is unlikely to be the effective location of an LF transmitting antenna. Stroke location is *expected to be slightly different for different kinds of instruments and it is not defined or meaningful below some distance scale. These considerations mean that one must be careful in finding meaning in stroke accuracy, at small value, from different instruments.*

Response. As we mention above, the DE calculation has been corrected in the sense indicated by the reviewer's comments on section 4 and all related text, figures, tables…, have been modified accordingly.

As regards the care that must be taken when talking about location accuracy of a lightning stroke, a sentence clarifying the difficulty in defining the lightning location will be included in section II after line 117 in the original manuscript, where lightning location is described. The paragraph will read as follows:

> "… is simultaneously detected by a minimum of 5 stations. In addition to the above-mentioned difficulties, it is worth noting that care must be taken when interpreting data of lightning location below some length scale. This is so because the distance determined by WWLLN corresponds to an equivalent VLF antenna transmitting from an effective point, but the actual lightning stroke path is not usually a vertical path, thus the distance detected will not exactly coincide with the stroke contact point on the ground. The meaning of this approximate distance is even more approximate because of the comparison with independent AEMET results, obtained with LF technology, where characteristic distances differ from those of WWLLN."

Reviewer's comments on Section 2, WWLLN

Comment: *Lines 91–93, 119–120: Fig 2 of 10.1029/2020GL091366 (Lightning in the Arctic) shows the history of the count of active WWLLN stations. The number of active stations is the important number for network performance, and is always less than the number of stations. Some stations are offline at any time due to network, power, or other technical issues.*

Response: The sentence at line 91-93 in the original manuscript will be modified mentioning the active stations and a reference to *10.1029/2020GL091366* will be added in the following terms:

> "The distribution of associated active stations around the whole Earth, slightly above 60 stations since 2014 (Holzworth et al., 2021), makes the WWLLN achieve global location of lightning strokes at a planetary scale with a constantly improved accuracy…"

The sentence in line 119-120 will be modified in similar terms:

> "The number of active stations increased until an almost stable number around 60 active stations since 2014, approximately."

Comment: *Lines 120–126: For a recent comparison over time, WWLLN detection efficiency compared to New Zealand lightning network is shown in Fig 1 of 10.1029/2019JD030975 (Global Distribution of Superbolts).*

Response: The paragraph beginning in line 119 will include a sentence with the recent comparison for New Zealand and the corresponding reference. The paragraph will read as follows:

> "The WWLLN had 40 receiving sensors in 2010, providing a DE~11% in 2010 for peak currents greater than 20 kA (Abreu et al., 2010) and a LA of around 5 km. A recent comparison over time of the WWLLN detection efficiency for different peak currents can be found in (Holzworth et al., 2019) for the New Zealand area…."

Comment: *Here and elsewhere (lines 416–418, 671–673), is the idea that a higher density of nearby stations might cause DE to be higher. Even assuming station density is high and that DE is high, there is no analysis in the paper showing a cause-effect relation. The link between WWLLN station density around Spain and the apparently higher DE is purely speculation in this paper, and that should be made clear wherever this possible link is mentioned.*

Many stations nearby is offered as a possible explanation for the high DE around Spain. However, there are other considerations for stations near a storm that work against this explanation: (1) close strokes can saturate the receiver, distorting the waveforms; (2) close strokes have less frequency dispersion, making it harder to extract the time of group arrival; (3) when several nearby stations see a distant stroke, much of the information is redundant; (4) nearby strokes have more high frequency content that is noise in the VLF analysis—these high frequencies decay quickly with distance. In the stroke location algorithm, stations closer than 300 km to a stroke are not used.

Response: The reviewer is right. The nearest stations are probably saturated when high energetic events happen (maybe this is not the case for the low intensity case, but the reviewer is right noting that the sentence was speculative). In addition, since we have no way of proving the link between the higher density of stations in Spain and the high results for DE, we will eliminate those unproved ideas from the paper.

Comment: *lines 136–145: Some details in the list are wrong. No power or peak current estimates are produced in the WWLLN stroke analysis. Instead, stroke VLF (5–18 kHz) energy and uncertainties, in Joules, are output. Stations used for energy calculation are restricted to be in the range 1000–8000 km from the located stroke.*

Response:

Dear reviewer you are right. The readme.txt file gives the format of files:

%The format for the APP files is:

%YYYY/MM/DD, hh:mm:ss, lat, long, uncertainty (μs), nstn, power (kW), power,… uncertainty (kW), nstn_power.

No power or peak currents are estimated, instead power in kW and power uncertainty in kW are given. This will be corrected in lines 136-145.

Comment: *Lines 157–158: Only stroke VLF energy is provided by WWLLN. An approximate linear relation between stroke VLF energy and peak current is sometimes used to estimate peak current. Of course, once a WWLLN stroke is matched to an AEMET stroke, peak current is available from the AEMET data.*

Response: Thank you for noting the error. The revised manuscript will eliminate the sentence from lines 157-158 and a sentence will be added at line 474 from the original manuscript to clarify that the peak current of the WWLLN strokes are those corresponding to the matched AEMET strokes. The paragraph will read as follows:

> "… strokes in the AEMET data, a 16.8% of the detected CG strokes. As regards the WWLLN, the peak current is not provided by this network, thus, each detected stroke is assigned the peak current corresponding to the matched AEMET stroke. The same ratio is preserved for …."

Comment: *lines 167–168: (DE and LA) must be considered as global value, since they correspond to the detected lightning strokes, independently of their current peak amplitude. If I understand what this sentence should mean, global is a confusing word to use here. Possible rewording: (DE and LA) values were calculated from all the matched lightning strokes, independently of their peak current.*

Response: This comment is also made by the first reviewer. We agree that WWLLN is a global network and the term global for DE may not be appropriate. We have changed "global" by "total detection values", and slightly modified the sentence in the following terms:

> "It is worth noting that these two quantities must be considered as total detection values, i.e., they correspond to the detected lightning strokes, independently of their current peak amplitude. More detailed information on the DE values for specific current peak amplitudes can be found in the works referenced in Table 1"

Comment: *line 185: DE in the early days of WWLLN was about 1%, but DE at these early times in the development of the network are not relevant for this study (2012 and 2020–*

2022). For 2012, WWLLN global DE was probably above 10%. For 2012, the median number of active stations on any day was 55. The total number of stations, 69, is a less useful number.

Response: We think that the historical review of WWLLN state of development and performances may be useful for interested readers, but the reviewer is right in noting that this low value corresponds to the early stage of WWLLN and that it soon improved the value above 10% around 2012. The sentences will be modified throughout the text to clarify his point.

Reviewer's comments on Section 3, AEMET

Comment: *line 294: Are AEMET stroke times rounded to the nearest second or truncated to the second? For instance, if a stroke was originally time-stamped at 01:23:45.678901 at microsecond accuracy, is that stroke's AEMET time published as 01:23:45 or 01:23:46? The method used affects DE.*

Response: We have no information on that aspect.

Comment: *lines 299–301: The description for how AEMET IC and CG strokes were separated is incomplete. How exactly was this done? How sensitive are DE calculations to the criteria used to separate strokes types?*

Response: Dear reviewer in lines 301-311 we give references where this issue is addressed. The reader can go further reading these references. We assume that AEMET data is CG. This was explained also to reviewer 1. The WWLLN data include both IC and CG. From our knowledge there is a ratio IC/CG that is obtained doing special surveys using videos of the storms.

Reviewer's comments on Section 4, WWLLN performance in Spain

Comment: *lines 406–411: The calculation of WWLLN DE relative to AEMET appears to be incorrect, in a way that over-estimates DE. The correct DE calculation is to count the number of AEMET strokes that match a WWLLN stroke, then divide by the total number of AEMET strokes. This ratio is the fraction of AEMET strokes also detected by WWLLN—a detection efficiency. The method in the manuscript finds the number of WWLLN strokes that match an AEMET stroke, then divides that by the total number of AEMET strokes. It is a ratio of WWLLN strokes to AEMET strokes, and is not a detection efficiency. It over-estimates DE because it is possible for several WWLLN strokes to match with one AEMET stroke, especially within a 1 second matching time window. Because WWLLN cannot* *detect the same AEMET stroke more than once, the numerator of the ratio becomes larger than it should be, and DE is over-estimated.*

Response: Thank you for noting this error. As we mention in our previous response to your general comments, the DE has been recalculated in the correct way you indicate: finding which AEMET strokes were also detected by WWLLN.

The following table shows the result obtained for Spain and four the subregions: the Spanish Plateau, the West Mediterranean coast, and the two new subregions considered, namely, the South Mediterranean coasts and West Atlantic region. The table shows the values obtained with the original method (incorrect) and the corrected one. The revised manuscript will include the correct values of the five regions in a new corrected Table 2 and throughout the text.

Table 2 for the revised manuscript

	DE (%) in the original manuscript	DE after correction (%)	Latitud/Longitude limits
Spain	38	29	[27ºN, 44ºN]/[18ºW,4.7ºE]
Spanish Plateau	14.5	13	[38ºN, 42ºN]/[6ºW,1ºW]
East Mediterranean coast	25	22	[37.5ºN, 41ºN]/[1ºW,1ºE]
West Atlantic region	67	49	[27ºN, 37ºN]/[18ºW,5ºW]
South Mediterranean coast (Alborán Sea)	79	53	[35ºN, 37ºN]/[5ºW,0ºW]

Comment: *lines 420–423: Although there is a resemblance, this is not a Rayleigh distribution. The tail is too heavy; Rayleigh falls fast, as exp(−x2). This distribution is also too narrow around its median value. Graphing a few Rayleigh distributions and comparing with the histogram shows this easily. Statistical methods, such as χ2 goodness-of-fit, would confirm this numerically.*

Response. The resemblance is only qualitative and does not introduce valuable information, therefore the following sentence will be removed:

> "It resembles a clear Rayleigh distribution, a distribution typical for nonnegative-valued random variables. This distribution is often observed when the over-all

magnitude values are related to two independent components. This is our case, where the location error depends on two parameters, latitude and longitude”

Comment*: lines 549–553: The claim of DE/LA differences in the two geographic regions seems plausible, but there is no evidence or a clear line of reasoning that explains how geography relates to DE/LA differences. For example, a study of the WWLLN stroke energies or the AEMET peak currents in the two regions could explore whether different stroke energy distributions explain the DE differences. The assertion that there are more intense atmospheric phenomena occurring in this region should have a reference. There is only speculation here, with the goal stated in the abstract, lines 25–26, not being met.*

Response: The reviewer is right in noting the speculative nature of our statement. It is based on our particular knowledge of differences in storms in Spain, the origin of the authors, but this is not a proper reference to support such a statement. The reviewer wisely proposes a study of stroke energy distribution for each region. As we mention when answering the general reviewer’s comments, we have done this study. A new figure 10 (see page 3 of this response) will be included and discussed. It can be seen from this figure a difference in the energy distribution: regions with more energetic strokes correspond to regions with higher DE values. The new figure and the possible explanation for the differences in DE values will be included in the revised manuscript.

Section 4 Conclusions

Comment: *lines 662–663: Number of stations in 2012 compared with now: what matters is number of active stations, not number of stations. Both have grown over the years. A correct statement is that based on WWLLN growth, it is reasonable to assume that the 2012 DE is a lower bound to the present DE in Spain. However, if the AEMET network has also improved enough, then WWLLN DE relative to AEMET might even be lower now than in 2012.*

Response: Thank you for the comment. We will include a sentence after line 663 about this comment.

Comment: *line 688: How does one decide that there is good agreement between AEMET and WWLLN? This seems like a subjective evaluation, which is ok. But it should be clear this is an opinion rather than a rigorous finding*

Response: The reviewer is right, we will change the sentences to clarify that this is a qualitative comparison based on visual comparison, not an objective quantitative one.

The typos/grammar will be corrected. Thank you for letting us know.