Thank you for the comments about the paper. They have been very helpful and we think that they can be used to improve our article.

First, we will try to answer the basic questions that, as we understand it, are similar in both referees, namely, a) why we use lightning data for the rain estimates and b) how significant is the use of precipitation data collected in one point to estimate the rain in the rest of the observational area.

Second, we will answer the comments affecting the formal questions, and make some change suggestions.

Answers to the Referees' Basic questions

a) Justification of the use of lightning data to estimate rainfall

In the open discussion, several questions have been posed related with the use of lightning data to estimate precipitation:

> *- Figs. 2, 3 and 4 show poor correlations between lightning and rainfall, however, the authors still decide to go forward and use such relations in their estimates of the rainfall. What is the justification of using the lightning data in this region for the estimates, when the agreement of the basic raw data is so weak? Stronger justification needs to be given.*
>
> *- The correlation found between rainfall depth and lightning flash number, displayed in Figures 2 are weak. I think with such parameters it will be difficult to make a reasonable correlation study between rainfall and lightning flashes produced by a storm.*

In the following lines, we will try to stress the reasons of that decision, probably not clearly enough in the article.

The Basque region is a mountainous area with steeped, narrow valleys in their northern part, where the rivers flow into the Bay of Biscay. In summer, storms developed under unstable local conditions produce showers that usually occur during 1-2 hours, and the stream rise in the rivers is produced very quickly, within 1-2 hours after the observation of the rainfall. The impact of those flash floods is considerable, causing high economic losses (P6470 lines 7-8), and in some cases, also fatalities. It is important to underline that the meteorological mechanism of those hazard situations in the region is not well understood, and that this is the first study aimed to characterize them.

The observational network deployed in the area includes radar and rain gauges. As mentioned in the article (P 6470 lines 9-13), there are several problems affecting rain measurements. For example, we can point out that during summer storms there are electrical failures in the grid that affect both rain gauges and radar data. Besides, radar data do not match rain observations due to the fact that the complex topography of the area introduces ground echoes. Also, it is found that the conversion of radar signal to rainfall estimates at ground level is not free of problems because radar backscattering signals and rain intensities do not show constants relationships.

Our first approach to study the phenomenology was to find a diagnostic equation for this kind of situations by using sounding data from the nearest sounding location sited in Santander, but we had negative results. We can also note that other more general studies show the difficulties of implementing downscaling techniques in order to estimate rainfall in the area (readers can refer, for example, to A. Fernández-Ferrero, J. Sáenz; G. Ibarra-Berastegi, J. Fernández (2009). *Evaluation of statistical downscaling in short range precipitation forecasting.* Atmospheric Research, 94(3), 448-461).

As it is well known, using lightning information to estimate rainfall has been suggested by several authors. This kind of diagnosis needs the previous selection of homogeneous meteorological situations in which estimates can be carried out.

In that sense, Ezcurra et al. (2008) already defined three meteorological patterns in the region that present rainfall similar yields. In this case the rainfall yields was calculated by using 10 km radius in order to establish the lightning flash counts around every rain observatory. Among those situations, there is one defined as "local instability situations during summer", which is the one studied in our paper.

At this point, we want to explain the use of R=10 km to count the lightning flashes around rain observatories, as one of the referees suggests,

> *- At least, the authors could consider a study of sensitivity with different values of the distance around the station to count the flashes (10 km in the study).*

During the development of the work we present here, we have compared the use of two different radius to count lightning flashes, trying 5 km and 10 km. In both cases the results found were very similar. Consequently, we decided to keep 10 km., as Ezcurra et al. (2008) used in his previous study.

When following this approach, as the referees mention, we found that the correlation between rainfall depth and lighting flash number (Fig.2a) was weak. But instead of dismissing the data, we reconsidered the issue focusing on the study of the dispersion of rainfall/lightning relationships, because we believed that this dispersion could present a spatial structure, as our data seemed to point out.

That is, we studied the difference between the daily rainfall measured in every observatory and the daily rainfall expected from the lightning counts observed around. We called those differences “anomalies”. If any geographical distribution were found in those differences, we could establish a diagnostic equation for the values of daily rain measured in the area during "summer local unstable situations".

At this point it must be stressed the fact that the possible diagnostic equation we could find following this method is no longer dependent on lightning data alone. However any kind of diagnostic equation would be a very useful source of information when other data were missing.

Finally we have ended up with a first diagnosis equation that can be used to estimate daily accumulated rainfall in the network, from which it is possible to deduce the daily maximum rainfall because, as we show in the paper, both magnitudes are correlated in the area during the analysed episodes. With the same diagnostic equation we can also obtain the mean precipitation, as one referee suggests (the mean precipitation is the total rain collected in the network divided by the number of rain gauges).

Regarding the use of daily rain in this study, method that has been questioned by one of the referees:

> *- The DAILY accumulated rainfall may be from gentle rain throughout the day, or a heavy rainfall in one hour. This would result in very different lightning amounts. So this may be the cause of the bad correlations.*

we remind, as it have been mentioned in the article (P6472 lines 19-21), that the convective phenomena we are studying has a typical lifetime of 1-2 h. In fact, we found that in 93% of the days the relationship between daily accumulates and daily maximum keeps around 1-2.

b) Method: how significant is the use of rainfall data relative to a point to estimate rainfall in the entire area

The referees have questioned the use of rainfall data measured in a particular point (in a particular observatory) to establish the final diagnostic equation that evaluates the total rain collected by the rain gauges:

- The whole idea of the paper is to give a reasonable "estimate" of rainfall for the region (equation 2), and the verification is done using correlations between rainfall observations and estimates. However, the estimates themselves use the observed rainfall in some way to predict the observed rainfall. Hence, these two parameters (observed and estimated rainfall) are not INDEPENDENT parameters. The estimates depend on the observed values, not only on the lightning data. Hence, I am not sure about the validity of these statistical correlations.

- The methodology leads to equation (2) at page 6473 and in this equation, the term Rj is effectively a rainfall parameter. Thus the rainfall is estimated from rainfall.

Those questions demand a more extended explanation of the followed method that we have shortly exposed in the paper due to the space restrictions.

1- As explained before, we have focused our work on the study of the anomalies, defined as the difference between the measured precipitation in one particular point and the expected one evaluated from the lightning flashes around (using the adjusting line in Fig.2b). This way, we create a matrix of 91 rows x 22 columns corresponding to the anomaly values referred to the 22 points of the rain gauge network during the 91 days studied. That is, we have 91 points in a 22-dimensional space. PCA analyse was carried out on that matrix.

   PCA analysis allows identifying in our 22 dimensional data space a reference base formed by 22 unitary vectors (called Empirical Orthogonal Functions – EOFs -) that determine a new orthonormal reference system in which the variance of data is better expressed. This way, every EOF is a linear combination of the initial reference base that defined the variation of the initial variables (in our case the so-called anomalies). Also, in this sense, every EOF represents a new axis of reference (also called synthetic axis) in the initial 22 dimensional space of data.

2- PCA results in our study show the existence of a first empirical orthogonal function (EOF1) that explains up to 50% of the variability of the rain anomalies. Consequently, we could assume, as a first approximation, the following equation:

$$(\mathbf{\Delta}_1, \mathbf{\Delta}_2, \mathbf{\Delta}_3, \ldots, \mathbf{\Delta}_{22})[d] \simeq \mathrm{PC1}[d]\mathrm{EOF1} \quad (1)$$

   Where,

- $((\Delta_1, \Delta_2, \Delta_3, . . ., \Delta_{22})[d])$ is the vector of rain anomalies observed every day. These anomalies represent the first order of approximation to the difference between the daily rain measured in every observatory and the expected rain deduced by linear approach from the number of lightning counts observed around.

- EOF1 is the first empirical orthogonal function found by the PCA. We have to remind that every EOF is a unitary vector formed by 22 values, each one representing the share of their corresponding original data. These values are the coefficients that have to be used to linearly transform the initial base to the new one found by the PCA analyse.

- PC1 is the first principal component associated to the day [d], also so-called predictor's value. Each PC1 value is a scalar number.

Assuming the approach represented Eq.1, this equation can be used in the following way. We can estimate the values of the 22 anomalies the day [d] by simply multiplying the 22 values of EOF1 by the corresponding scalar PC1 [d]. In this approximation, PC1 [d] values would be the ratio between rain anomalies in one observatory and the corresponding component in the vector EOF1.

Fig. 5 shows the spatial distribution of the EOF1 (this last acronym is missing in the figure caption). This figure shows that the values in EOF1 are spatially structured, showing their highest values in the north.

In Fig. 6 we present the frequency distribution of the 91 PC1 values that multiply the values of EOF1 to calculate every day the 22 rain anomalies. According to this, the anomalies are small and negatives in most of the days, but there are a few days when large positive anomalies are observed. Obviously, those last cases are the ones of interest from the point of view of flood hazard.

Those results concerning the geographical distribution of EOF1 have a physical interpretation that explains the observational evidence (P6477 lines 6-13). Most of the storms produce highly localized rain in their SW-NE trajectory, with a precipitation amount that approaches the expected from lightning counts, or even lower. However, in a few cases, the storms present high precipitation/lightning ratios, in particular in the northern side of the area.

As explained in the submitted paper, the geographical location of the extreme rains and their precipitation efficiency suggest the influence of maritime air in the storm development, but further research needs to be done. (P6477 lines 13-16).

Based on Eq.1, we can expect that the addition of rain anomalies observed in all rain gauge network could be related to the anomalies observed in one particular rain gauge, because if we assume Eq.1, all the anomalies vary linearly along the axe EOF1. That point is presented in Fig.7 of the paper, in which we also stress the fact that only a reduced number of rain observatories reach a good linear relationship between their anomalies and the addition of all anomalies observed in the area. Observatories that we will use as predictors in our diagnostic equation.

At this point we have to answer to one of the referees who asked about the fact that we found only 3 stations with good results.

- You mention only 3 stations giving good results. That is 3 out of 22 stations (< 15%). What about the other stations? How can you base your results on less than 15% of the stations?

Two simple reasons can be stated. The first one is that Eq.1 is only a first approximation of the problem. And the second one, connected to the first one, is that the stations that we found as the best predictors are the stations with the highest participation in the formation of the EOF1.

Also, regarding this matter, we can think that the reason why those three stations are the best "predictor observatories" could be that they are situated just in the middle of the analysed area, so they have the highest probability of being always affected by the summer storms.

We can interpret this result in the following way: the higher the rain anomalies are in the predictor observatories, the higher the values of all rain anomalies are expected. Consequently, we can expect that total rain collected in the area by the network (or the mean daily precipitation measured) will increase when the observatories used as predictors observe an increase in the difference between rain collected and rain expected from lightning counts.

3- Considering all those the results, we have proposed an **empirical** approach in order to obtain a **first diagnosis equation** (Eq. 2) for the estimation of the daily rainfall accumulated in the network, data that can be transformed directly in the values of the mean precipitation observed in the area. (Mean precipitation =Sum of collected rain /number of observatories)

In this sense, as one of the referees points out,

- They use also a cumulative rain parameter calculated by summing all depths found at each station. This parameter is therefore relative to the number of stations, it does not represent a physical quantity

we could have used the mean rainfall instead, because the mean does not depend on the number of observatories used in the study, and multiplied by the whole area gives the total volume of precipitation in the area. In any case, using the mean does not change the final result (the estimated maximum rainfall).

4- Finally, and regarding the point that referees signal about the use of rainfall in one point to estimate rainfall in the area, we have to say:

a) We are actually using precipitation and lightning in one point to estimate mean rainfall in the area, not only rain in this point.

b) The equation we found is a diagnosis equation, not a forecasting tool. That means that, for example, it can be used in climatological studies when there are missing data in the data base. Also, it can be used as a nowcasting tool in days of summer local storms in the area: if the ratios between rain and lightning increase in the so-called predictor stations, then heavy rain is expected to occur in the area.

c) For the first time we have been able to identify an important feature of the summer local storms that affects the area: the anomalies in the ratios of rain and lighting in the so-called predictor sites are a diagnosis tool to establish the maximum intensity of rainfall found in the area. This property seems to be linked to the anomalous changes observed in the productivity of lightning in the case of most severe thunderstorms.

In summary,

- We have studied the anomalies of the precipitation/lightning relationships in order to verify if they are spatially organized.

- PCA analysis has detected a main linear relationship in data that points out to a phenomenology of storms with high/low precipitation/lightning ratios that have a preferential north/south distribution respectively, which is in accordance with the observations. We think that the proximity to the sea and the entrance of maritime air mass is the cause of the geographical distribution of storms characteristics.

- From the PCA results, it could be postulated the existence of a possible relationship between rain anomalies and the total rain collected in the area by the rain gauge network (quantity that is related to the value of the mean precipitation observed in the area). Accordingly, we searched for an empirical formula to be used as diagnostic equation in order to establish the estimations of rainfall in the area. The empirical multilinear expression (Eq.2) found is the first diagnosis equation available to estimate the value of maximum rainfall expected in days of summer flood hazard situations.

- Daily data are used because the convective phenomenon happens in general in the afternoon and produces 1-2 h showers.

- Since lightning counts are not a good predictor, we introduce the **anomaly terms**. From the point of view of flood flash, we are looking for high precipitation/lightning ratios, and we have found that they are mainly observed in the northern side.

- We also introduce total lightning counts in our empirical approach because we found that the proposed empirical equation improves when this term is added.

As mentioned, the equation found explains a great deal of the studied problem, and this point can be understood analysing the weight of each term:

- In days of strong positive anomaly there is a high precipitation/lightning ratio, and lightning information alone is a bad predictor. In those cases, we have found that the rain instability is generalized, there is more precipitation accumulated in the network and intensity of the showers is higher.

- When showers are related not to a generalized precipitation but to isolated thunderstorms, mainly affecting the southern part of the area, precipitation/lightning ratio reduces its value, and lighting information becomes a good predictor.

Formal questions and suggested changes

a) Figure captions.
b) Changing text.
c) Changing figures.

Suggested changes are in bold

a) Figure captions, following referees suggestions:

- In Table 2. , highlighting the 3 stations discussed.

- Fig.1. Spanish Basque country area location in Europe. In zoom, **with topography background (altitudes)**, the studied region and the distribution of the 22 observatories and of the main cities (BI: Bilbao, SS: San Sebastian, VI: Vitoria).

- Fig.3. Maximum number of CG flashes around the observatories vs. the value of maximum rainfall **in the network** (in mm) for each day of the study.

- Fig.5. Spatial distribution of **EOF1**: isolines and corresponding value in each observatory.

- Fig. 10. Maximum daily rainfall (mm), estimated vs. observed. Estimation was based on **mean** rainfall from Eq. (2).

b) Changing text: small changes, mainly related with the use of mean rainfall instead of accumulates.

- One of the referees suggests changing the title.

  The first concerns the title: it would be better to say "Multilinear approach to the precipitation-lightning relationship : application to summer local: : : "

  We are not sure about the consequences of such a change in the title, should it be that the article is considered as a new one, then, we would like to avoid changing the title.

- P6469 lines 11-14: "… Based on those results, a multilinear expression has been developed as a **diagnosis equation** to estimate **daily mean rainfall** in the network **using** CG flashes registered in the area. Moreover, **mean** and maximum values of rain are found to be strongly correlated …".

- P6471 line 25: "…to estimate rain in the region **using** CG flashes."

- P6472 line 11-12: "…also, the number of CG flashes within 10 km around each one of the *j* observatories (*j* = 1 to 22), values referred in this paper as *Lj* [*d*]. **The area for lightning counting has been selected according to Ezcurra et al. (2008).**"

- P6473 line 10: "…EOF **(Empirical Orthogonal Function)**".
  Lines 19-23: "…In that case, it is possible to postulate that the mean rain depth collected in the network every day ***(<R> [d]***) can be estimated based on that anomaly and adding lightning information. According to that, we propose the following empirical formula:

$$\langle \boldsymbol{R} \rangle\ \boldsymbol{[d]} = \alpha R_j [d] + \beta L_j [d] + \gamma [d] + \delta \quad (2)$$

where, for the day [*d*], ***<R>* [*d*]** is the mean rain depth collected in the 22 observatories…"

- P6474 lines 1-2: "…The **mean** rain in the network every day is estimated using the number of CG flashes…"
  Lines 24-26: "…We found that the **mean** precipitation in the network each day is strongly related with the maximum that day ($r^2 = 0.8$). Also, the daily **mean** is correlated with…".

- P6475 line2: "…That is, the extension of the storm activity and the ~~**total**~~ precipitation that it produces…"
  Lines 15-16: "…the whole area, that is, **the mean value of** precipitation collected in the network against the number of CG flashes in the whole area (Fig. 2a),…".
  Line 26-27: "…We compared every day the maximum values of rainfall **in the network** with the maximum number of CG flashes…".

- P6477 line 3: "Figure 6 shows the frequency distribution of **PC1 [d]** found in our PCA analisis."
  Line 26: "…in order to see if the **over/under estimations of precipitation based on lightning flashes** was also reflected…"

- P6478 lines 9-12: "According to those results, we can estimate **mean** total rain depth using Eq. (2) by selecting the appropriate observatories. In Fig. 8 we compare the observed and estimates values of **mean** rainfall every day using observatories number 22, 18 and 19…".
  Lines 25-29: "…When we compare the frequency distribution of both observed and estimated **mean** rainfall in the network (Fig. 9), we observe that, in general, they fit quite well. **Considering all the data, the mean difference between observed and estimated mean rainfall does not reach 0,1 mm (< 2%).**"

- P6479 lines 4-7: "…the **mean** rainfall in the network is well correlated with the maximum value on a daily basis. As a consequence, we can obtain maximum rain depth expected every day based on estimates of **mean** rainfall. In Fig. 10 we compare observed maximum values **of rainfall** with estimated ones based on **mean** from Eq. (2),…".
  Line 15: "we could estimate **mean** rainfall in an area using lightning data…".
  Line 23: "…for estimating daily values of **mean** and maximum rainfall ..".
  Lines 26-27: "… **values of precipitation-lightning relationship** corresponding to each day and each location show …"

- P6480 lines 20-22: "…Therefore, we propose to use only one observatory to estimate each day **the value** of the total anomalous rain depth in the whole network."

- P6481 line 3-4: "…All those results allow the use of ~~the~~ an empirical multilinear expression **as a diagnosis equation** to estimate daily **mean** rainfall in the network."

  Line 6: "..adjusted ~~it~~ in terms…".

  Line 8:" in general, observed and estimated **mean** rain fitted quite well on a daily basis. Considering summer periods, the difference between observed and estimated rainfall was **under 2% in all years but one. For the whole period analysed, the difference did not reach 0,1 mm (< 2%).**"

  Lines 15-17: "**–** We found a strong correlation between daily values of **mean** rain and maximum rain ($r^2 = 0.8$). Therefore, first we estimated **mean rain in the network** using the multilinear expresión and then we calculated the maximum rain value. The results were encouraging, obtaining that actual and estimated values of maximum daily precipitation were correlated with r 2 = 0.8. This method seems to be a useful to estimate maximum rainfall in cases of strong convective events that can cause flood in the region studied here."

c) Changing figures:

- We agree with the referee, Fig.7 and Fig.8 are too small, because each of them contain three graphics, so we have separate each graphic producing 7a, 7b and 7c figures, and 8a, 8b and 8c figures that we add to this Final Response.

- Also, in Fig.8 and Fig.9 mean is used instead of accumulates. Accordingly, captions change:

  Fig. 2a. Daily precipitation–lightning relationships with data of the whole area.

  Fig. 7. Sum of anomalies in the network as a function of the anomalies in a observatory (number 22, 18 and 19, marked in the upper-left side of each box) for each day of the study (mm).

  Fig. 8. Comparing estimated and observed values of daily mean rainfall in the network (mm). Estimations are based on Eq. (2) with observatories number 22, 18 and 19 (marked in the upper-left side of each box).

  Fig. 9. Frequency distribution of observed and estimated daily mean rain depth in the network (mm).

- References in the text to those figures should change:

  P6477 line 29: "…or greater than 0.65 (Figures 7a, 7b and 7c respectively)".

  P6478 line 4: "There is another interesting feature in Figs. 7a, 7b and 7c."

Lines 10-11 : “In Figs. 8a, 8b and 8c we compare the observed and estimates values of rainfall…”.