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A nine-year climatology of thunderstorm days and lightning characteristics in Basque Country

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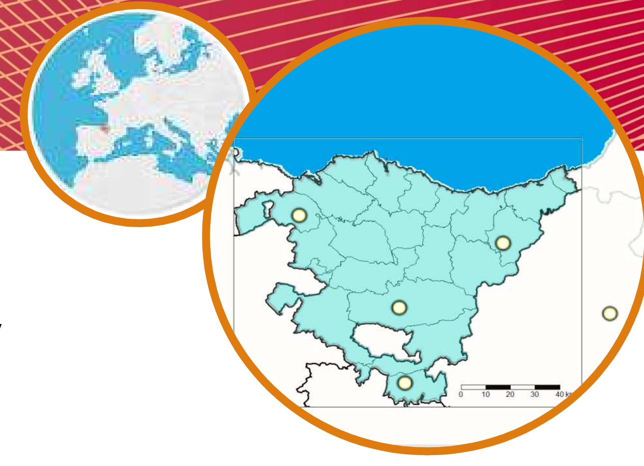

Figure 1: Location of Basque Country and LINET sensors

Abstract

Traditionally, thunderstorm activity is recorded at meteorological sites as a number of thunder-days (TD) per year. A thunder day is defined as an observational day during which thunder is heard at a particular site (station). Despite the fact that today automatic instrumental records of lightning incidence are available in many parts of the world, it is still useful for different purposes to have information about the TD. In this work we use different approximations for TD calculation, based on data from Lightning Detection System available in the area (part of LINET Network) and we check impact on results obtained.

We present a TD climatology for the Basque Country including lightning characteristics during 2010-2018 period. Monthly, seasonal and annual frequency distribution of TD and their temporal and spatial variations are analyzed for the Basque Country area. We also study daily lightning characteristics and determine how lightning characteristics vary between different TD types. We include daily statistics for relevant lightning parameters as TL, CG, IC, polarities and intensities. In such way we can examine relationships between lightning activity in the framework of a multi-year climatology of TD.

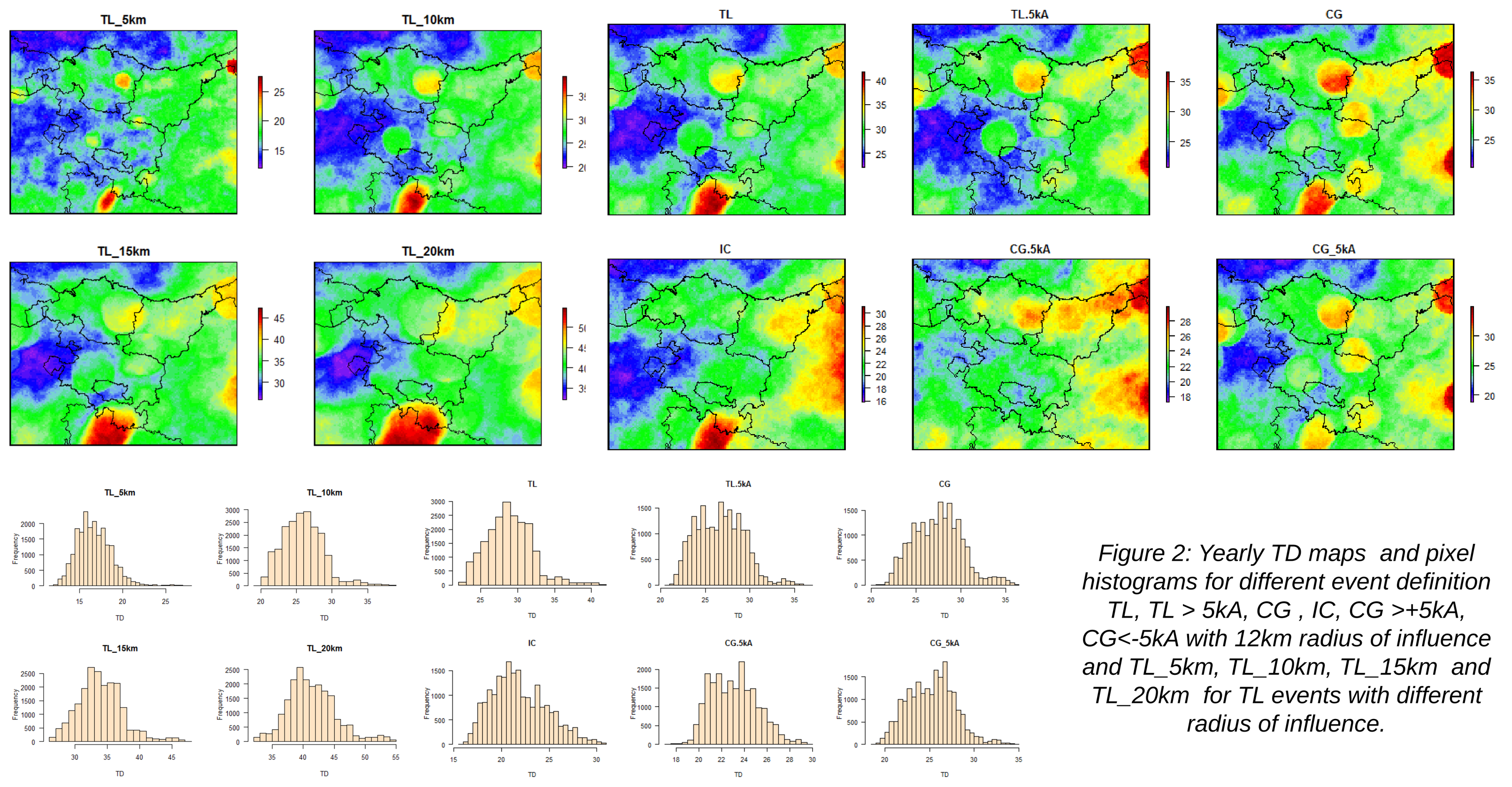

Figure 2: Yearly TD maps and pixel histograms for different event definition TL, TL > 5kA, CG , IC, CG >+5kA, CG<-5kA with 12km radius of influence and TL_5km, TL_10km, TL_15km and TL_20km for TL events with different radius of influence.

Methodology and Data

In this work a 9-yr (2010–2018) record of strokes data is used. Data set includes date, time, location, current (kA), height (km) and 2D-location error estimation (km) for each stroke. The Basque lightning network consist on four sensors installed by Euskalmet (fig 1) in the Basque Country (as part of LINET network (Betz et al 2005, 2007, 2009, Holler et al 2009, Lopez et al 2011, Nowcast 2016, Gaztelumendi et al 2017a, 2017b).

In order to determine if a particular day is a "Thunderstorm Day" or "Thunder day" (TD) we need to implement a plausible approximation to reproduce (based on 2082427 strokes information registered in the area) if a particular thunder could be audible for an human observer in a particular place. For this purpose, different approximations are possible (e.g. Nuñez et al 2019, Czernecki, B., 2016, Makela et al 2014, Enno et al 2014), in this work we consider on one hand different distance criteria (5km, 10km, 15km and 20km radius) and on the other the effect of using different thunder proxies (events) as total lightning (TL), Cloud to ground (CG) or intrer cloud (IC) with and without 5kA threshold.

For spatial-temporal analysis purposes the domain is gridded in 1kmx1km boxes considering daily intervals over the Basque Country domain shown in Fig. 1. We consider a Thunder Day (TD) to occur if more than one event are detected in a grid box or its surroundings (determined by a particular radius).

As we work with raw strokes data, an ad hoc quality control check removing non-plausible altitudes, isolated strokes, poor quality detections and outliers is done in order to minimize the possibility of false thunderstorm days detections.

Based on the final TD estimation considering a influence radius of 12km and a single TL stroke detection, and with a political boundaries mask, we calculate different spatial-temporal lightning characteristics for thunder days, including *relevant lightning parameters as TL, CG, IC, polarities and intensities with different spatial-temporal aggregation levels for the library.*

We use different R (core team 2014) libraries and scripts in order to temporal and spatial data segmentation and for different calculus and statistics presented.

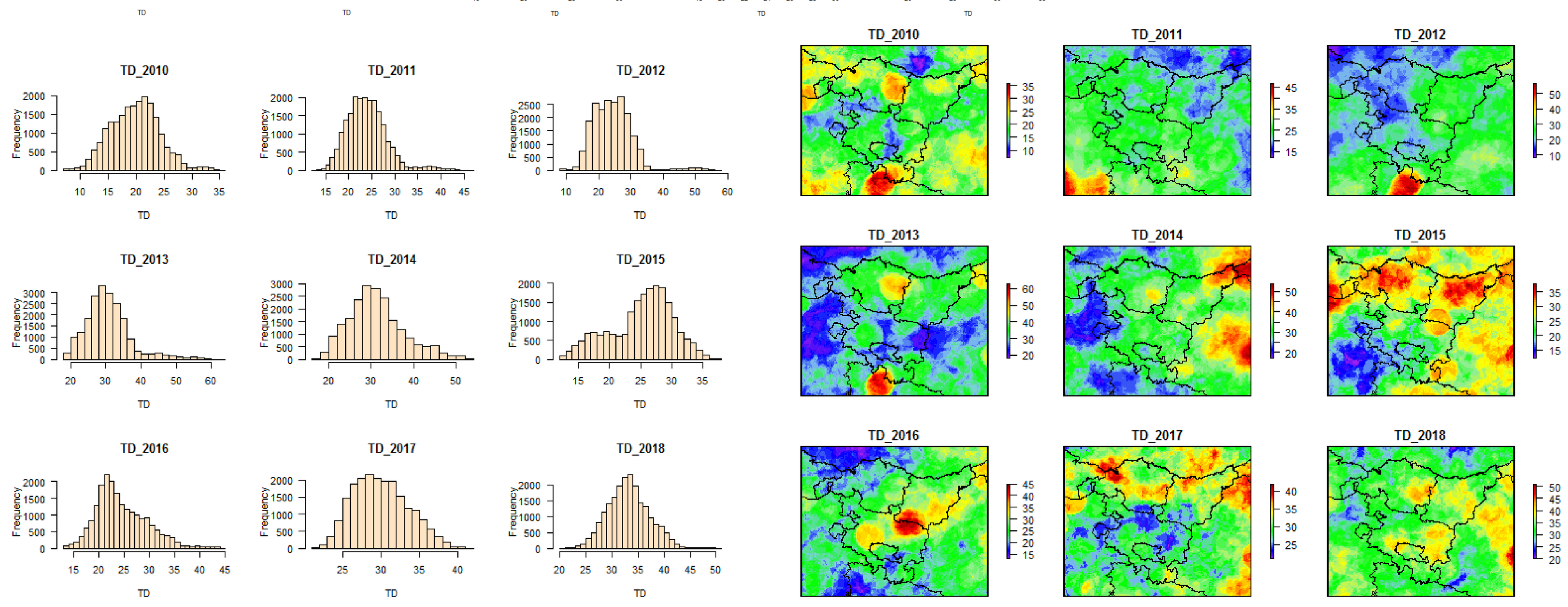

Figure 3: TD maps and pixel histograms for each year used in this work (2010 to 2018)

Results & Discussion

In Figure 2 we present the TD spatial distribution and histograms calculated considering different events as TL, abs(TL) > 5kA, CG, IC, CG > 5kA and CG < -5kA, and allowing different influence radius (5,10,15 and 20 km) on a TL event. We can appreciate the great impact that event choice has on TD distributions. Particularly it can be seen how a high density of TD appears in the south of the territory as a consequence of the influence of IC. The presence of artificial tall structures that are lightning precursors is clearly manifested in the different maps, particularly those that include negative CG and are absent in those made from IC. On the other hand the effect of the increase in the radius of influence is appreciable as an extension of the specific singularities.

The climatology of TDs based on lightning data from automatic networks present many advantages over those based on human observation (which suffer from a certain subjective character and lack of homogeneity), among which the possibility of developing high resolution maps is highlighted. However, the results are also strongly dependent on the methodology and approach to thunder estimation. In fact, if the TD calculus purpose is for comparison studies with other places, we should use CG events with some type of limitation in relation to intensities (for example 5kA). If the object were to have climatology with the greatest possible connection with the meteorology and the underlying storm dynamics, we should be careful with the lightning discharges induced by human structures' (wind farms, towers, radars, etc.) so we should focus on the use of IC and minimize the effect of negative CG. If we focus on classical climatology based on the concept of hearing thunder, we should use as much information as possible that could be associated with the production of thunder, in our case that is TL without intensities limitations.

In Figure 3 we present the maps and histograms of TD for the 9 years used in this study, we can see a high interannual variability both in relation to spatial distribution and TDs values, which could make difficult the generalization and usefulness of the results.

In Figure 4 we present the distribution of TD for an average year masked with political limits. We can see how the number of TD is located in 25-35 days with minimums to the SW and maximums to the NE, in mountainous areas and in the surroundings of different wind farms. This values are relatively high compared to other available studies as a consequence of the applied methodology and the effect of the winter months (see figure 5).

Monthly and seasonal TDs distribution (see figure 5 and 6) respond to the meteorological characteristics of the thunderstorms in our territory. With a predominance of maximums TD values in the north part near the sea during the winter months, and more interior distribution during the summer with a progressive transit to these configurations during the autumn and spring months.

Table 1 shows the lightning strokes characteristics for a mean TD for a mean year, season and month. During 22% of the days on a year thunders occurs in some part of the Basque territory, rising to 30% in summer and falling to 15% in winter. During 37% and 34% of the autumn and winter TD there are less than 5 lightning strokes. During 55% of summer TDs more than 100 strokes are produced, this only occurs in 18% of winter TDs. In 40% of January TDs the number of positive strokes exceeds negative ones, this amount drops to 8% in May. In 16% of summer TDs the number of IC exceeds that of CG, that amount is reduced to 2% during the winter. Strokes with intensities greater than 200kA occur in 5% of December TDs. In 64% of summer TDs strokes occur at heights above 10km

During mean summer TD 988 TL strokes are registered over Basque country in the winter case 70 TL strokes. During winter months mean stroke intensities (28kA) are higher than during summer (8kA). Maximum intensities registered in a TD correspond to February with a value of 330 kA.

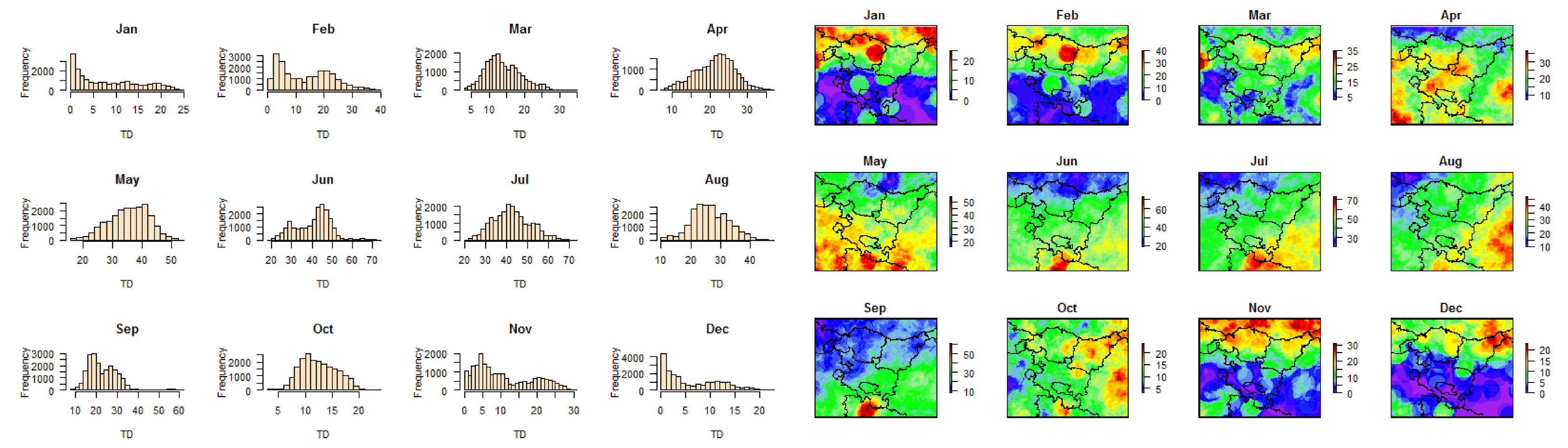

Figure 5: Mean monthly TD maps and pixel histograms (2010 to 2018)

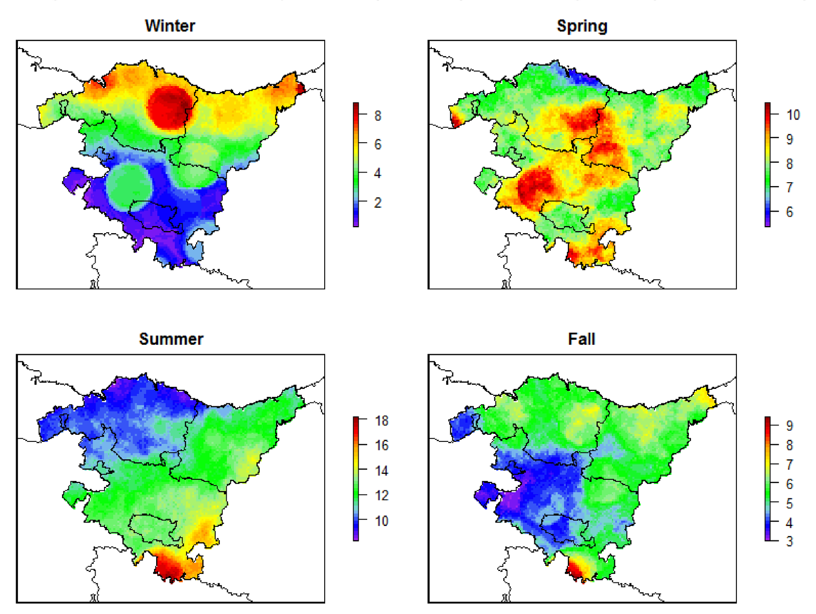

Figure 6: Mean seasonal TD maps (2010 to 2018)

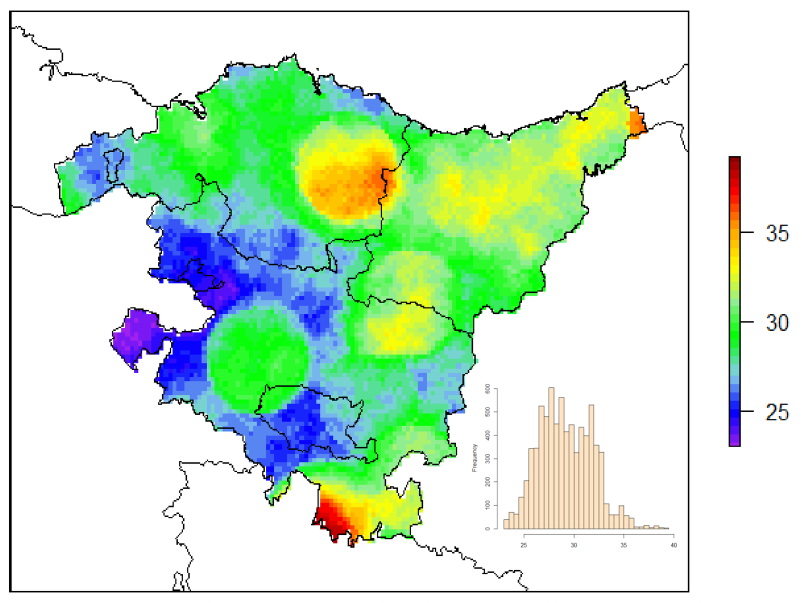

Figure 4: Annual TD map and pixel histogram (2010 to 2018)

Table 1: TD and lightning yearly, seasonal and monthly characteristics

	% TD	% TD #TL < 2	% TD #TL < 3	% TD #TL < 6	% TD #TL > 100	% TD #POS > #NEG	% TD #IC > #CG	% TD int > 200kA	% TD alt > 10km	Mean TL	Mean TL POS	Mean TL NEG	Mean CG	Mean IC	Mean TL > 5kA	Mean POS > 5kA	Mean NEG > 5kA	Mean CG > 5kA	Mean IC > 5kA	Mean TL Int (KA)	Max TL int (kA)
Year	22	14	20	28	39	22	10	31	30	492	204	288	310	182	229	86	143	160	69	13	332
Winter	15	15	22	34	18	26	2	52	46	70	30	40	60	10	53	22	30	45	7	24	332
Spring	24	10	15	24	39	15	4	27	64	312	111	201	230	82	142	48	95	114	29	12	320
Summer	30	11	16	23	55	26	16	25	39	988	426	562	587	401	434	166	268	288	146	8	303
Fall	19	22	30	37	31	22	13	28	26	279	110	169	175	104	159	59	100	108	51	12	291
Jan	13	14	20	37	20	40	3	51	25	57	24	32	47	9	42	18	23	35	7	28	289
Feb	22	18	23	37	17	13	0	50	35	78	33	46	68	10	63	26	37	55	8	23	332
Mar	20	11	20	30	20	20	0	33	42	88	32	56	76	12	58	20	38	51	7	14	297
Apr	24	12	13	25	40	18	3	22	56	192	66	127	145	47	98	33	65	78	20	11	282
May	29	6	11	18	51	8	6	27	65	566	204	363	407	160	238	79	159	187	51	11	320
Jun	32	9	14	22	53	17	11	32	67	813	319	494	515	298	354	128	226	245	109	8	279
Jul	33	9	15	21	60	30	21	25	59	1413	647	766	802	611	579	231	348	373	206	8	303
Aug	25	16	21	26	49	32	16	15	46	646	269	377	392	255	342	128	214	230	112	8	228
Sep	26	24	32	38	38	21	17	24	47	453	183	270	270	183	242	89	153	154	88	9	225
Oct	14	16	21	26	42	16	13	18	23	177	63	115	113	64	102	37	65	71	32	11	268
Nov	18	25	33	44	13	27	8	44	47	98	39	59	83	15	79	30	49	68	11	17	291
Dec	11	10	20	27	20	37	3	57	0	68	30	38	58	9	44	19	24	38	5	20	288

Summary & Conclusions

In this study, an attempt has been made to understand the temporal and spatial variation of thunder days and lightning characteristics in Basque Country.

Results shows an annual cycle with the highest number of TD during summer time (particularly in June and July) and a minimum during winter (particularly in December and January). Spatial patterns are very different during summer and winter time. While during November, December, January and March maximum TD are produced in Cantabric basin near the sea shoreline, during June, July, August and September maximum TD are displaced to the Southeast interior part of the territory

This is just a preliminary approach to reproduce a TD climatology in the classical perspective, some improvement is planned including:

- An adjustment with human observations where available.
- A new definition of event based on variable criteria (e.g. different number of strokes produced in different radius of a particular place).
- The inclusion of orography and a variable radius of influence depending on site characteristics.

TD climatology based on lightning network data and not in direct identification of thunders, has many advantages including high resolution capabilities and not subjective human observation dependencies. On the other hand results are absolutely dependent of methodology used when producing final product (particularly true in this preliminary work with non removal of lower amplitude strokes registered in LINET network). Results should be interpreted with caution particularly when a thunder day is defined as a consequence of far and scarce strokes detection where quality variability of data may be relevant.

The use of TL or CG in a small territory with many isolated high artificial structures (antennas, towers, radars, wind power plants, ..) could produce TD results difficult to interpret and not representative of the underlying meteorology (for this purpose IC proxies are better)

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The authors would like to thank the Emergencies and Meteorology Directorate - Security Department - Basque Government for public provision of data and operational service financial support and Nowcast GmbH for lightning data provision. We also would like to thank all our colleagues from EUSKALMET and TECNALIA for their daily effort in promoting valuable services for the Basque Community. Finally, we would also like to thank the Free Software Movement and all institutions and people that maintain and support availability of free data and tools.

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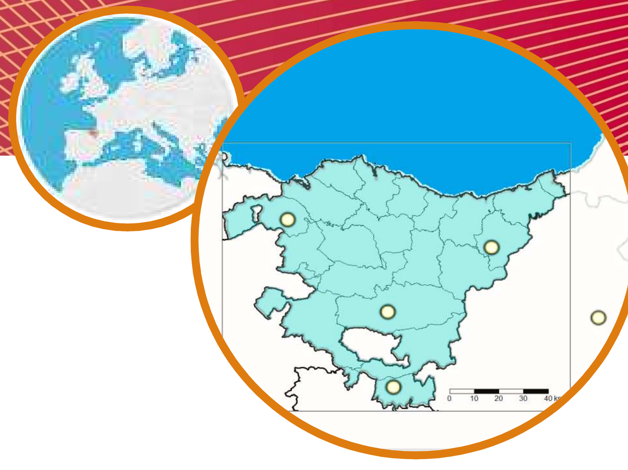

Figure 1: Location of Basque Country and LINET sensors

Abstract

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In order to determine if a particular day is a "Thunderstorm Day" or "Thunder day" (TD) we need to implement a plausible approximation to reproduce (based on 2.082.427 strokes information registered in the area) if a particular thunder could be audible for an human observer in a particular place. For this purpose, different approximations are possible (e.g. Nuñez et al 2019, Czernecki, B., 2016, Makela et al 2014, Enno et al 2014), in this work we consider on one hand different distance criteria (5km, 10km, 15km and 20km radius) and on the other the effect of using different thunder proxies (events) as total lighting, CG or IC with and without 5kA threshold.

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Based on the final TD estimation considering a influence radius of 12km and a single TL stroke detection, and with a political boundaries mask, we calculate different spatial-temporal lightning characteristics for thunder days, including *relevant lightning parameters as TL, CG, IC, polarities and intensities with different spatial-temporal aggregation levels for the territory.*

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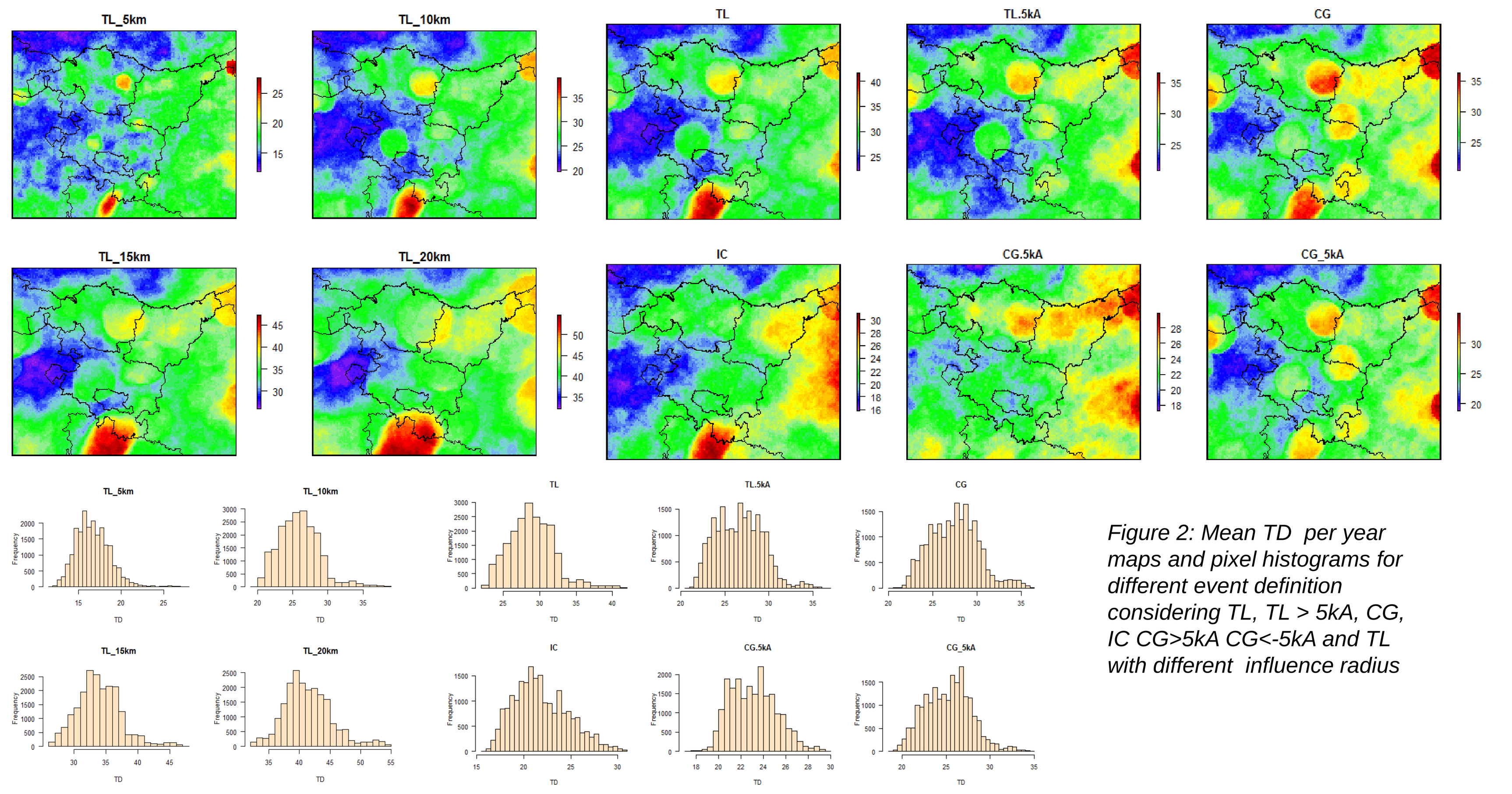


Figure 2: Mean TD per year maps and pixel histograms for different event definition considering TL, TL > 5kA, CG, IC CG>5kA CG<-5kA and TL with different influence radius

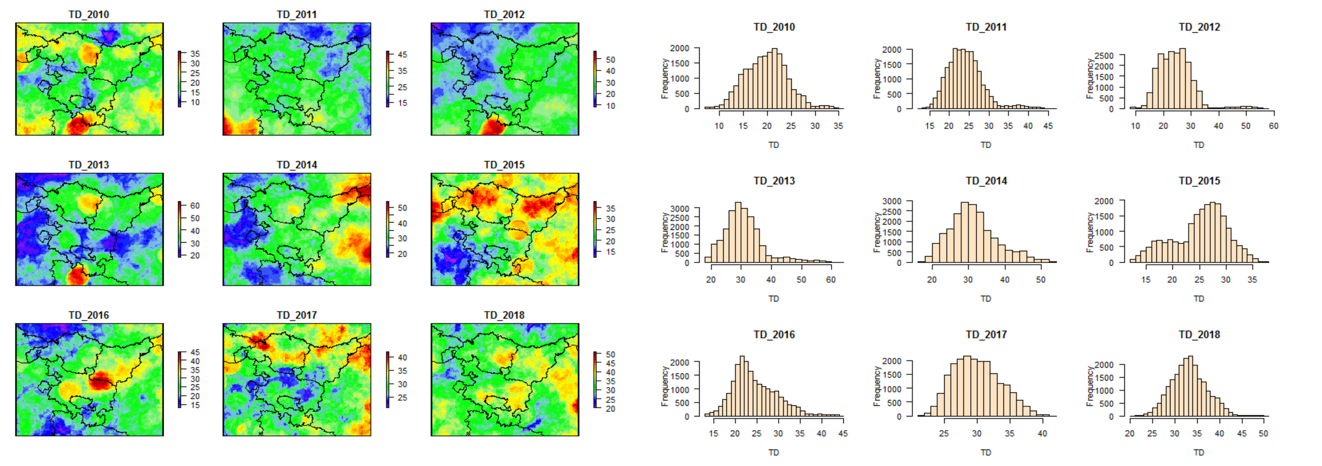
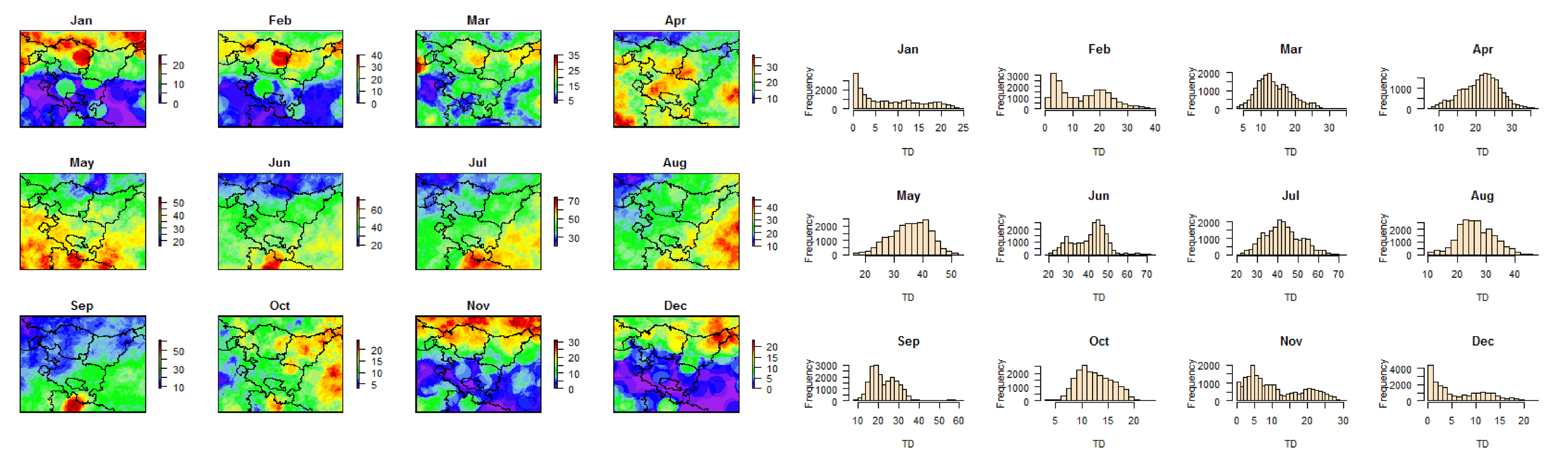


Figure 3 . Yearly TD distribution and pixel histograms for different years considered in the climatology (from 2010 to 2018)

Figure 5 . Monthly mean TD maps and pixel histograms.



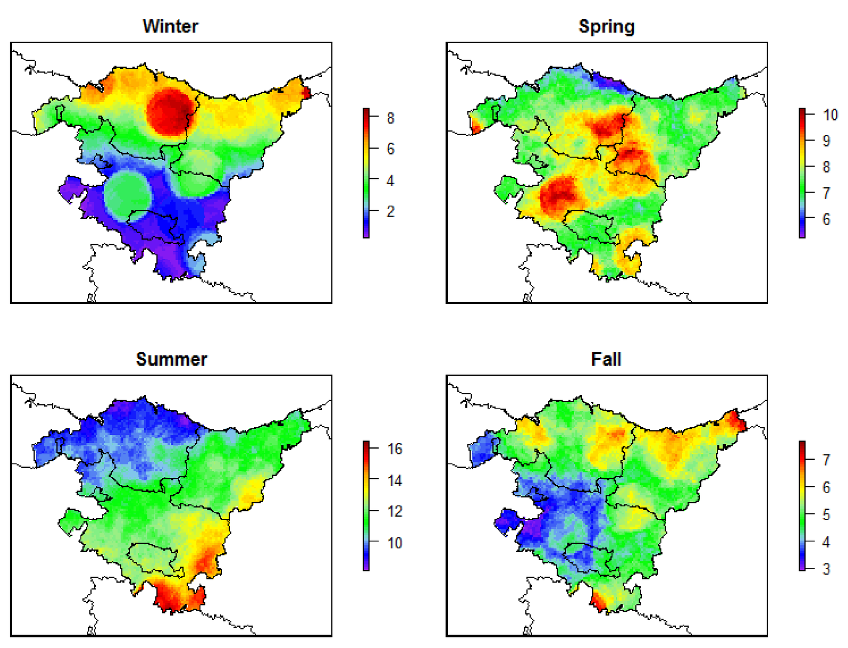


Figure 6 . Seasonal mean TD maps period 2010-2018)

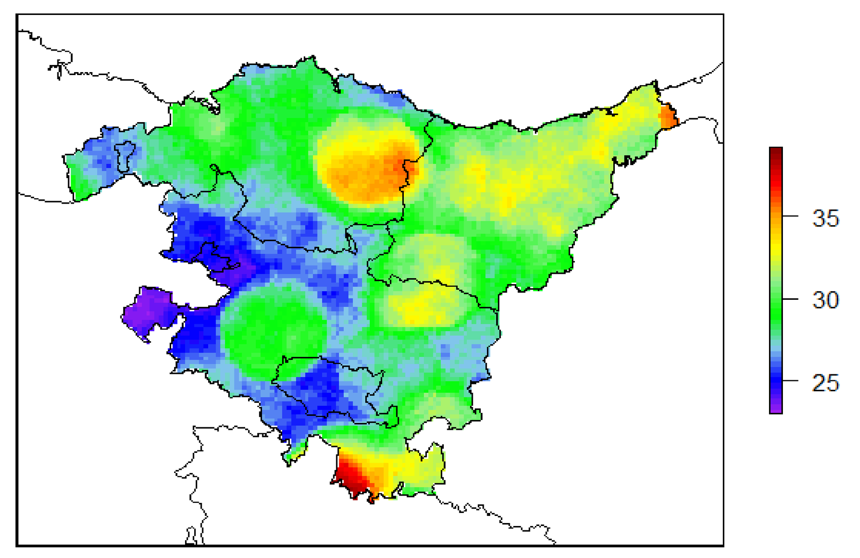


Figure 4 . Mean yearly TD maps period 2010-2018)

Results & Discussion

In Figure 2 we present the spatial distribution and TDs histograms estimated using different events, in particular considering TL, abs (TL)> 5kA, CG, IC, CG> 5kA and CG <-5kA, and different influence distance (5,10,15 and 20 km) on TL event. We can appreciate the great impact that event choice has on TD distributions. Particularly, it can be seen that in the South of the territory there is a large area of high activity related to the high density of IC and negative CG, and the influence of high artificial structures (particularly wind farms) in the increase of TDs in its surroundings, particularly in relation to negative CG events. In figure 2 we can also appreciate that a increase in radius results in an increase in the TDs detected, particularly obvious in the southern limit of the territory.

The spatio-temporal distribution of TD is highly dependent on the type of event considered and the methodology used for its calculus. In that sense its possible (if complete strokes data are available as is the case) to build different TD climatology depending on their purpose. If order to represent TDs in a classical way, close to the original definition based on the detection of thunder by an observer, probably it is preferable to include as many strokes as possible as precursors of thunder. If the aim is to compare TDs distribution with other places in the world it will be convenient to consider CG strokes with a intensity discrimination (eg 5-10kA). If the aim of the climatology is to connect with thunderstorm meteorological behavior, we need to remove the "artificial" effects, by instance considering just IC events and minimizing negative CGs presence. As is well known those effects could be produced by tall human made structures that trigger discharges that in the absence of them would not occur.

In figure 3 we show the spatial distribution and histograms for each of the years included in this work. We can appreciate a very high intra-annual variability in TD number and its spatial distribution.

In figure 4 we present the TDs map for a mean year and the seasonal distribution. Note the visible non-removed effects of summer TDs promoted by wind farms.

During the months of January, February, November and December the distribution of TD is clearly maritime-coastal. During March, April and May there is a progressive shift towards the SW. During the months of May, June, Jul, Aug and Sep the maximums occur in the south of the territory. In October the distribution has maximums to the NE part (see figure 5)

Remark that the seasonal patterns (figure 6) follow the seasonal distribution and typology of storms that affect the Basque Country where at any season it is possible to have atmospheric conditions that promote thunderstorms. From typically Atlantic winter storms that mainly affect coastal areas, to the summer ones generated by diurnal heating that affects mainly interior parts of the country .

In Table 1 we show some relevant aspects of lightning strokes for a given TD, reflecting the different thunderstorms typology that affect our territory at different times.

Note that at mean 22% of days are TD in some place in the territory (30% during summer and 15% during winter). Around 15-30% of TD (as defined in this work) are caused just for to a 1-2 strokes detection. During 35% of winter and fall lees than 5 strokes are registered. During more than 50% of summer TDs more than 100 strokes are detected. The proportion of TDs with more positives than negatives stokes are maximum (40%) during january. The proportion of TD with more IC strokes detected than CG are higher (20%) in July. The proportion of TDs with higher than 200 kA strokes are higher in January (28%). During 64% of Summer TDs a IC stroke is registered over 10km, during winter just during 30% of TD,

Table 1 . TDs and lightning characteristics for Basque Country.

	% TD	% TD #TL < 2	% TD #TL < 3	% TD #TL < 6	% TD #TL > 100	% TD #POS > #NEG	% TD #CC > #CG	% TD int > 200kA	% TD alt > 10km	Mean TL	Mean TL POS	Mean TL NEG	Mean CG	Mean CC	Mean TL > 5kA	Mean POS > 5kA	Mean NEG > 5kA	Mean CG > 5kA	Mean CC > 5kA	Mean TL Int (KA)	Max TL int (kA)
Year	22	14	20	28	39	22	10	31	8	492	204	288	310	182	229	86	143	160	69	13	332
Winter	15	15	22	34	18	26	2	52	23	70	30	40	60	10	53	22	30	45	7	24	332
Spring	24	10	15	24	39	15	4	27	8	312	111	201	230	82	142	48	95	114	29	12	320
Summer	30	11	16	23	55	26	16	25	4	988	426	562	587	401	434	166	268	288	146	8	303
Fall	19	22	30	37	31	22	13	28	5	279	110	169	175	104	159	59	100	108	51	12	291
Jan	13	14	20	37	20	40	3	51	29	57	24	32	47	9	42	18	23	35	7	28	289
Feb	22	18	23	37	17	13	0	50	25	78	33	46	68	10	63	26	37	55	8	23	332
Mar	20	11	20	30	20	20	0	33	15	88	32	56	76	12	58	20	38	51	7	14	297
Apr	24	12	13	25	40	18	3	22	6	192	66	127	145	47	98	33	65	78	20	11	282
May	29	6	11	18	51	8	6	27	5	566	204	363	407	160	238	79	159	187	51	11	320
Jun	32	9	14	22	53	17	11	32	5	813	319	494	515	298	354	128	226	245	109	8	279
Jul	33	9	15	21	60	30	21	25	3	1413	647	766	802	611	579	231	348	373	206	8	303
Aug	25	16	21	26	49	32	16	15	3	646	269	377	392	255	342	128	214	230	112	8	228
Sep	26	24	32	38	38	21	17	24	1	453	183	270	270	183	242	89	153	154	88	9	225
Oct	14	16	21	26	42	16	13	18	3	177	63	115	113	64	102	37	65	71	32	11	268
Nov	18	25	33	44	13	27	8	44	13	98	39	59	83	15	79	30	49	68	11	17	291
Dec	11	10	20	27	20	37	3	57	13	68	30	38	58	9	44	19	24	38	5	20	288

Summary & Conclussions

In this study, an attempt has been made to understand the temporal and spatial variation of thunder days and lightning characteristics in Basque Country.

Results shows an annual cycle with the highest number of TD during summer time (particularly in June and July) and a minimum during winter (particularly in December and January). Spatial patterns are very different during summer and winter time. While during November, December, January and March maximum TD are produced in cantabric basin near the sea shoreline, during June, July, August and September maximum TD are displaced to the Southeast interior part of the territory

This is just a preliminary approach in a near future we are going to improve this work including:

- An adjustment with human observations where available.
- A new definition of event based on variable criteria (e.g different number of strokes produced in different radius of a particular place).
- The inclusion of orography and a variable radius of influence depending on site characteristics.

TD climatology based on lightning network data and not in direct identification of thunders, has many advantages including high resolution capabilities and not subjective human observation dependencies. On the other hand results are absolutely dependent of methodology used and they should be interpreted with caution considering the spatio-temporal quality variability of strokes data, particularly when a thunder day are defined as a consequence of far and scarce strokes detection.

The use of TL or CG in a small territory with many isolated high artificial structures (antennas, towers, radars, wind power plants, ..) could produce TD results difficult to interpret and not representative of the underlying meteorology (for this purpose IC proxies are better)

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