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Towards a European climatology of meteorological parameters associated to the genesis of severe storms

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Abstract

In this paper, we analyse the relevance of some meteorological parameters to determine the presence of severe storms within the European domain. The exact values that these parameters take during a case of severe weather are not considered the most important matter, but rather the relation they have when being compared with local climatologies is taken into account. To do so, a list of events which occurred between 1970 and 2005 within the European domain is used, and they show how the CAPE (Convective Available Potential Energy), the contents of water vapour up to 850 hPa, the temperature at 850 hPa and the sea level pressure are very related to the severe weather phenomena; whereas others, such as the CAPEN (Convective Inhibition Energy), the temperature change between 700 and 500 hPa, the helicities relative to the storm and the geopotential height at 500 hPa, are less relevant.

1 Introduction

For the European domain, there is not a good database of severe weather phenomena that could be used as a starting point for further studies, such as the one we intend to do here, to relate these events to the specific climatologies and to employ it to improve prediction methods. Only some data bases of regional range have been created, often without institutional support (Barnolas, 2002-2004; Barnolas and Llasat, 2005) for Catalonia; Gayà et al. (2001) for the Balearic Islands; Gayà (2005) for Spain; Giaiotti et al. (2003) for northern Italy; Leitão (2003) for Portugal; Marcinoniene (2003) for Lithuania, Setvák et al. (2003) for the Czech Republic; Sioutas (2003) for Greece; and Tyrrell (2003) for Ireland. On the other hand, in the USA a database of this kind is available for some years (managed by the National Weather Service), where this type of phenomena are registered, including tornados, hail and strong winds of convective origin.

Beginning some years ago, the European project ESWD (European Severe Weather Database; http://www.essl.org/projects/ESWD) has tried to relieve this deficiency following the American example, but it is still under development and it is not enough to support all the weight of a project. In our case, the ESWD database has been used, to which other data have been added, such as the database of the ECSS project (European Climatology on Severe Storms; (Romero et al., 2006) http://ecss.uib.es/), specific cases of heavy rain provided by the GAMA group from the Universitat de Barcelona, and events found in different media. Despite this, the difficulty of having an adequate database has persisted along the study.

In addition to the above-mentioned events: tornados, hail (stones bigger than 2 cm-diameter) and strong winds of convective origin (with speeds equal or over 25 m/s), in this paper we have also considered it appropriate to include heavy rain episodes (some of which could have caused floods) due to the high frequency in which they occur, especially in the Mediterranean basin, and the similarity of the consequences that the people suffer. We have collected a total of 638 tornados, 223 hail episodes, 208 strong wind of convective origin episodes and 120 heavy rain episodes. In this paper, we will refer to these episodes as “tornado”, “hail”, “wind” and “rain”, respectively.

These events have not been collected in an uniform way throughout the period of the study: most of them are found in the last years, due to a larger conscience of the researchers about the necessity of improving the needed type of database.

When the relation between some meteorological parameter and the presence of severe weather is required, people tend to study it referring to the variable value. In this case,

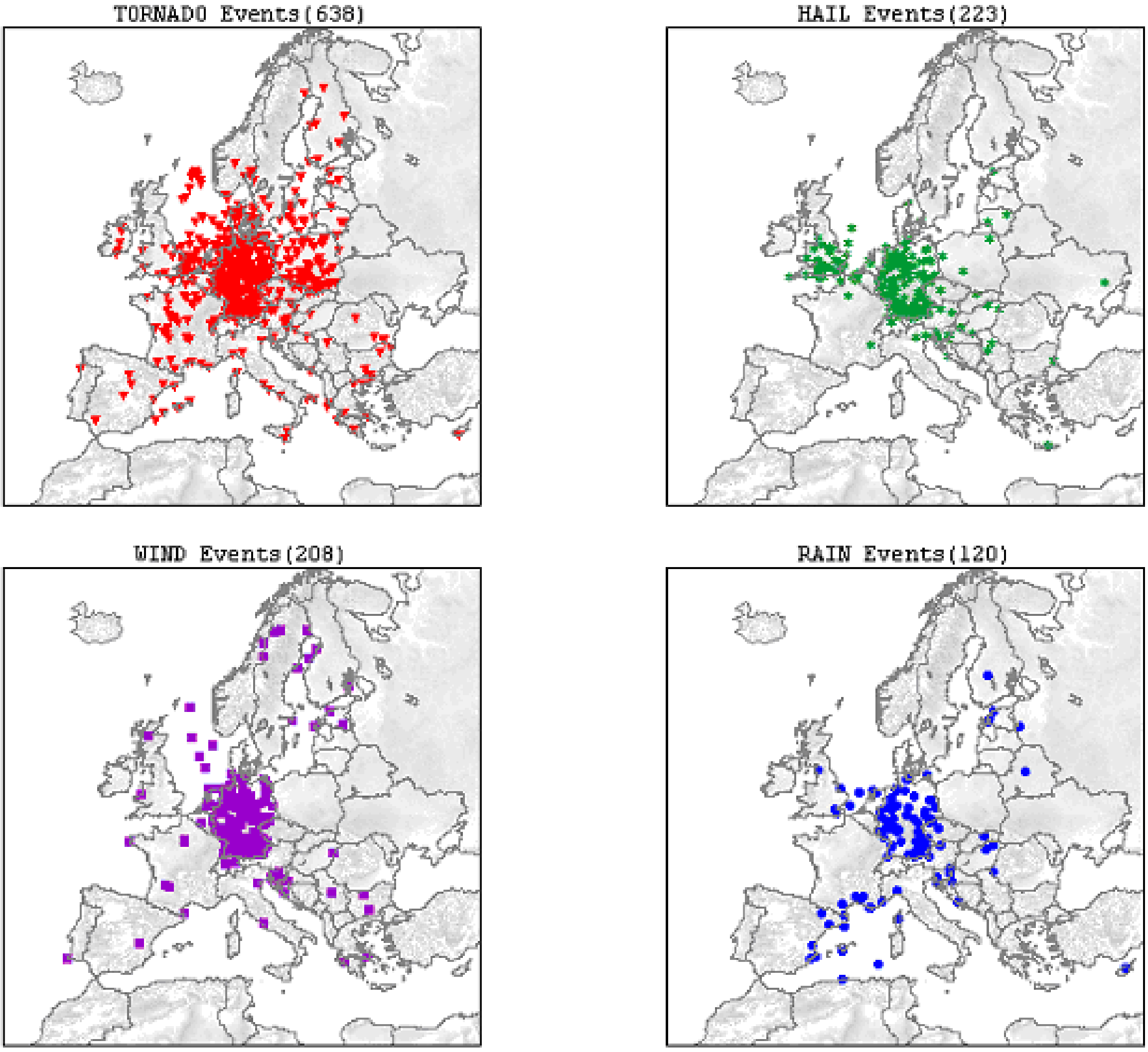

Figure 1. Geographical distribution of the selected events.

this is not the priority, instead it is done from the meteorological point of view, observing how common the value is at that specific place and month.

Ideally, our database should reflect the geographical distribution of severe weather in Europe, but when the location of the events is represented (Fig. 1), we can detect the inconvenience of not having achieved it, showing a clear tendency towards the central European data compilation due to the ESWD database's present composition. This heterogeneity of the data distribution causes a certain decrease statistical validity of the results.

We should remember that the climatologies of meteorological ingredients with which we work are representative of an area in a certain month, so looking at a monthly distribution of the events could also be useful (Fig. 2).

In this case, we can see that we have severe storm records during the whole year, but, above all, the months corresponding to the warm season, in which the energetic contribution is bigger and, therefore, these phenomena can develop more easily.

A hourly distribution (Fig. 3) also allows us to draw some conclusions:

The first thing we can observe is the peak at 12 h in all the diagrams, a fact that can lead to confusion. It is due to the fact that when there is not information of the time of the event, it has been considered noon, and therefore, the frequency in this time interval is clearly overestimated.

Disregarding this peak, we find another one, now with physical significance, that informs us that most of the events are concentrated in the afternoon, around 17 h. This is due to the diurnal cycle and, as it happened in the monthly distribution, the accumulation of energy throughout the day favours the development of this kind of phenomena.

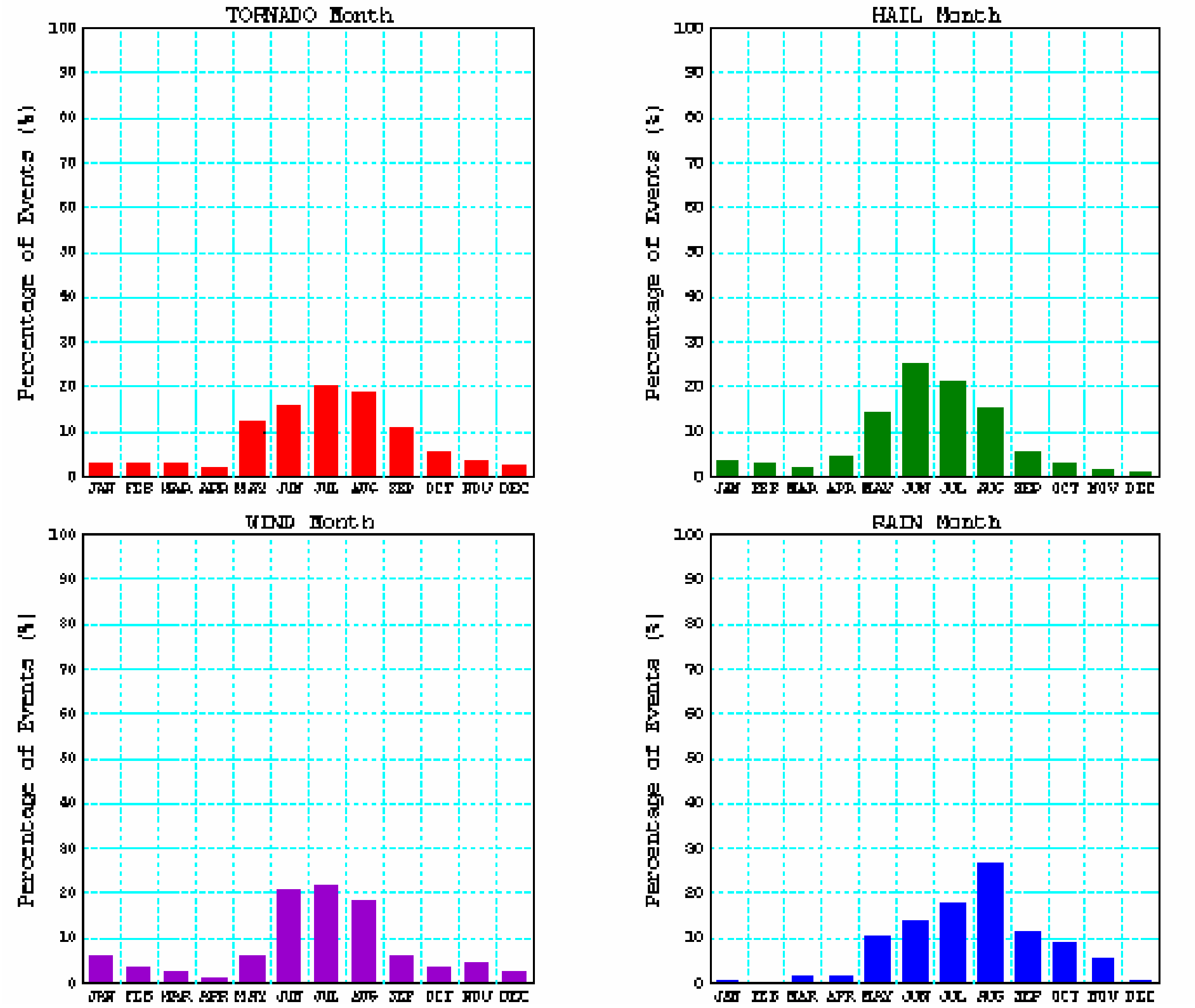

Figure 2. Monthly distribution of the selected events.

2 Meteorological parameters and statistic products

Soundings are a frequently used tool to feature the environmental conditions (Tudurí and Ramis, 1997)[i.e.], which in our case of study would help us to determine the probability of storms and convective severe phenomena. Their spatial density is acceptable in many continental areas. The defaults that we can find in them are the 12h lag between soundings and the limitation of the sounding points in peripheral areas, such as the Mediterranean Sea. Consequently, the climatologies have been built using the ERA-40 Re-Analysis data (ECMWF Re-Analysis Data), the project under development in the European Centre for Medium-range Weather Forecast (ECMWF).

The ECMWF ERA-40 project covers forty-five years (1957-2002) of re-analysis data of the global atmosphere and surface conditions, with a spatial resolution of 125 km, and a time resolution of 6 hour: 00, 06, 12, 18 UTC.

The data of this project, until August 2002, do not only

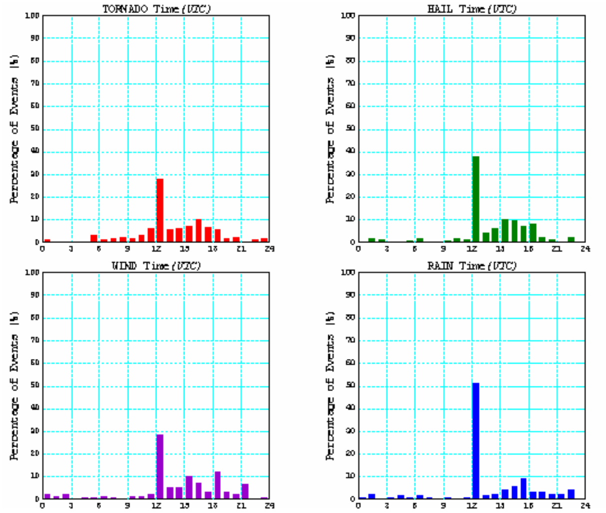

Figure 3. Time distribution of the beginning of the selected events.

help us create the climatologies (corresponding to the 1971-2000 period), but will also help us in the determination of the meteorological conditions during severe storm events. From then on, the data used are those of the operational analyses, also from ECMWF, with a spatial resolution of 30 km, and a 6 hour time resolution as well. These data have been analysed and all the necessary interpolations have been done to be able to generate a net of regularly separated (30 km) points above Europe according to a Lambert projection.

Due to the fact that the location of the severe weather events does not necessarily coincide with a point of the spatial net, or with one of the four possible hours in which we have data of the meteorological variables, we have done the approach to the nearest point of the net and to the immediately available hour preceding the beginning of the event.

The meteorological variables chosen to do the study are the result of the diagnosis calculations:

- Convective potential energy available for the surface particle: **CAPE** (J kg^{-1}).
- Convective inhibition energy for the surface particle: **CAPEN** (J kg^{-1}).
- Variation of the temperature with height, in the medium troposphere, between 700 and 500 hPa: **LR7050** (°C km^{-1}).
- Water vapour amount quantity, in the lower troposphere, up to 850 hPa: **PRWA85** (mm).
- Storm relative helicity, between 1000 and 350 hPa: **SRH35** (m^2 s^{-2}).
- Storm relative helicity, between 1000 and 850 hPa: **SRH85** (m^2 s^{-2}).

In the case of SRH35 and SRH85, the storm motion has been estimated applying the '30R75' rule (Johns and Doswell-III, 1992) on the average wind of the layer between 1000-400 hPa. This means that the storm motion vector can be found turning at 30° to the right of the average wind vector, and taking 75% of its speed.

In former studies it has been shown that this ensemble of small parameters has been linked to severe storm development (Doswell-III, 2001)[i.e.]. We are aware that we could take into account many other variables here, even a long collection of instability empirical indices (Doswell-III and D.M.Schultz, 2006), but we leave this for a possible future study.

In addition to this list of diagnosis parameters, we have also extracted three more parameters (from the re-analysis or analysis databases) directly related to the synoptic maps:

- Geopotential height, at 500 hPa: **H500** (m).
- Sea level pressure: **SLP** (hPa).
- Temperature, at 850 hPa: **T850** (°C).

During the event database treatment, we observe three types of statistical results:

- **HIST1:** it represents the number of events as a function of the value of the meteorological variable.

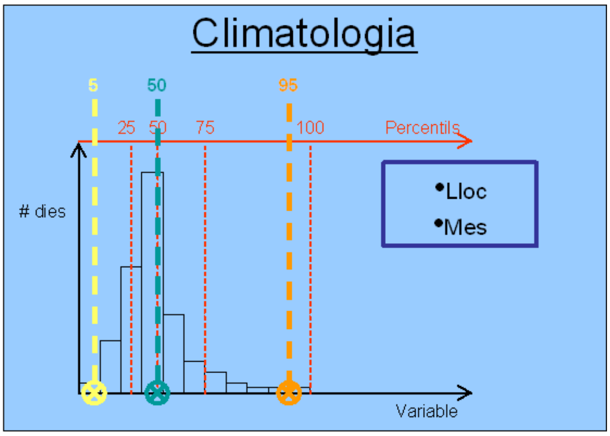

Figure 4. Relation between the simultaneous meteorological variable with a severe weather episode and the local and monthly climatology (see text).

- **HIST2:** it represents the number of events according to the climatology of the meteorological variable.
- **STATS:** it is a combination of HIST1 and HIST2.

As mentioned above, what is really interesting for us is relating the value of the meteorological parameters to the local and monthly climatologies. Therefore, what is interesting for us in this paper is HIST2 (the other statistical indicators can be found in http://ecss.uib.es/).

Saying that during a severe weather episode the temperature at 850 hPa is 15°C should not be something conspicuous, if we are talking about August in the Iberian Peninsula Mediterranean coast, but, on the other hand, it would be very significant if we were talking about January (in the same place) or Scandinavia (during any month of the year). That is why we want to work taking into account the climatologies. In these two last cases (in which we would be dealing with an abnormal temperature), the climatological study would show us a contribution of the high percentiles, since most of the time, the variable value (in this case, the temperature at 850 hPa) is inferior to the obtained value in this moment. On the other hand, a temperature at -5°C in Scandinavia in January is completely normal, but it would mean a contribution in lower percentiles if we were looking at August (at the same place) or at the Mediterranean Sea (see Fig 4 scheme).

- Percentile ∼ 5: T = -5°C in Scandinavia in August, or in the Mediterranean, at any month.
- Percentile ∼ 50: T = -5°C in Scandinavia in January; T = 15°C in the Mediterranean in August.
- Percentile ∼ 95: T = 15°C in Scandinavia at any month, or in the Mediterranean in January.

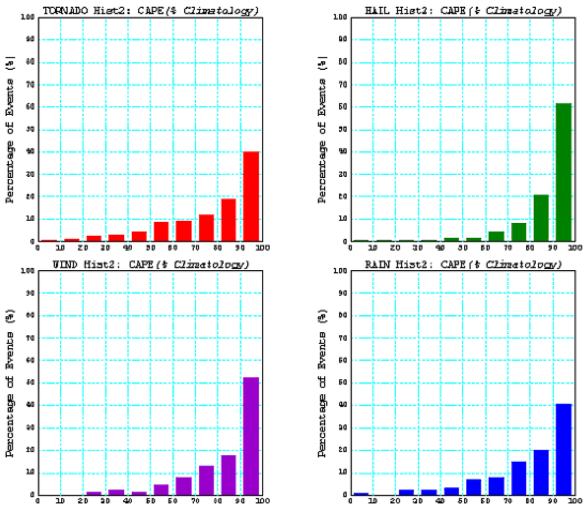

Figure 5. Events distribution according to the local and monthly climatology for the CAPE meteorological variable.

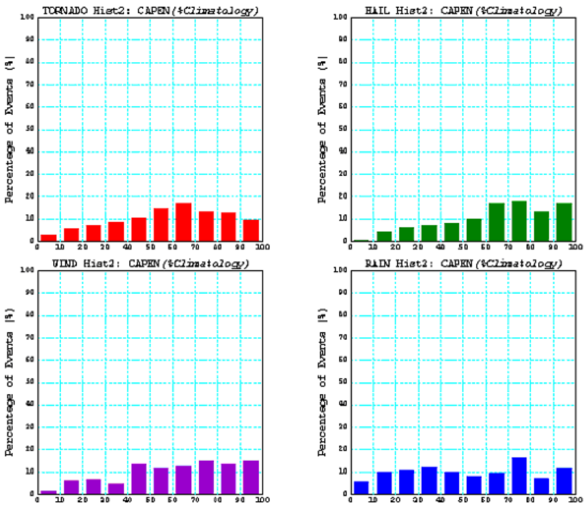

Figure 6. Events distribution according to the local and monthly climatology for the CAPEN meteorological variable.

3 Results

The results are presented in a way which allows the comparison among the different phenomena, to see if there are common parameters in all of them, and which are the discriminators. For this reason, the results for each parameter are presented in four images, distinguishable through their colour: red for tornados, green for hail, purple for convective wind and blue for heavy rain.

The existence of a high presence of high percentiles means that abnormally high values of the parameter may be related to the specific presence of the severe weather event. And on the contrary: a distribution that does not present any significant tendency for any of the percentiles indicates that this meteorological parameter is not relevant as an indicator.

3.1 CAPE

The CAPE represents the energy a particle can gain, initially located near the ground, during a hypothetic ascent due to buoyancy, and related to the release of latent heat. The CAPE values follow a sufficiently well defined cycle above the European regions, taking the highest values during the summer (July-August) and the lowest during the winter (January-February).

The CAPE value during all the severe weather phenomena (especially for the hail case) is much larger than the expected one according to climatologies (Fig. 5). This fact is predictable, since, with the presence of a large quantity of available energy, the capacity to develop severe weather phenomena is bigger.

It is worth noting that this result is not especially found in the case of tornados. It is probably due to the fact that in this study we have taken into account all kinds of tornados and not only the most significant, for example those superior to F2, according to the Fujita scale (Fujita, 1981).

3.2 CAPEN

The CAPEN represents the energy barrier to be overcome in order to be able to have CAPE, that is to say, so that the particle can freely ascend by buoyancy. The existence of this energy barrier can allow the environment to accumulate high values of convective energy high values in the lower layers. The CAPEN field has a seasonal cycle similar to the CAPE cycle (maximum during the summer and minimum during the winter), but the differences among the seasons is not that clear. The larger values are found in the inferior part of the European domain, with spatial differences more pronounced during the summer than during the winter.

In this case, the percentile distributions are more spread out (Fig. 6). We can see a small tendency, in both cases of hail and convective wind at higher percentiles. In the case of tornados, there is also this tendency (though smaller, probably due as well to the fact that all tornado categories have been considered).

In the case of heavy rain episodes, we observe a difference from the rest of the phenomena of severe weather: in this case, there is no tendency, and therefore we can state that CAPEN is not a variable which significantly affects the severe rain episodes.

3.3 LR7050

The inclusion of the "lapse rate", or change of temperature with height, in this study is to reflect the thermal contribution to the convective stability in the middle troposphere (between the 700 and 500 hPa levels). To characterise the convective instability degree, we would need to take into account humidity (especially in the lower levels), but it provides us a general first idea.

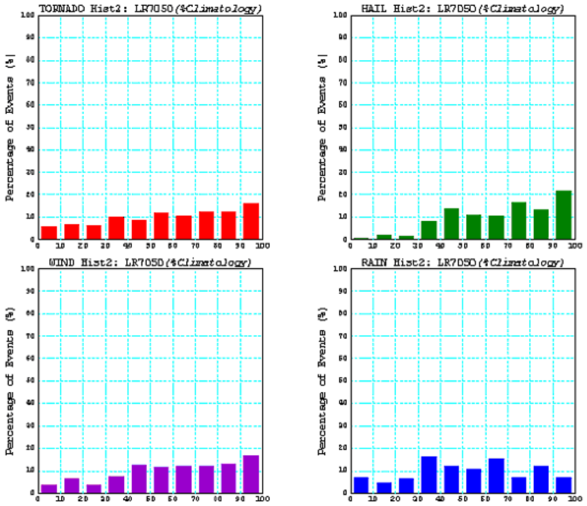

Figure 7. Events distribution according to the local and monthly climatology for the LR7050 meteorological variable.

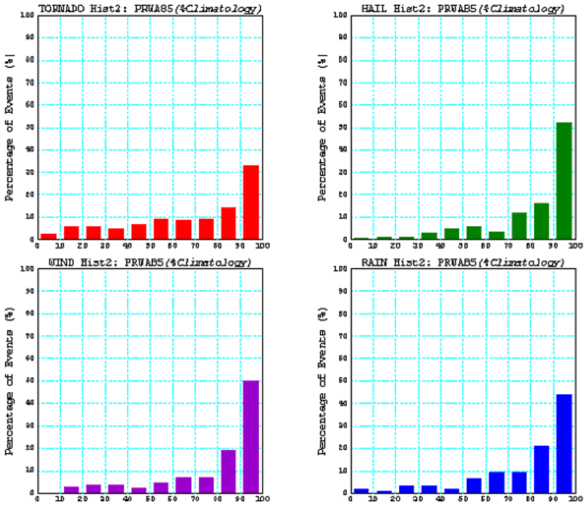

Figure 8. Events distribution according to local and monthly climatology for the PRWA85 meteorological variable.

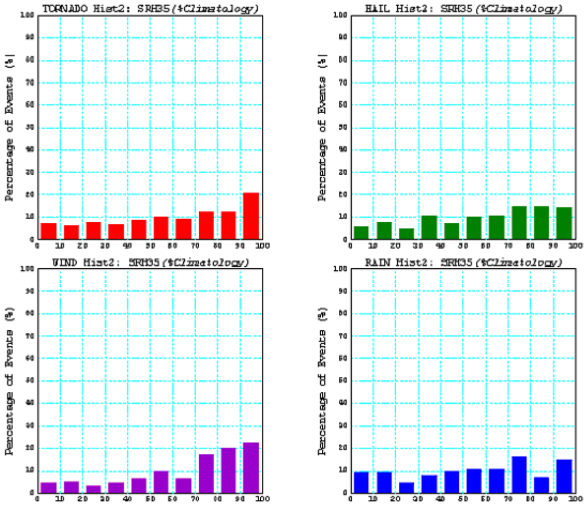

Figure 9. Events distribution according to the local and monthly climatology for the SRH35 variable.

We can observe that there is also a slight tendency towards high percentiles in the case of hail and convective wind, and slightly lower in the case of tornados (Fig. 7). For the rain, there is no tendency (the second parameter that differs from the rest of phenomena of severe weather).

3.4 PRWA85

The presence of humidity in the lower levels of the troposphere is the main ingredient to develop convective phenomena. In Europe, the most humid air is found in the Mediterranean Sea and the Atlantic Ocean. The Mediterranean Sea is relatively warm throughout the year, which favours evaporation (even during the winter); instead, the Atlantic Ocean maintains high temperatures only in the southern sector (near the Iberian Peninsula).

In all cases, the presence of high water vapour contents in the lower troposphere, as we have mentioned before, favours the development of these phenomena (Fig. 8). The fact that large evaporation takes place during the summer helps us to check the great dependence of this parameter with the severe weather phenomena, since we have also mentioned that most severe storms take place during the summer.

Taking into account the obtained results obtained in the typical CAPE profiles (very high), we can think that when the lower troposphere presents high water vapour contents is when there are the best conditions for a severe weather phenomena.

3.5 SRH

The vertical shear of the horizontal component of the wind in the troposphere is strongly influenced by the air baroclinicity, since the wind above the boundary layer is dominated by the geostrophic component. The larger values are associated with the passage of extratropical anticyclones, which are more frequent and deep during the cold season (the mean helicity is nearly double compared to the summer).

When SRH85 is considered, contrary to what occurs with the SRH35 in which almost all the troposphere is taken into account, the topography becomes more significant, the boundary layer has to be taken into account with more detail and, consequently, the ageostrophic contributions.

The storm-relative helicity is another of the parameters that also shows a tendency to the high values in the case of severe weather phenomena, but not in the case of heavy rain (Fig 9 and 10).

The qualitative difference between SRH35 and SRH85 is that in the case of convective wind, the latter becomes even more significant, and that even in the case of heavy

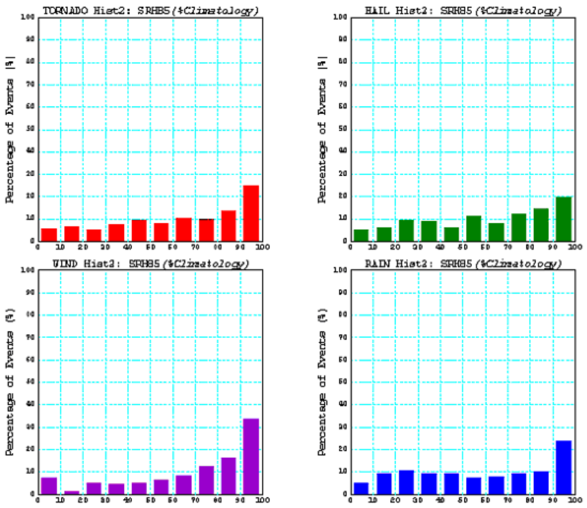

Figure 10. Events distribution according to the local and monthly climatology for the SRH85 meteorological variable.

rain, we could sense a certain tendency (but very small). Therefore, it is more useful for us to look at the SRH85 helicity.

3.6 H500

The first of the parameters added to the diagnosis is the geopotential height at 500 hPa, which gives us an idea of the pressure distribution near 5 km above the sea level.

At first, we can expect a contribution (for all the phenomena) which shows the larger presence of lower values (lower pressures in the shape of a trough or an isolated depression), but this is not confirmed by the results (Fig. 11). The forecasts are only fulfilled in the case of tornados, but in the case of hail, it even shows a tendency towards higher values. Let us remind that we are not evaluating this field in absolute terms, but in relation to climatology.

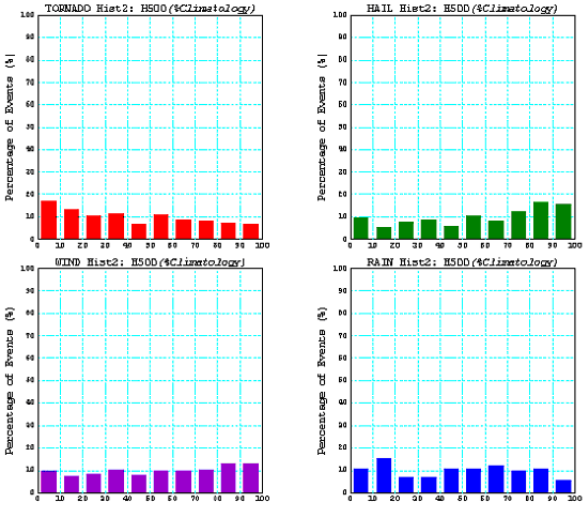

Figure 11. Events distribution according to the local and monthly climatology for the H500 meteorological variable.

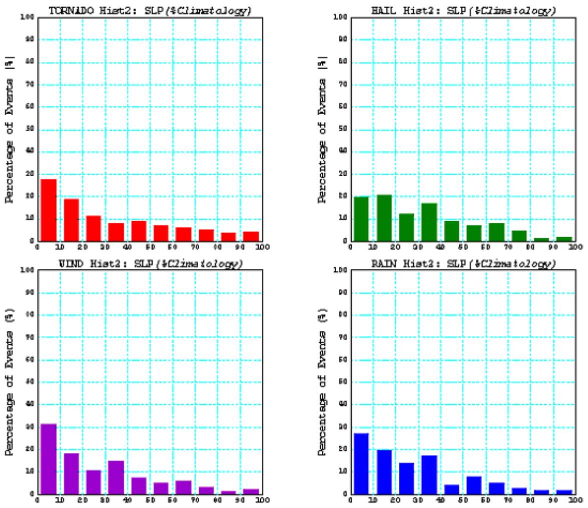

Figure 12. Events distribution according to local and monthly climatology for the SLP meteorological variable.

3.7 SLP

Another included parameter is the sea-level pressure. Data indicate that severe weather phenomena are favoured when there are lower pressures (Fig. 12).

3.8 T850

Finally, the last parameter in the list is that of the temperature at 850 hPa. We have mentioned earlier that high temperatures at lower levels favour evaporation and contribute energetically to the development of severe weather phenomena.

We can observe that in all cases (in hail and wind above all), the percentiles higher than 90 become very significant (Fig. 13). As for tornados, having considered the inferior categories of tornados has probably had an influence on this result.

4 Conclusions

Comparing the different results, we can build, in a subjective way, the following abstract-table in which we can distinguish (by shading them) the most significant parameters. These parameters are those which the severe convective air most clearly features, but without the possibility, in general, of discriminating the type of phenomena.

Very high CAPE values, high water vapour contents in lower levels, abnormally high temperatures at 850 hPa, and low values of pressure at sea-level seem to be associated

Table 1. Dominant percentiles for each meteorological parameter, in relation to each type of severe weather phenomena.

	TORNADO	HAIL	WIND	RAIN
CAPE	**very high**	**very high**	**very high**	**very high**
CAPEN	high	high	high	indifferent
LR7050	high	high	high	indifferent
PRW85	**very high**	**very high**	**very high**	**very high**
SRH35	high	high	high	indifferent
SRH85	high	high	**very high**	indifferent
H500	low	high	indifferent	indifferent
SLP	very low	very low	very low	very low
T850	high	**very high**	**very high**	high

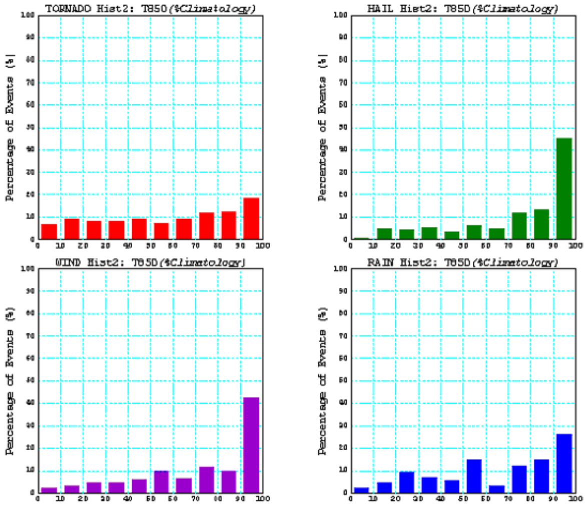

Figure 13. Event distribution according to the local and monthly climatology for the T850 meteorological variable.

with the development of severe weather.

The remaining parameters are not clear hallmarks of severe phenomena, but they can help us distinguish the type of event the former hallmarks refer to.

So, if H500 is low, it would indicate that the severe weather deduced using the former parameters is a tornado; if it is high, it would suggest the possibility of hail; and if it does not present any clear tendency, it would indicate rain or wind. We could still distinguish between these last two possibilities analysing the SRH85 behaviour, since the high values of this parameter seem to be related only to convective wind episodes and not to heavy rain.

This paper could be significantly improved by enlarging the database. The fact that most of the phenomena studied here are found in central Europe limits the global European vision which we aim for.

There are other parameters and empirical convective indices (i.e. SI, LI, K, TT, SWEAT, BRN, etc.) that we can take into account: we have only looked at some of them here. The future work would partly consist of checking the validity of these indices (most of which have already been studied in the USA) in the European region.

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