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Interactive comment on "The role of large-scale dynamics in an exceptional sequence of severe thunderstorms in Europe May/June 2018" *by* Susanna Mohr et al.

Anonymous Referee #2

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Overview: The paper presents a case study of a long-lasting thunderstorm series over France/central Europe in May/June 2018 that occurred south of a blocking high. The synoptic situation persisted for several weeks. The thunderstorms were associated with cut-off lows/potential vorticity filaments that formed on the south-west of the blocking high. As a result, numerous severe convective events such as flash floods, hail and wind gusts were recorded. The authors use multiple different data sets and methods to show how the large-scale dynamics contribute to the thunderstorm series and that this event was exceptional.

Overall, I like the author's idea of studying this event from synoptic down to the con-

vective scales. Moreover, it is an interesting case. However, I think the manuscript was difficult to follow and can still be improved considerably. In the current form, it was unfortunately no pleasure to read through the study. My main criticism is that large parts of the paper (chapter 2,3,4, but also in the introduction) read like a collection of single parts which are not really connected with one another. A central theme seems to be missing. I think, the authors should restructure the paper or parts of it and follow a clear path, e.g. from large-scale to the small scale or the other way around. If this is not possible, they should at least clarify the purpose of each (!) chapter at the beginning (as it is done in chapter 5) to facilitate the reading. Moreover, in my opinion, the writing can be improved, too. Some sentences are too long, which makes the text hard to read. Just write necessary information and just reference to papers that are relevant for your topic. Make the sentences clear and concise. Please connect the single chapters and (sub)sections with one another!

I will explain my criticism in more detail in the following:

(i) In the introduction, the authors switch strongly between different topics: first they introduce the case and its impacts in a few sentences. Then they describe convective development due to scale interactions (mainly lifting processes). Afterwards they describe the case again with focus on blocking which is described more general thereafter. In the successive part, the authors explain cut-off lows in the potential vorticity framework. Afterwards they switch back to the topic of blocking. However, these single parts are often unconnected with one another which is confusing for the reader!

(ii) In the data and methods chapter (chapter 2), data sources are often introduced without clarifying why the authors will need the data. At least some overview at the beginning of this section – how the study was designed and/or what data satisfies which purpose – would help the reader tremendously! Are there any new methods? Please clarify!

(iii) The same applies for chapters 3,4, and partly 5! Try to connect the single parts, try

not to jump unnecessarily between topics. In the current version, it is really confusing for the reader.

With respect to the methods my main concern is the usage of the 500hPa-wind instead of vertical wind shear. At least additionally analyzing shear had the advantage that your work can be compared more easily to the existing literature of convective events. Furthermore, I am missing evidence, that the thunderstorms have been single cells rather than multicells, MCS or slow-moving (HP) supercells.

Specific comments:

Abstract, p.1 line 2: "80mm" - what is the temporal range? a few hours?

p.2, line 25-36: I am missing the general ingredients of convection here: instability, moisture, lift and shear. The ingredients-based concept is first mentioned in the Discussion chapter (chapter 6), I think it would be fitting in the introduction, too. Moreover e.g. Markowski and Richardson, 2010 (their chapter 10.4) and Doswell III, C. A., Brooks, H. E., & Maddox, R. A. (1996) (Flash flood forecasting: An ingredients-based methodology. Weather and Forecasting, 11(4), 560-581) treat flash flood events. Especially in the Markowski and Richardson book, you can find a very similar synoptic pattern that led to flash flood events in the US (please refer to the publications mentioned therein).

p.2, line 34: "all these mechanisms" - which ones are meant here?

p.2, lines 51-61: There are some publications concerning the PV framework and convection: e.g. Russell A, Vaughan G, Norton EG. 2012. Large-scale potential vorticity anomalies and deep convection. Q. J. R. Meteorol. Soc. 138: 1627–1639. DOI:10.1002/qj.1875 ; Morcrette CJ, Lean H, Browning KA, Nicol J, Roberts N, Clark PA, Russell A, Blyth AM. 2007. Combination of mesoscale and synoptic mechanisms for triggering of an isolated thunderstorm: a case study of CSIP IOP 1. Mon. Weather Rev. 135: 3728–3749. Can you please put your work in context with the existing literature?

p.3, line 62: "A connection between atmospheric blocking and heavy precipitation events..." - Why again blocking? The sentence is almost identical to that on page 2, lines 49-50. Why don't you merge these parts?

p.3, line 68-70: "[..] such situations are usually associated with weak wind speeds at mid-tropospheric levels (cf. PIP16), so that thunderstorms become almost stationary and usually do not develop into organized structures such as large mesoscale convective systems or supercells." - first: where is the wind weak? in the high, the low, at the western flanks? second: what about HP-supercells (high precipitation supercells)? Can you please comment on HP-supercells.

p.3, line 83: What do you mean with "secondary effects"? Please elaborate.

p.3, line 85: "(May/June)" - These are the whole months (1.5-30.6)? It is confusing since you already stated two different periods in the text before.

p.4, line 87-93: Please clarify what the purpose of the ESWD data is. Do you use different quality levels or all? Why don't you show the reports also in e.g. Belgium or Italy?

p.4, line 88: It is good to know that the ESWD collects data about heavy rain, hail and wind gusts. However, what data did you use for the analysis?

p.4, line 90: better: "[..] mainly based on reports of storm chasers, [..]"

p.4, line 108: Is there a description of the REGNIE data in English for non-Germans, too?

p.4, line 104-111: Why did you decide to use the REGNIE data. The data seems to interpolate measured precipitation on a regulare grid. Is the REGNIE data suitable to analyse extreme convective precipitation which might be short in duration and small in scale? Or might these extremes be smoothed during the interpolation process? Did you consider to use a highly-resolved reanalysis data set for comparison reasons?

p.4, line 109-111: "Note that the REGNIE time series are affected by temporal changes in the number of rain gauges considered by the regionalization. For our purpose, the homogeneity of the data are sufficient." - Can you please give a reference here? Did the number of stations change in the analysed period?

p.4, line 115: "[..] appropriate for precipitation statistics [..]" - can you please give a reference here and explain a bit more in detail what was done in the previous literature with the Gumbel distribution.

p.4, line 112-123: General comment: Is this method new? If so, please state here, otherwise, please write something like: "we follow the methodology used in..."

p.4, line 116: R is not explained.

p.5, line 117: Can you please give a reference for the "Method of Moments". If it is also explained in the Wilks-book, maybe you can add the chapter to the reference here.

p.5, chapter 2.1.3: What will you use the data for?

p.5, line 132: what parameters will be taken into account to estimate the "atmospheric conditions"?

p.5/6, chapter 2.1.5: Can you conclude from the radar data, if the thunderstorms rotated? For example by comparing the direction of the mean tracks to the investigated severe thunderstorms?

p.6., chapter 2.2: What fields will you use?

p.6, line 172/173: "[..] but reflects important seasonal differences." - What do you mean here? A figure showing the weather regimes would be nice, at least later in the text, where you analyse the data, you could show the typical patterns of the prevailing regimes.

p.7, chapter 2.4: Is this method new or does it already exist? Please clarify.

p.7, line 197: general comment: The Brunt-Vaisala frequency is smaller in summer, too, due to decreased stability.

p.7, line 199-203: You could add a table to the supplementary material showing the change in associated lightning. Moreover, it would be nice to see this "buffer zone" in the figures.

p.8, line 211-214: Why do you use the wind speed at 500hPa instead of the deep-layer shear? Additionally, deep-layer shear is a widely used variable and the results would be better comparable to the existing literature. I do not understand the motivation here, especially since the authors later in the paper discuss the importance of shear on the organization of thunderstorms.

p.8, line 216: "Overview" - Can you please be more precise, there is another chapter which is also called overview. What is you intention of this whole chapter?

p.8, line 222/223: "The three-week period from 22 May until 12 June was the most active thunderstorm episode with a total of 868 heavy rain, 144 hail, and 145 convective wind gust reports based on the ESWD." - do you mean "the most active thunderstorm episode" in the year 2018 or inother period?

p.8, line 223/224: "An average area of 715,000 km2 was affected by lightning per day" - is that much, what is the average value for Europe?

p.8, line 227/228: "As shown in Figure 2b, most of the severe weather reports came from the western part of France, Benelux, central and southern Germany, and the easternmost part of Austria." - Can you explain the gap in central/eastern France? From your Fig. 8 lifte index was negative, too. Moreover, the mean wind was not much different from western France?

p. 8, line 241: Isn't the number of ESWD reports depending on the number of people reporting events? Is there a difference if you just use some of the quality levels?

p.9, line 252: "low wind speed [..] slow propagation" - You could mention here, that you

will give more details later in the text. While first reading through the text, I wondered if these statements will be verified later or just stated as a fact here?

p.9, line 257: What is meant with "The strength and spatial extent of the lifting forcing varied from day to day, [..]"? Can we see this in one of the figures?

p.9, line 260-273: Just write about the events that are explained in more detail. All other numbers will just lead to confusion and can be seen in the table.

p.10, chapter 3.3: It would be reader-friendly if you explained what the intention of this chapter is. Please give an introductory sentence.

p.10, lines 292-303: It would be a helpful addition if you overlayed the ESWD data. This would make it easier to follow your arguments.

p.11, lines 312-313: Can you please plot the typical patterns of the Zonal regime and the European Blocking.

p.11, lines 315-323/line 330: Can you plot in Fig 6/7a+b additionally to the regimes/sounding data, the lightning activity (out of Fig. 2a) for easier comparisons.

p.12, line 348/349: "Because of the low wind speed in the mid-troposphere, most of the thunderstorms moved very slowly or even became stationary." - The motion of thunderstorms is not necessarily determined by the wind at 500 hPa - can you please give a reference that shows that the storm motion correlates with 500hPa winds.

p. 12, lines 358-360: "The fact that relatively high PV cut-off frequencies expand over a larger region of western Europe underlines that multiple individual PV cut-offs form on the upstream flank of the blocking ridge, and intermittently move across Iberia, France, the British Isles, the North Sea, and Germany [..]" - How do you distinguish between a stationary cut-off low and newly-formed moving ones in Fig. 10?Please clarify.

p. 13, line 396: better: " To estimate the severity of the rainfall with respect to the rainfall climatology, [..]"

p. 13/14, chapter 5.1: I wonder if the return periods are dependent on the REGNIE data and how it is designed. Is it possible to get higher precipitation amounts than observed at the stations? Can you please comment on this?

p. 14, chapter 5.2: If I understand it correctly, the only thing one can directly compare in Fig. 14 - left vs. right boxes-and-whiskers - is the median on the left with the complete box-and-whiskers on the right? Maybe you could add the median of the actual period as an extra symbol to the right box-and whiskers.

p. 14/15, lines 435-448: Although, your main intention is presumably, that the investigated storm period is a rare event. From your text, I could not understand how Fig. 15 was produced. Can you please rewrite the text passage and clarify. What is meant by skip days and why do you use 3 instead of 1 as in the referenced paper? Please explain.

p. 15, lines: 463-466: ". A further relevant condition for the evolution of deep moist convection is the vertical wind shear or, more generally, the wind at mid-tropospheric levels, which is decisive not only for the organizational form, the longevity and thus the severity of the convective storms (e.g., Weisman and Klemp, 1982; Thompson et al., 2007; Dennis and Kumjian, 2017), but also for their propagation (Corfidi, 2003)." - As far as I know, all the cited papers talk about the vertical wind shear, but not about the wind at mid-tropospheric levels (although they might mention storm-relative winds, but this can be quite different from the mid-tropospheric wind). Of course, I can be mistaken, hence, please cite the text passages of the papers, where the mid-tropospheric wind is mentioned in your authors's response.

p. 16, lines 475/476: "[..] air masses were trapped [..]" - Is it possible to show, that the air masses were trapped over several weeks (e.g. by using trajectories)?

p. 16, lines 484-485: "In our investigated case, thunderstorms were often triggered by large-scale lifting associated with upper-level cut-off lows or filaments of high PV that separate from the main PV cut-off" - I am convinced that the cut-off lows provided good

environmental conditions for convection, however I doubt that the cut-off lows triggered the thunderstorms directly. What about (older) outflow boundaries? Can you please comment on that?

p. 16, lines 490-496: Especially since the precipitation amounts are so high, how do you know that the thunderstorms were mainly single cells? Moreover, did you mention at any point in your paper, how you differentiate between single cells and other convective thunderstorm types like multicells? Maybe you can put the radar movies for one of the extreme cases you talked about to the supplemental material?

Figures:

Fig. 2b: Please do not use the rainbow color scale. It is hard to differentiate between some days. Maybe if you switch to a sequential scale, it might be possible to see some temporal clustering? Are there really no events in northern Italy, the Czech republic or Poland?

Fig. 3b: I cannot see any difference between the blue colors here.

Fig. 4: Is it possible to add the locations of the ESWD reports of the associated day to maps?

Fig. 6: It is impossible to differentiate between ZO/SCTr, EuBL/SCBL and AT/GL. Can you add the affected lightning area (from Fig 2a) to the curves.

Fig. 7: Is it possible to add the lightning data from Fig 2a?

Fig. 12: There is no red hatching (in my print it looks black?). Is it possible to add the buffer zone?

Fig. 14: Can you please add the median from the left box-and-whiskers as an extra symbol to the right ones? Please also plot the deep-layer shear.

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